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Material flow analysis & City Blueprint Framework of Singapore

Bridging Science to Practice

Report

Material flow analysis & City Blueprint Framework of Singapore

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Summary

This report describes the desktop study aimed to identify opportunities for enhancing the circular economy, which is already developing in promising ways in the Netherlands, allowing for demonstration and implementation opportunities in Singapore, as well as generating a mutual learning between the two countries.

Singaporean Ministries and governmental agencies are currently developing a shared vision about the best way forward for a zero waste nation and circular economy in Singapore in addition to the Sustainable Singapore Blueprint. They are looking for support from the Netherlands because of our internationally recognised position as a frontrunner in this field. Moreover, there are clear similarities between Singapore and the Netherlands. Both countries have limited natural resources and land space, they are densely built, and have ageing populations. There is therefore pressure on liveability and productivity. A systematic understanding of water resources and waste flows constitutes an important step towards a circular economy.

Accordingly, in order to better understand both the Singaporean and Dutch approach to integrated water resources management (IWRM), waste streams and the potential for circularity, KWR Water Research Institute was engaged by the Netherlands Enterprise Agency (rvo.nl) as part of the Knowledge to Knowledge (K2K) project under the Partners for International Business (PIB) programme to produce an updated Trends and Pressures Framework (TPF) and a City Blueprint Framework (CBF) and to perform a material flow analysis (MFA) for both Singapore and the Netherlands. These three tools (TPF, CBF and MFA) will be instrumental for the identification of opportunities in the area of the circular economy. They will also be helpful in identifying challenges that could be tackled in Singapore by businesses, governmental organisations and knowledge institutes from the Netherlands.

From the assessment of the TPF, it was observed that both Singapore and Dutch cities face pressures related to flood risk and have relatively little concern with respect to social, financial or governance aspects. This means that in term of policy measures and urban planning, the similarity in required technologies and management solutions is high and exchange of the best practices can therefore be lucrative and meaningful.

The CBF's assessment of urban IWRM found that the largest learning potential that Dutch cities can offer Singapore may be with respect to recovery and reuse of resources from solid waste and wastewater. In the light of Covid-19 as well as trafficking and production of illicit drugs, sewer epidemiology also plays an increasingly important role in the Netherlands in addressing both issues. This forms another promising learning opportunity that Dutch cities can offer Singapore.

The development and application of material flows for four selected waste streams - namely incinerator bottom ash, food waste, plastics and materials in the water cycle – provided valuable insights into business opportunities in Singapore, the Netherlands and Singaporean-Dutch collaboration's that can foster the circular economy. The MFA identified challenges and opportunities that need to be addressed by businesses, governmental organisations and knowledge institutes.

- A significant amount of waste either in stock (landfilled) or converted as waste to energy that could be (profitably) recycled and reused. The Netherlands is leading in many respect when it comes to waste recycling and could offer support in the form of knowledge and expertise. This is particularly the case for food waste and plastic recycling and materials recovery in the water cycle.
- Similarly, Singapore is initiating some recycling efforts in its transition to a circular economy that could very well benefit the Netherlands, namely in water recycling and Incinerator Bottom Ash. Establishing a platform where the knowledge, learning and experiences can be shared could facilitate such exchange.

- Finally, Singapore is well poised to use the international playing field to give momentum to the circular economy transition, namely in Asia. With the results of this study, Dutch businesses, including Knowledge Institutes, are able to identify future business opportunities related to the Zero Waste objectives (circular economy) in Singapore. There is Singaporean interest in the Green Deal approach of the Netherlands. A starting point could be the Green Deal Circular Procurement and expanding the Material Flow Analysis conducted in this research by expanding waste flow monitoring in Singapore. In this way, conducting a detailed MFA for Singapore to adequately quantify the economic value of waste that can potentially be recycled and/or exported as raw materials for other products.

List of acronyms

BCI	Blue City Index
CBF	City Blueprint Framework
GL/a	Giga litres per annum
IBA	Incinerator Bottom Ash
IWRM	Integrated Water Resources Management
K2K	Knowledge to Knowledge
MFA	Material flow analysis
NEA	National Environment Agency
PIB	Partners for International Business
ReCirc Singapore	Joint development of resource recovery technology for circular economy
RVO	Netherlands Enterprise Agency
t/a	Tons per annum
TPF	Trends and Pressures Framework

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1 Introduction

KWR Water Research Institute was engaged by the Netherlands Enterprise Agency (rvo.nl) as part of the Knowledge to Knowledge (K2K) project under the Partners for International Business (PIB) programme.

Singaporean Ministries and governmental agencies are currently developing a shared vision about the best way forward for a circular economy in Singapore in addition to the Sustainable Singapore Blueprint. They are looking for support from the Netherlands because of our internationally recognised position as a frontrunner in this field.

Moreover, there are clear similarities between Singapore and the Netherlands. Both countries have limited natural resources and land space, they are densely built, and have ageing populations. As a consequence, there is great pressure on liveability and productivity. A systematic understanding of water resources and waste flows constitutes an important step towards a circular economy.

However, a clear picture of Integrated Water Resources Management (IWRM) performance and material/waste flows (food and plastic), and a comparison with the Dutch situation, is not yet available. Information of this kind will help Singapore to address its challenges in relation to the circular economy and waste management. Furthermore, this information will also help to identify business opportunities for Dutch companies. ReCirc Singapore focuses on a few circular-economy pillars. A material flow analysis (MFA) is currently missing and it will help to determine potential projects. Dutch governmental agencies, knowledge institutes and companies have established a unique partnership to work on creating circular solutions in the PIB programme ReCirc Singapore. Participants in the ReCirc Consortium are water utility Waternet, national public work authority Rijkswaterstaat, companies Witteveen+Bos, Nijhuis Industries, Blue Phoenix Group, Paques, CirTec, Asia Pacific Breweries, Heineken, Organic Village and Upp! UpCycling Plastic. Research institutes that participate are AMS institute with Delft University of Technology & WUR and KWR.

1.1 Project objective

The project provides clear insights into the performance and bottlenecks, main social, environmental and financial aspects, and material flows related to food waste, plastic, the water cycle and incinerator bottom ash in Singapore by comparison with the Netherlands.

The aim is to develop a single integrated, sustainable zero-waste solution with Singaporean partners. The ReCirc partnership aims to further the transition from a linear to a circular economy, not just in Singapore and the Netherlands but also worldwide. The objective is to promote innovative entrepreneurship and business opportunities for Singaporean and Dutch companies, targeting topics related to resource recovery from waste and used water, namely for the following streams.

- food waste systems
- plastic waste
- incinerator bottom ash
- resource recovery from the water cycle

In fulfilling this objective, this report provides a fully updated Trends and Pressures Framework (TPF) and a City Blueprint Framework (CBF) of Singapore and several Dutch cities. The TPF will summarise the main social, environmental, financial and governance aspects that form boundary conditions in which cities have to operate. The CBF on the other hand, provides an overview of a city’s IWRM performance and its bottlenecks. The CBF indicators break down into the following seven categories: water quality, solid waste treatment, basic water services, wastewater treatment, infrastructure, climate robustness and governance.

Expanding on this baseline assessment, a systematic overview of material flows will be instrumental for the identification of opportunities in the area of the circular economy, which is already developing in promising ways in the Netherlands, allowing for demonstration and implementation opportunities in Singapore. These tools will also be helpful in identifying challenges that could be tackled in Singapore by businesses, governmental organisations and knowledge institutes from the Netherlands.

1.2 Approach to meet the project objective

A desktop research was undertaken to achieve the project objective. The existing Trends and Pressures Framework (TPF) and the City Blueprint Framework (CBF) have been fully updated and applied to better understand the Singaporean approach to IWRM, waste streams and the potential for circularity. Data for the CBF have been obtained from KWR as well as from Singaporean organisation using the questionnaires that are part of the City Blueprint Approach (Koop and Van Leeuwen 2020 a,b,c). Singaporean and Dutch organisations and partners have also provided available data on the relevant streams, namely food waste, plastic, incinerator bottom ash and resources in the water cycle. This approach has also enhanced the cooperative situation and stimulate further knowledge exchange and prospective future collaboration. KWR collected and processed the data and made a comparison of the results from both countries.

For the MFA data, KWR developed the mass flow Excel spreadsheets with the flow diagrams to illustrate the flow of the four waste streams investigated in this study. These mass flow spreadsheets were sent to the relevant key partners including the ReCirc partners to seek their collaboration and input into collecting the data needed for the MFA. This was followed up by several meetings with the key partners to discuss and confirm the data set. In addition, some data were obtained from the literature, from both the Netherlands and Singapore government websites, and public reports released. Although a lot of the data needed could be obtained, there are some data gaps especially in Singapore where the individual values making up the total were not available. Several attempts were made to access and obtain these individual data but in vain. This could due to the fact that these data are not available or not yet collected to that level of detail. There could therefore be an opportunity to develop future projects to collect these missing data. These future studies could be jointly conducted by research institutes both in the Netherlands and Singapore.

1.3 Key result areas

Three key result areas have been identified in this project. They are:

1. An insight into the TPF and CBF comparing Singapore and several cities in the Netherlands, material flows related to food waste, plastic, incinerator bottom ash and the resources in the water cycle in Singapore by comparison with the Netherlands, and the performance and bottlenecks, the main social, environmental and financial aspects based on the TPF analysis of Singapore.

2. Business opportunities and recommendations for the Dutch sector will be derived from the research.

3. A final public report with all results will be published and presented to the Dutch and Singapore sectors.

2 Identifying the learning potential for improved water management

2.1 Brief introduction City Blueprint Approach

In order to identify specific opportunities to exchange best practices, technologies, policies and management experiences between Singapore and cities in the Netherlands, the City Blueprint indicator assessment methodology results are compared. The City Blueprint Approach consists of three complementary frameworks (Figure 1). This report will make use of the first two frameworks: the Trends and Pressures Framework and the City Blueprint performance Framework.

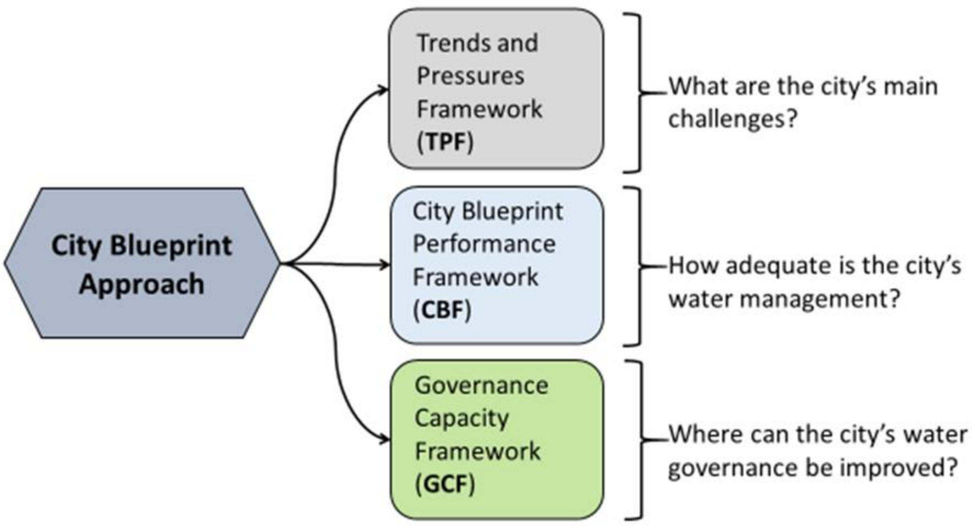

Figure 1 The City Blueprint Approach consisting of three complementary frameworks (Koop and Van Leeuwen, 2020a,b,c). This report makes use of the Trends and Pressures Framework and City Blueprint performance Framework to identify opportunities to exchange best practices, technologies, policies and management experiences between Singapore and cities in the Netherlands.

The TPF provides a baseline overview of the key social, environmental, financial and governance challenges that these cities may face. The framework consists of 24 indicators that are scored from 0 (no concern) to 10 (great concern). The indicators are scored in a transparent, simple and intelligible fashion through an online available questionnaire: https://library.kwrwater.nl/publication/61396712/. The indicators are scored in a transparent, simple and intelligible fashion through an online available questionnaire: The CBF consists also of 24 indicators and provides a comprehensive overview of integrated urban water management in a city. As such, the indicators are divided over seven broad categories: I basic water services, II water quality, III wastewater treatment, IV water infrastructure, V solid waste, VI climate adaptation and VII management and action plans. The indicators are scored from 0 (poor performance) to 10 (high performance) through the use of publicly available data and information validated and acquired with local authorities including water utilities, municipalities, flood risk authorities, waste companies and others. The geometric mean of the indicators is the Blue City Index (BCI). The indicators are scored in a transparent, simple and intelligible fashion through an online available questionnaire: https://library.kwrwater.nl/publication/61397318/.

The assessment has been widely accredited through the assessment of 125 cities in 53 countries across the globe (Figure 2) which are published in over 25 peer-reviewed publications (for a publication overview see: https://www.ipr.northwestern.edu/our-work/research-tools-apps/water-insecurity/). Recently, the methodology has been revised and as such this report provides updated assessments of Singapore in comparison with the Dutch cities. Based on this assessment it aims to identify the most viable opportunities for mutual learning between Singapore and the Netherlands in the area of urban water management. The most recent publications comprise the cities of Bandung (Rahmasari et al., 2021) and Antwerp (Huyghe et al., 2021).

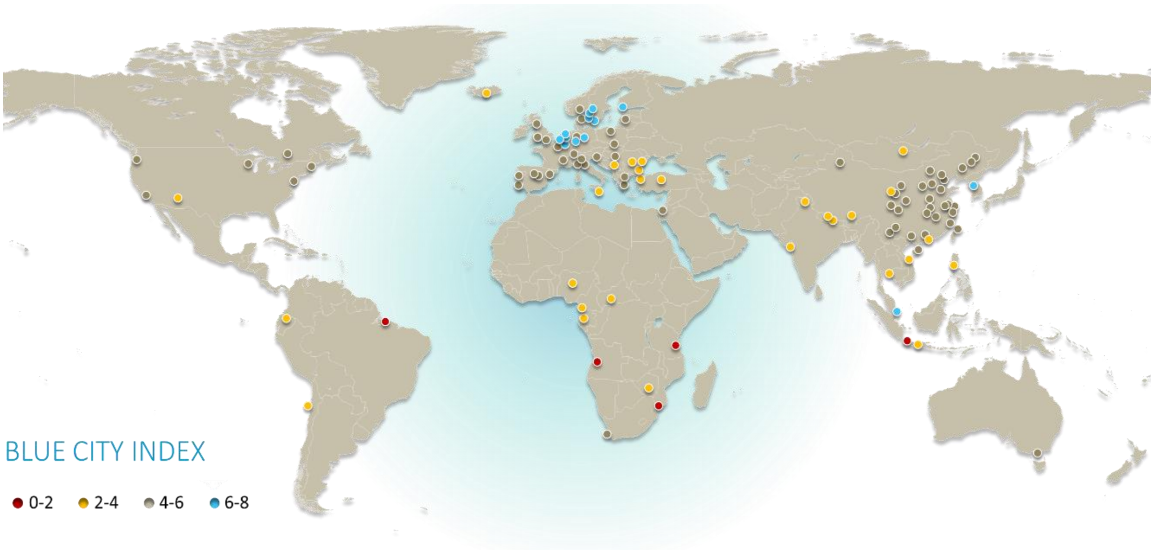

Figure 2 The overall score of the 24 water management indicators is the Blue City Index which is scored from 0 (poor performance) to 10 (high performance). A total of 125 cities have been assessed across the globe.

In total, 10 Dutch cities have been assessed by the City Blueprint methodology: Amsterdam (BCI= 8.7), Groningen (BCI= 7.2), Dordrecht (BCI= 7.1), Leeuwarden (BCI= 5.9), Nieuwegein (BCI= 6.8), Rotterdam (BCI= 6.7), Maastricht (BCI= 6.6), Utrecht (BCI= 6.1), Venlo (BCI= 5.9) and Eindhoven (BCI= 5.8). Singapore's BCI is 8.1 points. In order to identify the learning potential between Singapore and Dutch cities, the Dutch cities of Amsterdam, Groningen, Dordrecht and Rotterdam are included in this assessment because they have comparable scores and are not too small in terms of number of inhabitants. Both aspects are considered important for successful exchange of best practices, technologies, policies and management experiences that are reasonably compatible.

2.2 Results: comparing Singapore and the Netherlands

Trends and pressures

In cities across the globe, local water managers can face social, environmental, financial or governance pressures that may hamper an optimal performance in terms of water management performances. When comparing water management performances of cities, it is essential to take into account the challenges that are imposed on water managers. First of all, it may affect their level of performances. Second and perhaps most importantly, cities that face similar challenges are more likely to require similar solutions and therefore have a more meaningful exchange of knowledge, experiences and have higher chances of forming mutual business opportunities. Therefore, the TPF has been developed to provide a baseline overview of the key challenges that these cities face. The TPF framework consists of 24 indicators that are scored from 0 (no concern) to 10 (great concern). Figure 3 provides the indicator results for Singapore (red) and the Dutch cities (outlined in black). Because the trends and pressures affecting water management are very similar for Dutch cities, the figure provides an average indicator score of the previously mentioned 10 Dutch cities.

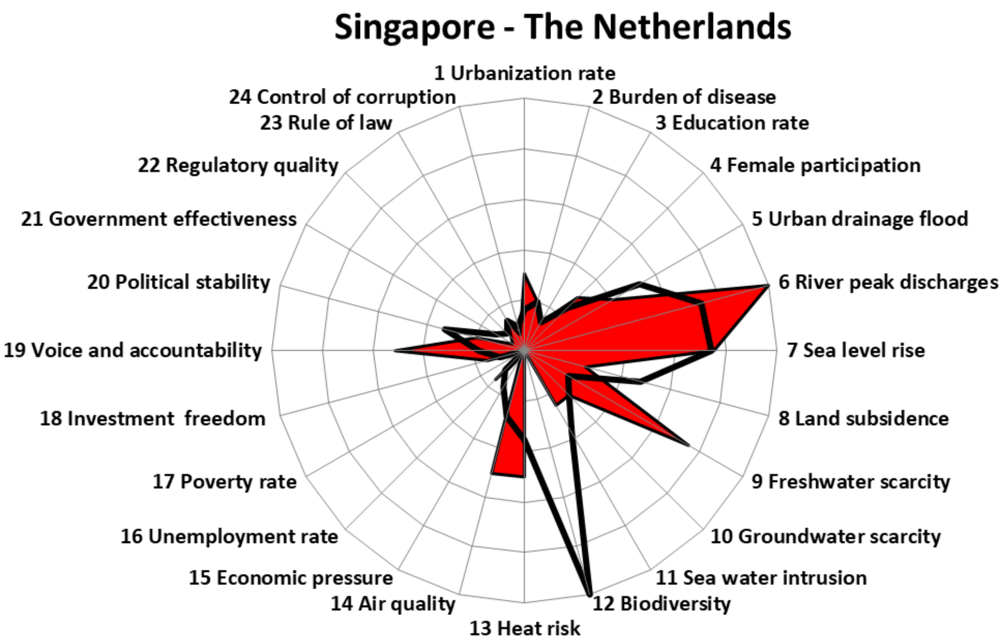

Figure 3 The social, environmental, financial and governance pressures that may affect urban water management. The more red the more concern. In ***red*** the scores of the TPF indicators for Singapore. Outlined in ***black*** the TPF scores for the Dutch cities.

Remarkably, the scores of the Trends and Pressures Index is 2.9 points both for Singapore and the Dutch cities. Overall, this indicates that most pressures are of little concern. Surface water biodiversity in the Netherlands is a major issue (indicator 12) due to the many modified water courses and pollution from agriculture, industry and the domestic sector in this densely populated country, as well as from pollution entering from neighbouring countries via the rivers Rhine and Meuse. As such biodiversity issues are rather different compared to Singapore where they predominantly involve coastline disturbance, nature conservation and more localised water pollution issues. Due to a lack of natural water resources, Singapore is particularly water-stressed (indicator 9) whereas water demand is expected to double by 2060. Singapore is already heavily vested in highly treated reclaimed wastewater (NEWater) and seawater desalinisation for its water supply and is also rather advanced in water-use efficiency, particularly for large water consumers. Although the more recent water-scarcity episodes in the Netherlands are far less severe, good practices in reuse of treated wastewater (for non-potable purposes) and water-use efficiency regulations and compliance of industry both provides extensive learning opportunities for the Netherlands. Apart from surface water biodiversity which is a major concern in the Netherlands and the concern of freshwater scarcity in Singapore, the pressures are rather similar. Both Singapore and Dutch cities face pressures related to flood risk (indicators 5, 6 & 7) and have relatively little concern with respect to social, financial or governance aspects. This means that in term of policy measures and urban planning, the similarity in required technologies and management solutions is high and exchange of the best practices can be lucrative and meaningful.

City Blueprint results Singapore

Singapore is the second highest scoring city of the 125 cities that have been assessed with the City Blueprint Approach so far.

Figure ***4*** provides the assessment results for Singapore (a web link for a detailed bibliography of the indicator scores including the calculations and justifications can be provided on request).

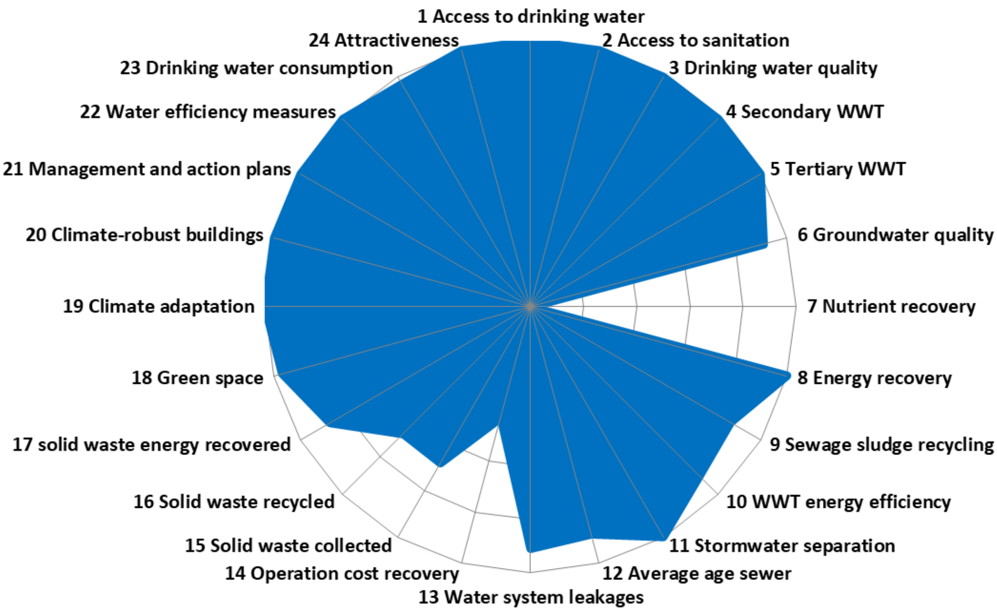

Figure 4 Updated City Blueprint results of the city of Singapore (1-10-2020). The message is simple: the bluer the better. Indicators are scored from 0 (poor performance) to 10 (high performance). Singapore with an overall BCI score of 8.1 points, is the second best performing city of the 125 cities that have been assessed.

Singapore is an absolute frontrunner in many aspects of urban water management and scores exceptionally high for indicators related to infrastructure management (indicators 10 – 13) and climate adaptation and urban planning (indicators 18 – 24). With respect to these aspects of integrated urban water management Singapore forms the lead example. Nevertheless, three points of improved can be identified:

1. Wastewater treatment and the recovery of energy and nutrients from wastewater (indicators 7 – 10) are all operating to the maximum, except nutrient recovery (indicator 7) and in particular the recovery of phosphorous from wastewater scores 0 points. Although the capacity is there to recover phosphorous, there is not yet a market where the recovered nutrient can be used as a fertilizer (application possibilities may include fertilizing public parks, sport fields or agricultural purposes). Hence, in terms of circular economy these nutrients are not being reused and therefore the system is not yet circular. Would these nutrients be applied in new markets, the indicator score would go from 0 to a score of 10 points. This would mean that Singapore's overall score, the Blue City Index, would increase from 8.1 points to 9.0 points, making Singapore the highest scoring city of the 125 cities assessed so far. It should be noted that other techniques are available to cover more materials from wastewater (Van Leeuwen et al., 2018).
2. The recycling of solid waste still provides room for improvement (indicator 16). The amount of solid waste that is collected (indicator 13) is 313.9 kg/day/person which is moderate for a wealthy city. The Dutch cities as well as most other wealthy cities produce more solid waste. Nevertheless, this indicators still shows room for improvement.
3. The operating cost recovery ratio for water services is 1.2. A ratio higher than 1 implies that there are more operational revenues than operational costs. Although this ratio is positive for Singapore, many other cities including Copenhagen, London, Shanghai and Toronto have more reserves (i.e., higher ratio's) to anticipate increases in infrastructure expenditures without being overly dependent on (sometimes irregular) government investments.

Learning potential between Singapore & Dutch cities

Figure 5 illustrates the learning potential if Singapore would adopt the best practices from Dutch cities and especially best practices of the city of Amsterdam.

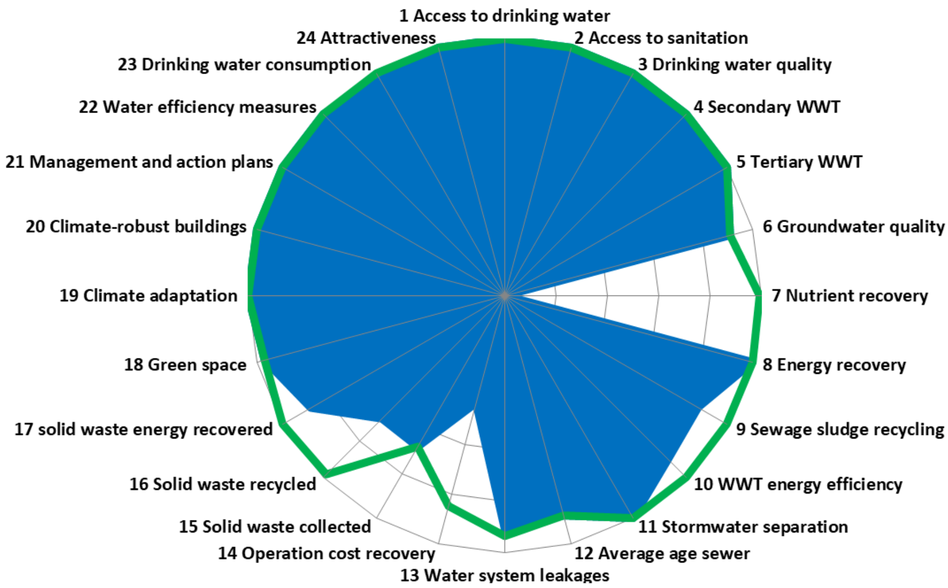

Figure 5 Score for the Singapore in blue. The green line shows the improvement potential if best practices from the Netherlands, and in particular Amsterdam, are being adopted.

The recovery and application of nutrients from wastewater for new markets such as fertilising public parks (indicator 7) as well as solid waste treatment (indicator 16 & 17) are areas where Singapore can learn from Dutch practices. Dutch cities can improve by adopting Singapore's best practices related to green space, infrastructure planning and stormwater separation (indicator 18, 12 & 11). The amount of solid waste that is collected (indicator 15) is moderately high for both Singapore and the Netherlands. The Dutch cities as well as most other developed cities produce more solid waste. Chinese cities such as Chongqing, Harbin, Nanning, Shijiazhuang and Tianjin score particularly well for this indicator (i.e., they produce very little waste). With respect to operation cost recovery (indicator 14), cities like Copenhagen, London, Shanghai and Toronto fully recover their operational cost for water services. If Singapore would adopt the best practices for these cities as well, it would have a Blue City Index of 10.0 points. Figure 5 provides a general overview of mutual learning, while Table 1 provides an overview of the indicator scores specified according to two Dutch cities that were included as suitable partners for mutual learning.

Table 1 City Blueprint scores of Singapore (Si) compared with the Dutch cities of Amsterdam (Am) and Rotterdam (Ro). In **dark green** indicators where Singapore scores higher than the Dutch cities. In **light green** indicators where one or more Dutch cities score higher than Singapore.

Category	Indicator	Score		
		Si	Am	Ro
I Basic water services	1 Access to drinking water	10.0	10.0	10.0
	2 Access to sanitation	10.0	10.0	9.7
	3 Drinking water quality	10.0	10.0	9.9
II Water quality	4 Secondary WWT	10.0	9.9	9.9
	5 Tertiary WWT	10.0	9.8	9.8
	6 Groundwater quality	9.1	6.1	6.1
III Wastewater treatment	7 Nutrient recovery	0.0	9.9	0.0
	8 Energy recovery	10.0	9.9	5.0
	9 Sewage sludge recycling	8.7	9.9	9.9
	10 WWT energy efficiency	9.0	10.0	7.0
IV Water infrastructure	11 Stormwater separation	10.0	8.3	0.5
	12 Average age sewer	8.9	6.4	5.4
	13 Water system leakages	9.1	9.4	8.8
	14 Operation cost recovery	4.3	8.5	8.5
V Solid waste	15 Solid waste collected	6.8	3.1	3.1
	16 Solid waste recycled	6.8	9.8	9.8
	17 Solid waste energy recovered	8.7	9.7	9.7
VI Climate adaptation	18 Green space	9.7	5.9	5.5
	19 Climate adaptation	10.0	10.0	10.0
	20 Climate-robust buildings	10.0	10.0	9.0
VII Plans & actions	21 Management & action plans	10.0	9.0	8.0
	22 Water efficiency measures	10.0	10.0	10.0
	23 Drinking water consumption	9.7	9.8	10.0
	24 Attractiveness	10.0	9.0	8.0
Blue City Index		8.1	8.7	6.7

2.3 Key recommendations

The largest learning potential that Dutch cities can offer Singapore may be with respect to recovery and reuse of resources from solid waste and wastewater. Another option is sewer epidemiology. Wastewater is a reliable source of information, i.e., “a fingerprint” of the use of chemicals as well as human health biomarkers as demonstrated in the Netherlands for Covid-19 as well as for the use of pharmaceuticals and trafficking and production of illicit drugs. This forms another promising learning opportunity that the Netherlands can offer Singapore.

2.3.1 Wastewater resource recovery and reuse

The use of recovered nutrients from wastewater (Indicator 7) is a clear best practice that Singapore can adopt from the Netherlands and particularly from Amsterdam. Amsterdam has been in a similar situation as Singapore is right now. Amsterdam was already able to recover the nutrients but was by law not allowed to sell the hygienically product to agricultural buyers because the law considers this a waste product with potential danger to public health. In this context, a new market was created within the municipality. That is, processing the struvite as a fertilizer for nonagricultural purposes such as maintaining public parks and sporting fields. Beyond struvite, the reuse of recovered resources such cellulose, bioplastics, Kaumera (alginate-like exopolymers from aerobic granular sludge (bio-ALE)) and biomass is being explored in the Netherlands through public-private partnerships and green deals that are now being effectuated. A prime example is the Energy and Resources Factory initiative. This initiative consists of the joint force of 21 Dutch water authorities and the Foundation for Applied Water Research (STOWA). The Energy and Resources Factory specifically focusses beyond merely technological development by working closely with various businesses in order to ensure market opportunities of recovered resources from wastewater: https://www.efgf.nl/english. For an early market analysis of various resources that can already be (partially) commercially recovered from wastewater, we refer to the following link: https://link.springer.com/article/10.1007/s00267-018-0995-8. One of the earliest commercially applicable products is the recovered phosphorus (i.e., struvite) from wastewater in Amsterdam. The wastewater treatment plant in Amsterdam treats about 2000 m^3 sludge each day. The investment costs are about €4 million and the expected savings are €400,000 per year (Van der Hoek et al. 2017). Accordingly, the return on investments is roughly 10 years. The savings of this process consists of selling the struvite, lowering the maintenance costs of wastewater treatment and better sludge dewatering. The struvite is processed into a fertilizer that is used for maintaining public parks and sport fields.

2.3.2 Solid waste management

The recycling of solid waste (indicator 16) is an interesting learning opportunity that the Netherlands has to offer. Recycling rates in the Netherlands are amongst the highest in the world. Waste recycling is more environmentally friendly than burning waste with energy recovery. In this respect, the ''ladder van Lansink" has been embedded in Dutch law since 1993 (**Figure 6**).

Figure 6 Dutch waste management adopted the principles outlined in this "ladder van Lansink" embedded in Dutch law since 1993. It provides a priority ladder for solid waste management.

Although the amount of solid waste that is produced in the Netherlands is rather high (due to a lack of applying principles A and B), the amount that is recycling is also one of the highest in the world (application of principle C). The main reason for this is the waste separation and collection system which is tailored to different material flows. More details are provided in the material flow analysis in chapter 3.

3 Material flow analysis Singapore & the Netherlands

3.1 Material flow analysis

Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time (Brunner and Rechberger 2004). It has been widely applied to material systems in providing useful information regarding the patterns of resource use and the losses of materials entering the environment. MFA allows cities to make smart decisions by clearly understanding where their greatest environmental impacts are taking place. In many ways, cities function very much like human bodies – they have an 'urban metabolism' that stocks up on resources, consumes, and then disposes of what is 'leftover' in the form of waste. Moreover, material flow analysis provides a solid basis for identifying where meaningful impacts can be made when implementing solutions. In addition, a MFA allows cities to monitor long-term goals and generating insights and evidence on which solutions are most effective in delivering the desired results.

MFA is widely applied for environmental education, particularly in waste management. More importantly, MFA has been used as analytics to support decisions-making on waste management policy and identify potential business opportunities.

As illustrated in Figure 7, an MFA visualises inflow and outflow of materials. In this example, the flows in and out related to water, food and energy consumption and their interconnection with the respective emissions and waste streams within the system are shown. By gaining this overview, it is possible to discern where it is most effective to put sustainability efforts.

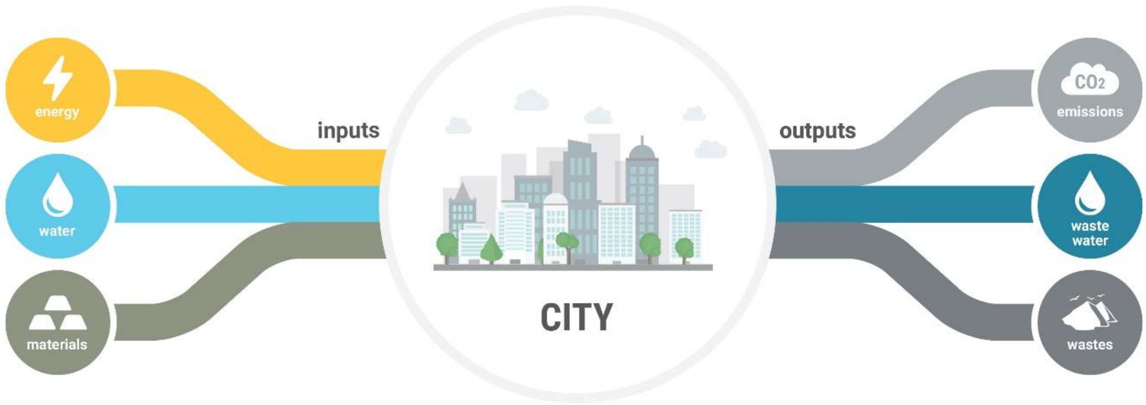

Figure 7 Illustration of inflow and outflow of materials in a city (Metabolic 2020).

3.2 Development of a material flow analysis for Singapore and the Netherlands

Recognising the importance of a Material Flow Analysis (MFA), an MFA related to food waste, plastic, incinerator bottom ash and the water cycle was conducted to identify opportunities in the area of the circular economy in Singapore based on the already promising ways observed in the Netherlands. This analysis allowed for demonstration and implementation opportunities in Singapore. The MFA identified and qualified the flow and stock of these four streams in both the Netherlands and Singapore. The results can support decision-making of the relevant authorities who need to carefully plan and implement waste management policies.

3.3 Results

3.3.1 Material Flow Analysis of Food waste

(i) The Netherlands

In the Netherlands, the amount of good food that is wasted per year counts up to billions of euros. Food waste is not only a waste of money, but also a waste of valuable resources (such as water, soil and energy) that is needed to produce and transport the food. A Material Flow Analysis (MFA) was conducted to quantify the flow of food waste from generation to disposal in the Netherlands. The food waste flows and mass balance are shown in Figure 8 and Table 2 respectively.

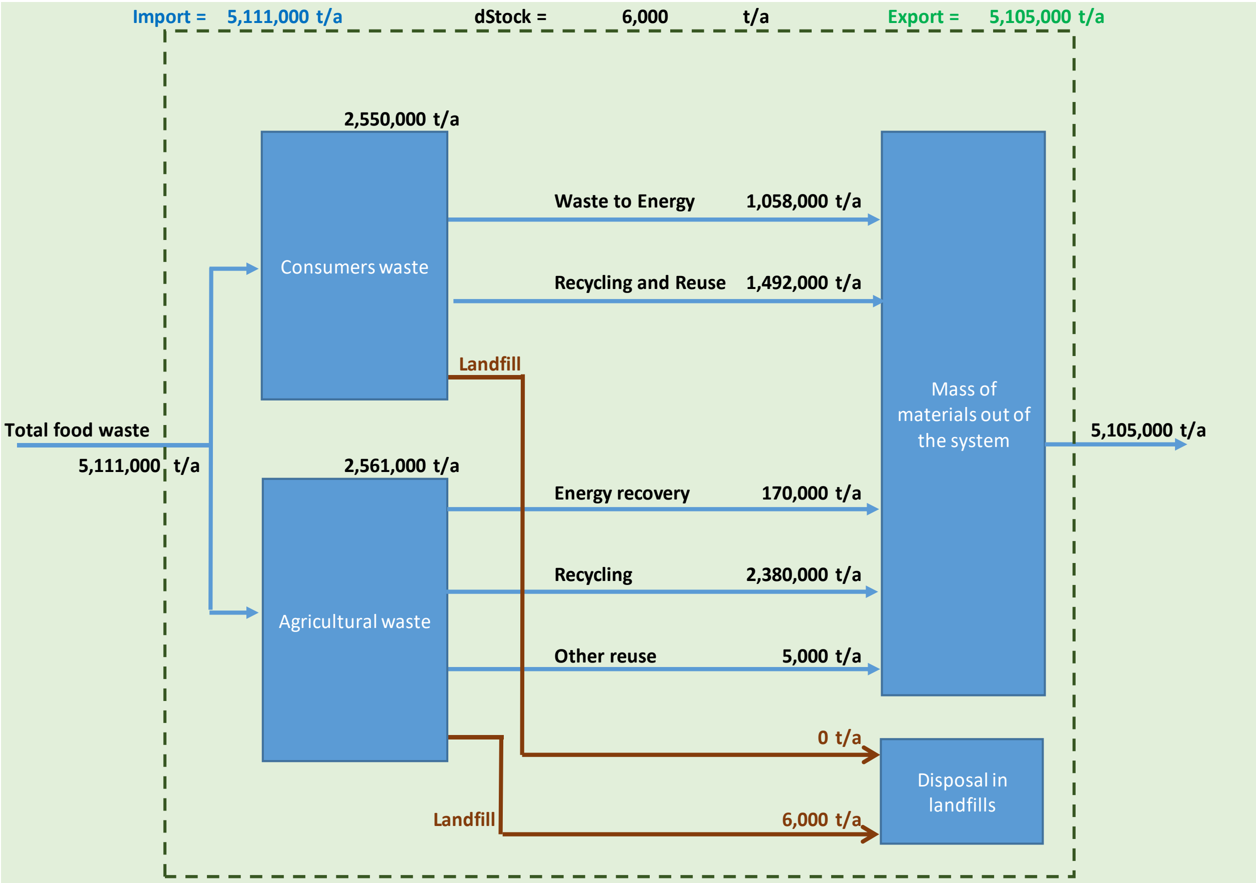

Figure 8 Material flow of food waste (tons per annum (t/a) in the Netherlands. Data retrieved from: https://afvalmonitor.databank.nl//Jive/. (Year 2018 data).

Table 2 Material flow balance of food waste (tons per annum (t/a)) in the Netherlands. Data retrieved from: https://afvalmonitor.databank.nl//Jive/. (Year 2018 data).

Food waste flow	Mass flow in (t/a)	Mass flow out (t/a)	Mass flow internal (t/a)
Total food and agricultural waste	5,111,000		
Consumers food waste	2,550,000		
Agriculture waste	2,561,000		
Consumers waste to landfill			0
Consumers waste energy recovery		1,058,000	
Consumers waste recycling and reuse		1,492,000	
Agriculture waste to landfill			6,000
Agriculture waste energy recovery		170,000	
Agriculture waste recycling		2,380,000	
Other agricultural waste reuse		5,000	
Total mass flow (t/a)	**5,111,000**	**5,105,000**	**6,000**
Mass in stock (t/a)	**6,000**		
Percentage mass flow out	**99.9%**		
% Food and agricultural waste recycled	**75.9%**		

As shown in Table 2 above, 75.9% of the total food waste is recycled mainly to animal feed, biomass and composting (Ministry of Agriculture, Nature and Food Quality, 2020). Although, only 6,000 t/a of food waste mass is in stock, meaning stored in landfill, a significant amount (~ 1,228,000 t/a combining consumers and agriculture waste) is lost in incineration and waste to energy recovery. Incineration of food waste to energy is not considered a desirable practice in the transition to a circular economy as the reliance and dependency on primary resources and raw materials remains the same. There is clearly a challenge and an opportunity to reduce this volume of food waste that is both incinerated (and the small amount landfilled) by practices of food recycling and increasing reuse in feeding livestock for example.

(ii) Singapore

According to the National Environment Agency (NEA) of Singapore, only 18% of food waste is recycled accounting for about 10% of the total waste generated in Singapore. The balance of the food waste is disposed at the waste-to-energy plants for incineration (NEA 2019). The MFA for Singapore's food waste is illustrated below in Figure 9 and Table 3, respectively.

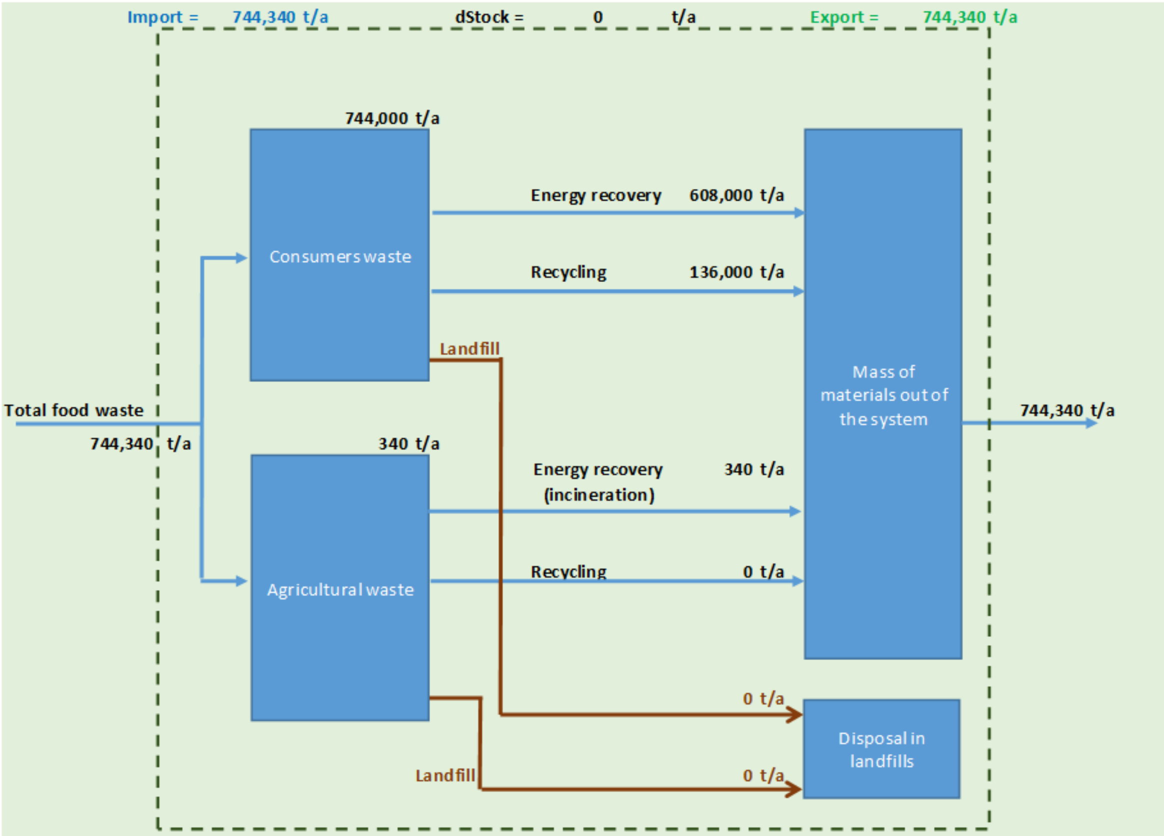

Figure 9 Material flow of food waste in Singapore. Data retrieved from: https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/food-waste-management. (Year 2019 data)

Table 3 Material flow balance of food waste in Singapore. Data retrieved from: https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/food-waste-management. (Year 2019 data)

Food waste flow	**Mass flow in (t/a)**	**Mass flow out (t/a)**	**Mass flow internal (t/a)**
Total food and agricultural waste	744,340		
Consumers food waste	744,000		
Agriculture waste	340		
Agricultural waste energy recovery		340	
Consumers waste energy recovery		608,000	
Consumers waste recycling		136,000	
Total mass flow (t/a)	**744,340**	**744,340**	**0**
Mass in stock (t/a)	**0**		
Percentage mass flow out	**100.0%**		
% Food waste recycled	**18.3%**		

As shown in Table 3, about 136,000 t/a (18.3%) of the food waste flows out of the system (i.e. is recycled), the rest (608,000 t/a) is sent to the waste-to-energy plants where it is incinerated, hence not recovered. Currently, food waste is converted into useful products like compost for landscaping purposes, and several composting systems making use of worms, larvae or yeast are currently in use in Singapore. Nevertheless, a significant amount of food waste is still being incinerated, and although not considered as a mass flow in-stock (i.e. mass accumulated) this is considered very high when it comes to promoting the circular economy and the Singapore food waste management hierarchy shown in Figure 10.

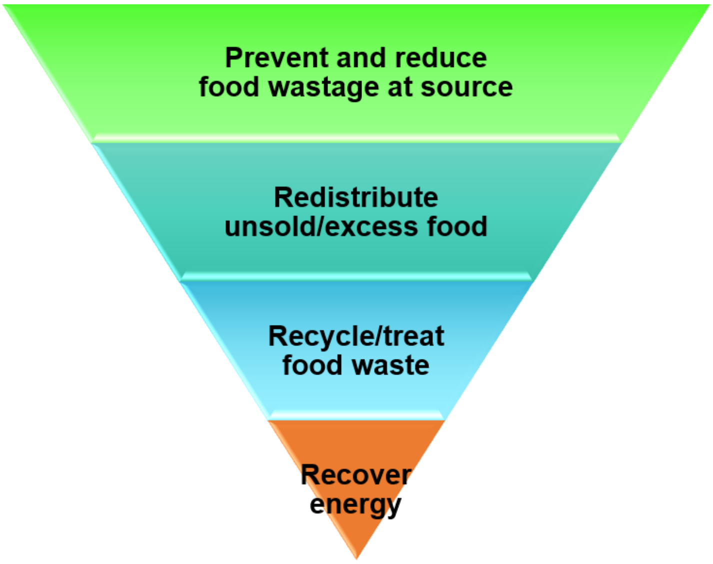

Figure 10 Food waste management hierarchy in Singapore (NEA, 2019).

Singapore currently has a small agricultural sector and therefore generates only 340 t/a of agricultural waste. However, with Singapore's "30 by 30" goal which aims to develop the capacity in its agri-food industry to produce 30% of the nation's nutritional needs locally by 2030. This is likely to increase the amount of agricultural waste which could be minimised by promoting circular economy practices and opportunities in Singapore. For instance, the anticipated increase in agricultural waste can be converted into compost and charcoal.

3.3.2 Material Flow Analysis of plastic

Plastic packaging is important for extending the shelf life of food and protects new products from damage during transportation. The issue with plastics is excessive packaging. The use of plastics is widespread in daily lives. For instance, grocery bags, beverage bottles and food containers are made of plastics and often used in excess and discarded in significant amounts.

(i) The Netherlands

In the Netherlands, there are initiatives to accelerate the transition to a circular plastic economy, where plastic remains of value and is made from recycled or renewable bio-based plastics of guaranteed quality. In order to close the plastics chain and reduce the incineration of plastics, producers, retailers and consumers need to ensure that macro and micro-plastics no longer leak into the environment. Understanding the plastics material flow is therefore important in realising this goal. The plastic mass flows and mass balance are shown below in Figure 11 and Table 4 respectively.

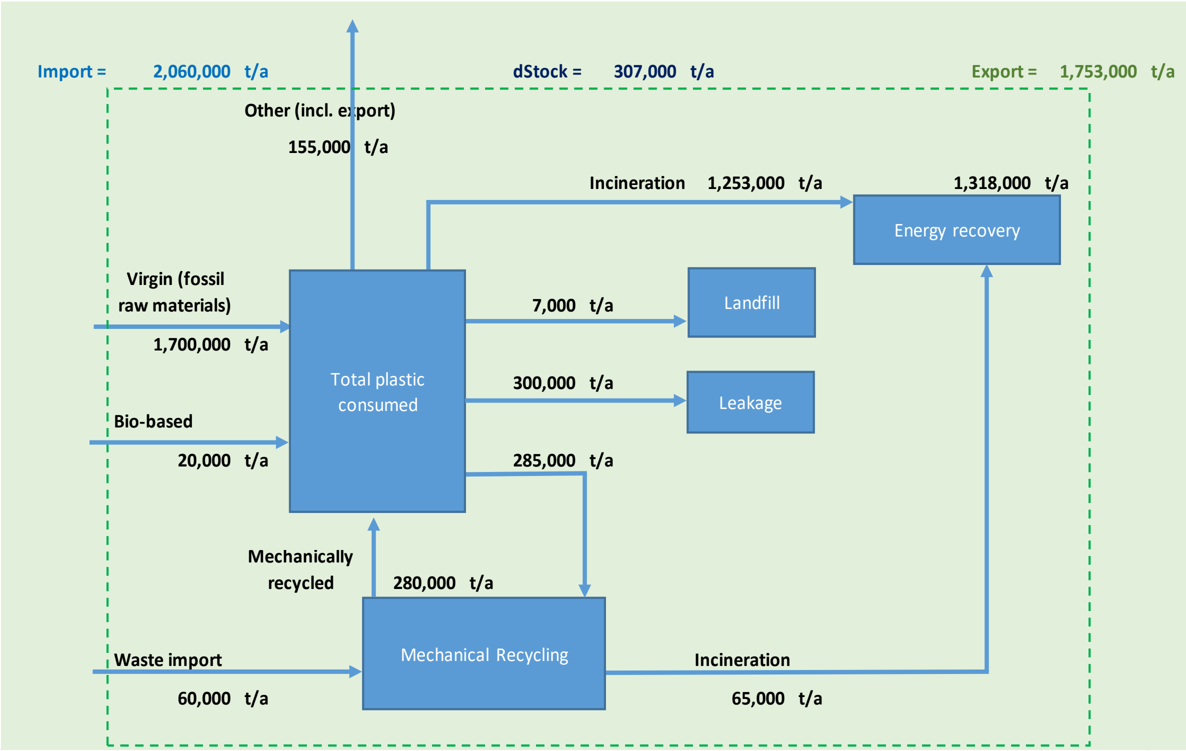

Figure 11 Material flow of plastics in the Netherlands. The data source is from the Transition Agenda – Circular Economy 2018 report (https://hollandcircularhotspot.nl/wp-content/uploads/2018/06/TRANSITION-AGENDA-PLASTICS_EN.pdf). (Year 2016 data).

Table 4 Material flow balance of plastics in the Netherlands.

Plastic flow	**Mass flow in (t/a)**	**Mass flow out (t/a)**	**Mass internal distribution (t/a)**
Total raw plastic generated	1,720,000		
Virgin (fossil raw materials)	1,700,000		
Bio-based	20,000		
Waste import	60,000		
Mechanically recycling	280,000		
Total plastic consumed	2,060,000		
Disposal	1,700,000		
Sorting for recycling	874,000		
No sorting	826,000		
Exported product		155,000	
Mechanically recycling		280,000	
Energy recovery (incineration)		1,318,000	
Landfill			7,000
Leakage			300,000
Total mass flow	**2,060,000**	**1,753,000**	**307,000**
Mass in stock (t/a)	**307,000**		
Percentage mass flow out	**85.1%**		
% Plastics recycled and exported	**21.1%**		

As listed in Table 4, presently only around 280,000 t/a of plastic is recycled in the Netherlands, while the total plastic consumed is around 2,060,000 t/a. When comparing this total utilisation with the amount of plastic mass flow out of 1,753,000 t/a, this means that 307,000 tons will remain in use annually (i.e. in stock). In addition, it is important to highlight that only 16% of the total mass flow of plastics is recycled, which is about 20% the mass that is currently being sent to waste incinerators (1,318,000 t/a).

(ii) Singapore

The National Environment Agency (NEA) of Singapore reported the 2019 waste and recycling statistics. Data for plastics mass flows were obtained from this report (NEA 2019). The plastic mass flows and mass balance for Singapore are shown in Figure 12 and Table 5 respectively.

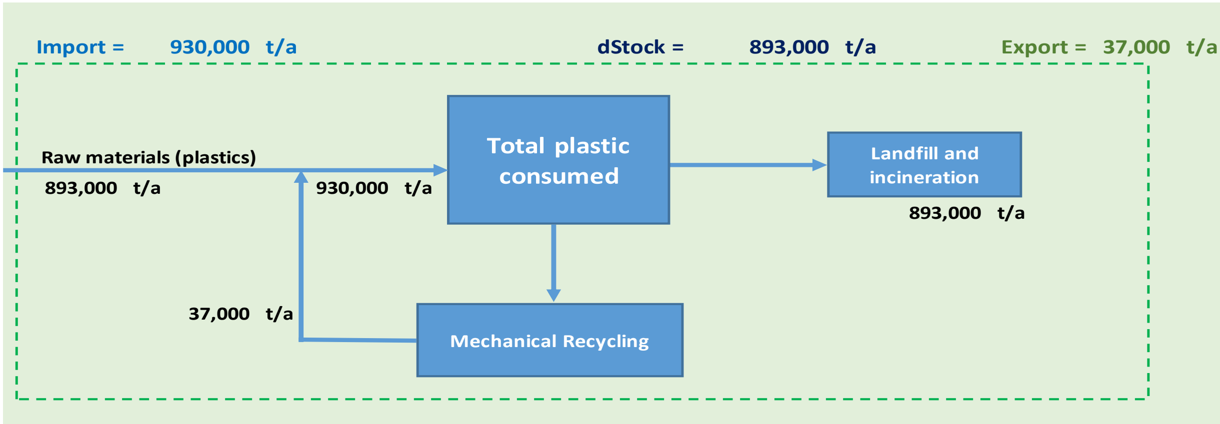

Figure 12 Material flow of plastics in Singapore. Data retrieved from NEA 2019.

Table 5 Material flow balance of plastics in Singapore (Year 2019 data).

Plastic flow	Mass flow in (t/a)	Mass flow out (t/a)	Mass internal distribution (t/a)
Total raw plastic generated	893,000		
Virgin (fossil raw materials)	893,000		
Bio-based	-		
Waste import	-		
Mechanically recycling	37,000		
Total plastic consumed	930,000		
Disposal	930,000		
Sorting for recycling	-		
No sorting	-		
Exported product		-	
Mechanically recycling		37,000	
Energy recovery (incineration)		-	
Landfill and Incineration			893,000
Leakage			-
Total mass flow	**930,000**	**37,000**	**893,000**
Mass in stock (t/a)	**893,000**		
Percentage mass flow out (through recycling)	**4.0%**		

Contrary to the plastic data from the Netherlands, Singapore's individual data (making up the total) were not available to compare the pathways of the plastic waste. As listed in Table 5, only 4.0% of the total raw plastic consumed (930,000 t/a) is recycled. Singapore therefore incinerates the majority (893,000 t/a) of the plastics consumed, although there is a push to adopt the circular economy approach through sustainable production and design, and establishing best practices in the 3Rs (reduce, reuse and recycle).

3.3.3 Material Flow Analysis of Incinerator Bottom Ash (IBA)

(i) The Netherlands

Incinerator Bottom Ash (IBA) from municipal solid waste incineration contains important raw materials, such as metals, that can be recovered by various treatment processes. The use of IBA fits very well in a circular economy. The Netherlands IBA mass flows and mass balance are shown below in Figure 13 and Table 6 respectively.

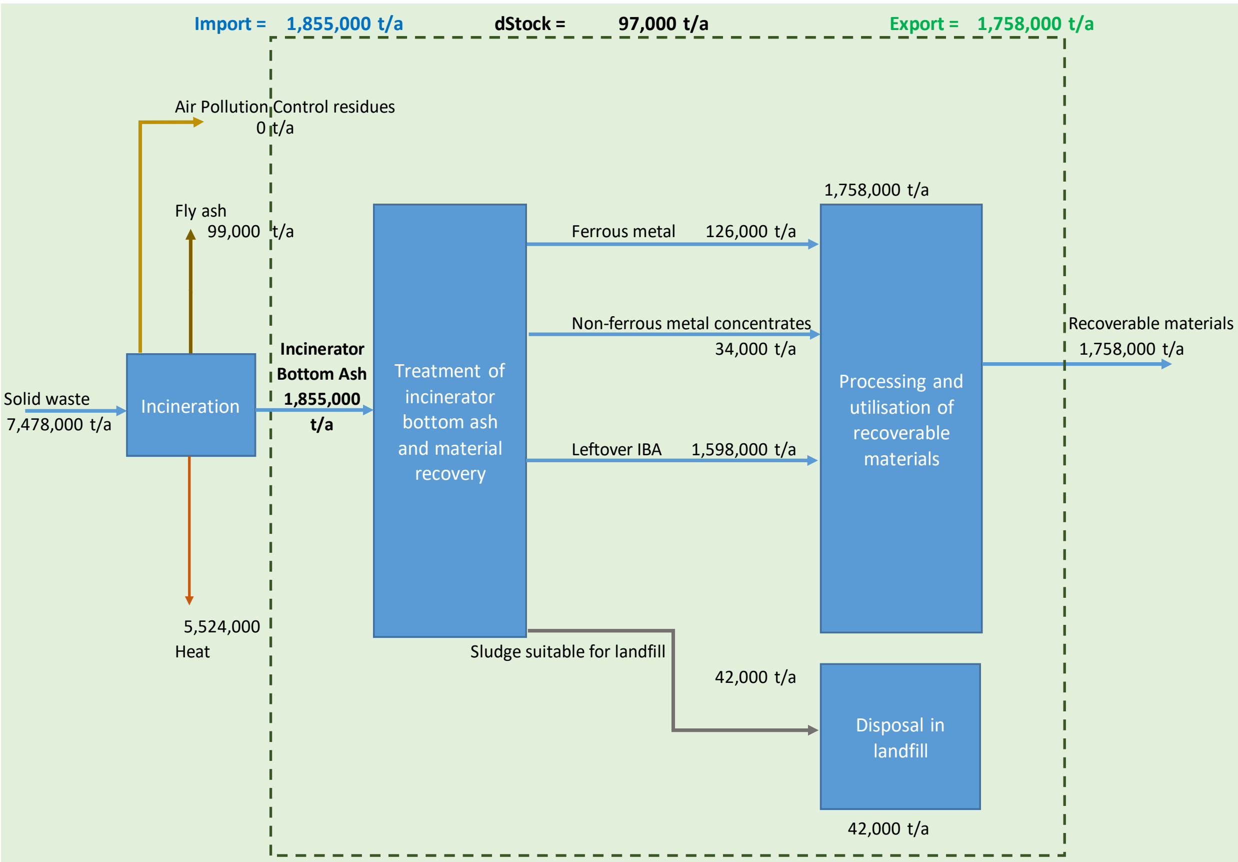

Figure 13 Material flow of incinerator bottom ash in the Netherlands. Data on incinerator bottom ash were obtained from the Ministry of Infrastructure and Water Management (https://www.afvalcirculair.nl/publish/pages/172856/afvalverwerking-in-nederland-gegevens-2018-def-09-03-2020.pdf). (Year 2018 data).

Table 6 Material flow balance of incinerator bottom ash in the Netherlands.

Incineration mass flow	**Flow in (t/a)**	**Flow out (t/a)**	**Flow internal (t/a)**	**%/t IBA**
Solid waste incinerated	7,478,000			
Fly ash			99,000	
APC residues				
Heat and Energy		5,524,000		
Incinerated bottom ash			1,855,000	24.8%
Incinerator bottom ash	**1,855,000**			
Bottom ash production processed		1,758,000		94.8%
Ferrous metal		126,000		6.8%
Non-ferrous metal concentrates		34,000		1.8%
Bottom ash processed leftover		1,598,000		86.1%
Bottom ash landfilled (incl. support layer)		42,000		2.3%
Recycling of IBA		**1,758,000**		94.8%
Total IBA mass flow	**1,855,000**	**1,758,000**		
Mass IBA in stock	**97,000**			

(ii) Singapore

Figure 14 and Table 7 show the IBA mass flows and mass balance for Singapore.

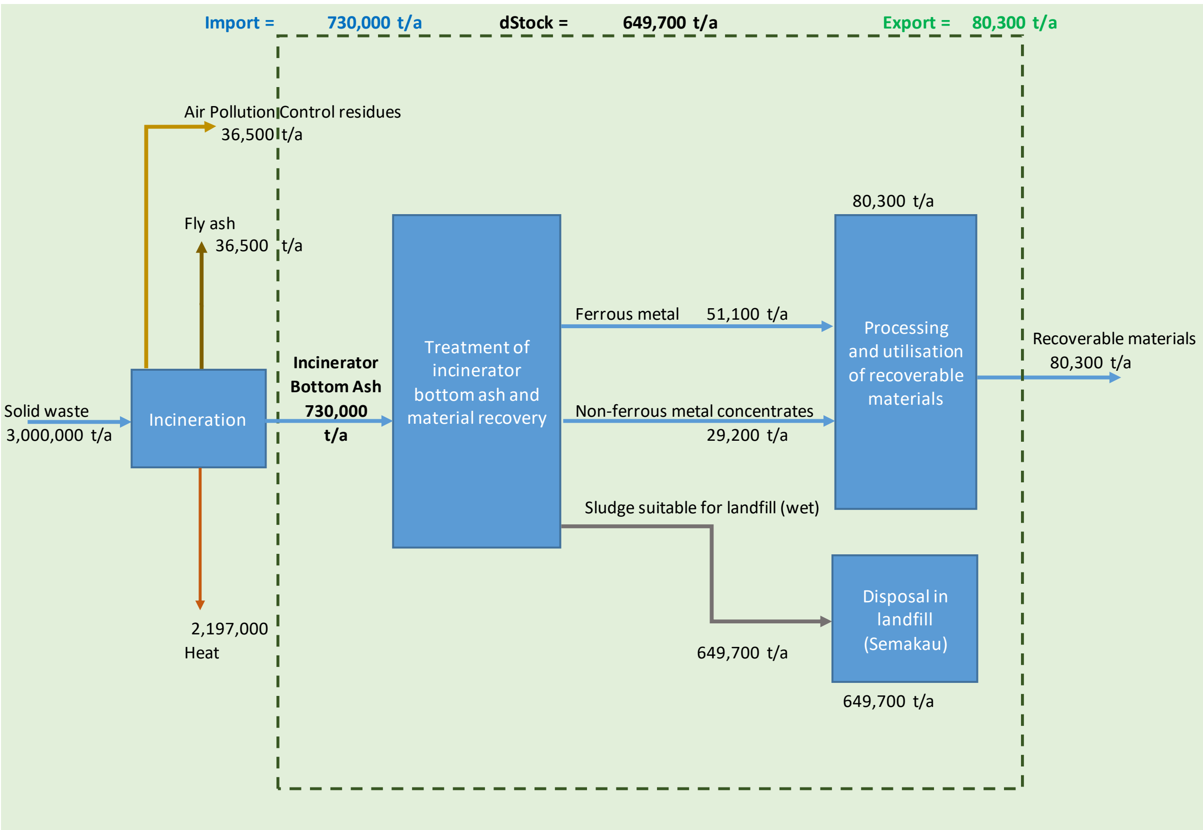

Figure 14 Material flow of incinerator bottom ash in Singapore. Source: https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling. (Year 2019 data).

Table 7 Material flow balance of incinerator bottom ash in Singapore (Year 2019 data).

Incineration mass flow	**Flow in (t/a)**	**Flow out (t/a)**	**internal (t/a)**	**%/t IBA**
Solid waste incinerated	3,000,000			
Fly ash			36,500	
APC residues			36,500	
Heat and Energy		2,197,000		
Incinerator bottom ash			730,000	24.3%
Incinerator Bottom Ash (IBA)	**730,000**			
Ferrous metal		51,100		7.0%
Non-ferrous metal concentrates		29,200		4.0%
Sludge suitable for landfill at Semakau (wet)		649,700		89.0%
Recycling of IBA		**80,300**		11.0%
Total IBA mass flow	**730,000**	**80,300**		
Mass IBA in stock	**649,700**			

The Netherlands is quite advanced when it comes to recycling of Incinerator Bottom Ash (IBA). The Netherlands recycles 95% of its IBA while Singapore is recycling 11%. Both countries are recovering metals and construction material. In the Netherlands, most of the bottom ash is processed after separation from ferrous metals. The non-ferrous metals are used as construction material often applied in large projects since the efficient demands and supply logistics in larger projects permit the viable application of these materials. Although IBA recycling in the Netherlands is high, it is currently only used as a secondary construction material in situations where there is no risk of leaching into the soil or groundwater. There are serious questions raised about the control of toxicity in public works, and as such future research should consider the environmental and public health related to the application of IBA in public works, roads and other uses. Consequently, there is a need to ensure that hazardous substances do not leak out of concrete of other building materials containing bottom ash.

It is expected that by 2035, Singapore's one and only landfill, on Semakau Island, will run out of space and that alternative approaches to manage the country's waste are necessary. The use of incinerator bottom ash instead of sand and stone has been investigated with the creation of NEWSand (materials generated from IBA recycling) and is planned to become a reality in the coming years. As such, there is potential to recycle more IBA in Singapore to minimise the amount that is sent to the landfill. Clearly both the Netherlands and Singapore can learn from each other on how to further improve the management and recycling of IBA.

3.3.4 Material Flow Analysis in the water cycle

An attempt to develop an MFA in the water cycle was also made based on the data available both in the Netherlands and Singapore. Conducting the analysis over the entire water cycle offers a complete overview of the flows of materials and water both in the drinking water and wastewater sector.

(i) The Netherlands

In the Netherlands, water data for the various modules of the entire water cycle are available. Figure 15 below illustrates the various components contributing to the water and material flows. The water flow and material mass balances are shown in Table 8. The various materials in and out of the water cycle are available in the Netherlands to follow the pathway of what is recovered and in what form. The Netherlands do not recycle a lot of wastewater as the demand is not there yet. On the other hand, several resources are recovered from the sludge. Increasingly sludge is being dealt with a more holistic view particularly in relation to the potential of recovering resources, namely biogas, struvite, cellulose and sand.

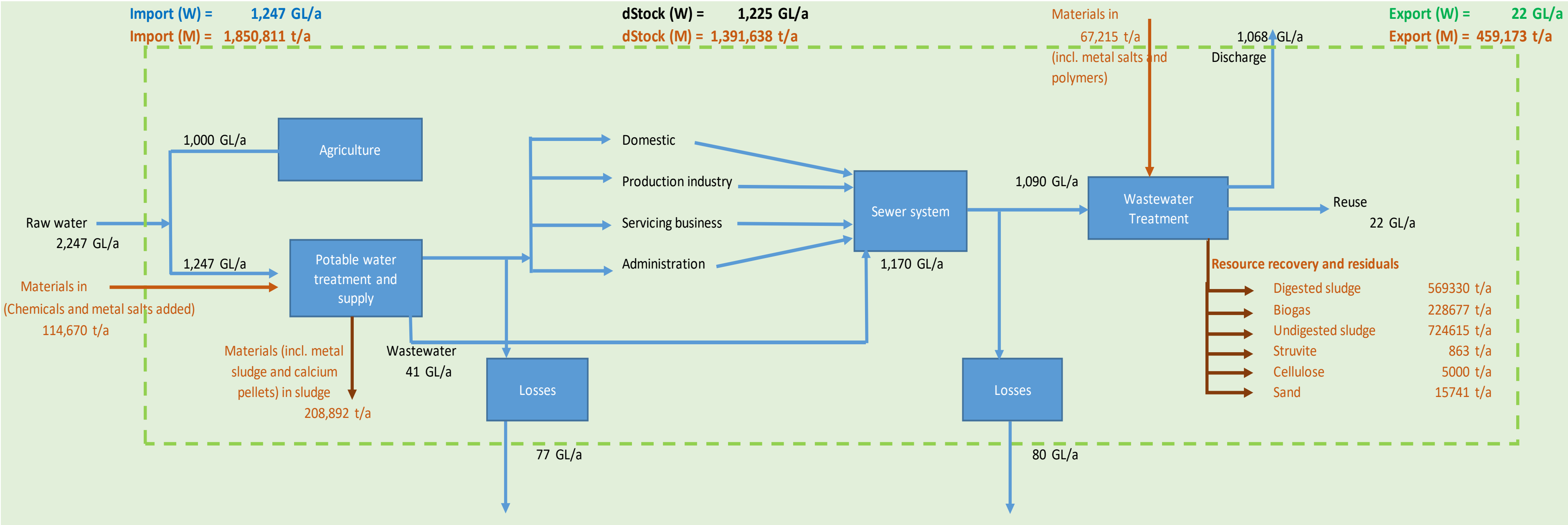

Figure 15 Material flow in the water cycle in the Netherlands. Data retrieved from KWR BTO 2020 report (https://library.kwrwater.nl/publication/61558390/)

Table 8 Material and water flow balances in the water cycle in the Netherlands. (Year 2018 data).

Netherlands data for the Water Cycle						
Water cycle	**Water flow (GL/a)**			**Materials flow (t/a)**		
	Flow in (GL/a)	**Flow out (GL/a)**	**Flow internal (GL/a)**	**Flow in (t/a)**	**Flow out (t/a)**	**Flow internal (t/a)**
Raw water	2,247					
Agriculture			1,000			
Potable water treatment			1,247			
Wastewater from production			41			
Losses in potable water network		77				
Potable water supply			1,129			
Domestic			565			
Production Industry			339			
Servicing business			113			
Administration			113			
Sewer system			1,170			
Sewer water loss		80				
Wastewater Treatment			1,090			
Water reuse			22			
Discharge		1,068				
Total potable water flow in (GL/a)	**1,247**					
Total water flow recycled (GL/a)	**22**					
Flow in stock (GL/a)	**1,225**					
% Recycled	**1.7%**					
Materials (solids) in raw potable water				124,700		
Chemicals (incl. metal salts added to potable water production				114,670		
Materials (incl. Metal sludge and calcium pellets) in sludge recovered from potable water production					208,892	
Materials stored in potable water production						30,478
Materials (incl. metal salts and polymers) added for wastewater treatment				67,215		
Sludge from wastewater treatment				1,544,226		
Digested sludge						569,330
Biogas production					228,677	
Undigested sludge						724,615
Struvite					863	
Cellulose					5,000	
Sand					15,741	
Total materials (t/a)				**1,850,811**		
Total materials recycled (t/a)					**459,173**	
Flow in stock (t/a)				**1,391,638**		
% Recycled				**25%**		
Biogas production from WWTP				**115,222,000**		m3/a

(ii) Singapore

In Singapore, water data for the various modules of the entire water cycle were not fully available. Data on the water use and recycling were available while data on the materials and their flows in the water cycle were not available. Figure 16 below illustrates the various components contributing to the water flows. The water flow and water mass balances are shown in Table 9.

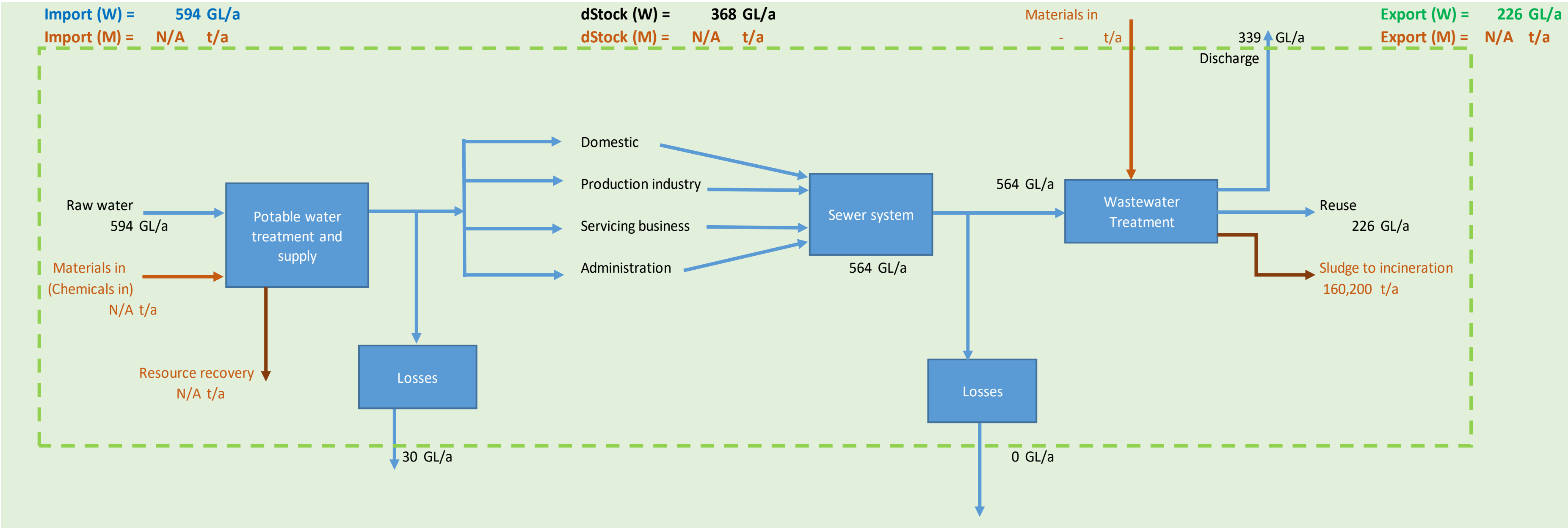

Figure 16 Material flow in the water cycle in Singapore. The data were obtained from the National University of Singapore (https://lkyspp.nus.edu.sg/gia/article/singapore-s-water-success-and-lessons-for-the-region).

Table 9 Material and water flow balances in the water cycle in Singapore.

Water cycle	**Water flow (GL/a) (2019 data)**			**Materials flow (t/a) (Year 2012 data)**		
	Flow in (GL/a)	**Flow out (GL/a)**	**Flow internal (GL/a)**	**Flow in (t/a)**	**Flow out (t/a)**	**Flow internal (t/a)**
Raw water	594					
From local catchment and imported water	208					
Desalination	149					
NEWater	238					
Potable water treatment			594			
Wastewater from production						
Losses in potable water network		30				
Potable water supply			564			
Domestic			254			
Non-domestic			310			
Servicing business						
Administration						
Sewer system			564			
Sewer water loss						
Wastewater Treatment			564			
Water reuse			226			
Discharge		339				
Sludge from wastewater treatment				160,200		
Sludge incinerated					160,200	
Sludge stored in WWTP						0
Total water flow in (GL/a)	594					
Total water flow recycled (GL/a)	226					
Flow in stock (GL/a)	368					
% Recycled	38%					

Compared to the Netherlands which recycles only approximately 2% of its wastewater, Singapore has a much pressing need to recycle its wastewater because of the unavailability of freshwater for potable and non-domestic uses. Currently, Singapore is recycling about 38% of its wastewater while the rest is discharged. NEWater (high-quality recycled water) is one of the four water sources in Singapore, along with local catchment water, imported water and desalinated water.

4 Business opportunities derived from the Material Flow Analyses

In addition to the learning opportunities identified in section 2.3, this chapter provides business opportunities for Singapore and the Netherlands based on the Material Flow Analysis.

Although some individual values making up the total mass flow data are not available for Singapore, namely in the case of food waste, plastic and materials in the water cycle, the MFA can be used to make supportive decisions regarding waste management within a circular economy. The circular economy, an inspiring concept that is turning into reality is gaining substantial traction both in Singapore and the Netherlands. The MFA developed in this project can be used to assess opportunities to extend the lifecycle of materials by keeping the value of products and materials in the loop as long and high (economically attractive) as possible. This can be achieved by looking at ways to reduce both the stock of materials and waste to energy through increased recycling and/or export as a raw material for other products. Both Singapore and the Netherlands can take full advantage of the opportunities still latent and untapped as reported in the material flow analysis and transition faster to a more circular economy.

The Netherlands is in a good position with regard to the circular economy as it has been working in this front for some years now and has learned a great deal. There are already a lot of activities related to the expansion of the circular economy for value creation with biotic waste streams. Being a densely populated country with an active agricultural sector and a large agro-food industry, significant biotic waste streams are available where reuse and recycling opportunities are being exploited.

Table 10 below summarises the potential recycling options in Singapore and the Netherlands with regard to the four waste streams considered in the MFA.

Table 10 Summary and potential of waste recycling in Singapore and the Netherlands.

Material streams	Flow in		Flow out*		In stock		% Recycling	
	NL	SG	NL	SG	NL	SG	NL	SG
IBA (t/a)	1,855,000	730,000	1,758,000	80,300	97,000	649,700	95%	11%
Plastics (t/a)	2,060,000	930,000	435,000	37,000	1,625,000	893,000	21%	4%
Food waste (t/a)	5,111,000	744,000	3,872,000	136,000	1,239,000	608,000	76%	18%
Water (GL/a)	1,247	594	22	226	1,225	368	2%	38%
Materials in the water cycle (t/a)	1,850,811	N/A	459,173	N/A	1,391,638	N/A	25%	N/A
* Does not consider incineration of waste as material flow out. Waste to energy is not desirable in the transition to a circular economy.								
N/A: Not available								

Note: 1GL = 1000ML = 1Million m³

From Table 10, other than water recycling, Singapore could benefit from the knowledge and experience of the Netherlands in the recycling of IBA, plastics and food waste. Despite the unavailability of data on the materials in the water cycle for Singapore, it seems that some opportunities for knowledge exchange can be identified in this area. The next section highlights the main business opportunities related to the above material streams (food waste, plastics, incinerator bottom ash and resources in the water cycle) to enhance the transition to a circular economy that could be considered in Singapore. Business enterprises and partners in both Singapore and the Netherlands would benefit from these opportunities created in Singapore's transition to a circular economy. Reciprocally, the Netherlands can also learn from the initiatives undertaken by Singapore in its transition to a circular economy namely in the fields of water and planned IBA recycling.

At present, there is a significant amount of waste either in stock or destroyed as waste to energy in both Singapore and the Netherlands. In order to enhance circularity of these waste products, it would be important to develop a consistent, multidisciplinary and well-founded long-term strategy intended to lead to a circular economy. For this strategy, the following initiatives and actions are suggested:

1. A landmark Resource Sustainability Act was enacted in October 2019 to give legislative effect to new measures to address Singapore's priority waste streams. For instance, the requirements relating to food waste are that:
    - From 2021, developers of new large commercial and industrial premises to allocate and set aside space for on-site food waste treatment systems in their design plans.
    - From 2024, large commercial and industrial food waste generators will have to segregate their food waste for treatment.

   Clearly these legislative requirements demand that new approaches to manage food waste will be initiated and that opportunities for food waste recycling will emerge as a consequence.
2. Quantify the economic value of waste that can potentially be recycled and/or exported as raw materials for other products.
3. Create a clear vision and strategy and implementation roadmap across public, private and civil society organisations for the circular economy.
4. Develop a coherent education, research and development approach towards a circular economy. This can enhance both human and technological capacity, generate further knowledge and facilitate the sharing of best practices in circular economy. Having a coherent plan would allow the inclusion of circular economy issues in research agendas, in the curricula at all levels in education, including vocational and universities.
5. Increase the knowledge and awareness of IBA, plastic, food and water streams in their respective value chain. Many businesses are not aware of the origin or the composition of the raw materials they utilise.
6. Promote and accelerate business symbiosis, where businesses learn how to reduce their waste streams or put them to use by working together with other businesses in the supply and value chains.
7. Create a platform that supports the development of new business models that foster the transition to a circular economy. This platform can inspire the businesses, knowledge institutes, non-governmental organisations and the government to work together according to a value chain approach. This platform will have ambitions related to circular economy, one of which can be to create a market that supports a sustainable value chains. It can bring together various market players and stakeholders, remove obstacles and establish sustainable business operating conditions.
8. Reviewing the effectiveness of fiscal and financial incentives to promote circular behaviour and initiatives and boost the implementation of the circular economy concept. This would help to correct the economics of circularity in order to make the circular business approach the preferred one compared with the still default linear business-as-usual approach.

4.1 Exploration of business opportunities in Singapore and the Netherlands

The next few sections highlight some concrete examples of how some of the waste streams considered in the MFA are being managed in the transition to a circular economy in both the Netherlands and Singapore.
The Netherlands government has drawn up a transition agenda for five priority sectors, including plastics, and biomass and food. Accordingly, an increasing group of organisations and stakeholders are now convinced that there is enough momentum to transition to a circular economy effectively.

(i) Food waste

The Netherlands committed itself to United Nations SDG 12 "Responsible consumption and production", namely Target 12.3 "Halving the food waste by 2030". Reducing food waste is crucial in a circular economy as it ensures that biomass is used judiciously and at a higher grade, and thus contributes to food security. Moreover, it increases the availability of biomass for other applications, such as animal feed and renewable materials. It also strongly reduces the ecological impact (such as the use of water and land, biodiversity, etc.). In the Transition Agenda Circular Economy 2018 (Biomass and Food), three different forms of action to maintain resources intended for human consumption in the food chain have been identified - 1. Preventing food waste (design issue). 2. Reducing food waste (innovation and chain issue). 3. Better valorisation of (unavoidable) residual streams within the food chain (human consumption, or upcycling of low-grade resources into high-grade nutrients through livestock farming).

As far as practical and safe, food waste streams are used for food applications again. In the Netherlands, there are business models and systems where food waste is reduced through the use of smarter packaging and by using unsold products for sauces and soups, from produce (vegetables and fruits) that would be otherwise wasted every day. If this is not possible, using it and/or upgrading it to animal feed (preferably) and bio-based products is the logical choice. Optimum valorisation of biomass and residual streams into circular, bio-based products is therefore a key action.

In Singapore, food waste is one of the biggest waste streams standing at 744,000 t/a in 2019. With the Zero Waste Masterplan (NEA, 2019), consumers are encouraged to adopt smart food purchase, storage and preparation habits in order to help minimise food wastage. In addition to that, the NEA has established the 3R Fund which encourages organisations to reduce waste disposed through the implementation of waste recycling initiatives. Singapore recycles about 18% of its food waste with the rest being sent to the waste-to-energy plants where it is incinerated. Currently, there are some initiatives to recycle food waste into useful products like compost for landscaping purposes, and several composting systems making use of worms, larvae or yeast. With about 608,000 t/a of food waste not recycled, there are business opportunities that both Singapore and the Netherlands can explore, especially learning from the examples and initiatives disseminated by the Holland Circular Hotspot (https://hollandcircularhotspot.nl/).

(ii) Plastics

In Singapore, there is a push to adopt the circular economy approach through sustainable production and design, and establishing best practices in the 3Rs (reduce, reuse and recycle). Singapore incinerates plastic waste minimising the amount of plastic that ends up as litter both on land and in the oceans. As part of the Zero Waste Masterplan (NEA, 2019), Singapore is also exploring more advanced technology to close the plastics loop. For instance, in addition to the current prevalent technology of using mechanical recycling to recycle plastics, the adoption of chemical recycling to turn plastic into feedstock or fuel is being explored. Chemical recycling technology involves converting separated or mixed plastics back into pyrolysis oil, naphtha, methanol and syngas. These products can be further processed into building blocks to make new plastic products, or be converted into fuel to replace fossil fuel sources. There are particular opportunities for mixed or dirty plastics, which currently cannot be recycled through mechanical means, to be recycled. In the Netherlands, mixed plastic waste that usually are down-cycled or incinerated are currently being recycled into clean streams using emerging/innovative technologies and approaches. This is another growth area in the circular economy and closing the plastics loop which Singapore is well-placed to exploit.

Another area where business opportunities can be forged is in the sorting of recyclable material (such as plastics) at the waste-to-energy facilities. Sorting prior to incinerating is practiced in the Netherlands and this could be an area where collaboration between the two countries can take place to look at practices that may be transferable. This might necessitate upgrading of the existing facilities to implement an integrated waste management system on-site.

Creating a market for recycled products from plastics is another key consideration. The demand for recycled plastics is low without an established market. This can be a barrier to developing a circular economy. Accordingly, business organisations both in Singapore and the Netherlands can capitalise on plastic waste to create a demand for recycled plastic products. Several business models exist in the Netherlands where companies have specialised in creating high-quality raw materials from post-consumer plastics. It is noteworthy mentioning that Europe's largest recycling plant for mixed plastics is located in the Netherlands where around 150,000 tonnes of plastic is recycled every year.

(iii) Resources from the water cycle

With regard to the water cycle, wastewater sludge represents one of the biggest challenges for water utilities. Despite the fact that over the years, treatment standards have improved, traditional and linear approaches have resulted in increasing the production of sludge. With more and more restrictions on sludge disposal to landfills, new and circular approaches and technologies are needed. The Netherlands is leading in this respect and sludge is currently one of the most important areas for innovation around water use, led by Dutch researchers and companies. Several resources are recovered from the sludge and increasingly sludge is being dealt with a more holistic view particularly in relation to the potential of recovering resources, namely biogas, struvite, cellulose and sand. Moreover, technologies to produce biofuel and other products from fats, oil and grease waste are also emerging in the Dutch water market (https://www.nijhuisindustries.com/solutions/resource-recovery/aeco-fat-fat-recovery). Dutch companies offer a wide range of established and innovative technologies to recover resources from sludge. This is another area of business opportunities that both Singapore and the Netherlands can explore further collaboration and partnership. On the other hand, the Netherlands do not recycle a lot of wastewater as the demand is not there yet, as compared with Singapore.

It is worthwhile to further explore options for the circular economy of water in Singapore. As a first step a quick update of the City Blueprint of Singapore can be carried out, after which a broader discussion can be held to explore the options. There are more options than energy and nutrient recovery only. Work of KWR on the energy & raw materials factory of the Dutch Water Authorities (Van Leeuwen et al. 2018) is one of the concrete options that can be explored for Singapore. The energy & raw materials factory approach is very relevant also because of the greatly reduced space (square meters) needed to build these compact treatment plants.

(iv) IBA

There is a need to critically assess the impact of incineration plants on the viability of circular business cases and determine appropriate actions that need to be taken to transition to a circular economy. In the Netherlands, the use of treated IBA is finding its place in the Netherlands' transition to a circular economy where around 95% of the IBA is recycled, although there are concerns over the impacts of using it in a wide range of applications in the construction sector. At the same time, there are specialised companies applying the latest separation techniques to remove ferrous and non-ferrous metals from IBA and sold as a high-grade raw material to smelters. There is an annual need for 120 to 140 million tons of building materials, which are for the main part imported from abroad. By using IBA, a saving is achieved on the use of primary raw materials, which prevents the living environment from being further negatively affected.

Although millions of tonnes of bottom ash are used in public works and roads, it is unclear where it is used and whether these locations are complying will the regulation requirements. There are serious questions raised about the control of toxicity in public works, and as such future research should consider the environmental and public health related to the application of IBA in public works, roads and other uses. Consequently, there is a need to ensure that hazardous substances do not leak out of concrete of other building materials containing bottom ash.

In Singapore, there are currently a few field trials underway to investigate the use of treated IBA as road base or sub-base material in road construction projects (NEA, 2019). The outcome of these studies will assist in providing environmental standards for the regulation of the use of treated IBA, namely NEWSand, to ensure that the material is suitable for use in Singapore without compromising its water resources and environment.

The use of treated IBA is clearly another area where both the Netherlands and Singapore can learn from each other through the various studies and projects carried out. In addition, collaborative studies looking at the life cycle assessment of IBA would lead to valuable outcomes when exploring the use of IBA aggregates in the transition to a circular economy. If the use of IBA is permitted, then business opportunities to treat and use IBA in the construction sector will flourish.

There are additional concrete business case examples and best practices of circular economy in the Netherlands with respect to the four waste streams investigated in this study. There are sufficient solutions to scale up and create mass and impact. The Netherlands is viewed by many countries as a living lab for innovative circular initiatives and entrepreneurship. Without citing any particular business organisation, creative ideas on circular projects can be found on the Holland Circular Hotspot website (https://hollandcircularhotspot.nl/) where many inspirational successful circular initiatives are shared and presented to stimulate international entrepreneurships and partnerships.

Moreover, the transition to the digital world is rapidly taking place in the Netherlands where artificial intelligence (AI) and machine learning tools are being developed and used to make complexity visual, understandable and actionable. Accordingly, AI is being used for a sustainable transition to a circular economy. It helps to evaluate dependencies between stakeholders, resources and infrastructure from a nexus (integrated) perspective, assess resilience of a system, identify risks and intervention points at different scales, and create a data-model reusable for other studies, such as evaluation of systemic impacts of the circular solutions on different parts of the system and cross-optimisation. It can be used to design integrated and zero-waste solutions, business models and policies in a multi-stakeholder environment. There are currently data-driven models that have been developed for the water cycle including phosphorous recovery and valorisation (www.infinitix.technology).

Furthermore, Singapore is strengthening its fundamental research and innovation capacity. Under the theme Urban Solutions and Sustainability, significant investment will be made. Singapore has no natural resources and after an extensive strategy for creating its own water supply, the government is now investing in building food security. Traditional agriculture is not an option, so there is a budget for high-tech urban agriculture, alternative proteins and making the food system circular. Large budgets for climate adaptation were announced in 2020 and additional investments will be made in making the urban environment more sustainable, for example by developing green and alternative energy and technologies such as CO_2 storage (RVO, 2021).

4.2 Other business opportunities to explore using the circularity ladder

The circular economy involves lowering of material consumption in order to reduce environmental pressures and dependency. Recycling is much better than incineration or landfill, however, circular economy is more than just recycling. Based on the principle of the Lansink's Ladder, a circular ladder or R-ladder (Figure 16) highlighting the order of priority for circularity strategies based on product function is proposed (Potting et al, 2016 and PBL, 2018). This circularity ladder is a seamless first step in the transition to a circular economy. It contains a wide range of hierarchically arranged options in the process towards a circular economy. In general, circularity strategies higher up the ladder require fewer materials. These materials are predominantly made from recycled (i.e. secondary) materials meaning that less natural resources need to be extracted to produce new (i.e. primary) materials.

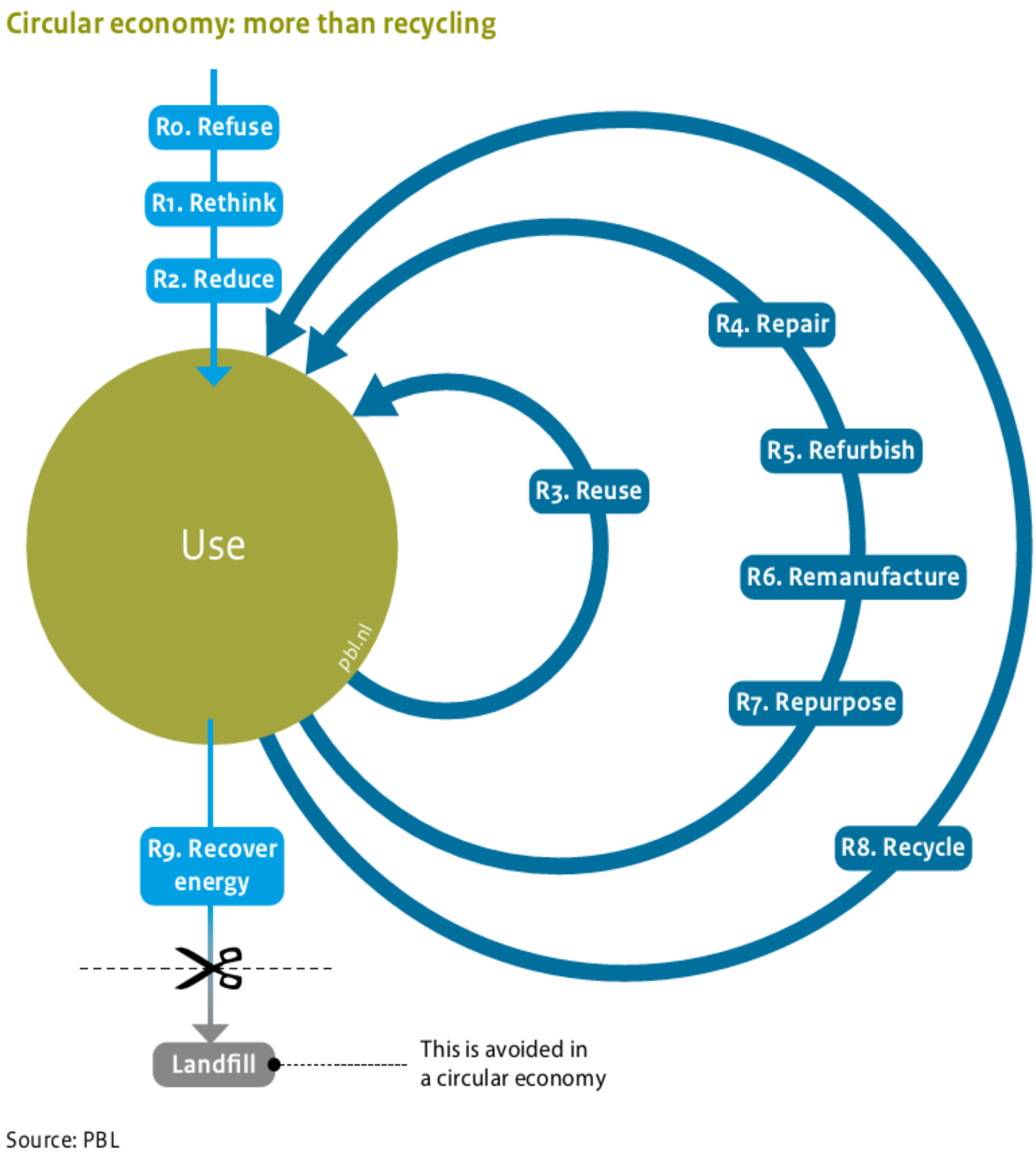

Figure 16: A circular ladder based on product function showing the order of priority for circularity strategies (Source: PBL, 2018)

To illustrate how the circularity ladder (9Rs approach) can be applied in the transition to a circular economy, two examples of waste stream (food and plastics) are shown below in Tables 11 and 12. These examples can serve as inspirations for business opportunities in redesigning of products, re-use and recycling to extend the lifecycle of products and resources, in turn reducing material consumption.

Table 11: Circular ladder applied to biomass and food (Source: PBL, 2018)

Biomass and food – food for people	
Circularity strategies	**Examples**
R0 Refuse	- Eat less by avoiding sweets and snacks - Eat less of certain types of food (e.g. meat, which can be replaced with protein-rich plant-based products (e.g. pulses and nuts))
R1 Rethink	- Use more parts of food crops for food (e.g. the leaves of carrots or radishes) - Use lower quality food ingredients in other ways (such as smoothies made from overripe fruit, soup from misshapen cucumbers, beer from lower quality potatoes) - Use old bread in other ways (e.g. to make toasted sandwiches, croutons or French toast) - Preserve excess food or food that is reaching its expiry date (e.g. pot fruit and vegetables or salt meat and fish)
R2 Reduce	- Use more efficiently prepared food (such as 'industrial' food like tinned vegetables and bags of soup) - Eat more 'efficiently' by choosing food that makes you feel full more quickly
R3 Reuse	- Reheat leftover food to eat later - Use leftover food ingredients or scraps in other meals (e.g. in soups, salads on omelettes) - Take food still in its packaging that has not reached its expiry date to a food bank
R4 Repair	n/a
R5 Refurbish	- Refresh vegetables in cold water
R6 Remanufacture	n/a
R7 Repurpose	- Use leftover food to feed cattle - Use crop residues to feed cattle
R8 Recycle	- Biorefinery of food waste and crop residues (e.g. for pharmaceuticals, colourings and other fine chemicals) - Use crop residues to produce materials (such as bioplastics, bioresins and biocomposites)
R9 Recover	- Anaerobic digestion of food waste and crop residues to produce biogas and substrate nutrients - Compost food waste and crop residues to produce substrate nutrients - Incinerate food waste and crop residues with energy recovery

Table12: Circular ladder applied to plastics (Source: PBL, 2018)

Plastics – food packaging (from Potting et al., 2015)	
Circularity strategies	**Examples**
R0 Refuse	- Plastic bag ban - Packaging-free shops - Label vegetables using laser marking instead of plastic packaging - No drinks packaging, consumers make their own drinks at home from concentrate (e.g. natural syrups or Cola from flavoured syrups and a CO_2 cylinder)
R1 Rethink	
R2 Reduce	
R3 Reuse	- Consumer cleans own bottle for refill at retailer - Consumer takes own packaging for dry products and vegetables
R4 Repair	
R5 Refurbish	
R6 Remanufacture	
R7 Repurpose	
R8 Recycle	- Higher level plastic recycling by using fewer types of plastic
R9 Recover	- Ferment bioplastic to produce biogas and substrate nutrients - Compost bioplastic to produce substrate nutrients - Incinerate fossil-based plastics and bioplastics with energy recovery

5 Conclusion

This desktop study aims to identify opportunities for enhancing the circular economy, which is already developing in promising ways in the Netherlands, allowing for demonstration and implementation opportunities in Singapore, as well as generating a learning alliance between the two countries. In order to better understand both the Singaporean and Dutch approaches to integrated water resources management, waste streams and the potential for circularity, an updated Trends and Pressures Framework (TPF) and a City Blueprint Framework (CBF) have been developed and an in-depth material flow analysis has been performed for both Singapore and the Netherlands.

First, the TPF's assessment observed that both Singapore and Dutch cities face pressures related to flood risk and have relatively little concern with respect to social, financial or governance aspects. This means that in term of policy measures and urban planning, the similarity in required technologies and management solutions is high and exchange of best practices can therefore be lucrative and meaningful.

Second, the CBF's assessment of urban integrated water resources management found that the largest learning potential that Dutch cities can offer Singapore may be with respect to recovery and reuse of resources from solid waste and wastewater.

Third, the development and application of material flows for four selected waste streams - namely incinerator bottom ash, food waste, plastics and materials in the water cycle – provided valuable insights into business opportunities in Singapore, the Netherland and Singaporean-Dutch collaboration's that can foster the circular economy. The material flow analysis (MFA) identified challenges and opportunities that need to be addressed by commercial companies, governmental organisations and knowledge institutes.

- A significant amount of waste either in stock (landfilled) or destroyed as waste to energy that could be (profitably) recycled and reused. The Netherlands is leading in many respect when it comes to waste recycling and could offer support in the form of knowledge and expertise. This is particularly the case for food waste and plastic recycling and materials recovery in the water cycle.
- Similarly, Singapore is initiating some recycling efforts in its transition to a circular economy that could very well benefit the Netherlands, namely in water recycling and what is planned for the safe recycling and use of IBA. Establishing a platform where the knowledge, learning and experiences can be shared could facilitate such exchange. Such a platform will have ambitions related to circular economy, one of which can be to create a market that supports a sustainable value chains. It can bring together various market players and stakeholders, remove obstacles and establish sustainable business operating conditions.
- Finally, Singapore is well poised to use the international playing field to give momentum to the circular economy transition, namely in Asia. With the results of this study, Dutch businesses, including Knowledge Institutes, are able to identify future business opportunities related to the Zero Waste objectives (circular economy) in Singapore. Singapore has developed the Zero Waste Masterplan which gives shape to Singapore's ambition regarding its Waste Management System (NEA, 2019). Moreover, there is Singaporean interest in the Green Deal approach of the Netherlands. A starting point could be the Green Deal Circular Procurement and expanding the Material Flow Analysis conducted in this research by expanding waste flow monitoring in Singapore. By conducting a detailed Material Flow Analysis for Singapore to adequately quantify the economic value of waste that can potentially be recycled and/or exported as raw materials for other products can be obtained.

6 References

Brunner PH and Rechberger H (2004) Practical handbook of material flow analysis. The International Journal of Life Cycle Assessment 9, 337-338.

Holland Circular Hotspot. https://hollandcircularhotspot.nl/

Huyghe, W., Hernández-Pacheco Algaba, M., van Leeuwen, K., Koop, S., Eisenreich, S. 2021. Assessment of the Urban Water Cycle in Antwerp (BE): The City Blueprint Approach (CBA). Cleaner Environmental Systems. Volume 2, June 2021, 100011. https://doi.org/10.1016/j.cesys.2021.100011

Infinitix: Artificial Intelligence for Sustainable Transition. https://infinitix.technology/

Koop SHA, van Leeuwen CJ. 2020a. Indicators of the Trends and Pressures Framework (TPF). Version August 2020. KWR Water Research Institute, Nieuwegein. https://library.kwrwater.nl/publication/61396712/

Koop SHA, van Leeuwen CJ. 2020b. Indicators of the City Blueprint performance Framework (CBF). Version August 2020. KWR Water Research Institute, Nieuwegein. https://library.kwrwater.nl/publication/61397318/

Koop SHA, van Leeuwen CJ. 2020c. Indicators of the Governance Capacity Framework (GCF). Version August 2020. KWR Water Research Institute, Nieuwegein. https://library.kwrwater.nl/publication/61397218/

KWR (2020) Operationalisering Circulaire Economie principe voor de waterketen. http://api.kwrwater.nl/uploads/2020/11/BTO-2020.020-Operationalisering-Circulaire-Economie-principe-voor-de-waterketen.pdf

KWR (2020) Operationalization of the Circular Economy principle for the water cycle. BTO 2020 report. https://library.kwrwater.nl/publication/61558390/

Metabolic (2020) Data-driven tools to accelerate and scale-up solutions for circular cities. https://www.metabolic.nl/news/data-driven-tools-for-circular-cities/ [Consulted at 14-01-2021]

Ministry of Agriculture, Nature and Food Quality (2020): Fact Sheet – Food Waste in the Netherlands http://www.fao.org/fileadmin/user_upload/nr/sustainability_pathways/docs/4_Fact%20Sheet%20Food%20Waste%20in%20the%20Netherlands.pdf

NEA (2019) National Environment Agency: Waste statistics and overall recycling. https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling [Consulted at 14-01-2021]

NEA (2019) Zero Waste Masterplan (Singapore): https://www.towardszerowaste.gov.sg/images/zero-waste-masterplan.pdf

Nijhuis Industries: https://www.nijhuisindustries.com/solutions/resource-recovery/aeco-fat-fat-recovery

Planbureau voor de Leefomgeving (PBL) (Netherlands Environmental Assessment Agency) (2018): Circular economy: what we want to know and can measure. Framework and baseline assessment for monitoring the progress of the circular economy in the Netherlands

Potting J, Hekkert MP, Worrell E and Hanemaaijer A. (2016). Circulaire economie: Innovatie meten in de keten [Circular economy: measuring innovation along the chain (in Dutch)]. PBL Netherlands Environmental Assessment Agency, The Hague.

Rahmasary AN, Koop SHA, Van Leeuwen CJ (2021). Assessing Bandung's Governance Challenges of Water, Waste, and Climate Change: Lessons from Urban Indonesia. Integrated Environmental Assessment and Management 17(2) 434–444 https://doi.org/10.1002/ieam.4334

RVO (2021): https://www.rvo.nl/sites/default/files/2021/02/Singapore-verstevigt-fundamenteel-onderzoek-en-innovatiecapaciteit.pdf

Singapore Environment Council (2019): Advancing a Circular Economy for Food: Key Drivers and Recommendations to Reduce Food Loss and Waste in Singapore.

Transition Agenda Circular Economy (2018): https://hollandcircularhotspot.nl/wp-content/uploads/2019/09/Transition-Agenda-Biomass-and-Food.pdf

Transition Agenda Circular Economy (2018): https://hollandcircularhotspot.nl/wp-content/uploads/2019/09/Transition-Agenda-Biomass-and-Food.pdf

Van der Hoek JP, Struker A, De Danschutter JEM (2017) Amsterdam as a sustainable European Metropolis: integration of water, energy and material flows. Urban Water J 14(1):61–68

Van Leeuwen K, de Vries E, Roest, K and Koop, S. (2018) The Energy & Raw Materials Factory of the Dutch Water Authorities: its Role in the Circular Economy of the Netherlands. Environmental Management 61(5):786-795 https://doi.org/10.1007/s00267-018-0995-8