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Original Article

Singapore's Zero-Waste Plan - A Masterstroke to Tackle Climate Change

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Abstract *- Singapore has pledged to reach peak carbon emissions by 2030 and reduce emissions by half to 33 $MtCO_2e$ (million tonnes of carbon dioxide equivalent) by around 2050. [1] To meet these targets, the country has made numerous plans. This research study analyses the country's most ambitious plan to become a zero-waste nation. Zero-waste can be achieved through several pathways. The study developed a "forecast model" of Singapore's waste market, which provides a great framework to model and observe different pathways and see what is required to reach a zero-waste target. The study presents its observations on a likely pathway to reach zero-waste status.*

The study forecast that to achieve zero waste, Singapore's total waste generation at source should see a major reduction from 1273 kg/capita/annum in 2021 to about 1000 kg/capita/annum by 2050. To reduce waste generation at the source, the prime focus must be on the domestic sector, where waste recycling rates are low even after a lot of effort from the government. Consumer awareness and participation are still low and the biggest barrier to achieving a zero-waste target. In addition to stepping up its consumer awareness programs, the government must roll out new and innovative rewards-based programs for consumers to increase their involvement in waste management. The share of domestic waste should also be reduced from 26% in 2021 to less than 20% in 2050.

Even if Singapore achieves a 70% recycling rate by 2030, it will be difficult to achieve zero-waste. Recycling must increase dramatically from 55% in 2021 to more than 95% by 2050 for a zero-waste status, mainly on the domestic front, where recycling was only 13% in 2021. The study shows that the three waste categories to focus on for recycling should be paper/cardboard, plastics and food. As the recycling rate increases, the domestic industry to handle recyclables must also grow simultaneously rather than relying on the export market for recyclables.

Even with a lower waste generation and high recycling rate, zero-waste cannot be achieved without reducing the amount of incineration ash generated. In 2021, about 520,000 tons of incineration ash was sent to landfill. New waste-to-energy technologies must be considered to reduce the current incineration ash sent to landfill. Alternative uses for ash must be developed and commercialised to recycle unavoidable ash generated.

Overall, the study believes that although it is challenging, Singapore's plan to become a zero-waste nation is a masterstroke in Singapore's climate action plan. Meeting the zero-waste target can help Singapore cut carbon emissions by 9.1 MtCO2e, equivalent to 30% of its climate change pledge by 2050.

Keywords *- Carbon emission, Circular economy, Climate change, Landfill, Waste management.*

1. Introduction

Greenhouse gases such as methane and carbon dioxide trap heat in the earth's atmosphere, resulting in rising temperatures, referred to as global warming or climate change. Higher temperatures cause seawater expansion and ice melting over land and glaciers. It can lead to a rising sea level and more frequent and extreme weather events.

To keep global temperature rise below 2 degrees celsius since pre-industrial times, the world must cut its carbon emissions. Cutting carbon emissions is a global challenge that needs every country's response. Each country must do its best based on its capabilities and national circumstances. Singapore has seen an increase in temperature by 0.25-degree celsius every ten years from 1948 to 2015. [2] Singapore must join the global efforts to cut carbon emissions to protect itself from the impacts of climate change. This study discusses in detail the feasibility of Singapore's zero-waste plan. It presents a forecast model of the Singapore waste market, which allows the study to evaluate the savings in carbon emissions by 2050 from achieving zero waste.

Lowering greenhouse gas emissions must also be done sustainably. Environment protection must be achieved together with economic growth and social inclusion. Each country must try to end poverty, fight inequalities and act on climate change simultaneously. A sustainable development framework of the UN comprising 17 sustainable development goals (SDGs) came into effect in

Jan 2016. [3] This framework requires participating countries to develop climate change policies sustainably to meet SDGs simultaneously.

2. Singapore's climate pledge

As a small country, Singapore's carbon emissions are only about 0.1% of global carbon emissions. [4] But the impacts of climate change on Singapore are huge. So Singapore must do its share to tackle climate change. As a first step, Singapore has been at the forefront of supporting and ratifying international discussions to support actions on climate change.

Singapore supported the United Nations Framework Convention on Climate Change (UNFCCC) in 1997. Next, it signed the Kyoto Protocol in 2006 and the changes to Kyoto Protocol in 2014 for the commitment period from 2012 to 2020. [5]

Singapore went on to sign the Paris Agreement in September 2016, together with 30 other countries. [5] The Paris agreement is legally binding for climate action commitments after 2020. The agreement, adopted at the 21st Conference of the Parties to the UNFCCC (COP-21) in December 2015, was enforced in November 2016 with 55 supporting Parties. Total emissions of supporting countries exceeded 55% of global carbon emissions. [6]

In July 2015, Singapore came up with its first climate pledge, Nationally Determined Contribution (NDC). The country set a target to reduce its carbon emission intensity by 36% by 2030 in 2005 and aims to have its emissions peak by 2030. [7]

Singapore continued with more rigorous targets. It enhanced its 2030 pledge and came up with a Long-Term Low Emissions Development Strategy (LEDS) in March 2020. The new target is to cap its emissions at 65 MtCO2e around 2030, and under LEDS, the country aims to halve its emissions to 33 MtCO2e by 2050, with an aspiration of reaching zero emissions in the second half of the century. [1]

3. Singapore's action plan

To meet the 2030 pledge, Singapore has chalked out a two-pronged climate action plan – adaptation and mitigation. [8,9]

- Adapting to the effects of climate change ("adaptation"). The impacts of climate change will be there even after the world reduces its carbon emissions. So every country must also prepare to adapt and invest in coastal and infrastructure protection measures
- Reducing the levels of greenhouse gasses in the atmosphere ("mitigation")
    - Improving our industry energy efficiency
    - Early Fuel Switch
    - Low carbon technologies and pricing carbon
    - Harnessing more solar power
    - Greening transport
    - Greening buildings and cities

4. Singapore's zero-waste plan

Reducing waste is one of the most effective ways to tackle climate change. Less waste eventually leads to lower consumption and production of resources, which means lower energy consumption and lower greenhouse gas generation. One of the common ways to dispose of waste is to send it to a landfill. During the landfill process, anaerobic decomposition of food and other organic wastes produces landfill gas, which has 45% to 60% methane and 40% to 60% carbon dioxide. [10] So if we send less waste to landfill, we will also have lower greenhouse gas emissions. Lastly, less waste means less incineration or combustion of waste before going to landfills, which is also a source of carbon emissions.

Singapore aims to achieve the gold standard of becoming a zero-waste nation with three objectives:

- Address climate change
- Become resource efficient for the security of supply of resources
- Keep the economy competitive even with carbon and resource constraints

A zero-waste plan helps Singapore meet its climate pledge and twelfth sustainable development goal, which pursues sustainable consumption and production. To reach zero waste, Singapore has set itself two immediate targets: [11]

- A 30% reduction in waste to landfill from 0.36 kg/capita-day in 2018 to 0.25 kg/capita-day by 2030
- Extend the lifespan of Semakau landfill beyond 2035

These targets are on top of an existing target of increasing recycling from 60% in 2018 to 70% by 2030 (non-domestic to 80% and domestic to 30%) under the sustainable Singapore blueprint. [12]

In this research paper, Singapore's zero-waste plan will be discussed under the lens of the following themes:

- Theme A - Key Environmental Statistics - Solid Waste Management
- Theme B - Circular Economy in Singapore
- Theme C - Semakau Island (The Green Landfill in Singapore)
- Theme D - Greenhouse gas savings from the zero-waste plan

5. Materials and Methods

This study built a "forecast model" with the following assumptions and calculations to forecast Singapore's waste market metrics.

Singapore's population forecast is the basic macro indicator for total waste generation. The study used projections from the world bank. Singapore's population will grow from about 5.5 million in 2021 to 5.9 million in 2050. [13]

To reduce waste generation at the source, the study assumes that total waste generated in kg/capita/annum will be reduced from 1273 in 2021 [13,14] to about 1000 in 2050. The study sets the target of 1000 kg/capita/annum of total waste in 2050 to achieve a very low waste to landfill rate. The study uses the historical share of domestic waste to forecast the future share of domestic waste. As the recycling percentage for domestic remains lower than non-domestic, the study slowly reduces the share of domestic waste generation from 26% in 2021 to 20% in 2050.

For 2030, the study assumes that the target recycling rates set by the government are met for domestic and non-domestic sectors. After 2030, the study assumes that domestic recycling rates will continue to increase from 30% in 2030 to 60% in 2050. In addition, the study assumes that the non-domestic recycling rates will increase from 81% in 2030 to 90% in 2050. These assumptions allow us to forecast that overall recycling rates will increase from 70% in 2030 to about 85% in 2050. It is worth highlighting that Singapore does not achieve a zero-waste to Semakau landfill target at these recycling rates. But the assumptions in the model can be easily changed to observe the requirements for a zero-waste to landfill target.

Once the recycling percentage is known, the study calculates the amount of waste disposed of, both domestic and non-domestic. Waste sent directly to landfills is assumed to stay at 8% [14], and weight reduction after incineration is assumed at 82% [14] of pre-incineration weight. Then the study calculates the waste sent for incineration and sent directly to landfill. The incineration bottom ash is assumed to be sent to a landfill. The above assumptions in the forecast define our "likely pathway".

The user can change the assumptions and remodel the output for Singapore's waste market. The study discusses one "likely pathway" that it believes is more likely in a journey towards zero-waste.

Another important aspect of the "forecast model" is that it provides the inputs required to calculate the savings in greenhouse gas emissions as Singapore travels on the likely pathway by 2050. The model provides the following parameters in the base year 2021 and forecast year 2050.

1. Amount of waste reduction at source by each category of waste
2. Amount of waste recycling by each category of waste
3. Amount of waste landfilled by each category of waste
4. Amount of waste combusted or sent to incineration by each category of waste

To evaluate the net savings in greenhouse gas emissions in 2050 when Singapore recycles more waste versus the 2021 baseline, the study used the US EPA's Waste Reduction Model (WARM). [15] This model provides high-level estimates of greenhouse gas emissions reductions with different waste management practices such as source reduction, recycling, anaerobic digestion, combustion, composting and landfilling. We used our forecast model output for 2021 and 2050 to evaluate the difference in greenhouse gas emission reductions in 2050 versus 2021.

Waste statistics data from Singapore are categorised as follows:

Table 1. Waste generation categories in Singapore

Singapore waste categories	Municipal waste	Recycling category
Ferrous metal		Category 1 - High recycling
Paper/Cardboard	Yes	Category 3 - Low recycling
Construction & Demolition		Category 1 - High recycling
Plastics	Yes	Category 3 - Low recycling
Food	Yes	Category 3 - Low recycling
Horticulture		Category 2 - Medium recycling
Wood	Yes	Category 2 - Medium recycling
Ash & sludge		Category 3 - Low recycling

Textile/Leather		Category 3 - Low recycling
Used Slag		Category 1 - High recycling
Non-ferrous metal		Category 1 - High recycling
Glass		Category 3 - Low recycling
Scrap tyres		Category 1 - High recycling
Others (stones, ceramics, etc.)		Category 3 - Low recycling

Source: [14]

6. Discussion

6.1. Theme A: Key Environmental Statistics - Solid Waste Management

Total waste generated in Singapore per capita is towards the high end. To show this, the study compares municipal solid waste (MSW) generated in Organisation for Economic Cooperation and Development (OECD) countries [16] with that in Singapore for the year 2019. The study chose 2019 to avoid the interference of the impact of Covid-19. Singapore's MSW in kg/capita/annum in 2019 was about 569, [13,14] which is almost 7% higher than the average in OECD [16] and almost 1.6 times that in Japan [16] (see Fig. 1). These statistics help the study propose that total waste generation at the source should be a key reduction target to achieve a zero-waste objective.

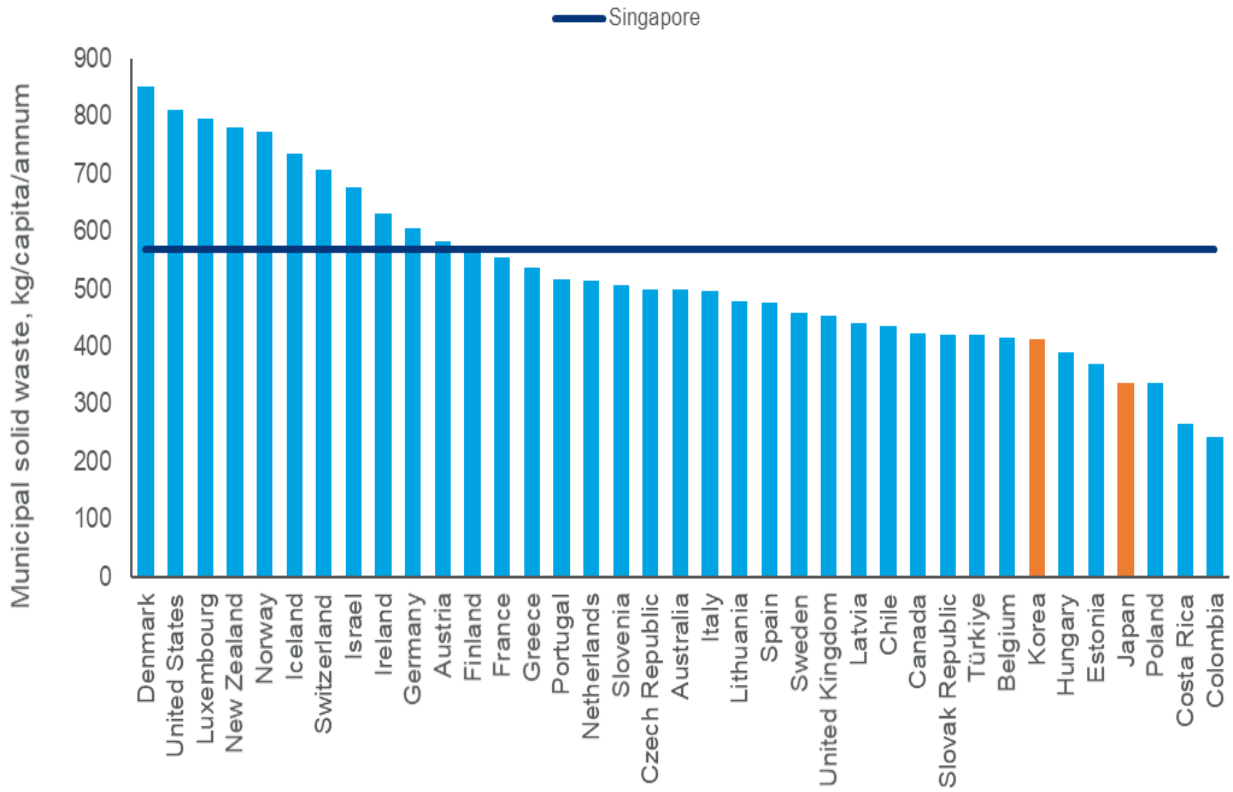

Fig. 1 Municipal solid waste generated in Singapore versus OECD countries (2019)

Source: [16]

Below we discuss further trends in historical solid waste statistics [14] in Singapore.

Category 1 - High recycling category: Ferrous metal, construction & demolition, used Slag, non-ferrous metal, and scrap tyres

Category 2 - Medium recycling category: Horticulture and wood

Category 3 - Low recycling category: Paper/cardboard, plastics, food, ash & sludge, textile/leather, glass, and others (stones, ceramics etc.)

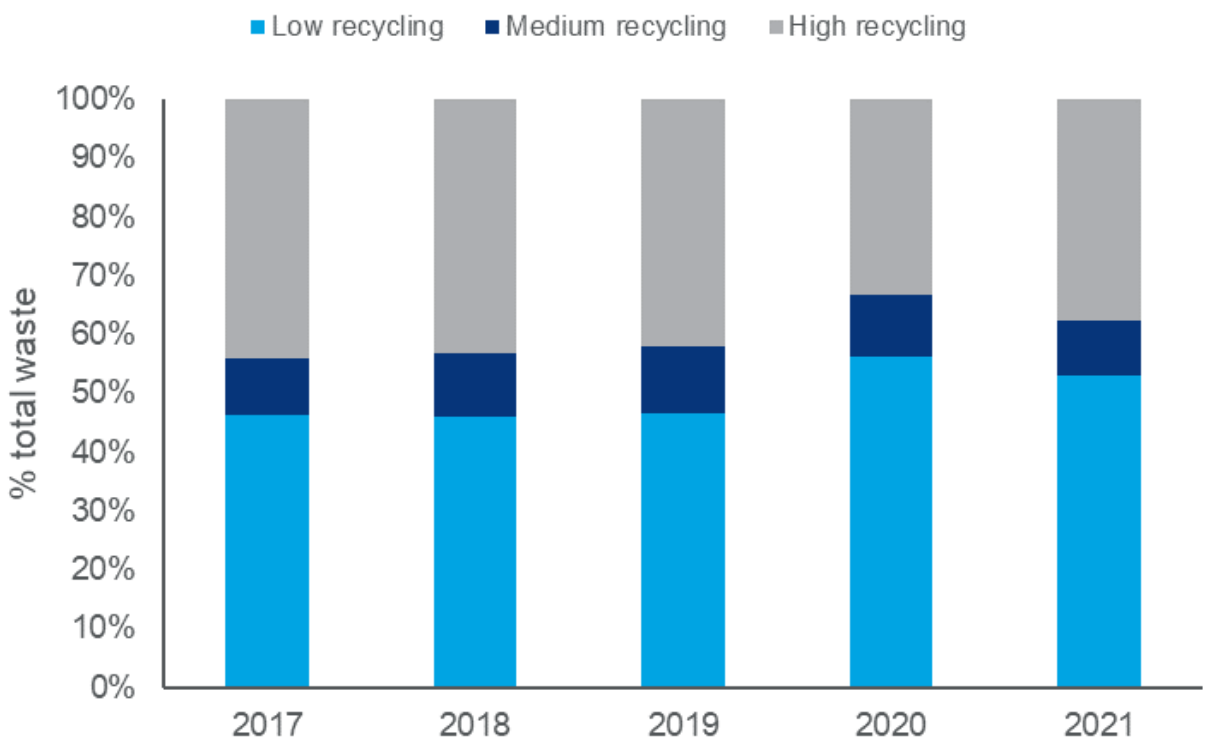

Fig. 2 Share of total waste generation for three major categories of waste

Source: [14]

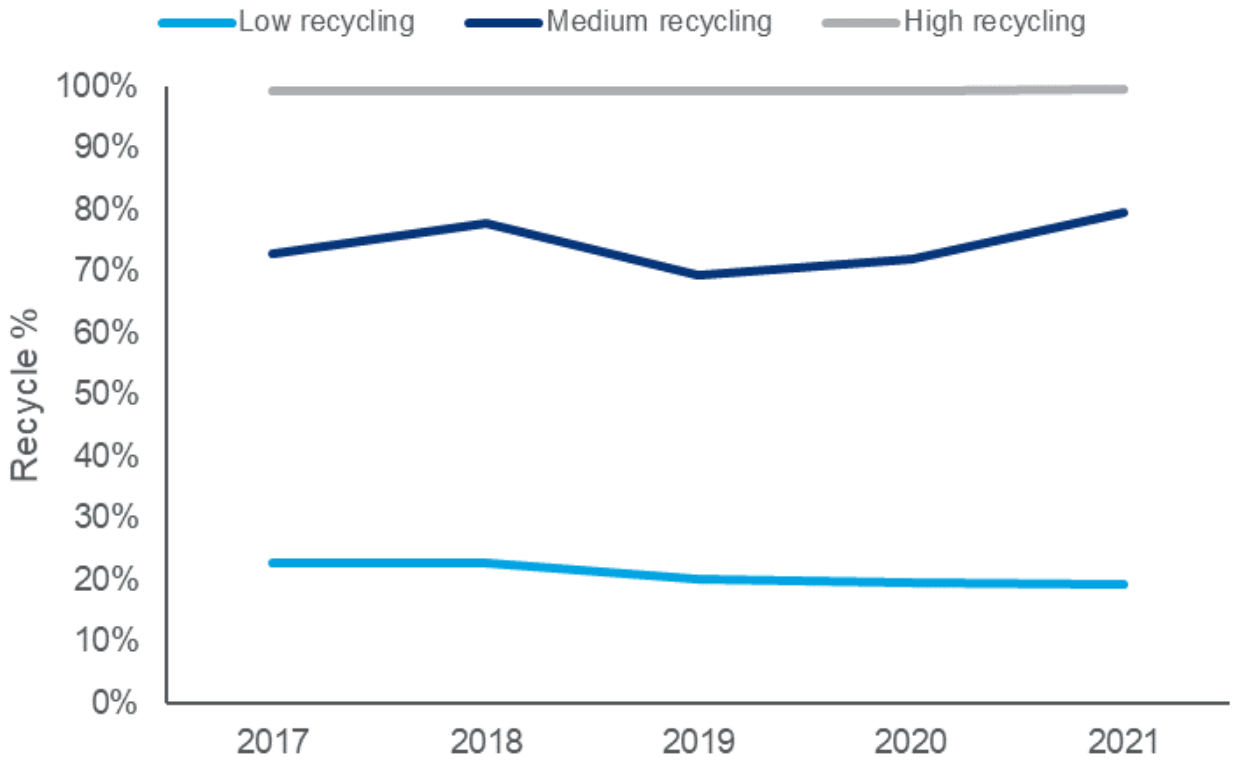

Fig. 3 Recycle percent in three categories of waste in Singapore

Source: [14]

The above Fig. 2 and 3 [14] show that:

- Category 3 (mainly food and packaging) has the lowest recycling, and it also accounts for the largest share of total waste generation, typically more than 45%
- The share of category 3, where recycling is the lowest, either remains flat or increases. At the same time, the recycling percentage in this category has also been dropping. This observation indicates that more focus and attention should be directed towards category 3 to achieve a zero-waste objective
- Category 1, which accounts for more than 40% of total waste, has maintained a very high near 100% recycle rate. Singapore has been successful in closing the resource loop in this category. Lessons and successes from this category should be transferred to other categories, mainly for category 3

A detailed look at the waste composition in Category 3 9 (see Fig. 4 and 5) clarifies that the focus should be on food and plastics. These two make up more than 45% of category 3 [14], and recycling rates are very low, particularly for plastics.

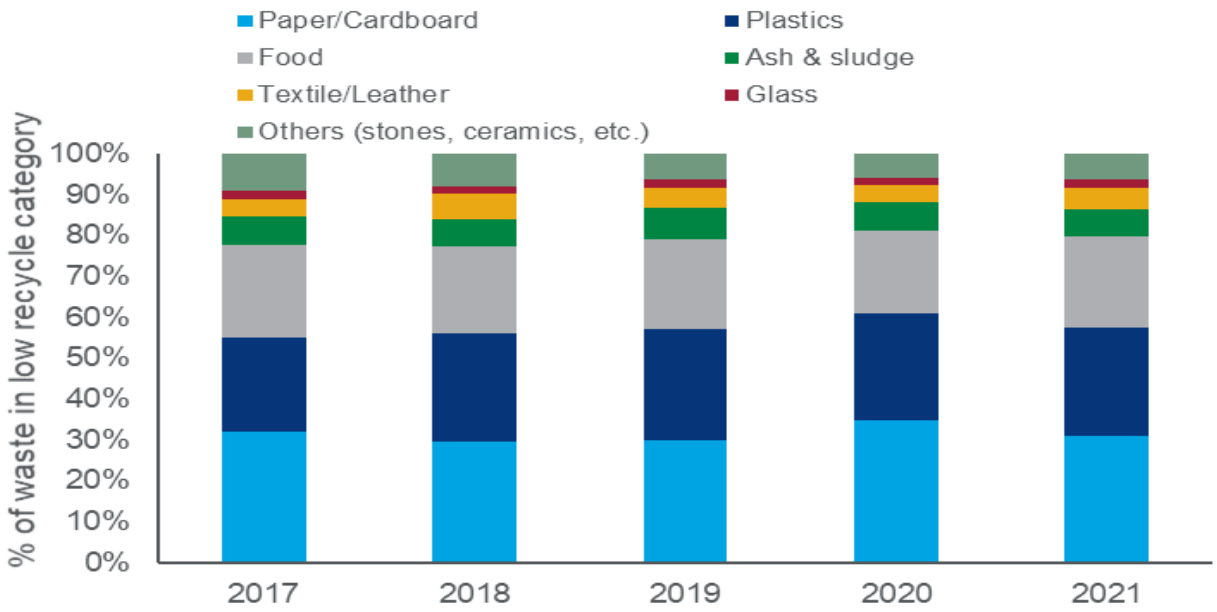

Fig. 4 Waste composition for category 3

Source: [14]

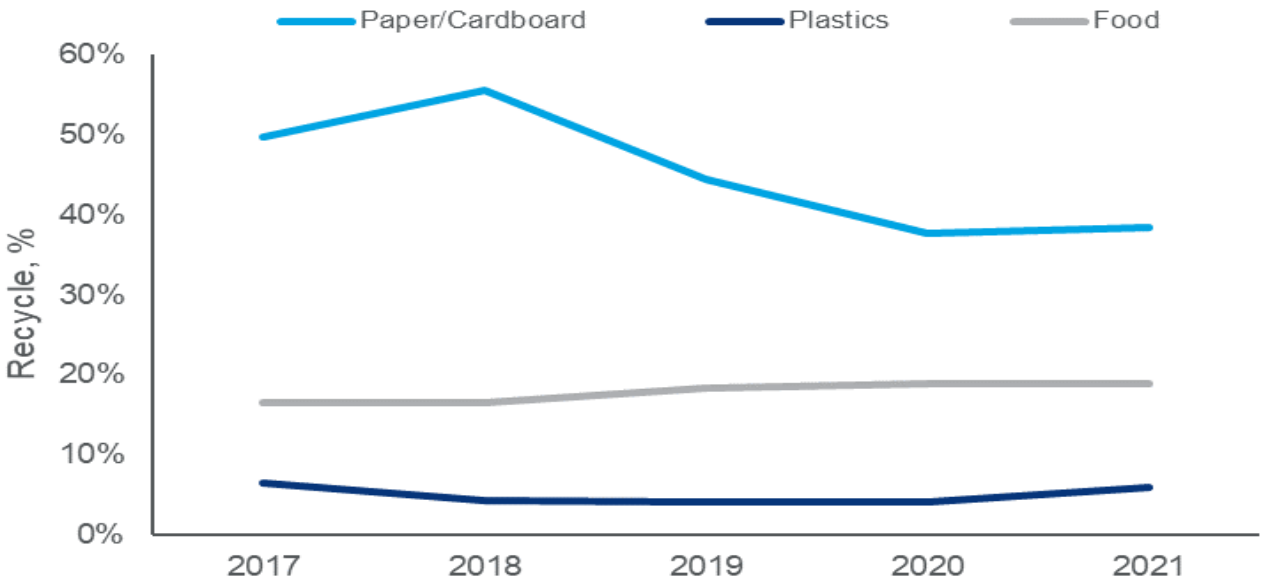

Fig. 5 Recycle percentage for three large types of waste in category 3

Source: [14]

Plastic waste is linked closely to the packaging sector. More than half of packaging is done from plastics. Packaging accounts for more than 30% of Singapore's domestic waste disposal. [17] Food waste is also a big issue in Singapore. It has grown by over 20% in the last 10 years. The country generated about 744,000 tons of food waste, approximately 2 bowls of
rice per person per day. [17] More concerning is that the recycling rates for both food and plastics have been maintained low even after a lot of government efforts to increase recycling. Only 6% of plastic and 19% of food were recycled in 2021. [14]

Therefore, Singapore has made food and packaging a priority waste stream. In addition to these two, the country also wants to focus on electrical and electronic waste, called e-waste. Although e-waste share is less than 1% [18] of total waste generated in Singapore, it can have a detrimental effect on the environment if not properly handled.

Singapore also depends on the export market for more than 30% of its recyclables. [19] The paper recycling rate fell from 56% in 2018 to 39% in 2021. [14] More paper-cardboard waste was disposed of during this period, but less recycled paper was exported because of bans on waste imports in China and other Southeast Asian countries.

6.1.1 Efforts and plans by the government to meet zero-waste

Consumer awareness and participation

Changing consumers' mindsets and habits is very important to achieve a higher domestic recycling rate and minimise waste at the source.

Many consumers throw away perfectly good food because they consider it less fresh. The National Environmental Agency (NEA) has launched several awareness campaigns, videos, and written guides to promote a reduction in food waste through education on the right habits for food purchase, cooking and storage. Recent campaigns include "Buy, Order or Cook Just Enough", "Food Waste Reduction Ambassadors (FWRAs) programme", "Say YES To Waste Less campaign", "Make the Right Choice", and "Choose Reusables". [20]

The NEA and Singapore Food Agency (SFA) have created simple guidelines to maintain food safety during food donation. Consumers and restaurants can donate excess food to organisations such as The Food Bank Singapore, Willing Hearts, Food from the Heart and Fei Yue Community Services, which distribute food to the needy. [20]

To move away from plastic disposables, NEA has banned plastic disposables at many food stalls across Singapore, and many supermarkets now charge extra for disposable carrier bags. To promote a culture of reuse, repair, donating and selling second-hand, NEA has started many centres to repair small household appliances and clothing. [20]

The National recycle programme (NRP) has provided recycling bins in all housing estates to facilitate recycling. But consumers contaminate the recycling bins by disposing of wrong items such as food or liquids. A recent study [21] indicated that about 40 percent of recyclables are sent to incinerators because of contamination. To tackle the contamination issue of recyclables, NEA spreads awareness through its "recycle right" campaign. The NEA has done new and clear labelling on the bins to avoid confusion on what cannot be disposed of in the bins. [20]

Government/Business Regulations

One of the big steps taken by the government is to implement the Resource Sustainability Act in 2019, which makes businesses responsible for their waste management. [22]

The law requires the separation and treatment of food waste by large food waste generators. It enforces the Extended Producer Responsibility (EPR) on manufacturers and retailers of electrical and electronic equipment. The law also demands that packaged product producers report packaging data and plans to reduce, reuse or recycle packaging. NEA has started a Packaging Partnership Programme (PPP) with the Singapore Manufacturing Federation to bring awareness to best practices and develop capability in sustainable packaging. [22]

The government has started a Mandatory Packaging Reporting (MPR) scheme in which manufacturers, importers and retailers are required to report their packaging information ranging from materials used to the type and weight of the packaging. The companies also must report their future 3R plans. By 2025, the government aims to enforce the EPR framework for the packaging sector as well. As the first phase of EPR for packaging waste, NEA will implement a beverage container return scheme in 2022. [22]

Many businesses also plan to reduce their plastics and packaging demand through innovative product design. Using Plastic Action (PACT), [23] an initiative of the World Wide Fund for Nature (WWF), about 270 retail outlets have stopped providing plastic straws.[24]

Many grocery businesses have gone package free. They encourage consumers to bring their bags or containers, allowing them to buy exactly what they need. These stores are ready to pass on the packaging cost savings to consumers.

NEA has also started audits on material usage and waste management of many companies in the commercial and industrial sectors. These audits and brainstorming sessions bring out new ideas for waste reduction. NEA is also promoting industrial symbiosis where one company's waste serves as raw material for another. [25]

As another initiative, NEA has made it compulsory for developers of commercial and industrial projects to provide space for on-site food waste treatment systems in their design plans. [25]

From 2024, large food waste generators will have to put treatment methods or systems in place, such as converting waste into animal feed or sending food waste for offsite management. [25]

Technology/Research

The development of new technologies will provide solutions to turn waste into resources.

NEA is running a research initiative called Closing the Waste Loop (CTWL) in collaboration with the industry on some projects to find solutions in areas such as optimisation of landfill space and recovery of resources from waste streams. NEA's 3R fund, other research areas include on-site waste treatment to convert unavoidable food waste into non-potable water, liquid nutrients, biogas and organic fertiliser.[25]

Research is also ongoing to find an alternative use for incineration bottom ash sent to the Semakau landfill. Alternative uses being explored are construction material, road construction aggregates, tiles for pavements, building facades, or even land reclamation. [25]

Incineration is the main waste-to-energy (WTE) technology used in Singapore for disposed waste. Alternative WTE technologies such as anaerobic digestion and gasification have great potential to complement the status quo.

To reduce plastic waste, NEA is looking into the chemical recycling of plastics on top of existing mechanical recycling. Contaminated plastics that cannot be mechanically recycled can be converted to pyrolysis oil which can be used as feedstock to produce plastics and petrochemicals. [25]

6.2. Theme B: Circular economy in Singapore

To achieve its zero-waste objective, Singapore is on a transformational journey. A transformation from a linear "take-make-dispose" economy toward a "Make-use-recycle", aka circular economy that reuses resources and transforms waste into resources.

The circular economy reduces waste and maximises resource value as the resources are used for longer. Implementing a circular economy requires changes, from production and consumption to waste management (see Fig. 6). A circular economy improves the quality of life because lower use of resources is needed to produce higher gains, leading to higher efficiency.

About 1/3rd of food produced yearly is wasted, equivalent to 1.3 billion tons or worth around US$1trillion. [26] Activities in the food sector consume about 30% of the world's total energy consumption and account for 22% of global carbon emissions. [27] A circular economy reduces the carbon footprint of resources used in an economy. Reduced production leads to lower carbon emissions, and recycling turns waste into resources, eventually leading to lower carbon emissions.

6.2.1. How to achieve a circular economy?

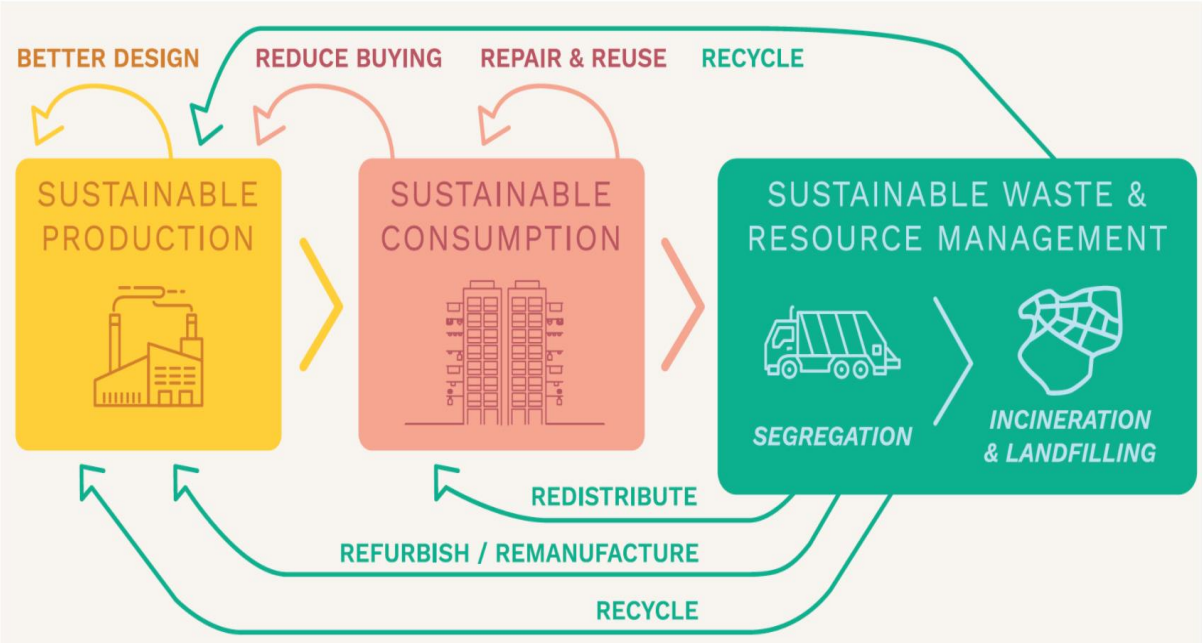

Fig. 6 Components of a circular economy

Source: [28]

Sustainable Production

Producing products by using fewer resources and reducing waste simultaneously is sustainable production. It will become unsustainable to meet growing consumer demand with limited resources if the world does not find new ways to produce more with fewer resources and less waste.

Areas of focus for sustainable production are as follows:

Sustainable design: Reinventing product design to reduce resource usage, increase the shelf life of products, make products more repairable and recyclable, use less packaging and create less waste during production.

Resource efficiency: Reimagining processes to reduce resource usage, improve material efficiency, and recycle more waste. Research [29] indicated that resource efficiency could save between U$2.9 and U$3.7 trillion a year by 2030, cut resource usage by 26% and reduce carbon emissions by 20% by 2050.

Industrial symbiosis: Collaboration between companies to work on various synergies that can be mutually beneficial and environmentally beneficial. For example, waste streams from one company can be a useful raw material for another. An example is illustrated in Singapore through the design of the Tuas Nexus, where an integrated waste management facility will be integrated with a water reclamation plant. Both facilities plan to exchange multiple streams. [28]

Sustainable consumption

Sustainable consumption is related to consumers. Changing consumer habits, mindsets and behaviors, they do more with less. The following focus areas can achieve it.

Reduce: Consumer awareness and education to help them understand the energy required to create a product or prepare a meal. This consciousness will help consumers to reduce wastage by keeping in mind to "Buy, Order or Cook Just Enough". [28]

Reuse and donate: Develop a habit of reusing faulty items by getting them repaired. If an item is not required, try and find someone who will use it and donate rather than a throw. [28]

Promote green-labelled products: Add a ¨green¨ criterion when buying products. Buy environmentally-friendly products. Businesses should bring out the environmental considerations in marketing their products by importing more green-labelled products or adopting a ¨green¨ procurement policy.

Tackling single-use disposables: Awareness to reduce single-use plastic disposables. Use reusable materials instead of disposables. [28]

6.3. Theme C: Semakau Island (The Green Landfill in Singapore)

At the heart of the issue of waste management in Singapore is the scarcity of land resources. Singapore only has one landfill, Semakau Island. The landfill is located about 8 km south of Singapore and was built in 1999. It has an area of 3.5 km^2 and can hold up to 63 million m^3 of waste. [30] The landfill structure was carefully built to ensure that waste does not seep into the seas.

In Singapore, waste disposal has increased over seven times in the last 40 years. At the current landfill rate, the Semakau landfill will be full by 2035. [30] Increasing the number of incineration plants or landfills is difficult in Singapore, given the land constraints. Therefore the only option for Singapore is to reduce waste.

6.3.1. Waste to landfill process

Waste is collected throughout the country and transported to Waste-to-Energy (WTE) plants. Waste is stored in refuse bunkers before further processing. The refuse bunkers are kept below atmospheric pressure so that waste odour does not escape outside. Big rotary crushers break waste material into smaller pieces to make them fit for incineration. After crushing, waste is combusted in the WTE plants. Both weight and volume of waste reduce after combustion. The volume of waste reduces by 90%. [30] The hot gasses from the combustion process drive turbines to generate electricity. Flue gasses (exhaust gas post-combustion of waste) are released into the atmosphere through tall chimneys after proper cleaning.

Metals contained in the incineration bottom ash are recovered and recycled. The remaining ashes are sent to the Semakau landfill by ships. Bulldozers are used to level the landfill, and then the land is covered with soil on which grass and plants grow.

6.4. Theme D: Reduction in greenhouse gas from zero-waste plan

With less waste generation at the source and higher recycling rates, we will see less waste disposed of in landfills. The study estimates that waste disposal will reduce from 3.1 million tons in 2021 to 2.1 million tons by 2030 when the overall recycling rate reaches 70%. Under a zero-waste target, waste disposal will have to fall close to zero. The study further forecasts a recycling rate of 85% by 2050, and waste disposal reduces to 0.9 million tons.

The study used the US EPA's WARM model [15] to evaluate the savings in net carbon emissions from base case 2021 to 2030 and further to 2050.

Singapore will save about 3.4 million tons of CO_2 equivalent if it achieves its target under the zero-waste master plan discussed above.

By 2050, if the country achieves a zero-waste to landfill target, it will save about 9.1 million tons of CO_2 equivalent. Singapore aims to halve carbon emissions by

2050 from its peak of 65 million tons in 2030. [1] Emissions reduction from a successful zero-waste could help the country meet about 30% of its target by 2050.

But in our "likely pathway" discussed below, based on the assumptions we set out in the methodology section, the study estimates lower savings in carbon emissions. The study estimates a reduction of about 5.5 million tons of CO_2 equivalent in 2050 conditions versus base case 2021. Almost 90% of the savings in emissions come from three sources - Paper/Cardboard, Plastics and Food **(**see Fig. 7**)**.

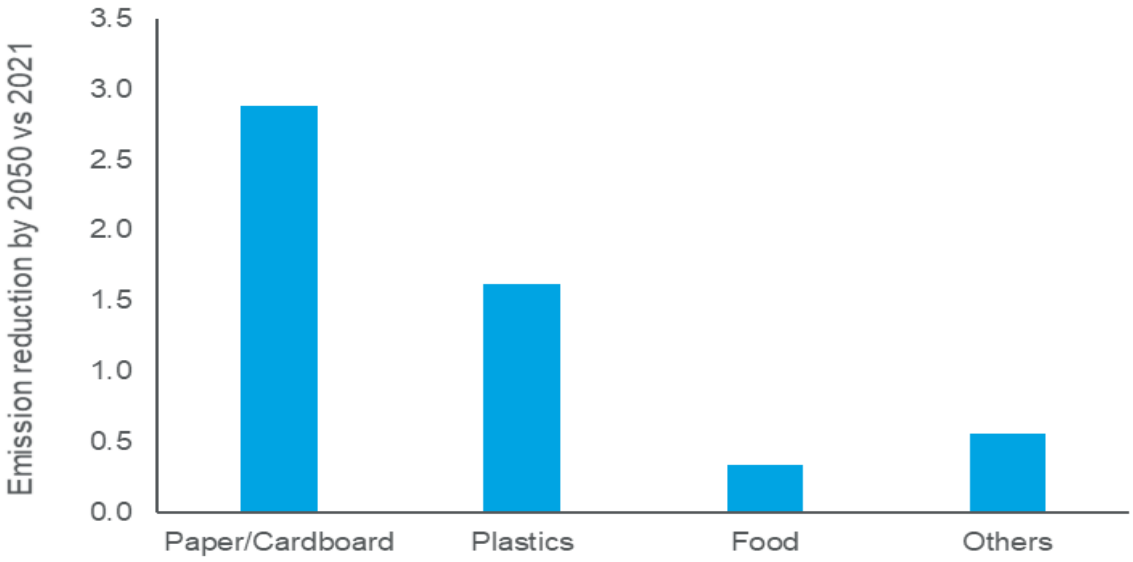

Fig. 7 Savings in carbon emissions $MtCO_2e$ (2050 vs 2021)

Source: History [14], forecast [15]

7. Result: Forecast of Singapore's waste market

Using historical waste generation data, the correlation between population and waste generation and government targets by 2030 in its journey to zero-waste, the study built a "forecast model" to project the total waste generation in Singapore and other waste-related metrics discussed in this section. After 2030, the study has assumed a waste reduction and recycling rate that would allow Singapore to reach its zero-waste target by 2050, but not zero. Here the study has assumed that zero-waste means zero-waste to its only landfill, Semakau island. The charts and discussions in this section are based on the assumptions described in the methodology section above.

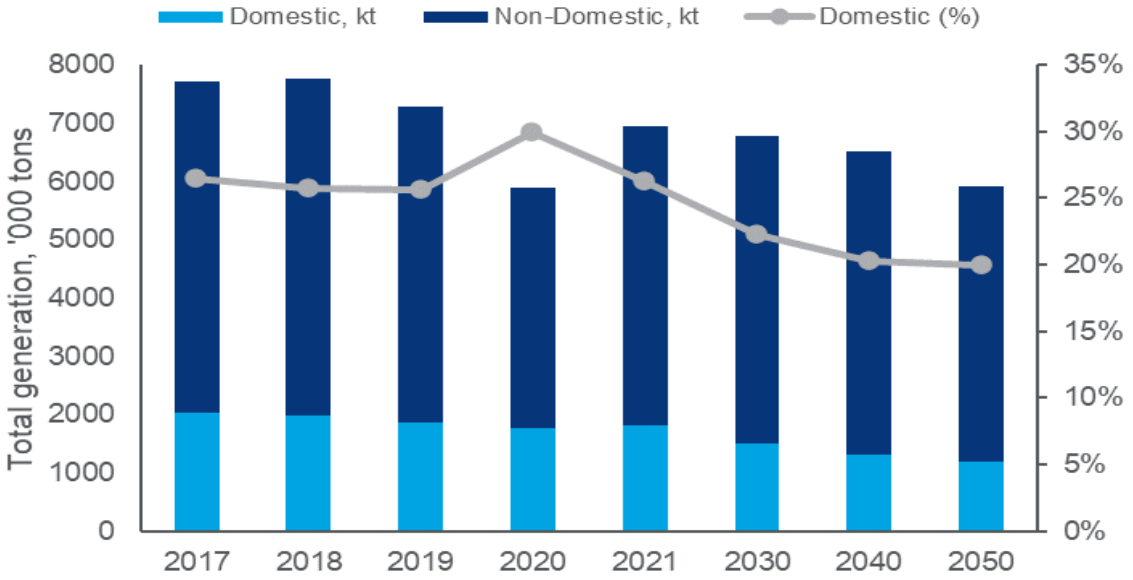

Fig. 8 Total waste generation forecast in Singapore

Source: History, [14] forecast - this study

As a first step, the study forecasts the total waste generation in Singapore (see Fig. 7). Total waste decreased from 6.9 million tons in 2021 [14] to about 5.9 million tons in 2050. To meet the overall zero-waste target, a decreasing waste generation profile will be necessary. According to EPA research, [31] waste prevention is the best waste management option regarding climate benefits. Recycling is the next best approach.

2020 was an unusual year with less waste generation and recycling because of the impact of Covid-19. The share of domestic waste increased because of the work-from-home trend. As businesses and social activities resume, we would see total waste generation increase and reach pre-pandemic levels. More effort is required to promote consumer awareness and increase consumer involvement in the domestic sector. Offering incentives and rewards to motivate waste-reducing behavior must be used as one option. For example, having discounts for products made of recyclables or charging less for consumers who bring their bags or food containers.

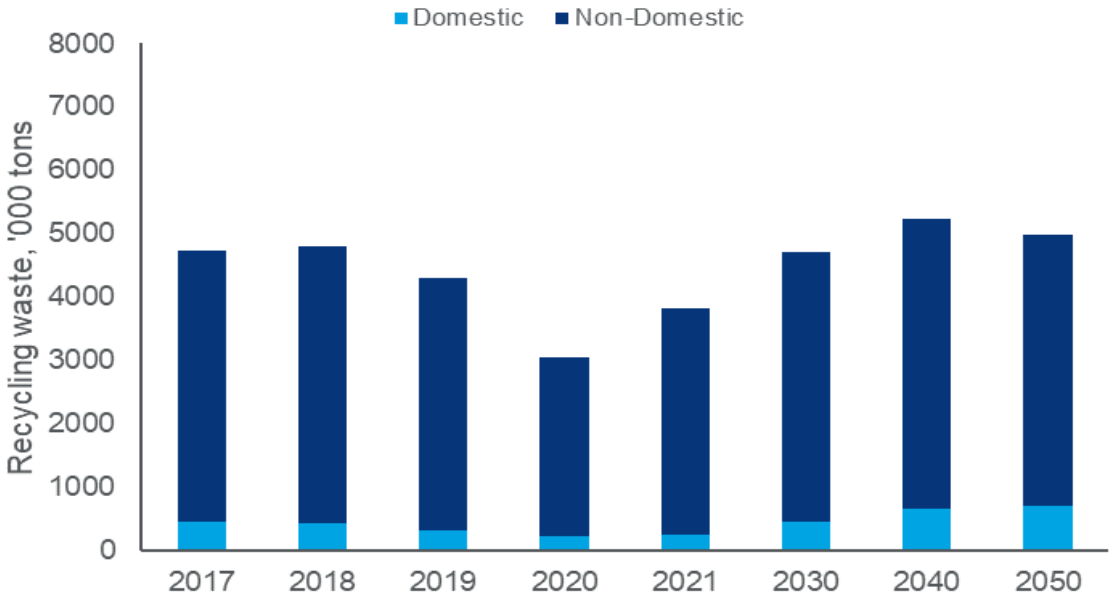

Fig. 9 Total waste recycling forecast in Singapore

Source: History, [14] forecast - this study

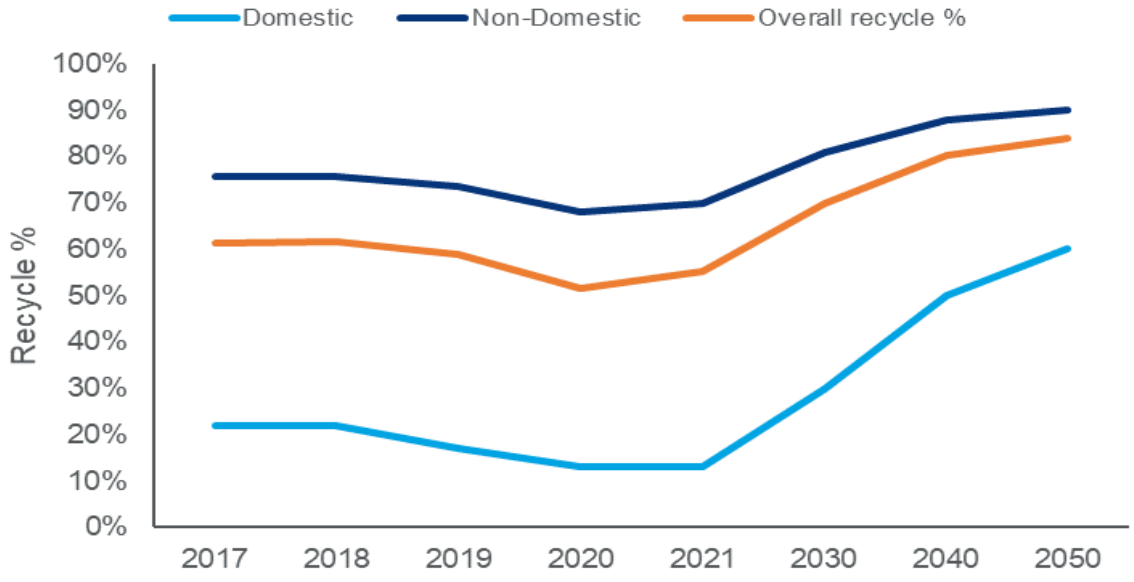

Fig. 10 Total waste recycle % forecast in Singapore

Source: History, [14] forecast - this study

Increasing recycling rates is an absolute necessity to meet the zero-waste target.

The current recycling rates for the domestic sector are very low, at about 13% in 2021 (see Fig. 9 and 10). [14] Despite government efforts to raise consumer awareness to reduce waste, reuse and recycle more, and designating 2019 as a 'Year towards zero-waste', recycling in the domestic sector dropped from 22 per cent in 2018 to 17 per cent in 2019 (see Fig 10). [14]

As the recycling rate in the domestic sector is low, the share of domestic waste generation must fall as it has been harder to implement recycling in the domestic sector. It is best to try and reduce waste at its source in the domestic sector. The study assumes that the share of domestic sector waste will drop from 26% in 2021 to 20% in 2050 (see Fig. 8).

The government wants to increase recycling from 55% in 2021 [14] to 70% by 2030. [12] To achieve this objective, domestic recycling should increase from 13% in 2021 to 30% in 2030, and the non-domestic sector recycling should increase from 70% in 2021 to 81% in 2030. These increases in recycling rates in the next eight years look ambitious, but the study has assumed that these are met as set by the Singapore government.

Further, to achieve a zero-waste target by 2050, the study models that the overall recycling rate, together with the domestic and non-domestic sectors, should reach close to 95%, which looks like a very high targets to achieve, particularly for the domestic sector. Therefore, the study has assumed that in the likely pathway, the domestic recycling rate will increase from 30% in 2030 to 60% in 2050, and the non-domestic sector recycling rate will increase from 81% in 2030 to 90% in 2050, taking the total recycling from 70% in 2030 to 85% in 2050. To achieve an 85% recycling rate (see Fig. 10), the study estimates that recycling in the three focus categories discussed above should increase. As we can see, achieving these as well looks very ambitious. We discussed the government's efforts in the previous section, 6.1.

Paper/cardboard - recycling to increase from 39% in 2021 [14] to 80% in 2030 to 90% in 2050

Plastics - recycling to increase from 6% in 2021 to 25% [14] in 2030 to 60% in 2050

Food - recycling to increase from 19% in 2021 [14] to 50% in 2030 to 90% in 2050

More should be done to develop local market capabilities to process more recyclables. Some examples could be developing infrastructure for mechanical recycling to convert waste plastics into pellets to produce new products or chemical recycling to convert plastic into oil or petrochemicals.

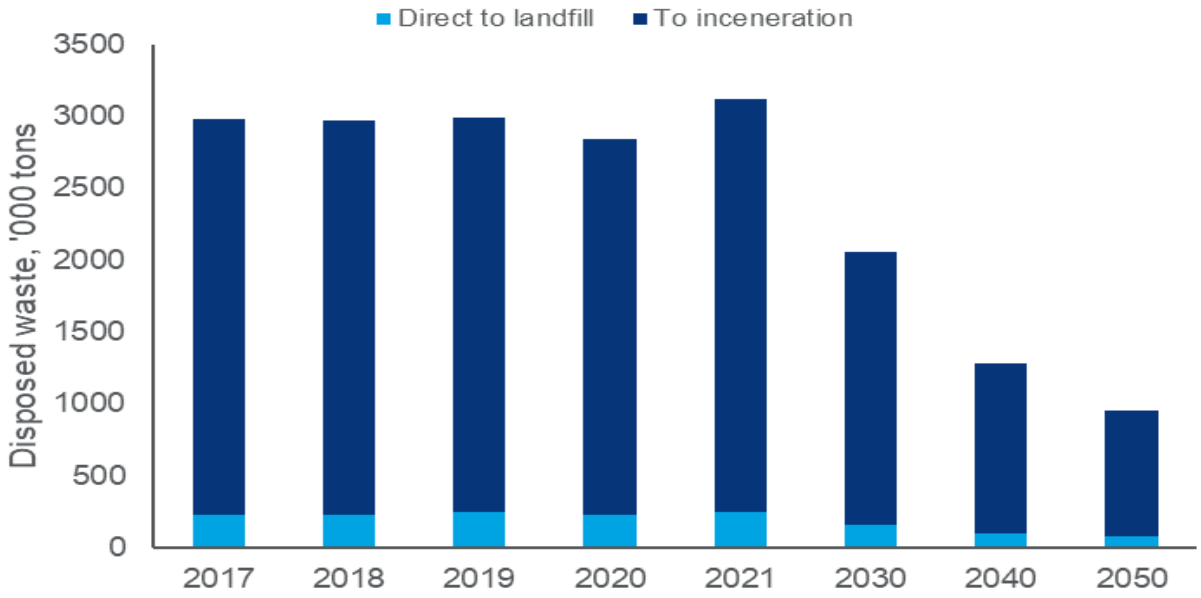

Fig. 11 Waste disposal forecast in Singapore

Source: History, [14] forecast - this study

A very small portion of about 8% of disposed waste, [14] not fit for incineration, is directly sent to landfills (see Fig. 11). The remainder is sent to incineration plants. Because of limited land availability for landfilling, Singapore's approach is to incinerate all disposed and combustible waste. A higher recycling rate in the forecast means that the amount of waste disposal reduces significantly.

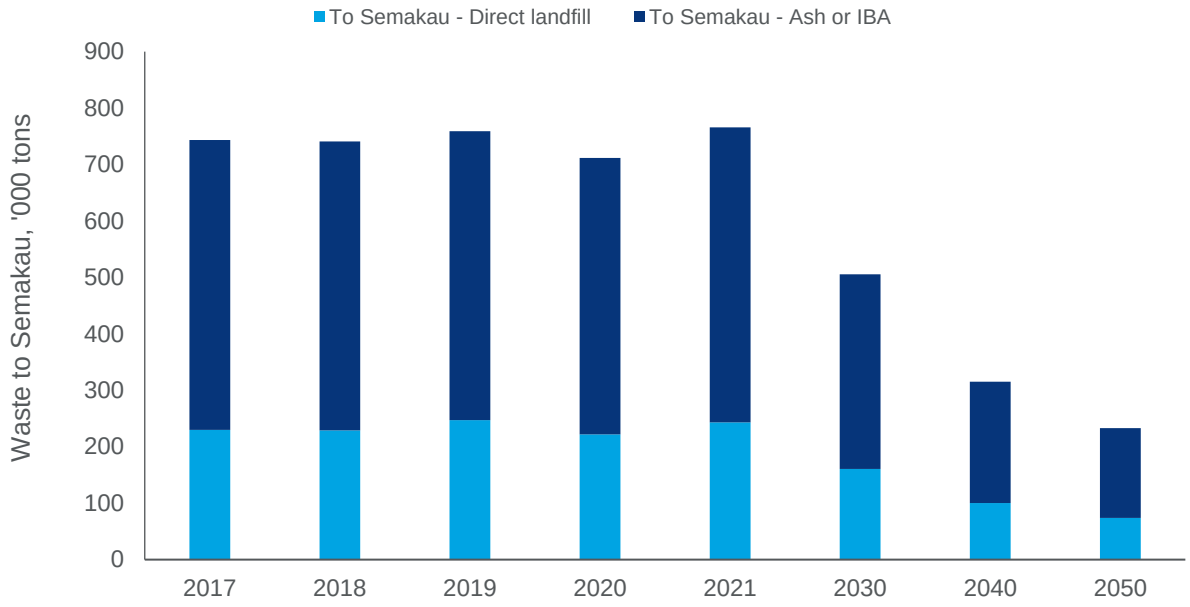

Fig. 12 Forecast of total waste to Semakau island in Singapore

Source: History, [14] forecast - this study

About 18% to 19% of the waste incinerated comes out as incineration bottom ash (IBA). [14] Incineration bottom ash is sent to the Semakau landfill. Even with an 85% recycling rate by 2050, the study estimates that ash will reduce from about 500,000 tons in 2021 [14] to 160,000 tons in 2050. Fig. 12 shows the total amount of waste (ash and direct) sent to the Semakau island landfill.

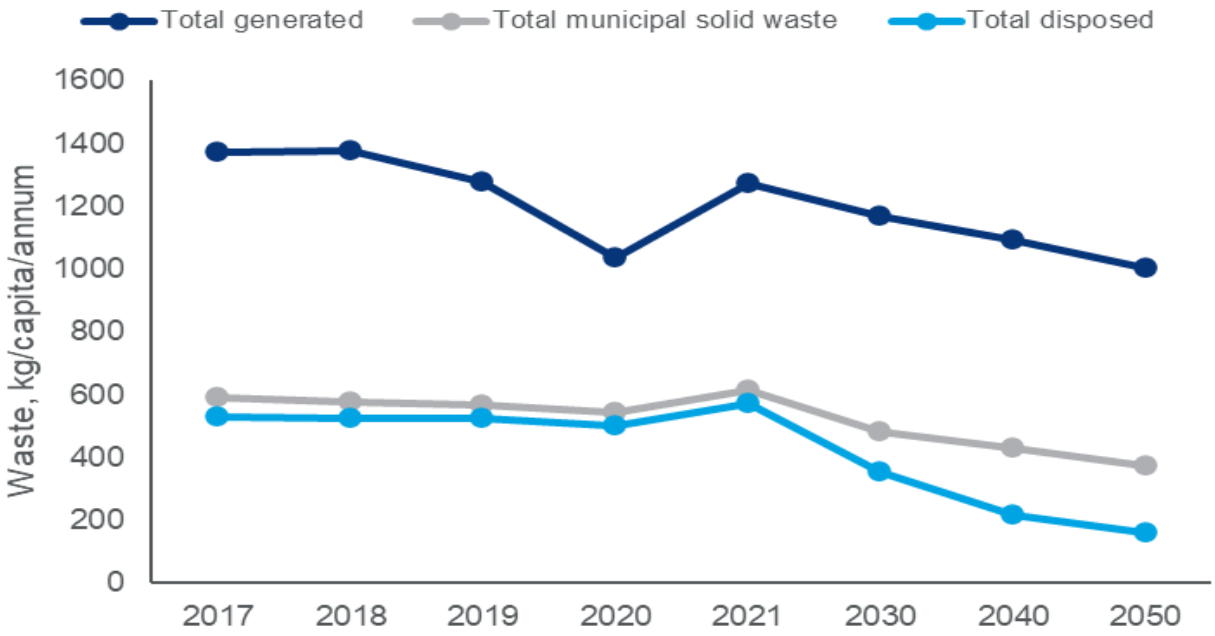

Fig. 13 Waste generation and disposal metrics forecast for Singapore

Source: History, [14] forecast - this study

Fig. 13 shows the key metrics of Singapore's waste over time for comparison. Singapore's MSW in kg/capita/annum in 2019 was about 569. It will increase to 616 kg/capita/annum in 2021, and the study forecasts it to reduce to 373 kg/capita/annum by 2050. To reduce waste generation at the source, the study assumes that total waste generated in kg/capita/annum will be reduced from 1273 in 2021 [13,14] to about 1000 in 2050. Total waste disposed of in kg/capita/annum correspondingly reduces from 571 in 2021 to about 160 in 2050.

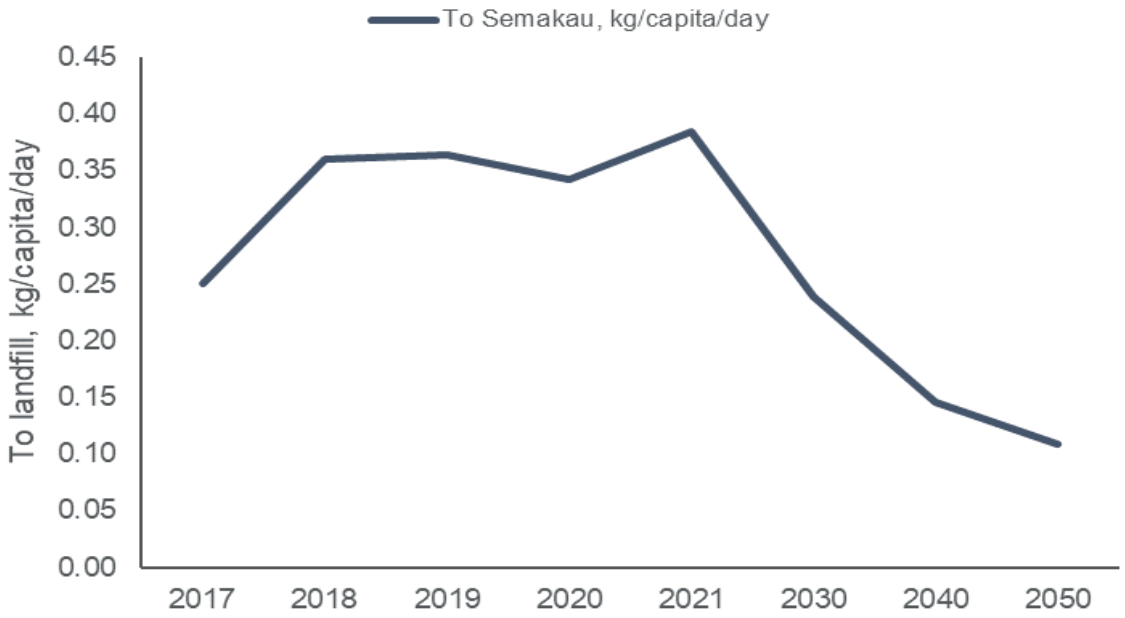

Fig. 14 Zero-waste metric - Waste to Semakau landfill

Source: History, [14] forecast - this study

We assume that Singapore can reduce waste sent to the Semakau landfill from 0.36 kg/capita/day in 2018 [14] to 0.25 kg/capita/day by 2030 (see Fig. 14). The study calculates that waste sent to Semakau daily reduces further to 0.1 kg/capita, but not to zero (see Fig. 14).

8. Conclusion

It will take a herculean effort to achieve the vision of a zero-waste nation. Singapore must rapidly scale up its current efforts in waste management. A big change is required to reduce waste at the source, increase recycling, reduce waste sent to incineration and landfill, and reduce incineration bottom ash. The government must continue to educate consumers and help businesses work on more sustainable practices. The country needs to transform how people, businesses and industries think, behave and practice waste management. The country needs participation and involvement from all sections of society, not just the government, for a successful journey towards zero-waste. To get to zero, Singapore must look at alternative waste management techniques to reduce or utilise the ash sent to landfill for other purposes, in addition to taking the recycling rate to more than 95%.

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