Chapter 4
Quest for Water Security in Singapore

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Abstract For decades, the main goal of Singapore in terms of water resources has been to become water-secure. As a result, water availability, accessibility, and affordability have traditionally been decided at the highest political level. Singapore's overall development is linked to a great extent to 'blue development', the amount of water available in sufficient quantity and quality and at affordable prices for the growing number of uses and users in every sector. The city–state aims to be water-secure, self-sufficient, and resilient by 2060, when water consumption will be twice today's level. An important global city, Singapore will continue improving its economic and social conditions to match both local expectations and global prospects. Trends indicate that it will become more urban, more industrialised, and more competitive, which will result in higher water demand. Known for its key policies and innovations, Singapore will have to continue planning within a long-term framework to become water-secure and achieve its overall development goals.

4.1 Introduction

Singapore is a city-state of 719.2 km^2 in Southeast Asia. It has a total population of 5.6 million and a population density of 7797 persons per km^2 (Singapore Department of Statistics 2017a).

Singapore has to be considered within its own context: a small island, and thus area-constrained, that has grown continuously only through land reclamation. It has no natural resources and no hinterland to provide them, and a historical dependence on outside sources of water, energy, and food. These seemingly serious limitations have been overcome, however, with long-term comprehensive planning, key

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policies, and innovation in all the sectors, where the overall development of the city-state, rather than the individual sectors, has been the main priority.

Since independence, when planning for water resources, water security (availability, accessibility, and affordability) has been a main consideration. To become more water-secure, the city-state has developed forward-looking, comprehensive strategies that have ensured that Singapore can meet present and projected requirements (Tan et al. 2008). These strategies have included all aspects of water resources policy, planning, management, development, governance, finance, technology, and most recently, consideration of societal behaviour. This has included diversification of water supply sources within and outside of Singapore; cleaning-up of rivers and waterways; protection of water catchments; water conservation measures; development of infrastructure; wastewater treatment and disposal; production of high-grade reclaimed water for potable and non-potable purposes (known as NEWater); and desalination. The last two have been planned to supplement local catchment and imported water, and they have effectively enhanced water security (Parliament of Singapore 2016a). All this is within a regulatory and institutional framework that is modified and improved when and as required (Tortajada et al. 2013).

The constraints of land area and competing land uses have added complexity to water resources planning and implementation. The constant need to increase provision of water due to population growth and economic and social development forces numerous trade-offs between land use (housing, commerce, industry, defence, farming, fisheries, leisure activities, etc.) and water resources development. In fact, land availability has been the main consideration when deciding on the amount of land that can be converted into watersheds to collect water, and thus on the size of the watersheds; the places where water and wastewater treatment plants, as well as desalination plants, are built; which ones have to be built either underground or on top of existing facilities in the most innovative ways; etc. This balancing act continues until today (Ng 2018; Tortajada et al. 2013).

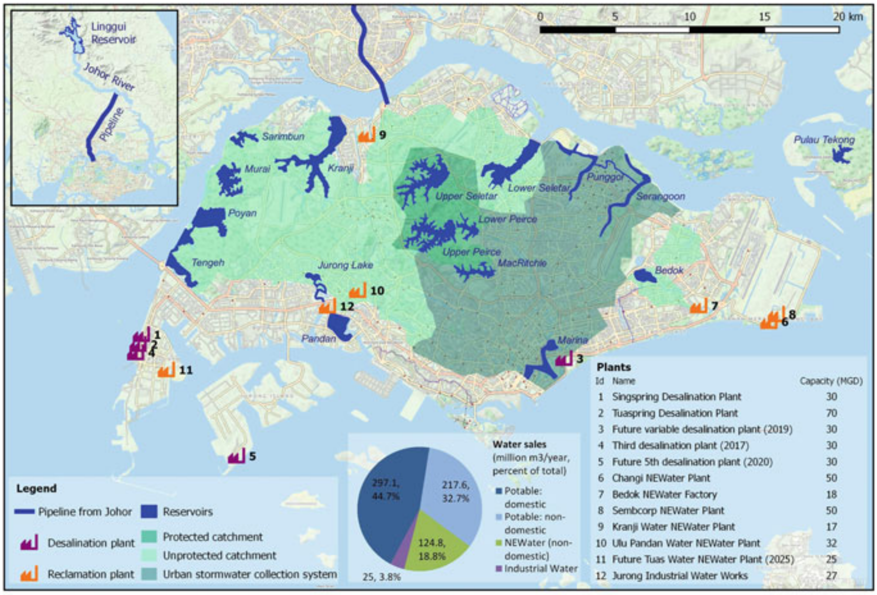
Water resources are strategic for Singapore. Johor, Malaysia, has historically been an important source of water for the city-state, and about 50% of its water is still imported from there. Several water agreements have been signed with this purpose: in 1927 (no longer in force), 1961, 1962, and 1990. This paper will not discuss the agreements or the related differences of opinion in different periods; they have been discussed extensively elsewhere (e.g., Kog 2001; Long 2001; Kog et al. 2002; Lee 2003, 2005, 2010; Ministry of Information, Communications and the Arts 2003; National Economic Action Council 2003; Chang et al. 2005; Saw and Kesavapany 2006; Sidhu 2006; Dhillon 2009; Shiraishi 2009; Luan 2010; Tortajada and Pobre 2011; Tortajada et al. 2013).

Total water demand in Singapore is projected to double by 2060. Long-term water security strategies towards this time horizon include continuing to augmenting supply from local sources and increasing the production capacities of NEWater and desalination. Already, two-thirds of Singapore can be considered water catchment areas where stormwater is collected.

There are plans to increase this proportion to 90%. Regarding NEWater and desalination, PUB (Singapore's National Water Agency) plans to double their production capacities by 2030. By 2060, the two sources are expected to supply up to 85% of Singapore's water requirements. This water portfolio will be decisive to ensure that water is available for all uses and also to reduce vulnerability to climate-related uncertainties (Parliament of Singapore 2016b). Figure 4.1 is a map of Singapore, its water resources and also the water sales figures in 2016.

Climate change is likely to add constraints in terms of water security, and Singapore is already planning for it. Extreme weather events, including heavy rainfall and prolonged dry periods, are projected to occur more frequently, not only in Singapore but across Southeast Asia (Chow 2017). This has been a concern for Singapore for several decades. To develop unconventional sources of water (recycled wastewater and desalination) that do not depend on climate, major investments were made in the 1970s in research and development to support technological developments such as membrane technology and reverse osmosis. The construction of the Marina Reservoir, the most urbanised reservoir on the island, for drinking purposes and flood control, was conceived in the same decade. Four decades on, all these initiatives have been realised (Parliament of Singapore 2010).

In 2014, Singapore experienced a two-month drought, the worst in many decades. February 2014 was the driest month since 1869, with near-zero rainfall. In



Notes: Locations and years of future plants are approximate. Data sources: OpenStreetMap, Google Earth, Singstat and various media articles. Water sales data are for 2015.

Fig. 4.1 Map of Singapore's water resources and water sales figures *Source* Buurman et al. (Forthcoming) neighbouring Malaysia, water rationing was implemented in Johor (from where Singapore imports water), Selangor, Negri Sembilan, Kuala Lumpur, and Putrajaya. In Thailand, 20 provinces were declared drought disaster areas. But in Singapore there was no rationing; in fact, water consumption increased by 5% (Parliament of Singapore 2017a). This has been taken as a sign that Singapore's strategies are on the correct path. But even so, there have been comments that this drought presented an opportunity to implement water conservation strategies (Salleh 2014) that was not realised (Tortajada 2016).

Therefore, within a framework of water security, planning and investment in water resources ahead of time have become even more relevant (Parliament of Singapore 2017c), as has the participation of the population and commercial and industrial sectors in using water more efficiently. The more involved the economic and social sectors are in water conservation, the more secure the city-state will be in the longer term.

Singapore has not followed any specific paradigm that has been prevalent internationally at any time. On the contrary, given its specific characteristics, it has searched for its own most appropriate alternatives, looking for solutions that will be cost-efficient in the long-term. Priorities have changed with time: from water availability to self-sufficiency, then to security and, finally, to resilience. This analysis presents a historical review of the decision-making, policies and practices that have contributed to Singapore's water security. It discusses some of the trade-offs that have been made at different times in terms of land use, energy, and food to develop water resources. In this land-constrained city-state, it has been essential to use land as efficiently as possible and for as high-value uses as possible. This explains many of the decisions taken.

The analysis extensively refers to discussions in the parliament. The objective is to show that water security, trade-offs, and related decisions have been a constant concern for the leadership.

4.2 Water Security: Development of Water, Energy, and Food Resources in Land-Constrained Singapore

The interlinkages and interdependencies among the water, food, and energy sectors in land-constrained Singapore are not intuitive. While in general water is needed for energy and food production, this is not the case in the city-state, which imports nearly 100% of its energy, 90% of its food, and 50% of its water resources. This means that water resources are not necessary to produce energy and that only a small percentage is used for local agriculture. On the other hand, energy is needed to pump, treat, recycle, desalinate, and distribute clean water, especially for production of NEWater and desalinated water. The development of the various sectors, and how they have affected each other when this has been the case, are presented in the following sections.

4.2.1 Development of Water and Energy Resources

The limited land in Singapore means that any land that is available has to be put to the best and most productive possible uses. To make sure that Singapore would have the necessary land for development, it introduced the Land Acquisition Act (Parliament of Singapore 1966b). The act gave the government the power to acquire land for public development. The impacts of this act have been much discussed. In terms of development, because the demand for land was high and escalating due to increasing and competing uses, control of land prices was necessary to ensure that the cost of public projects could be met, including those related to water resources.

At the time of independence in 1965, there were three reservoirs: MacRitchie (formerly Thomson Road Reservoir), Lower Seletar, and Lower Peirce. However, population growth in both urban and rural areas, along with industrialisation, resulted in higher demand for water and electricity.

To develop local capacity for water resources, several projects and reservoirs were built in the 1960s and 1970s. These include the Jurong Industrial waterworks, expansion of Upper Seletar Reservoir, Kranji-Pandan scheme, Chestnut Avenue waterworks, and Murai, Pandan, Poyan, Pulau Tekong, Sarimbun, and Tengeh Reservoirs (Tsang and Perera 2011). Regarding electricity, Phase I of the Pasir Panjang Power Station was completed in 1965, adding 120 megawatts of generating capacity (Parliament of Singapore 1965). The added energy also supported the government's ongoing Rural Electrification Scheme, which brought electricity to 155 *kampongs* (villages) (Parliament of Singapore 1965).

Two pump houses were built in Pontian and Tebrau, in Johor, Malaysia (Mohamad 2015). Approximately at the same time, a booster station was built to increase the pumping capacity of MacRitchie Reservoir (Parliament of Singapore 1965).

The average water consumption of 32 million gallons per day (MGD) in 1949 had increased to over 80 MGD by 1965 (Parliament of Singapore 1965). In August 1969, Seletar Reservoir opened (Parliament of Singapore 1970). It impounded water not only from its own catchment, a protected area where development has not been allowed historically, but also from eight neighbouring streams: the Sembawang, Sembawang Kechil, Simpang Kiri, Bukit Mandai, Mandai, Mandai Kechil, Pang Sua, and Peng Siang. Water from these streams had to be pumped into the reservoir because all eight were at lower elevations (Parliament of Singapore 1970).

Energy was increasingly needed for sewage pumping stations and treatment plants (Parliament of Singapore 1966a). This resulted in the construction of a sewage pumping house in Ulu Pandan (Parliament of Singapore 1967b). The government had the long-term objective to provide sewerage services to the entire island, including urban and rural areas, to prevent water resources being polluted with sewage. However, given the limited human and financial resources, the development of the sewerage scheme was carried out in phases and according to priorities. For example, the developed areas of Toa Payoh, Jurong, Kallang Basin, and other similar big new towns, where new projects were already taking place, were given highest priority so that facilities would be ready in time for population when they moved to the new housing (Parliament of Singapore 1967a).

The sewerage system was continuously expanded, and by 1969 it served over half the population, a significant increase from a quarter of the population in 1949 (Parliament of Singapore 1969).

To serve industrial development, more power stations were built. The power station in Jurong was built to provide electricity for the Jurong Industrial Complex, west of the island. Stage I of the Jurong Power Station was completed in March 1971, with a generating capacity of 120 megawatts. With the increasing demand for power for both housing and industry, construction of Stage II had to start immediately after (Parliament of Singapore 1971). In mid-1974, Stage II was completed, and three more 120 MW units were commissioned (Parliament of Singapore 1975). This was followed by the building of the Senoko Power Station, completed in 1976 (Senoko 1976).

As generating capacity expanded, substantial investments were made to extend the network for transmission and distribution, including to the rural areas (Parliament of Singapore 1966c). In the third quarter of 1974, PUB's 10-year rural electrification programme (Energy Market Authority 2017a) was completed. Through this programme, electricity was provided to rural areas and newly built public housing (Energy Market Authority 2017b). It included approximately 500 projects in 18 stages of implementation. Electricity was now available to all parts of the island, except remote rural sites earmarked for redevelopment (Parliament of Singapore 1975). A 230 kV underground transmission network was constructed to transmit power from Senoko Power Station to load centres on the island (Senoko 1976).

As industrialised and populated land area expanded, more energy was required for water treatment. Water from the Pandan Reservoir initially flowed through an industrialised and populated area and was prone to pollution. To make it safe for human consumption, the water had to undergo more advanced treatment (Parliament of Singapore 1976b). A wastewater treatment plant was also constructed to treat the liquid effluents of the petrochemical complex in Pulau Ayer Merbau.

In 1977, the Ministry of Environment conducted a survey to identify all sources of pollution affecting rivers and water catchments. The main sources of pollution were found to be pigs and ducks, trade and backyard industries, rundown urban areas, squatter pockets, street hawkers, and riverine activities. A programme was developed to coordinate the efforts of the ministries to eliminate such pollution. Together with a clean-up programme, premises would be connected to sewers, reducing the number of premises served by over-hanging latrines and nightsoil buckets. These were phased out by 1987 (Tan et al. 2008).

In rural areas where houses were not due for clearance within the next two years, population had to install their own onsite wastewater treatment systems to treat the wastewater (Parliament of Singapore 1982b). Street hawkers (food sellers) were relocated to proper markets and food centres with treatment facilities. All but one of the pig farms in the Kallang River catchment were relocated. Later, they were phased out or encouraged to change to a different activity. The overall objective was to prevent pollution of the reservoirs (Parliament of Singapore 1982b).

To this end, in 1981, a comprehensive plan was issued to clean up the Singapore River, Kallang Basin, and water catchments by 1987 (Tan et al. 2008; Tortajada et al. 2013; Joshi et al. 2012a, b). This enormous effort was carried out together with the redevelopment of Singapore.

Until the 1990s, Singapore's power stations relied entirely on imported oil to generate electricity (Parliament of Singapore 1981). In response to the oil crises of 1973 and 1979, which affected the world economy, the government came up with a policy to tap alternative sources of energy (Parliament of Singapore 1982a). Power stations were modified so that they could use different types and grades of fuel oil (Parliament of Singapore 1981). In addition, an 80 MW gas turbine was constructed at the Pasir Panjang Power Station to supplement the power supply during peak hours and emergencies (Parliament of Singapore 1981). PUB (then responsible for water, gas, and electricity; now the National Water Agency) converted five boilers at Senoko Power Station to burn gas rather than oil (Parliament of Singapore 1990a). Its 250 MW boilers were modified to use both natural gas and fuel oil (Senoko 2014).

Between 1982 and 1984, the demand for water rose at an increasing rate: in 1982, by 3.5%; in 1983, by 5.1%; and in 1984, by 7.2%. Discussions in the Parliament (Parliament of Singapore 1985b) noted that if Singapore continued consuming water at the current rate, in 15 years, it would need more water than was available in all the reservoirs in Singapore, in addition to the water imported from Johor.

The development of more reservoirs and projects followed. The Western Catchment scheme and Choa Chu Kong waterworks were completed in 1981, and Sungei Seletar, Bedok Scheme, and Bedok waterworks in 1986. Since at that time almost half of Singapore was a catchment area from where rainwater was collected (Parliament of Singapore 1985a), PUB started looking to develop further water resources outside the island. It developed three schemes in Johor to draw the water resources Singapore was entitled to: the extension to the Scudai waterworks, the extension to the Johor waterworks, and the Johor River pipeline (Parliament of Singapore 1985a). Singapore recognised that the scope for further development of surface water resources was seriously constrained. If the rapid growth in consumption continued, more expensive solutions, such as desalination, would be necessary. Desalinated water was calculated to be more than 10 times as expensive as water from the local catchments (Parliament of Singapore 1985a, 1986).

In 1990, Singapore and Malaysia signed a new water agreement as a supplement to the 1962 Johor River agreement. The new agreement allowed Singapore to build a dam across Sungei Linggiu (a tributary of the Johor River) to facilitate the extraction of water from the Johor River (Parliament of Singapore 1989, 1990b). During negotiations between the two countries, it was also agreed that Malaysia would supply Singapore with gas on a long-term basis (Parliament of Singapore 1989).

Also in 1990, to further diversify water sources, Singapore signed a water agreement with Indonesia on 'economic cooperation in the framework of the development of the Riau Province'. Under this agreement, Singapore and Indonesia agreed to cooperate on the sourcing, supply, and distribution of water to Singapore. The agreement also included cooperation over trade, tourism, investment, infrastructural and spatial development, industry, capital, and banking (Government Gazette 1990). The water agreement provided for the supply of 1000 MGD for 100 years from sources in the Province of Riau. The sources would be harnessed at the appropriate time after evaluating various options, including desalination (Parliament of Singapore 1998b). This water agreement was not implemented. It is now only of historical interest.

In 1995, the power industry was restructured to increase efficiency and competition in both electricity generation and supply, starting with the corporatisation of the Electricity and Gas Departments of PUB to form Singapore Power Ltd. To facilitate competition, Singapore Power was structured as a holding company with five separate subsidiaries: two generation companies (PowerSenoko and PowerSeraya), a transmission and distribution company (PowerGrid), a supply company (Power Supply), and a piped-gas company (PowerGas). Another power station being built in Tuas was put under a separate company, Tuas Power Ltd, owned directly by Temasek Holdings, so that it could compete against the Singapore Power generation companies. To facilitate competition in the generation and supply sectors, the Singapore Electricity Pool was established as an exchange for trading electricity. In March 1999, the government decided that the next step in restructuring the electricity industry was for Singapore Power to fully divest its generating companies to Temasek Holdings in 2001. This separated ownership of the generators from the transmission and distribution network. In 2001, there were several competing generation companies: PowerSenoko, PowerSeraya, Tuas Power, and SembCorp Cogen.

The government continued looking for additional local water sources. With experts' support, PUB carried out geophysical and hydrogeological investigations of groundwater resources. None were found, even at relatively great depths. Therefore, PUB focused on unconventional sources of water: desalination, and sources of non-potable water to supplement mainly non-potable uses (Parliament of Singapore 1998a). In 2002, after years of investment in research and development, NEWater was introduced with the first plant in Bedok. It was used for industries which required large quantities of high-grade water, such as wafer fabrication plants (Parliament of Singapore 2001a). In September 2005, PUB also introduced desalinated water, as its cost had reached an affordable level (Parliament of Singapore 2003a); the first plant was established in Tuas.

NEWater and desalination are energy-intensive processes, raising energy demand (Parliament of Singapore 2003a). Energy is necessary to treat and produce freshwater, to pump it to the reservoirs, and later on to distribute it. NEWater is very clean, and blending it with reservoir water is not necessary. It also requires more energy. However, Singapore has implemented this practice following the recommendations of an international panel of experts (Parliament of Singapore 2003a, b). NEWater is less energy-intensive and cheaper to produce than desalinated water. Therefore, it has been produced in larger amounts. Each of the NEWater plants has a separate reticulation system to distribute the water to the industrial estates and commercial areas where it is used (Parliament of Singapore 2003a, b). NEWater has become one of the main sources of water for the city-state (PUB n.d.).

Information on the energy used for all water-related activities is not publicly available. However, we have compiled data from several sources on the amount of electricity supplied in the system between 1963 and 2016. It is presented in Table 4.1. According to Singapore Power (SP) between 1995 and 2002 this includes energy generated from power stations and waste-to-energy incineration plants from the then Ministry of Environment (ENV) now Ministry of the Environment and Water Resources (MEWR). From 1995 to March 1998, the electricity generated data was made up of generation from power stations plus purchase from ENV (energy sent out to grid). Due to the formation of Singapore Electricity Pool (SEP) in Apr 1998, the purchase from ENV data has since changed to generation from ENV. With the introduction of autoproducers in 2000, the generation data also includes generation from autoproducers (personal correspondence with Singapore Power, November 2017). According to Energy Market Authority (EMA), 2003 onwards, the data includes electricity from power station and waste-to-energy plants (WEP) (personal correspondence with EMA, November 2017).

In terms of fuel, according to the Energy Market Authority (2016), oil used to be the predominant fuel. From 2001, it changed to natural gas with which approximately 95% of electricity in Singapore used to be generated, most of it via pipelines from Indonesia and Malaysia. A Liquefied Natural Gas terminal was opened in May 2013 allowing the city-state to import from markets globally. In 2016, natural gas accounted for 95.2% of fuel mix, same percentage since 2014. Main Power Producers represented 93.2% of total electricity generated, with the remaining 6.8% generated by autoproducers (Energy Market Authority 2017c).

4.2.2 Development of Water Resources and Food Production

Efforts to keep the reservoirs clean have had an impact on Singapore's food production. Farming and pig-raising activities have been relocated in some cases and phased out in others. In 1965, family farming was considered an essential element of food security (Chou 2015; Kai 2012/2013). There were 20,000 farms, using approximately 25% of the land (145 km^2), and producing 60% of the vegetables that were consumed on the island.

Table 4.1 Total units of electricity supplied in the system in Singapore, 1963–2016 (based primarily on PUB annual reports)

Year	Total units of electricity supplied in the system	Sources
1963	822,922,790 kWh	Public Utilities Board Annual Report 1964 (p. 29)
1964	914,232,150 kWh	1. Public Utilities Board Annual Report 1964 (p. 29) 2. Public Utilities Board Annual Report 1965 (p. 31)
1965	1,047,583,900 kWh	1. Public Utilities Board Annual Report 1965 (p. 31) 2. Public Utilities Board Annual Report 1966 (p. 50)
1966	1,236,471,850 kWh	1. Public Utilities Board Annual Report 1966 (p. 50) 2. Public Utilities Board Annual Report 1967 (p. 32)
1967[a]	1,424,434,000 kWh (reference 1) 1,424,534,000 kWh (reference 2)	1. Public Utilities Board Annual Report 1967 (p. 32) 2. Public Utilities Board Annual Report 1968 (p. 24)
1968	1,639,449,100 kWh (reference 1) 1,639 million kWh (reference 2)	1. Public Utilities Board Annual Report 1968 (p. 24) 2. Public Utilities Board Annual Report 1969 (p. 18)
1969	1876 million kWh (reference 1) 1,876.1 million kWh (reference 2)	1. Public Utilities Board Annual Report 1969 (p. 18) 2. Public Utilities Board Annual Report 1970 (p. 17)
1970	2,205.2 million kWh (reference 1) 2,205,207,100 kWh (reference 2)	1. Public Utilities Board Annual Report 1970 (p. 17) 2. Public Utilities Board Annual Report 1971 (p. 16)
1971	2,585,272,000 kWh	1. Public Utilities Board Annual Report 1971 (p. 16) 2. Public Utilities Board Annual Report 1972 (p. 18)
1972	3,143,560,910 kWh	1. Public Utilities Board Annual Report 1972 (p. 18) 2. Public Utilities Board Annual Report 1973 (p. 19)
1973	3,719,368,250 kWh	1. Public Utilities Board Annual Report 1973 (p. 19) 2. Public Utilities Board Annual Report 1974 (p. 16)
1974	3,864,322,500 kWh	1. Public Utilities Board Annual Report 1974 (p. 16) 2. Public Utilities Board Annual Report 1975 (p. 22)

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
1975	4,175,980,480 kWh (references 1 and 2) 4,175.7 GWh (reference 3)	1. Public Utilities Board Annual Report 1975 (p. 22) 2. Public Utilities Board Annual Report 1976 (p. 24) 3. Department of Statistics Singapore 2017[b]
1976	4,604,920,600 kWh (references 1 and 2) 4,604.9 GWh (reference 3)	1. Public Utilities Board Annual Report 1976 (p. 24) 2. Public Utilities Board Annual Report 1977 (p. 20) 3. Department of Statistics Singapore 2017
1977	5,114,681,650 kWh (reference 1) 5,114.68 million kWh(reference 2) 5,114.7 GWh (reference 3)	1. Public Utilities Board Annual Report 1977 (p. 20) 2. Public Utilities Board Annual Report 1978 (p. 30) 3. Department of Statistics Singapore 2017
1978	5,897.99 million kWh (reference 1) 5,897.9 GWh (reference 2)	1. Public Utilities Board Annual Report 1978 (p. 30) 2. Department of Statistics Singapore 2017
1979[c]	6483 million kWh (reference 1) 6483 million kWh(Adding the values from references 2 and 3)	1. Public Utilities Board Annual Report 1979 (p. 22) 2. Public Utilities Board Annual Report 1979 (p. 23): 35.2 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017[d] *Electricity generated from power stations:* 6,447.8 GWh
1980	6,967.2 million kWh (Adding values from references 1 and 2) 6,967.7 million kWh (Adding the values from references 2 and 3)	1. Public Utilities Board Annual Report 1980 (p. 29): 6940 million kWh *generated from power stations* 2. Public Utilities Board Annual Report 1980 (p. 29): 27.2 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 6,940.5 GWh
1981	7,462 million kWh (Adding the values from references 1 and 2) 7,461.9 million kWh (Adding the values from references 2 and 3)	1. Public Utilities Board Annual Report 1981 (p. 22): 7442 million kWh *generated from power stations* 2. Public Utilities Board Annual Report 1981 (p. 22): 20 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 7,441.9 GWh

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
1982	7884 million kWh (Adding values from references 1 and 2) 7,883.5 million kWh (Adding values from references 2 and 3)	1. Public Utilities Board Annual Report 1982 (p. 21): 7860 million kWh *generated from power stations* 2. Public Utilities Board Annual Report 198 (p. 21): 24 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 7,859.5 GWh
1983	8665 million kWh (Adding values from references 1 and 2) 8,664.9 million kWh (Adding values from references 2 and 3)	1. PUB Annual Report 1983 (p. 21): 8626 million kWh *generated from power stations* 2. PUB Annual Report 1983 (p. 21): 39 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 8,625.9 GWh
1984	9452 million kWh (Adding values from references 1 and 2) 9,451.7 million kWh (Adding values from references 2 and 3)	1. PUB Annual Report 1984 (p. 21): 9421 million kWh *generated from power stations* 2. PUB Annual Report 1984 (p. 21): 31 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 9,420.7 GWh
1985	9917 million kWh (Adding values from references 1 and 2) 9,917.3 million kWh (Adding values from references 2 and 3)	1. PUB Annual Report 1985 (p. 17): 9876 million kWh *generated from power stations* 2. PUB Annual Report 1985 (p. 17): 41 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 9,876.3 GWh
1986	10,576 million kWh (Adding values from references 1 and 2) 10,576.5 GWh (reference 3)	1. PUB Annual Report 1986 (p. 17): 10,466 million kWh *generated from power stations* 2. PUB Annual Report 1986 (p. 17): 110 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017[e] *Electricity generated:* 10,576.5 GWh
1987	11,814 million kWh (Adding values from references 1 and 2) 11,813.8 GWh (reference 3)	1. PUB Annual Report 1987 (p. 18): 11,625 million kWh *generated from power stations* 2. PUB Annual Report 1987 (p. 18): 189 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 11,813.8 GWh
1988	13,017 million kWh (Adding values from references 1 and 2) 13,017.5 GWh (reference 3)	1. PUB Annual Report 1988 (p. 18): 12,821 million kWh *generated from power stations* 2. PUB Annual Report 1988 (p. 18): 196 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 13,017.5 GWh

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
1989	14,039 million kWh (Adding values from references 1 and 2) 14,038.9 GWh (reference 3)	1. PUB Annual Report 1989 (p. 19): 13,847 million kWh *generated from power stations* 2. PUB Annual Report 1989 (p. 19): 192 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generate:* 14,038.9 GWh
1990	15,618 million kWh(Adding values from references 1 and 2) 15,617.6 GWh (reference 3)	1. PUB Annual Report 1990 (p. 29): 15,398 million kWh *generated from power stations* 2. PUB Annual Report 1990 (p. 29): 220 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 15,617.6 GWh
1991	16,597 million kWh (Adding values from references 1 and 2) 16,596.6 GWh (reference 3)	1. PUB Annual Report 1991 (p. 16): 16,374 million kWh *generated from power stations* 2. PUB Annual Report 1991 (p. 16): 223 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 16,596.6 GWh
1992	17,543 million kWh (Adding values from references 1 and 2) 17,543.1 GWh (reference 3)	1. PUB Annual Report 1992 (p. 17): 17,283 million kWh *generated from power stations* 2. PUB Annual Report 1992 (p. 17): 260 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 17,543.1 GWh
1993	18,962 million kWh (Adding values from references 1 and 2) 18,962.4 GWh (reference 3)	1. PUB Annual Report 1993 (p. 19): 18,508 million kWh *generated from power stations* 2. PUB Annual Report 1993 (p. 19): 454 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 18,962.4 GWh
1994	20,675 million kWh (references 1 and 2) 20,675.4 GWh (reference 3)	1. PUB Annual Report 1994 (p. 19): 20,234 million kWh *generated from power stations* 2. PUB Annual Report 1994 (p. 19): 441 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 20,675.4 GWh
1995	16,447 million kWh (references 1 and 2)[f] 22,057.4 GWh (reference 3)	1. PUB Annual Report 1995 (p. 33): 16,156 million kWh *generated from power stations* 2. PUB Annual Report 1995 (p. 33): 291 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 22,057.4 GWh
1996	24,101 GWh (reference 1) 23,909.4 GWh (reference 2)[g]	1. PUB Annual Report 1999 (p. 17) 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 23,909.4 GWh

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
1997	26,898 GWh(reference 1) 26,709.4 GWh (reference 2)[h]	1. PUB Annual Report 1999 (p. 17) 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 26,709.4 GWh
1998	28,424 GWh(reference 1) 28,374.8 GWh (references 2 and 3)[i]	1. PUB Annual Report 1999 (p. 17) 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 28,374.8 GWh 3. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
1999	29,520 GWh (reference 1) 29,520.1 GWh (references 2 and 3)	1. PUB Annual Report 1999 (p. 17) 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 29,520.1 GWh[j] 3. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305)
2000	31,665 GWh (reference 1)	1. Department of Statistics Singapore 2017[k] *Electricity generated from power stations:* 31,665 GWh
2001	33,061.0 GWh (references 1 and 2)	1. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 33,061 GWh 2. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309)
2002	34,664.6 GWh (reference 1)	1. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 34,664.6 GWh
2003	35,281.5 GWh (references 1 and 2)	1. Department of Statistics Singapore 2017[l] *Electricity generated from power stations:* 35,281.5 GWh 2. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2004	36,809.6 GWh (references 1 and 3) 36,809.5 (reference 2)	1. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 36,809.6 GWh 2. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305)

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Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
		3. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2005	38,212.7 GWh (references 1–4)	1. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 38,212.7 GWh 3. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305) 4. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2006	39,480.4 GWh (references 1 and 2) 39,442.0 GWh (reference 3) 39,480.1 GWh (reference 4) 39,442.1 (reference 5)	1. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 39,480.4 GWh 3. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305) 4. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327) 5. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2007	41,134.1 GWh (references 1 and 2) 41,134.2 GWh (references 3, 4 and 5) 41,137.7 GWh (reference 6)	1. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 41,134.1 GWh 3. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305)

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
		4. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 5. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327) 6. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2008	41,669.1 GWh (reference 1) 41,669.6 GWh (reference 2) 41,716.7 GWh (reference 3) 41,716.8 GWh (references 4, 5 and 7) 41,669.7 GWh (reference 6)	1. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 41,669.6 GWh 3. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330) 4. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305) 5. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 6. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327) 7. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2009	41,800.6 GWh (references 1–6) 41,816.7 GWh (reference 7)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 41,800.6 GWh

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Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
		4. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330) 5. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305) 6. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 7. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006-2012) (p. 327)
2010	45,366.5 GWh (references 1–5) 45,367.8 GWh (reference 6) 45,366.4 GWh (reference 7)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 45,366.5 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330) 6. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 7. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327)

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Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
2011	45,999.4 GWh (references 1–5) 45,999.3 GWh (reference 6) 45,998.4 GWh (reference 7)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 45,999.4 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330) 6. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 7. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006-2012) (p. 327)
2012	46,936.2 GWh (references 1–5) 46,936.0 GWh (reference 6)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 46,936.2 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330)

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
		6. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327)
2013	47,963.5 GWh (references 1–4) 47,948.4 GWh (reference 5)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 47,963.5 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330)
2014	49,309.65 GWh(references 1 and 2) 49,309.7 GWh (references 3 and 4) 49,304.5 GWh (reference 5)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 49,309.7 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330)

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
2015	50,271.6 GWh (references 1–4)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 50,271.6 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343)
2016[m]	51,586.6 GWh (references 1–4)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 51,586.6 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 339, p. 343)

[a]There is an inconsistency in reported amounts of total units of electricity supplied in the system in certain years. For example, in 1967 in the 1967 and 1968 PUB annual reports. This is indicated in all the cases

[b]Department of Statistics Singapore (Singstat), M890841—Electricity Generation and Consumption, Annual, http://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=3726

[c]According to the 1979 PUB Annual Report, PUB started purchasing electricity from the Ministry of the Environment's (ENV) waste-to-energy (WTE) incineration plant in 1979. Hence, the value for the total units of electricity supplied in the system from 1979 onwards includes electricity generated from the power stations and electricity bought from ENV's WTE plants

[d]Data from Singstat for years 1979–1985 only reflects the amount of electricity generated from power stations and does not include the amount of electricity bought from ENV's WTE plants

[e]Singstat data started accounting for electricity bought from ENV's WTE plants, in addition to electricity generated by power stations, for years 1986–1994. This is in contrast to footnote d whereby the same Singstat dataset did not account for electricity bought from ENV's WTE plants for years 1979–1985

[f]There may be an error in the electricity generation values from the 1995 PUB report as it had mentioned that there was a 7.0% increase in electricity generated in 1995 compared to the year

1994 (p. 33). This would mean that the total electricity supplied in 1995 should be 22,122.3 GWh. Yet, this value does not correspond with the Singstat value. However, Singapore Power (the data source for the Singstat electricity generation data for years 1995–2002) has confirmed that the Singstat data for the year 1995 includes electricity generated from the power stations and electricity bought from ENV's WTE plants (SP, personal correspondence, November 2017)

[g]From years 1996 to 1998, electricity generation values reported by Singstat are lower than the electricity generation values reported by the PUB annual reports. However, Singapore Power (the data source for the electricity generation data for Singstat from 1995 to 2002) has confirmed that the Singstat data for years 1996–1998 includes electricity generated from the power stations and ENV's WTE plants (SP, personal correspondence, November 2017)

[h]Refer to footnote g

[i]Refer to footnote g. Up till March 1998, the Singstat electricity generation data consisted of electricity generated from power stations plus electricity purchased from the ENV's WTE plants. However, due to the formation of Singapore Electricity Pool (SEP) in Apr 1998, "purchase from ENV" data has since changed to "generation from ENV" (SP, personal correspondence, November 2017)

[j]Same Singstat source as the data obtained for years 1995–1998 where the values differ from that reported in the PUB annual report (footnotes f and g), but the value for year 1999 corresponds with the 1999 PUB annual report value

[k]With the introduction of Autoproducers in year 2000, the generation data from year 2000 onwards also includes generation from Autoproducers (SP, personal correspondence, November 2017). Autoproducers are "enterprises that produce electricity but for whom the production is not their principal activity". Source: https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Publications/SES%202016/Publication_Singapore_Energy_Statistics_2016.pdf (pg 22)

[l]The Energy Market Authority (the data source for the electricity generation data for Singstat from 2003 onwards) has confirmed that the Singstat data for electricity generation from 2003 onwards includes both energy generated from power stations and ENV's WTE plants (EMA, personal correspondence, November 2017)

[m]From Jan. 2016, the data incorporates output from solar generation: http://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=3726

As Singapore developed, farming changed from traditional to more intensive and high-tech. Farms became fewer in number and smaller in size. Between 1960 and 1967, in spite of the shrinking farmland, the value of production of vegetables, pigs, fowl, ducks, cattle, goats, and eggs was SGD 285 million. Between 1964 and 1990, family farms achieved near self-sufficiency in pigs, poultry, and eggs. They also produced leafy vegetables throughout the year for the local markets (Chou 2015).

However, farming and animal raising were increasingly associated with pollution of water resources. For example, the catchment area of one of the reservoirs, Seletar Reservoir, was inhabited mainly by squatters and vegetable, pig, and poultry farmers (Parliament of Singapore 1968). Additionally, the catchment area of the eight streams that carried water to the reservoir, approximately 8000 acres, was unprotected (Parliament of Singapore 1970) and thus exposed to pollution sources. In 1968, when Seletar Reservoir was built, it was not possible to resettle the farmers and their activities to keep the waters clean. Instead, latrines, cess-pits, and pigsties were constructed. The cost was divided between the government and the farmers (Parliament of Singapore 1968, 1970).

In 1970, a total of 361 pigsties were relocated and 692 demolished in the eight catchment areas (Parliament of Singapore 1970). Five years later, due to pollution from pig waste in Kranji Reservoir, the government decided to acquire certain parts of Punggol, in the northeast of Singapore, for the pig-farming industry. Numerous families were relocated there (Parliament of Singapore 1976a). Farmers who were not deemed *bona fide* were not allowed to retain their plots of farmland, and some were given compensation in the form of three-room apartments, as an *ex gratia* payment (Parliament of Singapore 1976a). Over a period of six years, 547,000 pigs were relocated to Punggol (Tortajada et al. 2013). Fishing was also affected by development activities. With the construction of Changi Airport, 25 *kelongs* (fish farms) had to move because of land reclamation. This affected the livelihood of 60 fishermen and their families (Parliament of Singapore 1976a).

In 1980, the government decided that farming would not be subsidised but that it would become fully commercial. In 1984, in its most important policy on food security, the government decided not to pursue food self-sufficiency. Since land had been always limited, Singapore would not use it for traditional agriculture to achieve self-sufficiency but instead would import food from the global markets and focus on producing goods and services in which it would have a competitive advantage (Goh 1984).

Farmers who decided to retire received a one-time compensation grant. Those who were not using land required for development and who wanted to keep their farms could keep them, as long as they were able to control pollution within specific standards (Parliament of Singapore 1984b). Following the reduction in agricultural land and employment, overall production declined irreversibly, with pig farms disappearing in 1989–1990 (De Koninck et al. 2008).

Measures put in place to protect water resources included not only reducing farming and animal-raising activities, but also limiting development. Between 1983 and 1999, overall urbanisation was capped at 34.1%, and a population-density limit of 198 dwelling units per hectare was imposed on anticipated developments up to 2005 (Tan 2015; Tortajada et al. 2013).

Table 4.2 presents an overview of the 1983 Water Catchment Policy. The timeframe for the policy dates back to 1971, with the establishment of the Pollution Survey Unit, enactment of legislation such as the Water Pollution Control and Drainage Bill and Environment Pollution Bill, pollution control measures, caps on urbanisation and population density, and so on.

The 1983 Water Catchment Policy ended in 1999, when the urbanisation and population-density limits were lifted, subject to strict water pollution control measures. Less intensive development and more stringent pollution control measures enabled Singapore to ensure the good quality of the water collected even from unprotected sources.

In terms of farming, the Primary Production Department, responsible for developing and regulating the local farming industry, was also given the responsibility to open investment opportunities for the development of agro-technology projects and services in aquaculture, horticulture, livestock, and other services. Farmland was transformed into agro-technological parks for high-technology

Table 4.2 1983 Water catchment policy

Timeframe	Historical development/milestone
1971	Pollution Survey Unit is set up. Initially meant to serve the Kranji/Pandan Reservoir Scheme, it eventually oversaw all anti-pollution work in connection with the water supply
1972	The Ministry of National Development announces that farms would be planned to reduce the pollution of water by pig waste in the catchment areas of the Kranji and Pandan Reservoirs
1974	Cabinet discussion on high-rise pig farming
1975	Relocation of pig farms
1975	Introduction of the Water Pollution Control and Drainage Bill for more effective protection of water resources and prevention of water pollution. Population growth and rapid industrial and economic development in the past 10 years had led to a corresponding increase in the demand for water and, with rising affluence, a demand for a healthier and cleaner environment In the Kranji and Pandan catchment areas, pig farms and some polluting industries have to move to non-catchment areas. In the catchment areas, only non-polluting industries and activities are allowed. All wastewater from premises, including trade effluent, has to be discharged into the sewers to minimise the pollution of water in streams and canals, some of which feed into reservoirs Authority for sewage, drainage and water pollution control is vested in the Director of Water Pollution Control and Drainage, who also has the powers to control the quality, extraction, storage, and use of water in Singapore
1977	Further discussion of the resettlement of farmers. Sembawang Pig Farm, under the Primary Production Department, is eliminated. Protecting the supply of water is deemed more important than the rearing of pigs. An alternative pig farming area is developed in Punggol
1982	Decision to phase out all nightsoil buckets by 1984, because their use increased the risk of infectious diseases and the workforce of nightsoil workmen was dwindling Installation of R2 wastewater treatment system
1983	Introduction of the 1983 Catchment Policy. Key provisions: • Housing Development Board is allowed to develop to its normal density of 198 dwelling units/ha • Developed land is restricted to 34.1% of unprotected water catchment area, excluding the water surface • A list of pollution control measures is agreed between the Ministry of Environment and the Ministry of National Development
1983	New section 14A of the Water Pollution Control and Drainage Act prohibits the discharge of toxic substances into any inland water. Penalties include fines and imprisonment. This came about due to the threat of water contamination of one reservoir through indiscriminate dumping of toxic waste
1984	Pig farms are phased out
1989	PUB accommodates recreational activities in the reservoirs and catchment areas that do not pollute the waters, such as fishing and paddle boating

(continued)

Table 4.2 (continued)

Timeframe	Historical development/milestone
1999	The Water Pollution Control and Drainage Act is consolidated with the Clean Air Act and the Drainage Act under the new Environment Pollution Bill. Part V of the new bill deals with water pollution control. Some key points: • Under Clause 15, any person who intends to discharge trade effluent, oil, chemical, sewage or other polluting substances into any drain or land must obtain a licence • Clause 16 requires any occupier to treat such trade effluent before it is discharged • Clause 17 prohibits the discharge of any toxic or hazardous substance into any inland water • Clause 18 empowers the Ministry of Environment to require any person who has discharged any polluting matter onto any land or into any drain or sea to remove and clean up that substance or matter within a specified time • Clause 19 empowers the Ministry of Environment to require any person to take measures to prevent water pollution due to the storage or transportation of toxic substances or other polluting matters
1999	Pollution control measures for golf courses within water catchments: • Water quality of runoff closely and regularly monitored • Use of pesticides and chemical fertilisers in golf courses regulated to prevent pollution
1999	A review of the Water Catchment Policy concludes that water pollution control measures have been largely successful, and therefore land in unprotected catchments could be opened up for other uses beyond housing • Urbanisation cap and population-density limit are also removed • Water treatment plants are upgraded to cater to water from developed areas • Stringent pollution control measures continue to be enforced to prevent water pollution from community-based activities

Source Centre for Liveable Cities and PUB National Water Agency (2012) WATER: From Scarce Resource to National Asset. Singapore's Urban Systems Studies Booklet Series. Ministry of National Development and Ministry of Environment and Water Resources. Singapore: Cengage Learning Asia

farming (Ministry of National Development 1989). In April 2000, the Primary Production Department was restructured into a statutory board, the Agri-Food & Veterinary Authority with broader responsibilities. These include diversification of food resources globally and simultaneously developing the city-state into a regional centre for agrotechnology and agri-business (Agri-Food & Veterinary Authority of Singapore n.d.)

By 2000, local farm production supplied only 1.5% of the poultry, 10% of the fish, 30% of the eggs, and 6% of the vegetables consumed in Singapore. Most of the primary food requirements have been met for years from overseas sources. This heavy dependence on food imports may make Singapore vulnerable to disruptions of primary food supplies due to unforeseen circumstances at the source. Therefore, the Agri-Food & Veterinary Authority's strategy is to continually diversify sources of food (Tortajada and Zhang 2016) and increase trade of agricultural and food products through Singapore (Parliament of Singapore 2000).

Singapore has just launched a Farm Transformation Plan, trying to implement next-generation farming concepts where more local produce is obtained with less resources: less land, less labour, and less water. More vertical spaces, roof-tops and under-utilised spaces would be used more efficiently and more productively (Urban Redevelopment Authority 2017). This plan is part of the Three National Food Baskets: imports from around the world, internationalisation (which includes opening new markets), and local production. Farming will continue to be a fundamental part of Singapore's future, but it will have to be different: more modern, more efficient, more productive, and more innovative (Parliament of Singapore 2017b).

Water security has been a concern for Singapore for decades, but so have food and energy security. Singapore has learnt that the only way to progress is to plan for the long-term, and the future will not be different.

4.3 Lessons Learnt and Looking to the Future

In Singapore, water security has been understood in its broadest sense, going well beyond the traditional definitions. It has meant an overarching strategy using policies, laws, and regulations that are updated as required; systems of governance; a national water agency that is responsible for the entire water cycle (water supply, sanitation, desalination, and wastewater that is recycled and supplied for potable and non-potable uses); business plans to make commercial use of recycled water; educational and awareness strategies that contemplate every sector of society; research and development; and technology.

One of the characteristics of Singapore in its search for water security has been innovation. Its limited natural resources, small size, and historical dependence on outside sources of water, energy, and food, instead of holding back its development, have triggered numerous innovations in planning, management, development, governance, research, and technology adoption. These innovations have been the result of numerous discussions at the policy and political levels. They have been thoroughly discussed because they have been meant to be implemented in the most pragmatic manner. Even after implementation, there has been room for experimentation, and even then, there is still room for improvement.

PUB has made major investments to build up water supply sources, including development of local catchments and imported water from Johor, protection of water resources, and production of freshwater through NEWater and desalination. All the investments have borne fruit. The water portfolio has contributed to water security and is expected to continue contributing more in an uncertain future where change will be the only certitude.

Singapore cannot be compared to many cities due to its unique position as an island. Addressing and resolving most difficulties has proven even more critical due to the lack of hinterland to rely on for natural resources and the state of dependence in drawing part of its water, food, and energy resources from outside sources. This has meant that the small island has always absorbed the adverse impacts of growth on the environment. But it has also meant that all development-related decisions have traditionally been dealt with at the highest political level (Ng 2018).

The broad vision of Singapore for water resources has relied on holistic planning that has gone well beyond the boundaries of the water sector to focus on its overall development. As discussed by Neo and Chen (2007), policymaking has followed a 'think ahead, think again and think across' philosophy that proposes a comprehensive, holistic vision including for the management of water resources. Within this philosophy, decision-making considers possible future events (think ahead), re-evaluates and modifies decisions in the light of different scenarios (think again), and looks for experience and know-how worldwide to enrich its pool of knowledge (think across).

To augment its water resources to provide clean water to all users and for all uses, under uncertain conditions, the city-state will have to develop an even more comprehensive strategy that focuses much more on water demand and that leverages pricing, more public engagement, and the understanding of human behaviour. Behavioural economics, a new field of knowledge, has the potential to provide new ways of reducing water use, which, in turn, could provide a much-needed new 'water source'.

Given its goal of water security, Singapore's plans for future overall development will have to pay more attention to societal responses. Unless society becomes part of the water security and resilience processes, difficult times lie ahead for the city-state.

Singapore has excelled in the past, but the future is uncertain. Its water supply systems may still not be robust enough to cope with prolonged droughts, and energy availability and prices do not depend on the city-state. Planning will have to consider more innovations to face the uncertain future. This will require not only all that has been learnt in the past, but also much more of the highly structured and forward-looking policy innovation and implementation that has guided the city-state so far.

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