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Review

Towards sustainable airport waste management through the adoption of a "green" airport strategy: The case of Incheon International Airport

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Abstract: One of the most significant environmental challenges confronting airports is their sustainable management of solid wastes. This is because airport's produce large volumes of wastes as a byproduct of their operations. Considering this, airports are increasingly focusing on managing their wastes in an environmentally sustainable manner. Using an in-depth longitudinal case study research approach, this study has examined Seoul's Incheon International Airport sustainable waste management. Incheon International Airport is a major air hub and is the home base for Korean Air. The study period was from 2010 to 2020. Incheon International Airport has six discrete waste streams: construction wastes, designated wastes, general wastes, incinerated wastes, landfill disposed wastes, and recycled wastes. The case study revealed that the airport aims to recycle wastes wherever possible. This policy has resulted in recycled wastes becoming the airport's largest source of wastes during the study period. At the airport, suitable combustible wastes are incinerated and the waste heat from the incineration is captured for further use by the airport. Incheon International Airport has undertaken substantial construction works during the study period, and these were the airport's second most significant waste stream during the study period. In the case of waste construction items, these wastes are handled by external waste treatment firms or alternatively they are incinerated by the airport. To underpin its sustainable waste management, the airport operates a recycling center that is equipped with can compressors and separators which ensures an efficient resource cycling system. A resource classification treatment facility is also used to efficiently manage and enhance the recycle rate of wastes from the airport's facilities and its operations.

Keywords: airports; airport wastes; case study; Incheon International Airport; sustainable airport waste management

1. Introduction

Despite airports contribution to a region's economic development, airports have an adverse impact on the environment and on the communities surrounding them [1]. In recognition of their impact on the environment, airports are increasingly becoming environmentally conscious, and, as a result, have increased their efforts to reduce their impact on the environment [2]. This focus on the mitigation of the environmental impact of air transport operations has given rise to a strategy by airports to "green" themselves, that is, to become more sustainable in the medium to long-term [3–5]. A "green airport" is an airport which has a minimal impact on the environment and is one that endeavors to become a carbon neutral facility in terms of carbon emissions [6]. The key concept underpinning a "green airport" is for that airport to create a centre of sustainable practices [7]. The principal features of a "green airport" are their focus on resource savings, low carbon operation, and being environment friendly [8].

One of the most significant environmental challenges confronted by the air transport industry is the sustainable management of solid waste at airports. Increasing passenger volumes and expansion of airport activities have substantially increased the types and quantities of waste generated at airports in recent times [9]. Consequently, waste management (WM) and the way that it is disposed are now considered to be one of the most significant environmental management problems in the global air transport industry [10]. Because of these concerns a very important environmental concern for airports is the annual generation of wastes that are required to be handled in an environmentally sustainable manner [11]. This is because each year airports produce large volumes of waste [12–14]. The amount of waste generated at an airport is determined by the number of passengers handled at the airport together with the aircraft operating at the airport. In most instances, waste generated at an airport is primarily comprised of solid urban waste, non-hazardous waste, and special hazardous waste generated in the airport's terminals or by airlines and other entities operating at the airport [15]. Airports generate both general (non-hazardous wastes) [3,11] and hazardous (toxic) wastes [16,17]. Thus, sustainable waste management has now become increasingly important to airports, and consequently, many airports have now implemented sustainable waste management programs [18,19]. Considering this, airports are making a considerable effort to enhance their waste management and reduce waste generation wherever possible.

South Korea-based Incheon International Airport was selected as the case study airport in this study due to their long-term sustainable waste management approach and their adoption of a "green" airport strategy and the related policies that have been implemented so that they can achieve this goal. The availability of a comprehensive data set covering the period 2010 to 2020, was a further factor in selecting Incheon International Airport as the case airport. The objective of this study is to analyze the sustainable waste management strategies at Incheon International Airport, as well as the sources, types and volumes of waste generated at the airport. A further objective was to examine the methods used to mitigate the environmental impact of the wastes produced at the airport [20].

The remainder of the paper is organized as follows: The literature review that sets the context of the case study is presented in Section 2. The research method that underpinned the case study is

presented in Section 3. The Incheon International Airport case study is presented in Section 4. Section 5 presents the findings of the study.

2. Background

2.1. Sources and types of airport wastes

At an airport, wastes are produced by the various actors participating in the air transport value chains. These actors include the Airport Authority, airlines, airport concessionaires and shops, airport hotels and motels, car parks, cargo terminal operators, air freight forwarders, government agencies, ground handling organizations, passengers, meters and greeters, railway station (where applicable), restaurants, car rental firms, and taxi holding bays [11,21].

There are seven discrete types of waste that are produced at airports: (1) municipal solid waste (MSW); (2) construction and demolition waste (C&D); (3) green waste; (4) food remediation waste; (5) waste from aircraft flights (deplaned waste); (6) lavatory waste; and (7) spill clean-up and remediation waste [21,22].

Solid waste is produced in airline offices, airport concessions (for instance, restaurants, shops), flight catering centres, aircraft maintenance areas, landscaping, construction, and demolition activities [23]. Airports as well as airlines also generate substantial quantities of wastes from engineering and terminal facilities [24]. Hazardous waste may be present at an airport due to aircraft fuelling, aircraft maintenance (if conducted at the airport), rental car maintenance (waste oils), emergency generators, and may come from other activities. In addition, hazardous waste may be present at the airport because of past activities that have contaminated soil or water or because hazardous waste is being transported by aircraft or vehicle onto airport property [25].

Airport non-industrial wastes come from flight catering services that have removed wastes from aircraft and the wastes involved in the preparation of in-flight meals, and from the consumption of food and drinks by airport employees and visitors (cans, newspapers, food, and paper) to the airport. Industrial wastes originate from the daily activities associated with washing and cleaning aircraft and other ground service equipment (GSE), aircraft and engine maintenance, repair, and testing (which includes painting and metal work), aircraft de-icing, as well as maintenance of ground vehicles. These wastes comprise both hazardous and non-hazardous wastes [3].

2.2. Waste management hierarchy

According to the Organisation for Economic Development [26], “waste refers to materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation, or consumption, and of which he/she wants to dispose”. The waste management hierarchy ranks the various types of wastes disposal methods from the most to the least desirable [27,28]. The waste management hierarchy is as follows: reduce, re-use, recycle, recovery, and disposal (Figure 1) [27,29]. For firms using the hierarchy, reducing waste should be their primary concern [19]. In an ideal situation, waste should be avoided wherever possible. This means that in the waste management hierarchy, reducing or preventing waste should be the primary objective of the firm [11].

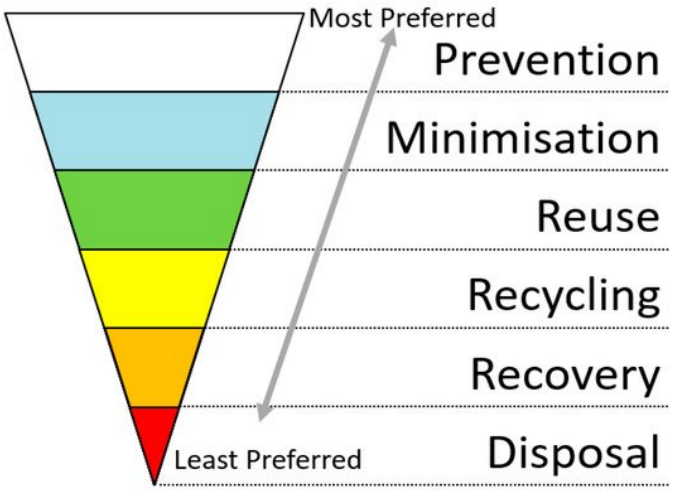

Figure 1. Waste management hierarchy.

The waste management hierarchy seeks to minimize the generation of wastes in the first instance. The aim of the hierarchy is for the firm to optimize the opportunities for reuse and recycling of materials, and to minimize the quantities of wastes that need to be disposed to landfill [30]. According to the waste management hierarchy, re-use and recycling are the best methods of dealing with unavoidable waste [28]. Re-using waste, wherever possible, is regarded as more favorable than recycling because the waste items does not require further processing prior to being used again [31]. Reuse of wastes occurs when something that has already achieved its original function is once again used for another purpose. The recycling of wastes involves the reprocessing of used materials that would otherwise be considered as waste [32]. Recycling of wastes involves the collection, sorting, processing, and their conversion into raw materials that can be used in the production of new products [33]. Recovery relates to the recovery of energy that can be recovered from waste [32]. Wastes that are regarded as unsuitable for reuse or recycling can be incinerated to generate heat or electricity [32,34,35].

Waste-to-energy (WtE) refers to the recovery of useable heat and power produced from waste [36,37]. Waste-to-energy (WtE) involves the generation and utilization of energy by treating solid wastes [38]. The use of energy produced from waste, and waste-to-energy (WtE), has become increasingly significant in recent times [39]. Consequently, waste to energy (WTE) has become an important strategy in waste treatment [40]. Indeed, the conversion of waste into energy has become one of the most effective tools in waste management and energy generation in recent times [41]. Furthermore, the process of waste-to-energy also supports a circular economy by reducing the volumes of waste that are disposed to landfill [42]. Waste to energy (WtE) conversion technologies can be used to convert residual wastes into clean energy. This practice avoids the requirement to dispose of wastes to landfill [43]. Airport waste typically contains a large proportion of substances and raw materials which should be sorted and recycled [44]. Airports may decide to implement a strategy to recover their wastes. This strategy primarily relates to the recovery of energy that is recovered from waste [11]. Osaka's Kansai International Airport [18] and London Gatwick Airport [45], for example, utilize waste-to-energy systems as part of their sustainability policies.

Disposal in landfill sites is regarded as the least desirable waste management option [46–48].

3. Research methodology

3.1. Research methods

The present study was based around a longitudinal case study research design [49–51]. The major advantage of a qualitative longitudinal research design is that it reveals change and growth in an outcome over time [52]. A case study allows for the in-depth examination of complex phenomena [53–55]. A case study approach also enables the researcher(s) to collect rich, explanatory information [56,57]. A further advantage of case studies is that they enable researchers to connect with practice [58].

3.2. Data collection

The qualitative data gathered for this study was obtained from Incheon International Airport annual "Green Insight" environmental reports. Hence, in this study, secondary data was used for the case study analysis. The study followed the recommendation of Yin [55] in the data collection phase, that is, the study used multiple sources of case evidence, the data was stored and analyzed in a case study database, and there was a chain of case study evidence.

The key words used in the database searches included "Incheon International Airport environmental policy", "Incheon International Airport annual construction wastes", "Incheon International Airport annual designated wastes", "Incheon International Airport annual general wastes", "Incheon International Airport annual incinerated wastes", "Incheon International Airport annual recycled wastes", and "Incheon International Airport annual construction wastes handling methods".

3.3. Data analysis

The data sourced for the case study was examined using document analysis. Document analysis is a research technique that is commonly used by researchers when conducting their case studies [59–61]. Document analysis focuses on the information and data from formal documents and company records that are collected for the study [55,62]. The documents were examined according to four key criteria: authenticity, credibility, representativeness and meaning [63,64].

The document analysis was conducted in six discrete phases. Phase 1 involved planning the types and required documentation and ascertaining their availability. The second phase involved collecting the documents and developing and implementing a scheme for their management. In the subsequent phase, the documents were reviewed to assess their authenticity, credibility and to identify any potential bias. In Phase 4, the content of the collected documents was interrogated, and the key themes and issues were identified. Phase 5 involved reflection and refinement to identify any difficulties associated with the documents, reviewing sources, as well as exploring the documents content. The analysis of the data was completed in Phase 6 [65].

The documents used in the study were downloaded and stored in a case study database [55]. The documents were all in English. Each document was carefully read, and key themes were coded and recorded [66].

4. Background

4.1. An overview of Incheon International Airport

Incheon International Airport (IIA) has been constructed on an island that is 50 kilometers from Seoul [67]. The construction of Incheon International Airport (IIA) was planned to satisfy Korea's rapidly increasing air transport (passenger and cargo) demand. The new airport was also planned to be a major hub airport in the Northeast Asia region [68]. The new airport was constructed on reclaimed land that came from two islands. The airport was developed in three phases. Phase one and Phase two were completed in 2001 and 2008, respectively [69]. In 1996, construction works commenced on the terminal building complex, including two terminals, four remote concourses, as well as the Incheon Airport Transportation Centre. Phase two of the airport construction commenced in February 2002 and was completed in June 2008 [70]. Incheon International Airport officially opened in March 2001 [71–73], at which time Incheon International Airport replaced Seoul's Gimpo Airport as Seoul's international airport [74,75]. The opening of the new Incheon airport permitted curfew-free operations at the new airport [76]. In addition to being a major air passenger hub, Incheon International Airport is also a major air cargo hub [77]. Incheon International Airport is a major hub for Korean Air [78].

Incheon Airport's two runways, passenger terminal complex and other facilities were officially opened and became fully operational on 29 March 2001. The airport's Phase two expansion included the construction of a third runway, a terminal, and an automated people mover (APM) system. As part of the phase two construction project, the 4000 m-long third runway 16L/34R was constructed and this new runway was opened in July 2008. The airport's Phase three expansion project commenced in September 2013 [70].

Figure 2 presents Incheon International Airport's annual enplaned passengers and the year-on-year growth (%) from 2010 to 2020. One passenger enplanement measures the embarkation of a revenue passenger, whether originating, stop-over, connecting or returning [79]. As can be observed in Figure 2, the airport's annual enplaned passengers displayed an upward growth trend from 2010 to 2019, when the annual passenger volumes handled at the airport increased from 33478925 in 2010 to a high of 71169722 million in 2019. Figure 2 shows that there was a very significant decrease in the annual passenger traffic handled at the airport in 2020, when it declined by 83.06% on the 2019 levels. This large decrease could be attributed to the adverse impact that the COVID-19 virus pandemic had on air passenger demand in 2020. During the COVID-19 pandemic, the demand for passenger air transportation services declined significantly [80–82]. The Korean government introduced border controls in 2020 in response to the COVID-19 pandemic [83].

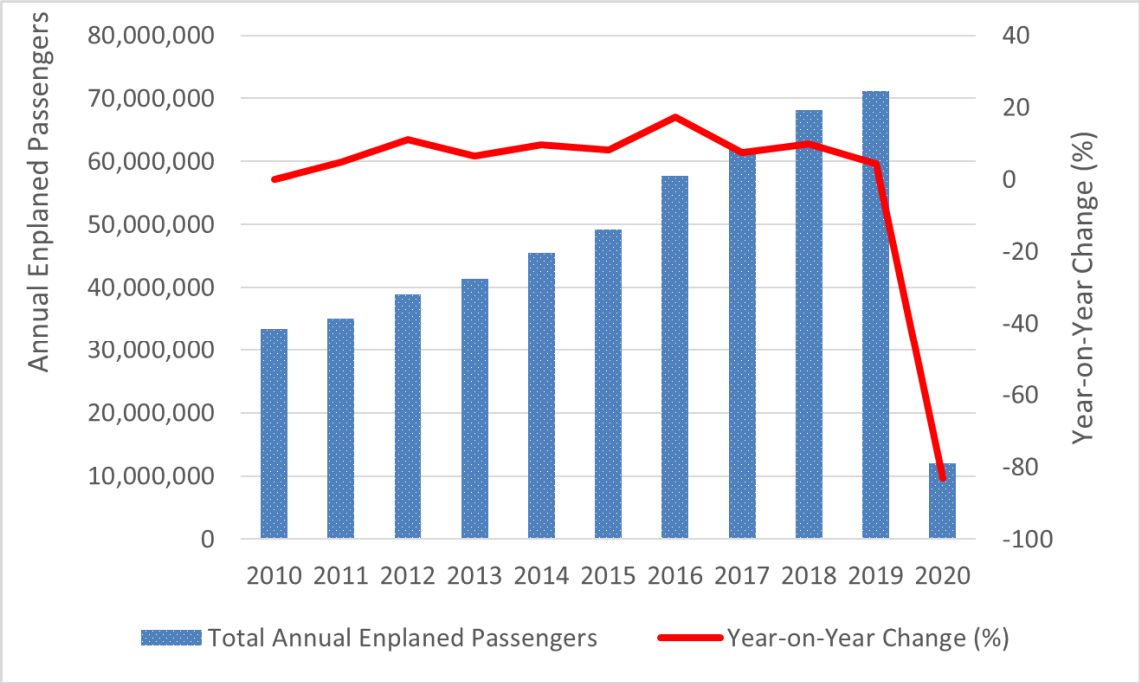

Figure 2. Incheon International Airport's annual enplaned passengers and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [84].

Incheon International Airport's total annual aircraft movements and the associated year-on-year change (%) for the period 2010 to 2020 is presented in Figure 3. Figure 3 shows that the number of aircraft movements at the airport displayed an upward trajectory increasing from 214835 annual movements in 2010 to a high of 404104 annual movements in 2019. In 2020, the total annual aircraft movements decreased by 62.88% on the 2019 levels because of the downturn in airline demand and the government COVID-19 pandemic related measures (Figure 3).

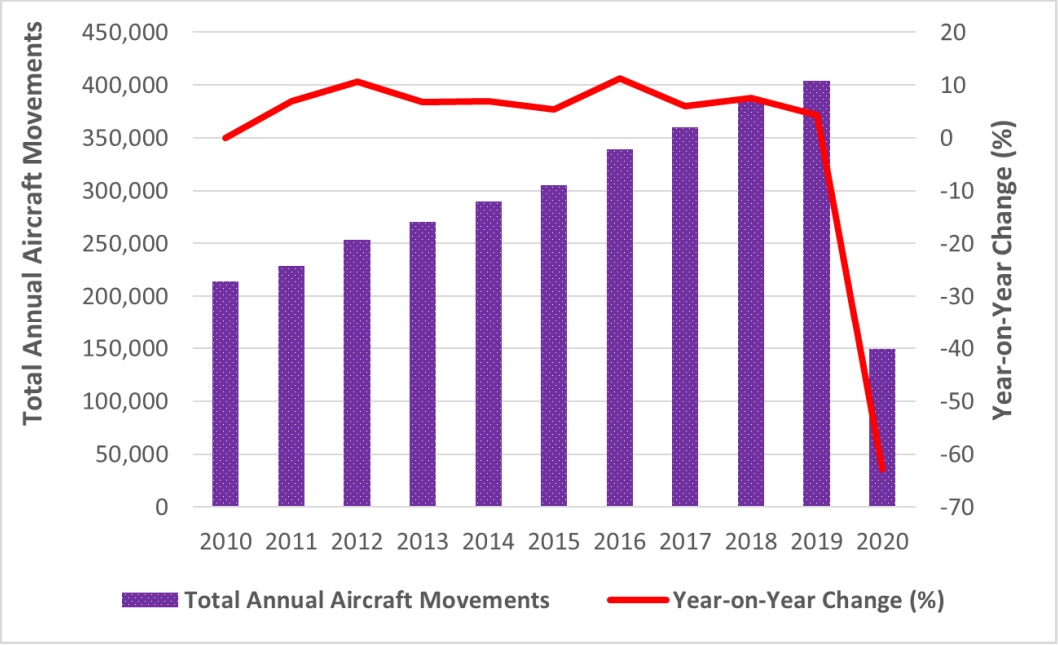

Figure 3. Incheon International Airport's annual aircraft movements and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [84].

4.2. Incheon International Airport "green" airport goals

Incheon International Airport Corporation's eco-friendly management vision is to be a low-carbon, and eco-friendly airport. The Corporation has established goals for its core values for the purpose of ensuring a sustainable future of the aviation industry. The Airport's current level of Airport Council International (ACI) "Airport Carbon Accreditation" is "Level 3", but the airport's goal is to acquire "Level 3+" accreditation. Furthermore, the Corporation will turn Incheon Airport into an airport based on circular resources by improving the recycling rate of 60% in 2021 to 70% by 2030. This goal will be achieved through the installation and operation of resource recollection equipment and discovery of waste that can subsequently be recycled. The Corporation will also lead the effort to reduce the airport's greenhouse gas (GHG) emissions [85].

Incheon International Airport Corporation (IIAC) was the first airport operator to acquire the Environmental Management System ISO14001 accreditation. This accreditation was awarded in 1998 during the construction of Incheon International Airport. Since the opening of the airport, the corporation has maintained its ISO 14001 Environmental Management System accreditation [86]. ISO 14001 is a worldwide meta-standard for implementing Environmental Management Systems (EMS) [87–89]. The ISO 14001 Environmental Management System (EMS) has become one of the most widely used systems for managing corporate environmental aspects throughout the world [90].

4.3. Incheon International Airport waste handling system

Incheon International Airport operates a recycling center that is equipped with can compressors and separators for operation which ensures an efficient resource cycling system. The airport also has

an incinerator that burns flammable items [91]. A resource classification treatment facility has been constructed at the airport, and this facility is used to efficiently manage and enhance the recycle rate of wastes from the airport's facilities [92]. Combustible wastes are also incinerated and the waste heat from the incineration is captured for further use by the airport [86]. In the case of construction wastes, these wastes are handled by external waste treatment firms or alternatively they are incinerated by the airport [91]. After sorting the wastes, recyclable materials are processed depending on their types.

Incheon Airport treats construction wastes in accordance with the *Construction Waste Recycling Promotion Act* and the *Wastes Controlled Act*. The waste treatment plans for waste material produced from construction within the airport are reported to the relevant authorities. The waste material is subsequently treated through an appropriate outside company or alternatively through the airport's resource recovery facility. Incheon Airport requires all construction wastes to be separated when the airport is utilizing an outside company to dispose of such wastes [92].

4.4. Total annual wastes at Incheon International Airport

Incheon International Airport's total annual wastes and the associated year-on-year change (%) for the period 2010 to 2020 is depicted in Figure 4. As can be observed in Figure 4, Incheon International Airport's total annual wastes oscillated throughout the study period reflecting differing annual waste patterns. As discussed below, during the study period the airport undertook a range of construction projects which had an impact on the total level of wastes generated at the airport in each year when construction works were undertaken. Figure 4 shows that there were three significant increases in the airport's annual wastes, with these increases occurring in 2011 (+208.99%), 2014 (+97.72%), and 2018 (+175.42%), respectively (Figure 4). In 2011, there were very significant increases in construction wastes, designated wastes, general wastes, and recycled wastes. During 2014, the airport's annual construction and recycled wastes grew quite significantly. In 2018, there were marked increases in the airport's annual construction wastes, incinerated wastes, landfill disposed wastes, and recycled wastes. Figure 4 also shows that there were five years during the study period where Incheon International Airport's total annual wastes decreased on a year-on-year basis. These decreases were recorded in 2012 (−24.86%), 2013 (−74.08%), 2015 (−74.08%), 2016 (−15.26%), and 2020 (−44.67%), respectively (Figure 4). In 2012, all the various types of wastes produced at the airport decreased. Construction and recycled wastes volumes were lower in 2013 and this had a marked impact on the airport's annual waste volumes. A similar trend occurred in 2015, when the airports construction and recycled wastes decreased quite significantly. Once again in 2016, the airport produced lower amounts of construction and recycled wastes. In 2020, Incheon International Airport's construction waste, designated waste, general waste, incinerated waste, and recycled wastes all decreased on a year-on-year basis and this decrease could have been caused by the lower levels of air transport activity due to the COVID-19 virus government and airline-related pandemic response measures.

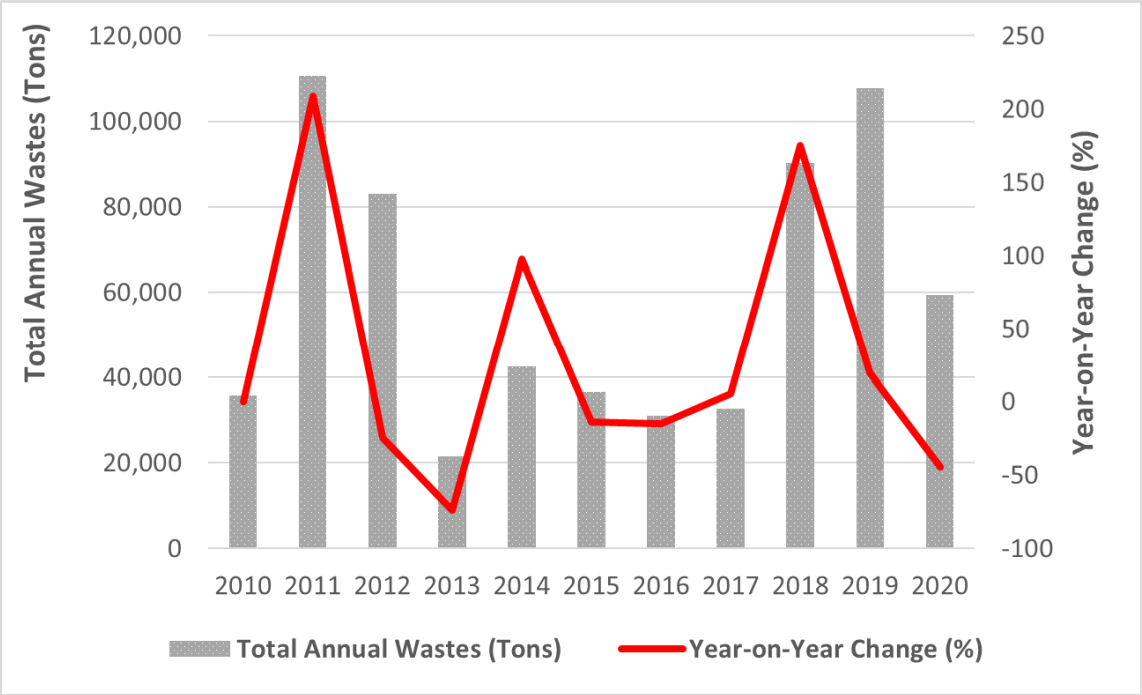

Figure 4. Incheon International Airport's total annual wastes and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

One of the key waste management efficiency indicators used by airports is the waste generated per enplaned passenger [3,18,93]. Figure 5 shows the total annual wastes generated at Incheon International Airport relative to the annual enplaned passengers and the year-on-year change (%) for the period 2010 to 2020. As can be observed in Figure 5, the airport's annual wastes per enplaned passenger have oscillated throughout the study period. There were four very significant annual increases in this metric during the study period. These annual increases were recorded in 2011 (+195.32%), 2014 (+80.76%), 2018 (+153.84%), and 2020 (+227.15%), respectively (Figure 5). In 2011, there was a very significant increase in the airport's annual wastes (+208.99%), which was the result of a large increase in construction wastes. In the same year, the airport increased its annual passenger traffic by 4.72%. These factors led to the very significant increase in the airport's total annual wastes per passenger in 2011. A similar situation occurred in 2014, at which time the airport's annual wastes increased by 97.72% and enplaned traffic by 9.71%, which once again resulted in the higher amounts of wastes per enplaned passenger in 2015. In 2018, the airport recorded a significant increase in its annual wastes (+175.42%), which exceeded the growth in passenger traffic (+9.95%), and consequently, this led to the higher overall wastes per enplaned passenger in 2018. In 2020, the airport's annual passenger traffic declined at a higher rate than the annual decrease in the amount of annual wastes and this resulted in the airport recording higher annual amounts of wastes per enplaned passenger in 2020. Figure 5 shows that there were five years during the study period where the airport's annual wastes per enplaned passenger decreased on a year-on-year basis. These annual decreases were recorded in 2012 (−32.59%), 2013 (−75.58%), 2015 (−21.27%), 2016 (−27.02%), and 2017 (−3.7%), respectively (Figure 5). In 2012, 2013, 2015, and 2016, the airport's annual wastes decreased on a year basis, whilst in contrast, the airport's annual passenger traffic increased in

each of these years, and this enabled the airport to reduce its annual wastes per enplaned passenger in each of these years. This was a favorable outcome as it showed that the airport was able to handle greater levels of passenger traffic, whilst at the same time reducing its annual wastes volumes. As discussed below, the airport's total annual wastes have been influenced by the construction works undertaken at the airport, and this in turn, has had an impact on the annual wastes per enplaned passenger. As noted earlier, construction waste materials are treated through an appropriate outside company or alternatively through the airport's resource recovery facility. These measures help to mitigate any adverse impact upon the environment.

Figure 5. Incheon International Airport's annual wastes per enplaned passenger and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [84,86,91,92,94,95].

4.5. Annual construction wastes at Incheon International Airport

Construction waste is typically comprised of the wastes produced from construction works, such as, new build, renovation, demolition works, and road works [96]. It is important to note that there can be heterogeneity in construction activities [97], and this will therefore affect the wastes from the project. Incheon International Airport's annual construction wastes and the year-on-year change (%) from 2010 to 2020 is depicted in Figure 6. Figure 6 shows that the airport's annual construction-related wastes have oscillated quite markedly throughout the study period reflecting the various levels of construction works undertaken at the airport. There were several pronounced spikes in the airport's construction wastes, with the most significant single annual increase being recorded in 2011, when the airport's construction wastes increased by 191.04% on the 2010 levels. There was a further pronounced spike in the airport's construction wastes in 2014, when they increased by

286.03% on the 2013 levels (Figure 6). Figure 6 also shows that there were two smaller but significant increases in construction wastes in 2018 (+69.43%), and 2019 (+32.12%), respectively (Figure 6). During the study period, there were five years where the airport's annual construction wastes decreased on a year-on-year basis. These decreases occurred in 2012 (−2.62%), 2013 (−90.1%), 2015 (−27.1%), 2016 (−38.29%), and 2020 (−51.02%) (Figure 6), reflecting lower levels of construction-related wastes in those years.

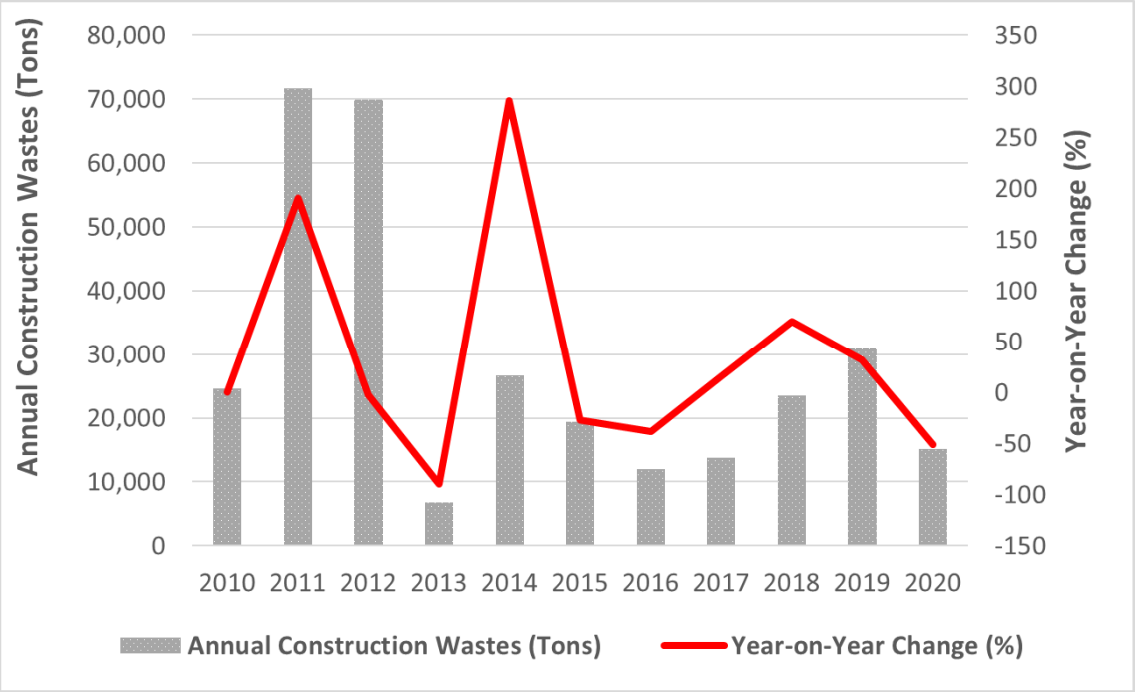

Figure 6. Incheon International Airport's annual construction wastes and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

4.6. Annual designated wastes at Incheon International Airport

At an airport there are wastes that are produced from aircraft refueling, aircraft operations, aircraft, and ground service equipment (GSE) maintenance and equipment and facilities cleaning. Major aircraft overhauls also use toxic chemicals to remove paint, and these wastes pose an environmental threat [25]. Other contaminants originating from an airport's operations or activities include detergent formulations, solids, oils, greases, residues, solvent residues, and heavy metals [98].

In South Korea, hazardous waste is always defined as designated wastes, and such wastes are controlled under the *Solid Waste Management Act* [99]. Also, in South Korea, hazardous wastes that are to be recycled are managed through the "Environmental Impact Assessment of Recycling" (EIARS) system. The "Environmental Impact Assessment of Recycling" (EIARS) system prevents environmental pollution whilst also enabling the active recycling of wastes by surveying and predicting the impact of waste recycling's impact on both human health and the environment. Consequently, the system for managing hazardous characteristics during waste recycling has been

established and operated. Hazardous characteristics are managed in the EIARS system by nine distinct categories: corrosiveness, infectiousness, leaching toxicity, explosiveness, flammability, combustibility, oxidation, reaction with water, and ecotoxicity [100]. According to El-Din M. Saleh [101] (p. 4), "hazardous wastes are classified as hazardous if they exhibit one or more of ignitability, corrosivity, reactivity, or toxicity".

Incheon International Airport's total annual designated wastes and the associated year-on-year change (%) for the period 2010 to 2020 is depicted in Figure 7. As can be observed in Figure 7, Incheon International Airport's annual designated wastes have largely exhibited an upward trend over the study period. This is demonstrated by the year-on-year percentage change line graph, which is more positive than negative, that is, more values are above the line than below. Figure 7 shows that there were three years when the airport's annual designated wastes handled decreased on a year-on-year basis. These decreases occurred in 2012 (−88.62%), 2017 (−1.95%), and 2020 (−9.36%) (Figure 7), with these decreases reflecting lower designated waste volumes at the airport. As can be observed in Figure 7, there was a very significant increase in this metric in 2011, when the airport's annual designated wastes increased by 901.9% from 842 tons in 2010 to a high of 8436 tons in 2011. This substantial increase in 2011 suggests that there was a distinct requirement for hazardous products at the airport in 2011. Figure 7 also shows that there were two smaller annual increases in the airport's designated wastes during the study period. These increases were recorded in 2013 (+27.18%), and in 2019 (+20.46%) (Figure 7). These increases could be attributed to the higher use of hazardous materials in both 2013 and 2019, respectively. In addition, chemical wastes are typically very heterogenous in nature [102], and thus, there can be considerable annual variations in the hazardous wastes produced by a firm.

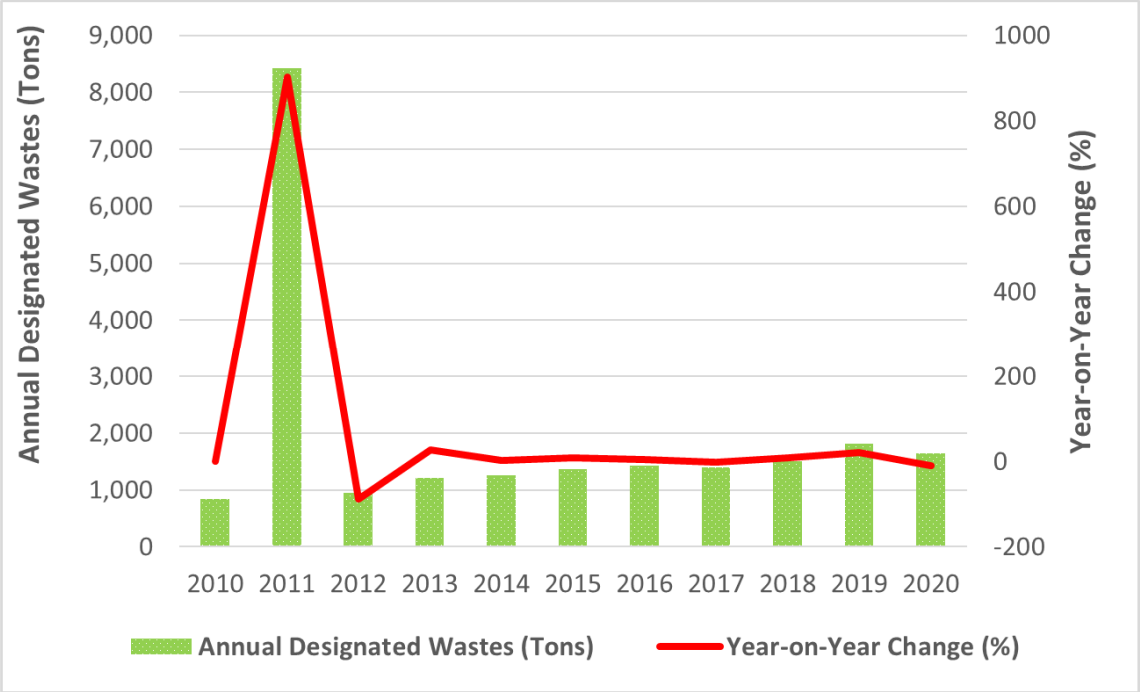

Figure 7. Incheon International Airport's annual designated wastes and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

4.7. Annual general wastes at Incheon International Airport

Incheon International Airport's total annual general wastes and the associated year-on-year change (%) for the period 2010 to 2020 are depicted in Figure 8. Figure 8 shows that Incheon International Airport's annual wastes have exhibited an upward trend throughout the study period. This overall upward trend is demonstrated by the year-on-year percentage change line graph, which is more positive than negative, that is, more values are above the line than below. There was a very pronounced spike in the airport's general wastes in 2011, at which time they increased by 195.36% on the 2010 levels (Figure 8). In 2011, 30461 tons of general wastes were produced at the airport (Figure 8). This significant increase reflected varied waste patterns in 2011. There were five smaller annual increases in the airport's annual general wastes during the study period. These annual increases occurred in 2013 (+9.1%), 2014 (+9.18%), 2015 (+7.54%), 2016 (+11.5%), and 2018 (+15.0%), respectively (Figure 8). These annual increases reflected the annual growth in passenger traffic and aircraft movements in these respective years. Figure 8 also shows that there were three years in the study period where the airport's annual general wastes decreased on a year-on-year basis. These annual decreases were recorded in 2012 (−59.62%), 2017 (−0.49%), and 2020 (−38.29%), respectively (Figure 8). The annual decreases in 2012 and 2017 were very favorable as the airport handled more passenger traffic and aircraft movements in both years, yet it was able to decrease its annual general waste volumes. As previously noted, Incheon International Airport's annual passenger traffic and aircraft movements were adversely impacted by the COVID-19 virus pandemic, and the lower levels of air transport activity, enabled the airport to reduce its annual general wastes in 2020.

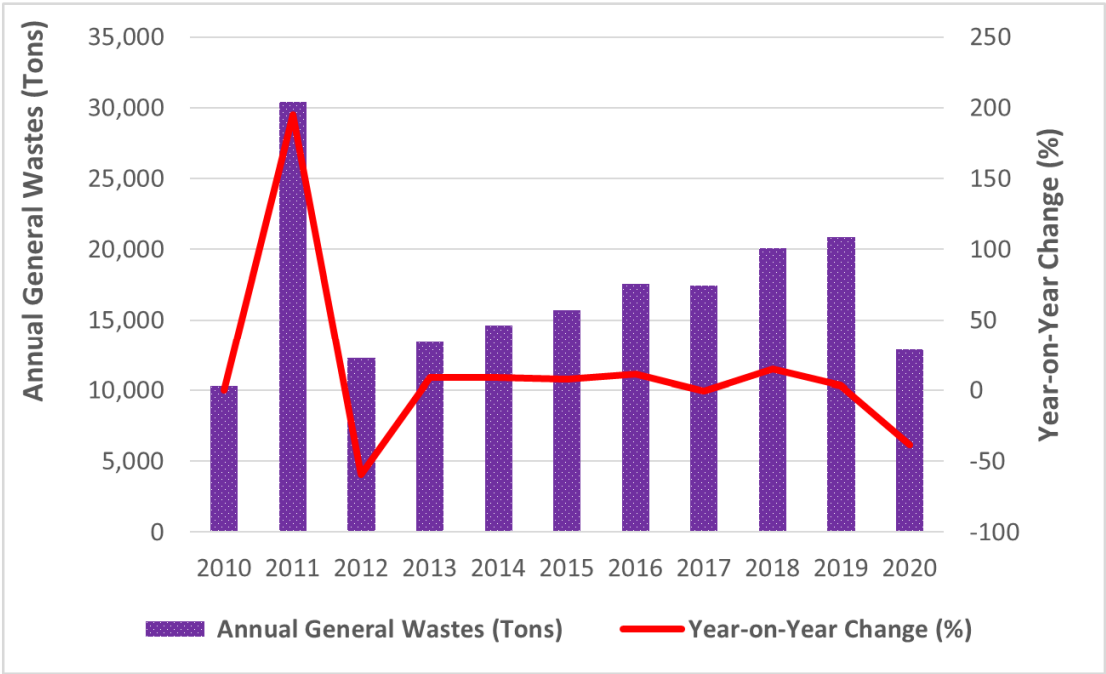

Figure 8. Incheon International Airport's annual general wastes and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

Incheon International Airport's total annual general wastes per enplaned passenger and the associated year-on-year change (%) for the period 2010 to 2020 are depicted in Figure 9. Figure 9 shows that Incheon International Airport's total annual general wastes per enplaned passenger oscillated over the study period. There were two quite pronounced spikes in this metric during the study period, with these spikes being recorded in 2011 (+180.64%), and 2020 (+268.96), respectively (Figure 9). As has been previously noted, the airport's annual general wastes spiked in 2011, and this led to the large increase in this metric in 2011. In 2020, the airport's annual general wastes declined on a year-on-year basis by 38.29%, whilst the airport's passenger traffic declined by 83.06%. As a result, in 2020 there were fewer passengers to spread the annual general wastes over and this led to the significant spike in this metric in 2020. Figure 9 shows that there was a very pronounced annual decrease in this metric in 2012, when it decreased by 63.21% on the 2011 levels. This reason for this annual decrease can be attributed to the very significant reduction in general wastes in 2012 plus the increased passenger traffic handled at the airport in 2012. Figure 9 shows that this metric remained constant at 0.32 kilograms per enplaned passenger from 2012 to 2015. In 2016 and 2017, this metric once again decreased on an annualized basis, at which time it decreased by 6.25% in 2016, and by 6.66% in 2016. In 2016, the airport's annual passenger traffic increased by 17.61%, whilst the airport's annual general wastes increased by 11.5%. Consequently, in 2016, the airport increased its output, that is, passenger traffic, at a greater rate than the growth in general wastes, and this resulted in the annual decrease in this metric in 2016. The same situation applied in 2017 whereby the airport's annual passenger traffic grew faster than the annual general wastes, and thus, the airport was able to lower its annual general wastes per enplaned passenger in 2017. Figure 9 also shows that the airport's annual general waste per enplaned passenger remained constant in both 2018 (0.29 kgs per enplaned passenger) and 2019 (0.29 kgs per enplaned passenger), respectively.

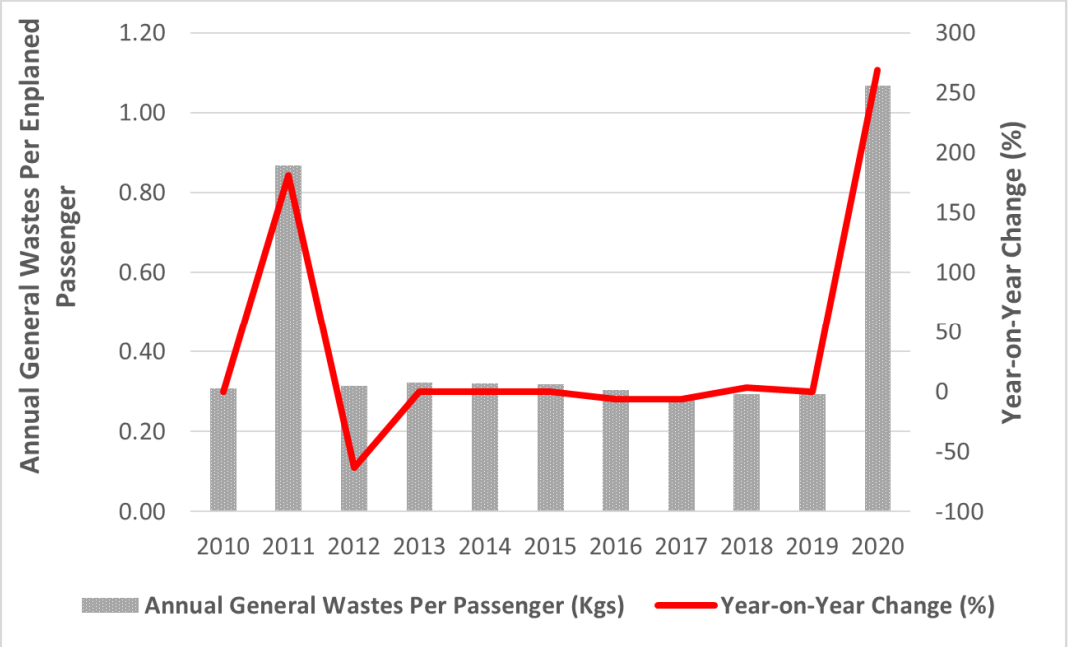

Figure 9. Incheon International Airport's annual general wastes per enplaned passenger and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

4.8. Annual incinerated wastes at Incheon International Airport

At Incheon International Airport, combustible wastes are incinerated and the waste heat from the incineration is captured for further use by the airport [86]. Incineration with energy recovery is regarded as important option to recycling for waste management [103]. According to Buekens [104], "waste incineration is the art of completely combusting waste, while maintain or reducing emissions levels below current emissions standards and, when possible, recovering energy, as well as eventual combustion residues. Importantly, incinerators can be made to avoid air pollution through air pollution control units. The key features of waste incineration include the attainment of a deep reduction in waste volume, obtaining a compact and sterile waste residue, yet at the same time treating a voluminous flow of flue gas whilst deeply elimination a wide array of pollutants [104]. Energy may be recovered from incineration through many ways, for example gas to water heat exchange [105]. The key advantages of the incineration of wastes include a reduction in the volume and weight of wastes that have a high combustible content, incineration enables the destruction of some wastes and detoxification of others, destruction of the organic component of biodegradable waste which disposed to landfill directly generates landfill gas (LFG), the recovery of energy from organic wastes with sufficient calorific value, and the replacement of fossil fuel for energy generation with the consequential advantage of reducing the greenhouse effect [106].

Incheon International Airport's total annual incinerated wastes and the year-on-year change (%) for the period 2010 to 2020 is depicted in Figure 10. As can be observed in Figure 10, Incheon International Airport's annual incinerated wastes exhibited an upward trend from 2010 to 2018, at which time they increased from a low of 7181 tons in 2010 to a high of 16490 tons in 2018. This overall upward trend is once again demonstrated by the year-on-year percentage change line graph, which is more positive than negative, that is, all bar one value is above the line during this period. Between 2010 and 2018, there were four years where the airport's annual incinerated wastes decreased quite significantly on a year-on-year basis. These annual increases occurred in 2011 (+9.81%), 2013 (+26.85%), 2016 (+14.77%), and 2018 (+31.99%), respectively (Figure 10). During these respective years, Incheon International Airport handled greater volumes of passenger traffic and aircraft movements and this higher level of air transport activity could have influenced the types of combustible wastes generated at the airport, and which were deemed suitable for incineration. Importantly, combustible waste is very heterogenous in nature [107], and thus may vary upon the airport's requirements for combustible materials to support its operations. Figure 10 shows that there were three years in the study period where the airport's annual incinerated wastes decreased on a year-on-year basis. These decreases were recorded in 2012 (−7.22%), 2019 (−15.29%), and 2020 (−45.19%), respectively (Figure 10). In both 2012 and 2019, the airport handled increased passenger volumes and aircraft movements, yet at the same time it was able to reduce its incinerated wastes, which is a favorable outcome. As noted earlier, the airport recorded a substantial decrease in its annual passenger traffic and aircraft movements in 2020, and this had a concomitant impact on its wastes.

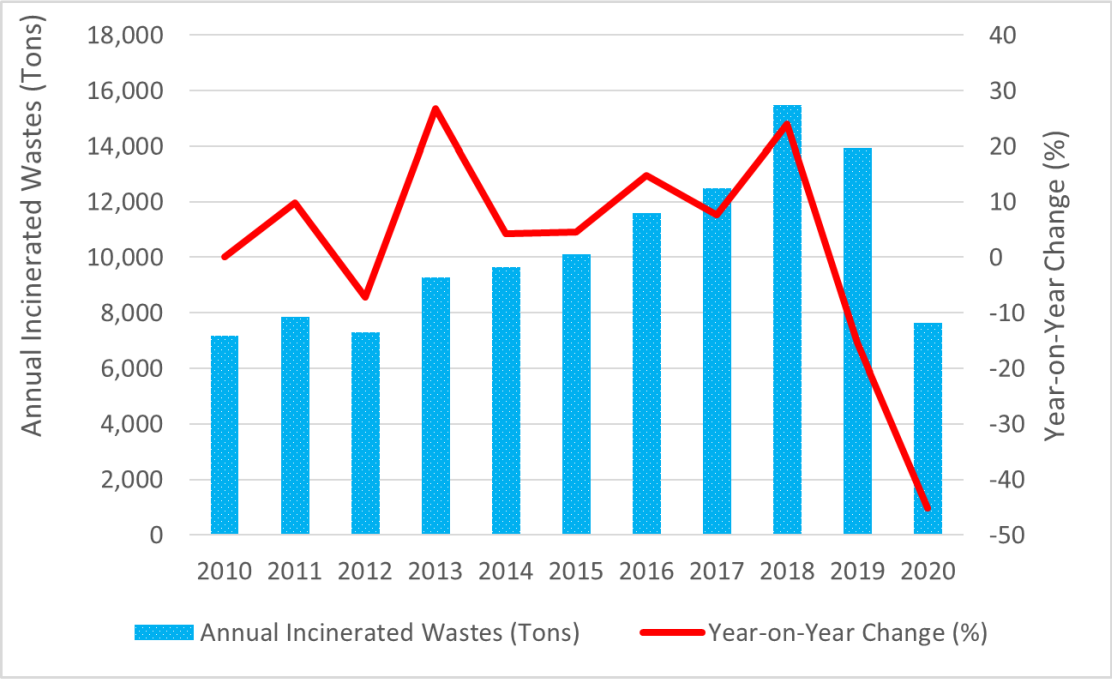

Figure 10. Incheon International Airport's annual incinerated wastes and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

4.9. Annual wastes disposed to landfill at Incheon International Airport

Incheon International Airport's total annual wastes disposed to landfill and the year-on-year change (%) for the period 2010 to 2020 is presented in Figure 11. As can be seen in Figure 11, Incheon International Airport's annual landfill disposed wastes exhibited an upward trend from 2010 to 2018, at which time they increased from a low of 584 tons in 2010 to a high of 2461 tons in 2018. This overall upward trend is once again demonstrated by the year-on-year percentage change line graph, which is more positive than negative, that is, all bar one value is above the line during this period. Figure 11 shows that there were four quite significant annual increase in Incheon International Airport's landfill disposed wastes during the study period. These increases were recorded in 2011 (+15.92%), 2013 (+86.20%), 2018 (+32.90%), and 2020 (+47.45%), respectively (Figure 11). As previously noted throughout this study, Incheon International Airport was able to increase its annual passenger traffic and aircraft movements in 2011, 2013, and 2018, respectively, and these increases had a concomitant impact on the airport wastes in these respective years. In 2020, an increased portion of the types of wastes handled at Incheon International Airport required disposal by landfill. During the study period, there were two years where the airport's annual landfill disposed wastes decreased on a year-on-year basis. These annual decreases occurred in 2012 (−14.32%), and in 2017 (−1.99%), respectively (Figure 11). These decreases are favourable from an environmental perspective as the airport was able to increase its annual passenger traffic and aircraft movements in both 2012 and 2017, whilst at the same time reducing the amount of wastes that required disposal to landfill in both these years. It is important to note that, landfill wastes are heterogenous in

nature [108–110], and this heterogeneity is demonstrated by the annual variance in Incheon International Airport's landfill disposed wastes.

As previously noted, disposal in landfill sites is regarded as the least desirable option in the waste management hierarchy [46–48]. Ultimately, some airport waste must be disposed of. Whilst the waste management decisions such as reducing and reusing materials have the objective of waste minimization and recapturing materials and energy, there may be cases where this is not feasible. In some instances, disposal to landfill (or by incinerator) are often the method of disposal for airport waste that cannot be processed in other ways [111]. Importantly, airports should endeavor to promote effective and efficient waste management based on circular economy principles, for example, by developing processes and procedures that maximize re-cycling, re-use, and waste reduction in construction as well as airport operations [112]. Furthermore, the objective of the circular economy is to transform the economy into a circular operating system that improves resource efficiency and involves resource recovery and re-use [113,114]. For a firm to achieve the benefits of a circular economy approach, the following steps need to be undertaken reuse, recycling, recovery, and waste prevention [115].

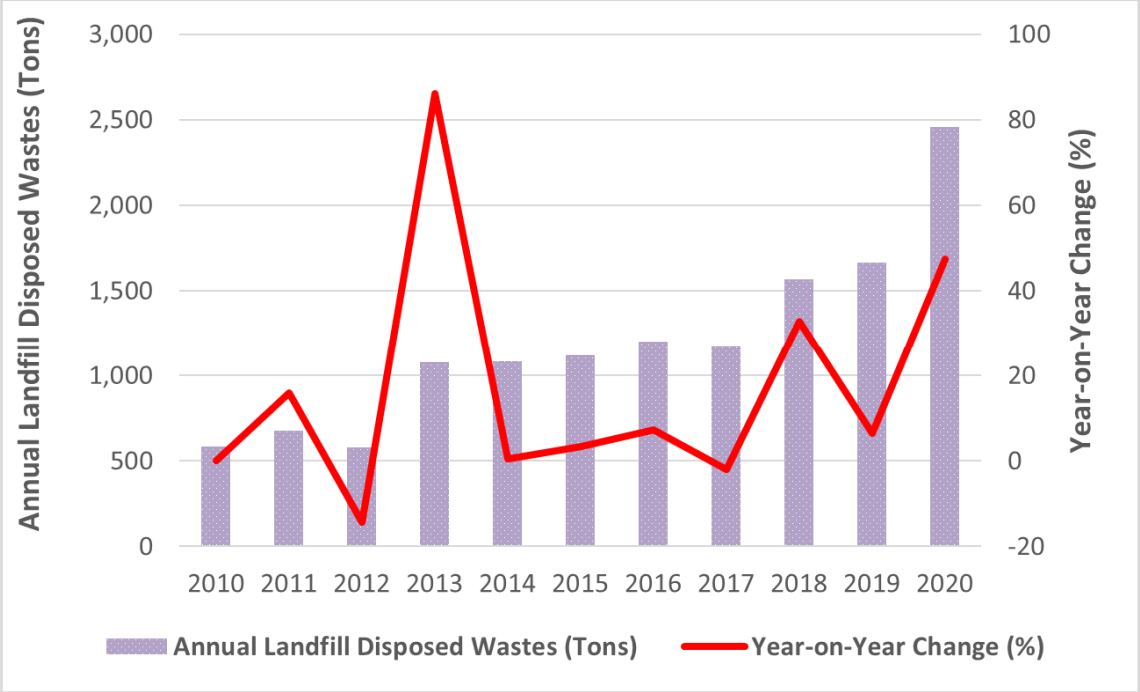

Figure 11. Incheon International Airport's annual wastes disposed to landfill and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

A further important airport environmental efficiency measure is the proportion of wastes disposed to landfill sites [19,93]. Incheon International Airport's annual wastes disposed wastes as a share of the airport's total annual wastes and the year-on-year change (%) from 2010 to 2020 is depicted in Figure 12. As can be observed in Figure 12, this metric has fluctuated quite markedly throughout the study period. Figure 12 shows that there were two very significant annual increases in this metric during the study period. These significant annual increases were recorded in 2013

(+615.71%), and in 2020 (+166.45%), respectively (Figure 12). In 2013, the airport's annual wastes decreased by 74.08%, however, the annual wastes disposed to landfill increased by 86.20%, and this, in turn, resulted in the landfill wastes as a portion of total wastes increasing in 2013. In 2020, the airport's landfill disposed wastes increased on a year-on-year basis whilst construction wastes, designated wastes, general wastes, and incinerated wastes all decreased on an annualized basis. As a result, landfill wastes accounted for a higher share of the airport's annual wastes in 2020. During the study period, there were five years where this metric decreased on a year-on-year basis. These annual decreases occurred in 2011 (−62.57%), 2014 (−49.10%), 2017 (−7.21%), 2018 (−51.66%), and 2019 (−10.91%), respectively (Figure 12). In 2011, the airport's annual wastes increased by 208.99% (due to a lot of extra construction-related wastes) and landfill wastes increased by 15.92%. As a result, landfill disposed wastes as a share of total wastes decreased quite significantly. The same situation applied in 2014 whereby total annual wastes increased very significantly (+97.72%), whilst the airport's annual landfill disposed wastes increased slightly (+0.46%), and this resulted in the decrease in the landfill disposed wastes as a share of total wastes in 2014. The reason for the decrease in this metric in 2017 could be attributed to the annual decrease in landfill disposed wastes in 2017 together with the overall increase in wastes of 5.70%. In 2019, the airport's annual landfill disposed wastes increased by 6.50%, which was considerably lower than the annual growth in total wastes of 19.19%. The differences in these growth rates resulted in the decrease in the airport's landfill wastes as a share of total wastes in 2019 (Figure 12).

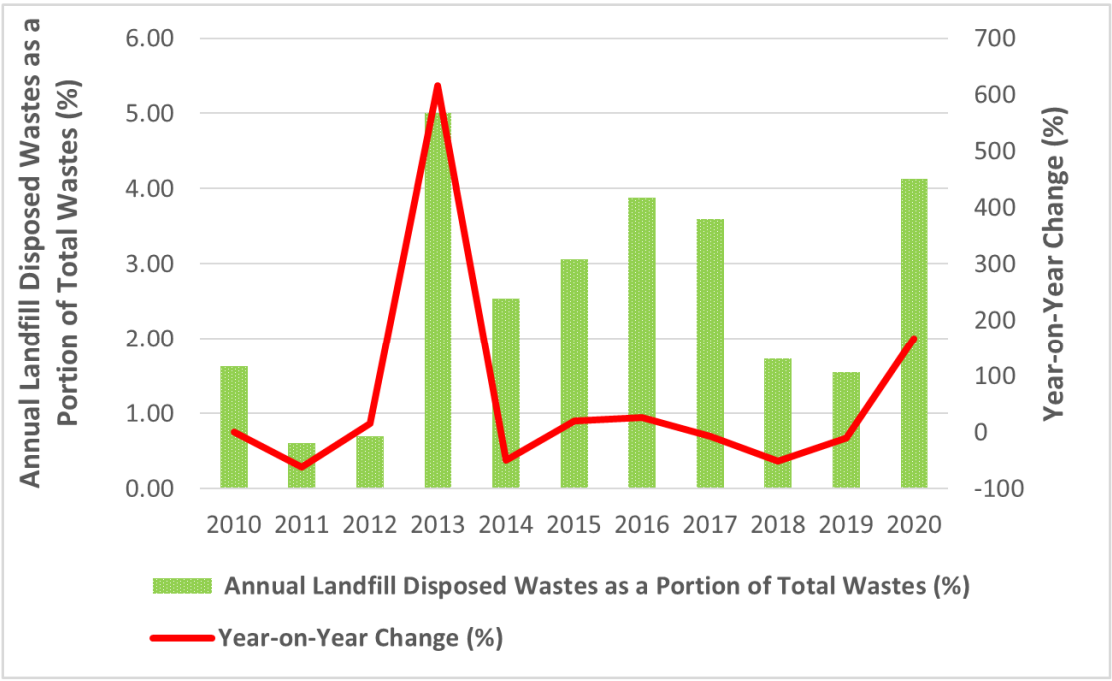

Figure 12. Incheon International Airport's annual wastes disposed to landfill as a share of total annual wastes and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

4.10. Annual recycled wastes at Incheon International Airport

Prior to examining Incheon International Airport's annual recycled wastes, it is important to note that airport wastes are heterogenous in nature [18,19]. Furthermore, airlines, a key stakeholder in the air transport industry value chain, wastes can also be heterogenous in nature [116]. Consequently, the wastes handled by an airport may not always be suitable for recycling, Incheon International Airport's total annual recycled wastes and the associated year-on-year change (%) for the period 2010 to 2020 is depicted in Figure 13. Figure 13 shows that Incheon International Airport annual recycled wastes have fluctuated quite markedly throughout the study period. Figure 13 shows that there was a very significant increase in the amount of waste recycled in 2011, at which time it increased by 168.38% on the 2010 levels. There was a further significant increase in the airport's recycled wastes in 2014, at which time it increased by 184.58% on the 2013 levels. The very significant increases in the airport's recycled wastes in both these years has important environmental benefits. Recycling wastes reduces the amount of waste sent to landfills and incinerators, recycling wastes also prevents pollution by reducing the requirement to collect new raw materials, saves energy, and recycling of wastes conserves natural resources [117]. Incheon International Airport was once again able to increase its recycled wastes in both 2018 and 2019, respectively. In 2018, the airport's annual recycled wastes increased by 46.86% on the 2017 levels (Figure 13). In 2019, the airport's annual recycled wastes increased by 36% on the 2018 levels (Figure 13). Wastes are heterogenous in nature, and there can be a significant variation in the composition of wastes [48]. Thus, the significant increases in recycled wastes at the airport in 2011, 2014, 2018 and 2019 suggest that the composition of the wastes produced at the airport provided the opportunity for the airport to implement its strategy of recycling wastes wherever possible. Figure 13 shows that there were five years in the study period where the airport's annual recycled wastes decreased on a year-on-year basis suggesting that the composition and characteristics of the wastes in these respective years did not permit their recycling for subsequent reuse. These annual decreases occurred in 2012 (−0.02%), 2013 (−85.12%), 2015 (−20.41%), 2016 (−28.24%), and 2020 (−48.51%), respectively (Figure 13). These annual decreases could be attributed to differences in the types of wastes produced in these years at the airport, with some wastes not being suitable for recycling.

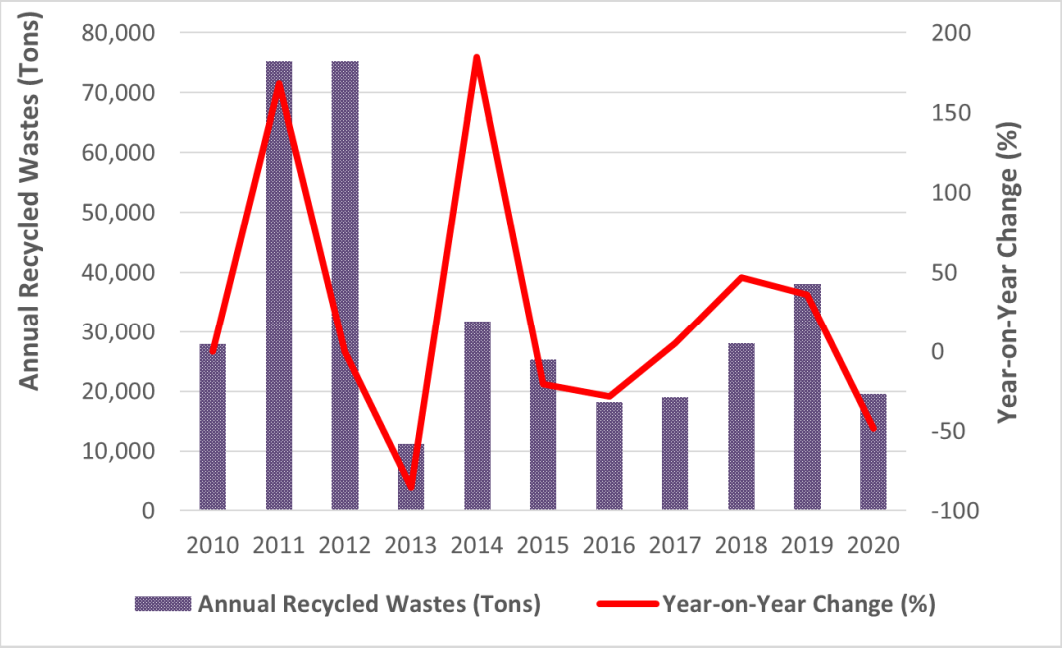

Figure 13. Incheon International Airport's annual recycled wastes disposed and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

A further environmental efficiency measure is the annual volume of recycled wastes per enplaned passenger is depicted in Figure 14 [19,93]. As can be observed in Figure 14, Incheon International Airport's annual recycled wastes per enplaned passenger have oscillated throughout the study period. Figure 14 shows that there were three very pronounced spikes in this metric, with these spikes being recorded in 2011 (+155.95%), 2014 (+159.25%), and 2020 (+201.85%), respectively. The large increase in this metric in 2011 could be attributed to the very significant increase in recycled wastes in 2011 (+168.38%), which grew more quickly than the passenger growth in 2011. However, this situation resulted in the strong growth in recycled wastes per enplaned passenger in 2011, which was a favorable outcome for the airport. A similar situation occurred in 2015, at which time the airport was able to significantly increase its recycled wastes (+184.58%), whilst at the same time being able to handle higher levels of passenger traffic. This enabled the airport to significantly increase the amount of recycled wastes per enplaned passenger in 2014. In 2020, the airport's passenger traffic decreased by 83.06% on an annualized basis, whilst the recycled wastes decreased in the same year by 48.51%. This situation led to the large increase in recycled wastes per enplaned passengers in 2020. Figure 4 shows that there were two smaller, but still significant, increases in this metric throughout the study period. These increases were recorded in 2018 (+32.25%), and 2019 (+31.7%), respectively (Figure 14). In both 2018 and 2019, the airport was able to considerably increase its recycling of wastes whilst also accommodating higher levels of passenger traffic. In both these years, the growth in the airport's recycled wastes was higher than the passenger traffic growth rates, and this in turn, led to the higher increase in the amount of recycled wastes per enplaned passenger in both 2018 and 2019, respectively. Figure 14 shows that there has been an upward trend in this metric during the latter years of the study period, that is, from 2017 to 2020, which once again shows that the airport has been able to handle higher passenger volumes and, at the same time,

increase the recycling of wastes at the airport. During the study period, there were four years where the annual recycled wastes per enplaned passenger decreased on a year-on-year basis. These annual decreases occurred in 2012 (−10.23%), 2013 (−86.01%), 2015 (−27.14%), and 2016 (−39.21%) (Figure 14). In each of these years, the airport's annual recycled wastes decreased on a year-on-year basis, whilst its annual passenger traffic increased, this, in turn, led to the decrease in recycled wastes per enplaned passenger in these respective years. It is important to note that an airport's recycled wastes can vary on a year-on-year basis [18,19].

Figure 14. Incheon International Airport's annual recycled wastes per enplaned passenger and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

Another important waste management efficiency measure used in the airport industry is the portion of recycled wastes as a share of total wastes produced at the airport [19,93]. Incheon International Airport's annual recycled wastes as a share of total wastes (%) and the year-on-year change (%) for the period 2010 to 2020 is presented in Figure 15. As can be observed in Figure 15, Incheon International Airport's annual recycled wastes as a share of total wastes (%) has oscillated throughout the study period. During the study period, there were three years where the airport's annual recycled wastes increased as a proportion of total wastes. These annual increases occurred in 2012 (+33.0%), 2014 (+43.91%), and 2019 (+14.12%), respectively (Figure 15). The reason for the increase in this metric in 2012 can be attributed to recycled wastes declining at a smaller rate than the other types of wastes handled at the airport in 2012. In 2012, construction wastes, designated wastes, general wastes, incinerated wastes, and wastes disposed to landfill all declined on a year-on-year basis, with recycling wastes declining by 0.02% in 2012; this was the smallest annual increase and led to the recycled wastes accounting for a higher share of the airport's total annual wastes in 2012. In 2014, the airport handled a significantly greater amount of recycled wastes (+184.58%), which also led to recycled wastes accounting for a higher share of the airport's total annual wastes in 2014.

In 2019, the airport's recycled wastes increased at a higher rate than the other wastes handled at the airport, and this too resulted in the annual recycled wastes higher share of the airport's total annual wastes in 2019.

Figure 15 shows that there were two quite significant annual decreases in this metric during the study period. These annual decreases were recorded in 2013 (−42.61%), and 2018 (−46.68%), respectively (Figure 15). As previously noted, the airport's annual recycled wastes decreased on a year-on-year basis in 2013, and this decrease impacted the airport's recycled wastes as a share of total wastes. In 2018, there was a variation in the wastes produced at the airport. This variation is demonstrated by the varying growth rates for each waste source. Recycled wastes increased at a lower rate than construction wastes (+69.43%), and consequently, this resulted in the decrease in recycled wastes as a share of total wastes. Figure 15 also shows that there were two slightly smaller annual decreases in this metric throughout the study period. These smaller annual decreases occurred in 2011 (−13.14%), 2015 (−7.30%), 2016 (−15.32%), and 2020 (−6.93%), respectively (Figure 15). In 2011, the airport recorded very substantial increases in its construction wastes, designated wastes, and its general wastes, and this resulted in recycled wastes accounting for a smaller share of the airport's total annual wastes. As previously noted, the airport's annual recycled wastes decreased on a year-on-year basis in 2015, 2016, and 2020, and this, in turn, resulted in recycled wastes accounting for a lower share of the airport's total annual wastes in these respective years.

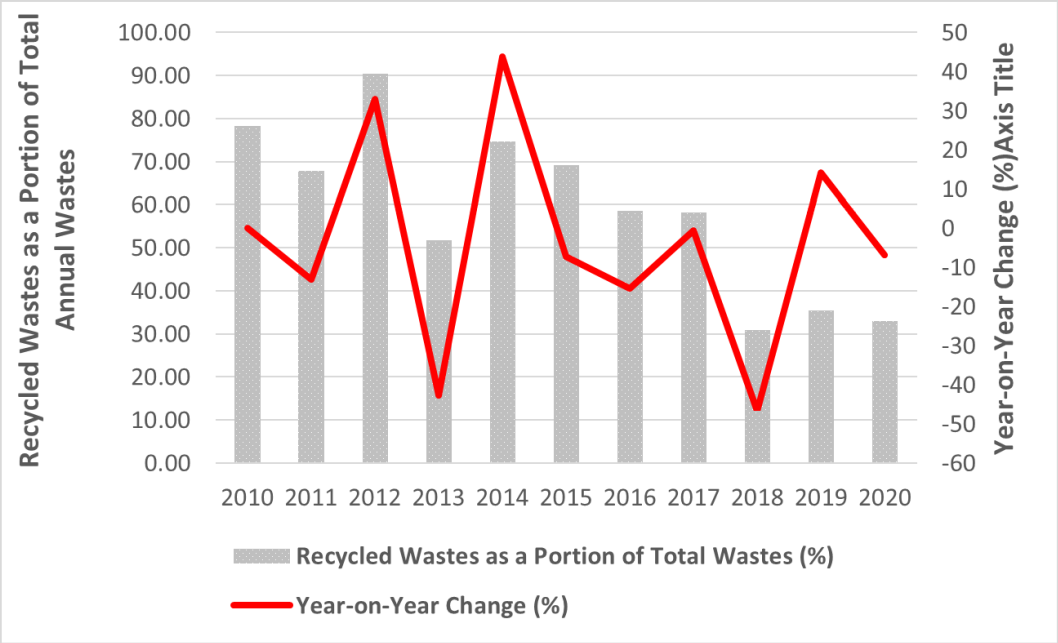

Figure 15. Incheon International Airport's annual recycled wastes as a share of total annual wastes and the year-on-year change (%): 2010–2020. Source: Data derived from Incheon International Airport Corporation [86,91,92,94,95].

5. Conclusions

One of the most significant environmental challenges confronting airports is their sustainable management of solid wastes. The strong growth in passenger traffic together with the expansion of

airport activities has now greatly increased the types and quantities of waste generated at airports. Considering the environmental impacts of wastes, airports now need to handle their wastes in an environmentally sustainable manner. One such airport that handles its wastes in an environmentally sustainable manner is Seoul's Incheon International Airport. Considering this, Incheon International Airport was selected as the case airport for the present study. To achieve the research objectives, an in-depth longitudinal case study approach underpinned the study. The data gathered for the study was analyzed by document analysis. The study covered the period 2010 to 2020.

The case study revealed that Incheon International Airport has six discrete types of wastes: construction wastes, designated wastes, general wastes, incinerated wastes, landfill disposed wastes, and recycled wastes. Incheon International Airport operates a recycling center that is equipped with can compressors and separators for operation which ensures an efficient resource cycling system. The airport also uses incinerator to burn combustible wastes. A resource classification treatment facility has been constructed and this facility is used to efficiently manage and enhance the recycle rate of wastes from the airport's facilities. In the case of wasted construction items, these wastes are handled by external waste treatment firms or alternatively they are incinerated by the airport. Following waste sortation, recyclable materials are processed depending on their types. Thus, the case study revealed that Incheon International Airport aims to recycle wastes wherever possible. The re-use of the heat from the incineration of wastes is a further sustainability measure implemented by the airport. The case study also found that some of the airport's annual wastes need to be disposed to landfill. However, landfill wastes only account for a small share of the airport's annual wastes.

The airport's total annual wastes oscillated throughout the study period reflecting differing waste patterns at the airport. During the study period, Incheon International Airport undertook various construction projects and the wastes produced from these projects were often quite large. This was especially so in 2011 and 2014. During the study period, Incheon International Airport's construction projects produced a total of 315279 tons of construction wastes. This was the airport's second largest waste stream during the study period. The airport's annual construction wastes oscillated throughout the study period, reflecting the scale of the projects undertaken at the airport. Like other airports, Incheon International Airport also handles hazardous or designated wastes. During the study period there was a total of 21924 tons of designated wastes handled by the airport. The airport's designated wastes largely displayed an upward trend during the study period, reflecting the variations in the airport's use of hazardous materials. This waste stream was the fifth largest source of wastes handled by the airport during the study period. Once again, like other airports, general wastes were produced at the airport as a by-product of its operations. The case study revealed that these wastes have largely exhibited an upward trend during the study period and reflected the airport's growth in passenger traffic and aircraft movements, both of which produce assorted general wastes. During the study period there was a total of 185800 tons of general wastes handled by the airport. This represented the third largest source of wastes handled by the airport during the study period. As previously noted, a key waste management strategy adopted by the airport is to incinerate suitable combustible wastes, and subsequently, reuse the waste heat to heat facilities. The case study found that there was a total of 112677 tons of waste that was incinerated at the airport and these wastes largely displayed an upward trajectory during the study period. Incinerated wastes were the fourth largest source of wastes handled by the airport during the study period. Once again, Incheon International Airport is like many other airports that has wastes requiring final disposal to landfill. These landfills disposed wastes displayed an upward trend throughout the study period. There was a

total of 13206 tons of wastes disposed to landfill during the study period. Landfill wastes were the sixth most significant source of wastes handled by the airport during the study period. The final type of wastes handled at Incheon International Airport is its recycled wastes. The case study found that over the study period these wastes oscillated quite markedly, thereby displaying their heterogeneity. During the study period there was a total of 370265 tons of wastes recycled by the airport. This represented the largest source of wastes handled by the airport during the study period. According to the waste management hierarchy, re-use and recycling are the best methods of dealing with unavoidable waste. Incheon International Airport's policy to recycle wastes wherever possible helps to mitigate their environmental impact, whilst at the same time helping the company to achieve its goal of being a "green" airport. Finally, the case study revealed that there was a very significant reduction in both passengers and aircraft movements in 2020, and consequently, the airport's waste streams also decreased on a year-on-year basis, with the only exception to this trend being landfill wastes, which increased by 47.45% in 2020.

In general, Incheon International Airport has proven to be an interesting case study for examining airport sustainable waste management. While many of the strategies are typical in the context of sustainable waste management, the review of the initiatives here will hopefully help future airport developments ensure that adopt sustainable waste management strategies and systems. The primary waste handling methods, that is, recycling and incineration of wastes, could be implemented by other airports, who may be aiming to manage their wastes in a more environmentally sustainable manner. The recycling of wastes reduces the amount of waste sent to landfills and incinerators, saves energy, and helps to mitigate any potential pollution from the waste disposal. Incineration of wastes reduces the amount of wastes to be disposed to landfill, and produces heat that can be used in an airport's buildings. A limitation of the present study was that it was restricted to a single site: Incheon International Airport. Should comparable airport waste data become available then a future study could benchmark the waste management efficiency and waste handling methods vis-à-vis another major Asian-based airport.

Conflict of interest

The author declares that there was no conflict of interest in this study.

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