Setting the foundations and looking towards the future: The case of Singapore

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1. Introduction

Long-term developments such as population growth, urbanization and industrialization in emerging markets as well as the impending threat of climate change, have resulted in increasing impacts on natural resources globally. The increasingly globalized and interconnected world as well as the growing consumption of goods and services has resulted into societies becoming less resilient with respect to the availability of natural resources on which their own development relies (Tortajada & Keulertz, 2015). A new paradigm for global resource availability is necessary at global scale.

A resource-constrained country that has traditionally prided itself on planning ahead of future events that may have an impact on its economic growth and on the well-being of its population is Singapore. The search for more and better development alternatives has made the country follow a 'think ahead, think again and think across' philosophy (Neo and Chen, 2007)[3]. This approach has rendered very positive results throughout the history of the city-state in the overall sectors.

Singapore is one of the most open and competitive markets in the world, globally recognized for creating opportunities and seizing risks if these have the potential to bring benefits. With a population of 5.4 million in 2014, a GDP of US$295.7 billion, GDP per capita US$63,050, its global competitive index is the second in the world only after Switzerland.[4] According to the Global Competitiveness Report, it is also an economy that is driven by innovation:

"Singapore ranks 2nd overall for the fourth consecutive year, owing to an outstanding and stable performance across all the dimensions of the GCI. Again this year, Singapore is the only economy to feature in the top 3 in seven out of the 12 pillars; it also appears in the top 10 of two other pillars. Singapore tops the goods market efficiency pillar and places 2nd in the labor market efficiency and financial market development pillars. Furthermore, the city-state boasts one of the world's best institutional frameworks (3rd), even though it loses the top spot to New Zealand in that category of the Index. Singapore possesses world-class infrastructure (2nd), with excellent roads, ports, and air transport facilities. Its economy can also rely on a sound macroeconomic environment and fiscal management (15th)—its budget surplus amounted to 6.9 percent of GDP in 2013. Singapore's competitiveness is further enhanced by its strong focus on education, which has translated into a steady improvement of its ranking in the higher education and training pillar, where it comes in 2nd, behind Finland. Singapore's private sector is also fairly sophisticated (19th) and becoming more innovative (9th), although room for improvement exists in both areas, especially as these are the keys to Singapore's future prosperity (pages 12, 21)."

Singapore's stage of development can be observed in Figure 1. The city-state is considered factor, evidence and innovation-driven.

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3. Neo and Chen (2007) define these three concepts as follows: 'Think ahead is the capability to identify future developments in the environment, understand their implications on important socio-economic goals, and identify the strategic investments and options required to enable a society to exploit new opportunities and deal with potential threats' (p. 30). 'Think again is the capability to confront the current realities regarding the performance of existing strategies, policies and programs, and then to redesign them to achieve better quality and results' (pp. 35–36). 'Think across is the capability to cross traditional borders and boundaries in order to learn from the experience of others so that good ideas may be adopted and customized to enable new and innovative policies or programs to be experimented with and institutionalized' (p. 40).
4. According to the World Economic Forum competitiveness is defined as the set of institutions, policies and factors that determine the level of productivity of a country (Schwab, 2014).

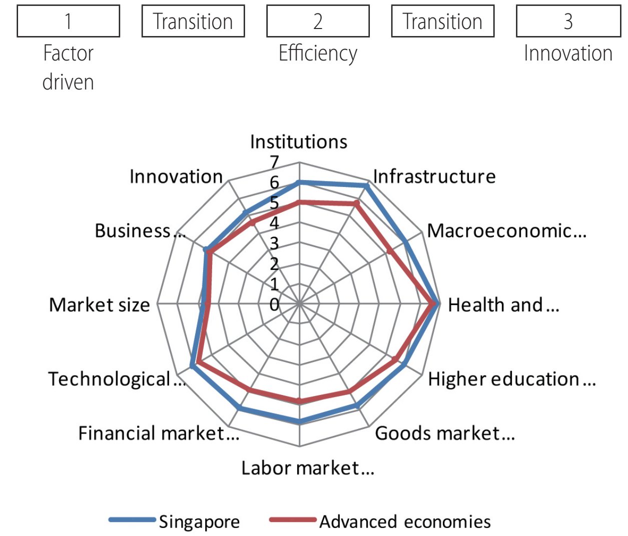

Figure 1. Stage of Development, Source: Schwab, 2014.

Its pathway towards development has seen the city-state moving from a 'trapped transition' in 1965 at the time of independence to a 'room to manoeuvre' stage only some two decades later. In the first case, decisions taken were driven by changing and unforeseen situations while later on, changes were anticipated and planning was implemented having a long-term vision in mind (Shell, 2013; Tortajada et al., 2013).

It is said that Singapore needs to identify and cultivate the right kind of niche areas in which it can specialize and, within these niches, move as close to the level of developed countries as it is possible to achieve (MIT, Ministry of Trade and Industry, Singapore Strategic Economic Plan, http://www.mti.gov.sg/ResearchRoom/Documents/app.mti.gov.sg/data/pages/885/doc/NWS_plan.pdf). Nevertheless, this is not necessarily the case as Singapore has become a global example for others to follow in many areas. This is the case of the water sector, as the excellent water resources policy, planning, management and development have sustained the growth and development of the city-state and its population historically.

This paper will analyze the water resources history of the city state as well as the present status of water management and development, including water policies and institutional and financial issues. It concludes by discussing the achievements, plans and challenges ahead for the city-state looking towards the future.

2. Water Resources

Singapore is an island city-state of 718 m2 in 2014. When it became an independent state in 1965, the main source of water supply was water imported from Johor, Malaysia, and supplemented by water from reservoirs (or local catchments). During the early period of post-independence, Singapore focused primarily on enhancing its indigenous capacity, cleaning its water bodies and constructing and expanding catchments areas and reservoirs within an overall framework of sustainable land use. This in turn shaped urban development patterns and facilitated land and water conservation as well as strict implementation of regulations for storm and inland water management. Since 1965, the number of reservoirs has increased from 3 to 17. The Marina Reservoir has the most urbanized catchment area that covers 10,000 ha or one-sixth the size of the city-state. Together with the rest of the reservoirs, it has increased Singapore's water catchment from half to two-thirds of the total land area. With all of the major rivers in Singapore dammed up for the formation of reservoirs, Singapore has looked for an array of the possibilities to tap on the smaller streams and canals as well (see Table 1).

Table 1. Key Statistics on Singapore, 1965 and 2014

	1965	2014	Change
Land Area (km^2)	580 km^2	718 km2	+138 km^2
Population	1,887,000	5,469,000	3,582,000
GDP per capita1	$ 1,580	$ 63,050	$ 61,470
Water consumption per capita	75 l/person/day	150.4 l/person/day	+76 l/person/day
Total Water Consumption	70 Mgal/day	400 Mgal/day	330 Mgal/day
No. of Reservoirs	3	17	+14
Land Area as Water Catchment	11 %	67 %	+56 %
Desalination Capacity	0	100 Mgal/day	+100 Mgal/day
NEWater Capacity	0	117 Mgal/day	+117 Mgal/day
Industrial Water Capacity	0	15 Mgal/day (2010)	+15 Mgal/day
Water Availability	24 hours/day	24 hours/day	-
Service Coverage	~80%	100%	
Unaccounted-for-Water	8.9 %	5.2 %	-3.7 %

Sources: Department of Statistics Singapore (2014), Latest data; MEWR (2014), Key Environmental Statistics; PUB (2014a); Tortajada, et al. (2013).

The Singapore government recognized that water coming from Malaysia and from the local catchments would not be enough to ensure a stable and sustainable water supply for the country's growing economy and population, and sought to develop further sources of water. Throughout the years, consistent and considerable investment has been poured into developing not only conventional sources of water but also unconventional ones. NEWater (ultra-clean, high-grade reclaimed water) was introduced in 2003, and the first seawater desalination plant was operational in 2005 with a second one (Tuaspring desalination plan) in operation in 2013. Collectively, the diversified water supply is made up of four sources: local catchments, imported water, NEWater and desalinated water, known as the "Four National Taps" (see http://www.pub.gov.sg/water/Pages/default.aspx).

Currently, the two unconventional water sources – NEWater and desalinated water - supply up to 30% and 25% of total demand for the city-state respectively. NEWater is pumped to the reservoirs for non-direct potable use, but primarily supplied to the industries and commercial buildings for non-potable uses. There are plans to augment the capacities of NEWater and desalinated water to supply up to 80% of Singapore's total water demand by 2060 (MEWR and MND, 2015). This would entail the development of new NEWater and desalination treatment facilities, as well as increasing the conveyance capacities of the water supply network (PUB and IWP, 2014).

Singapore is currently exploring the availability of groundwater, as well as, assessing the sustainable abstraction yield of groundwater to supplement the existing water supply. With regard to climate change, the city-state is studying the impacts of climate change, possibly more frequent and severe droughts, on its water resources. To build up its capabilities and knowledge in climate science and modelling, the Meteorological Service Singapore has established a Centre for Climate Research Singapore. This will contribute towards augmenting national preparedness for climate change and informing policy decisions (PUB and IWP, 2014).

3. Urban development and water resources

In a few decades after Independence, the city-state built a well-deserved sense of national pride and achievement based on the many achievements it had made in the pursuit of the development path it had embarked on. In 1985, the International Monetary Fund declared Singapore a first world country. According to the Ministry of Trade and Industry (MTI), the official foreign reserves stood at $33.2 billion in 1988 at that time (Quah, 1991).

Striving to always look forward, the city-state's consciousness of quality and quest for identity pervaded all ways of life, including water, the economy and even public housing (Cheong-Chua, 1995). In the 1960s, the country had to address two priority matters. It had to ensure water supply, an issue that grew even more crucial after independence in 1965, and, in economic terms, its first priority was to attract investment and generate employment to pursue the advised industrialization model. In the 1970s, the water focus entirely shifted and moved towards sustainability by exploring conventional and non-conventional means. With this aim, Singapore tried technologies that were not economically viable at that time such as desalination and water recycling, and that only with time, matured as feasible solutions. At that point in time, the economy started awarding an ever larger and more relevant importance to diversifying its income base and upgrading its workers' skills. This paradigm evolution continued, and with it, the responses given to pervasive and new challenges. By the 1980s, the country had put in place the infrastructure required to efficiently deliver clean water; it then immersed itself in the redevelopment of the city-state, cleaning of waterways, which constituted a big improvement towards making the inland water resources pollution free; and it could claim that severe floods had become a thing of the past. The economic prosperity that developed over the years established and firmly rooted Singapore as a first world country. Later that decade, the city-state embarked on a 'second industrial revolution' involving the use of increasingly sophisticated and cutting-edge technology and setting the foundations to build a knowledge-based economy (Tortajada et al., 2013; Turnbull, 2009). Unlike many big metropolises worldwide, Singapore's industrialization process has not led to environmental decay.

With economic growth, total urbanization and intensified industrialization, the demand for water grew rapidly over the years. Between 1963 and 1993, the population rose from 1.8 to 3.3 million driving the steady expansion in both the domestic and industrial demand for water. Between 1965 and 1993, consumption of water more than doubled from 75 l/capita/day to 173 l/capita/day. On their part, the industrial and commercial sectors had prospered to the extent that, in 1993, their share of water consumption had reached 36.25 % of total volume sold, a 144 % increase from the 1983 level, and 264 % from what was used in 1973. To further illustrate the magnitude to which water demand was tied and driven by economic imperatives, regardless of how advanced the established industries were, the post-1990 electronic revolution put an unprecedented toll on water supply. For example, the fabrication of silicon wafers used in the semi-conductor industry was a water-intensive and highly specialized operation. One plant alone operated with 600 gallons of water per minute, or what comes to account for 0.39 % of total water consumption in Singapore (Ooi, n.d.).

With economic success, the country's built landscape was substantially transformed. Intensive use of limited land resources and high opportunity costs significantly reduced the number and size of farms, forests and marshes, while the space occupied by constructed areas increased from 18.5 % to 48.6 % between 1950 and 1993 (Low, 1997).

After the consolidation of the economy and the completion of the first cycle of urban development, policy-makers began considering the second round of urban improvement aiming at enhancing quality, providing for variety, and innovating in the design of urban spaces. It was also sought to make a more efficient use of the country's natural assets, namely its water bodies, tropical weather and abundant vegetation. For an island, finding ways of making water a part of urban development was perceived as imperative. The first steps would then be to seize the many advantages presented by the waterfronts of several areas such as Marina South, the Singapore River, the Kallang Basin, Tanjong Rhu and Kampong Bugis.

4. The 1991 Concept Plan

Singapore's development over the next 40-50 years is guided by a strategic land use and transportation plan. This is the Concept Plan.
Reviewed every ten years, the Concept Plan ensures that there is sufficient land to meet long-term population and economic growth needs while providing a good quality living environment for the population. It plays a vital role in helping balancing the multiple land use needs, such as housing, industry, commerce, parks and recreation, transport, defence and community facilities. The infrastructure the country needed and that was included in the Concept Plan of 1971 was all developed already by 1989. Institutionally, to start mapping Singapore's future urban vision, the Urban Redevelopment Authority (URA) merged with the Planning Department and Research & Strategic Unit of the Ministry of National Development (MND) the same year. The new body became the national planning and conservation authority and allocated many more resources to lead the island's physical development into the year 2000 and beyond. In 1989, the 1971 Concept Plan was revised. This resulted in new policies and direction for the future environment of the city-state. It considered that many social and economic changes had occurred since the previous Concept Plan had been developed: population had considerably increased, industrial developments posed new demands and extra land was required to make possible a better lifestyle for more recreation-conscious citizens (Waller, 2001).

Planners felt they had to bring housing closer to the water and facilitate commercial and other leisure activities at waterfront locations: the sea, at rivers and even canals. The work carried out under previous plans had reasonably landscaped and cleaned the rivers and had made them safe for water sports. New beaches near the downtown waterfront would now provide attractive venues for boating and water-skiing. Thus, a combination of vision and planning skills initiated the task of transforming Singapore into a vast tropical resort and named it 'A Tropical City of Excellence'. Consequently, the Concept Plan 1991 included three staging plans for the years 2000, 2010 and the unknown year 'X' when population would reach four million (URA, 1991). These staging plans would then be used as a reference point to help in the preparation of the 55 detailed Development Guide Plans (DGPs) that would map out concise initiatives for the entire city-state. These 55 DGPs would gradually replace the 1985 Master Plan. More detailed and flexible than its 1971 predecessor, the 1991 Concept Plan retained the idea of laying out a framework for the island's physical development according to Singapore's vision of and for its future (Waller, 2001). By that time, Singapore had already become the first developed country in the equatorial belt, so it initiated the task of creating an international investment hub and leading it towards becoming 'A Tropical City of Excellence' (Liu, 1997). This planning roadmap analyzed in detail a variety of issues like economic infrastructure, transportation networks, housing, green networks and waterways, social and cultural facilities, and pollution control measures.

The importance of water in enhancing the value of real estate and creating business opportunities was clear to everybody. New market opportunities and prospects were created for the private sector to invest and transform dilapidated areas or virgin land into highly valuable assets. The government supported private initiatives with timely land releases and infrastructural development. Areas developed next to the Singapore River, Tanjong Rhu and Marina Bay areas are examples of this public–private collaboration (Cheong, 2008). The URA and PUB turned to working closely together to utilize canals and inland reservoirs to create attractive and landscaped 'lakes and streams'. As a result, more leisure space was made available and real estate values soared. More than a decade later, in 2006, PUB would start the Active, Beautiful, Cleans Water (ABC Waters) programme to realize the full potential of the water infrastructure and improve the quality of life of the population (see ABC Waters Programme, http://www.pub.gov.sg/abcwaters/Pages/default.aspx).

5. Water management from 1991 onwards

Urban development and its emphasis on recreation and better quality of life could give the impression that there has been a shift from immediate water issues to more aesthetic ones. Nevertheless, in practice, core water concerns have never ceased to be a priority. Water has consistently been recognized as a strategic resource and its conservation has always been considered as a vital national security aspect (Hansard, 1989). PUB has continued working towards an ever more efficient provision of water services and better planned and managed water resources, whilst trying to keep a balance between the lifestyle that people would expect to lead in a developed country and the need for water conservation.

Concurrently with the rapid development of the city-state, appropriate control strategies were adopted, older legislation and regulations were amended and new ones were drafted. Even though by 1980 a basic legal framework was already in place to meet Singapore's environmental needs, new issues coming up as a result of development activities demanded more suitable laws. Some examples include the Water Pollution Control and Drainage Act (Chapter 348) 1975 which was repealed and relevant powers were streamlined into the Sewerage and Drainage Act (SDA, now under Chapter 294) administered and enforced by the PUB and the Environmental Pollution Control Act (now known as the Environmental Protection and Management Act (EPMA), Chapter 94A) as well as their regulations, which are administered and enforced by the National Environment Agency (NEA) (See Singapore Statutes online for further information, http://statutes.agc.gov.sg/aol/search/display/view.w3p;ident=acc1b181-1147-4dfc-bc9a-1b0b41877fe7;page=0;query=DocId%3A%227cc197 1c-6237-4f5a-a75c-dd378fc80179%22%20Status%3Ainforce%20 Depth%3A0;rec=0#legis) (For a detailed analysis on legislation, see Tortajada and Joshi, 2014).

Throughout the years, strong emphasis has also been put on water conservation campaigns. Nonetheless, after 25 years of carrying out awareness raising efforts, it was clear that the campaigns were only one part of the strategy to conserve water: pricing was the other part. It was then decided to make use of every possible source and technological device and process to achieve this goal. In 1997, water pricing was revised not only to cover the full cost of production and supply, but also to reflect the higher cost of alternative sources. This sent a strong signal to the population and it encouraged the adoption of technical solutions for water fittings and their economic use (Tan et al., 2009).

All non-domestic premises were required to install water-saving devices such as self-closing delayed action taps and constant flow regulators. Since 1992, low capacity flushing cisterns employing 3.5 to 4.5 litres per discharge were installed in all new public housing apartments, a mandatory measure for all new premises since April 1997.

In 1983, and for ten years, the PUB started a $55 million pipe replacement programme. It involved changing all unlined water mains with cement-lined ductile iron and galvanized iron pipes with corrosion-resistant stainless steel and copper pipes. Some 182 km of old unlined cast iron water mains and 75,000 of old galvanized iron connecting pipes were removed. This project ensured that water supply remained at its best and that leakage losses were kept to a minimum (PUB, 1992). This also made it possible for the PUB to have one of the lowest ratios of unaccounted-for water in the world, averaging 5 % in 2014 compared to 10.6 % in 1989.

Competing land uses in a fast-growing Singapore made land a premium commodity and thus its efficient use became a priority. Innovations and technological advancement were vigorously

pursued with this aim in mind. For example, conventional water reclamation plants with open tanks had a 1 km-long buffer zone where very limited development was allowed. In the 1990s, the majority of them were covered, odour treatment facilities added and the buffer zone reduced to 500 m. Later on, all water reclamation plans were covered and made even more compact.

Even when land is scarce, Singapore has been able to commit 9 % of the total land area to parks and nature reserves by carefully planning for it. Between 1986 and 2007, despite population surging by 68 % from 2.7 to 4.6 million, the country's green cover grew from 35.7 % to 46.5 % (Ng, 2008). Figure 1 as well as the photographs below show the green cover of Singapore in 2011. (Note: The satellite map was produced by DHI Water & Environment Pte Ltd by processing satellite data acquired and processed by Centre for Remote Imaging, Sending and Processing (CRISP), National University of Singapore. The method and algorithms used in producing the map were developed by CRISP.

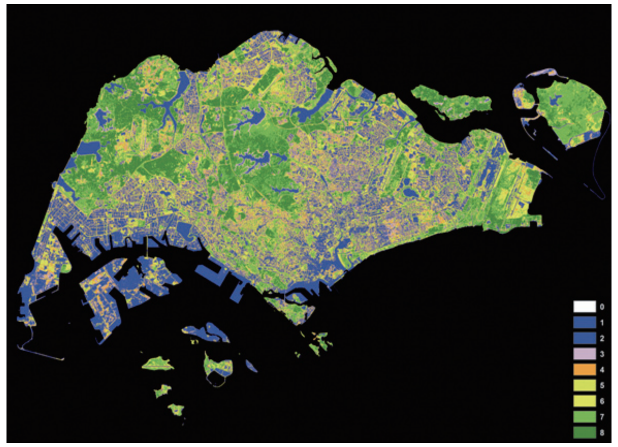

Figure 2. Green cover of Singapore in 2011

Currently, about 10% of Singapore's total land area is for parks and nature reserves (Credits: National Boards Parks, Singapore).

Despite having constant pressure from reclamation and coastal modifications, Singapore's waters still support a good number of marine biodiversity. Land reclamation along the coast has decreased the coral reef cover by about 60%. Development pressures and coastal modifications continue to be the main threats to Singapore's remaining intertidal habitats. Sedimentation and water clarity issues stemming from coastal works also threaten marine biodiversity.

Oil spills, ship groundings and other navigation-related impacts on the reefs have been minimal. Other threats such as climate change and ocean acidification are less defined or understood. For example, high sea surface temperatures were the cause of the 1998 mass bleaching event in Singapore (the first known record locally). An encouraging trend observed from some reclaimed areas is the recolonization of marine life (National Parks Board, 2010).

Damming up of rivers to form reservoirs and canalization of streams or waterways, land reclamation and natural degradation such as coastal erosion have resulted in the reduction of mangrove forest, which in turn drive out species dependant on mangrove habitats for survival. In recent years, mangrove planting and enrichment planting efforts have been implemented to help recover mangroves at various sites. These include Sungei Buloh Wetland Reserve, Pulau Ubin, Pulau Semakau and Pasir Ris Park. Over 400,000 mangrove saplings were planted as part of the efforts to replace loss of mangroves during construction of a landfill at Pulau Semakau (National Environment Agency, 2009).

6. Water demand management

Water demand in Singapore has been increasing steadily along the years similarly to what has often been witnessed in most other countries. As population grows, standards of living improve, and the progress of urbanization brings about the acceleration of commercial and industrial developments, water demands have the tendency to rise unless specific policy countermeasures are taken.

Around the time of its independence in 1965, the situation in Singapore was very similar to what has been witnessed in other nations undergoing rapid growth. From a daily average consumption of about 32.5 Mgal/day in 1950, demand increased 2.52-fold to 81.9 Mgal/day by 1965, and to 110 Mgal/day by 1970 (PUB, 1970). During these two decades, Singapore's policies focused on supply management to tackle its serious urban water management problem. For example, when the island faced a prolonged drought in 1960 and unusually low rainfall in 1961, thousands of Singaporeans woke up on 19 August 1961 to find there was not even a single drop of water available. The government reacted by instituting a strict water-rationing system.

In 1995, the PUB launched yet another 'National Save Water Campaign' to raise awareness on water scarcity and the need for the conservation of the resource. The initiative mainly targeted community groups and students, and for the first time, major shopping centres staged campaign exhibitions to more widely disseminate information about the need to conserve water among the general public. The same year, in an unusual campaign that ran for six days, an island-wide water rationing exercise was conducted involving 30,000 households. During this period, water supply was interrupted for 14 hours on each exercise day (PUB, 1995). The aim was to shake up public inertia, especially among youths, and remind Singaporeans about the importance of water.

Regarding reservoir construction, the PUB had expanded the catchment and storage capacity of Seletar Reservoir (finalized in 1969) and completed the Upper Peirce Reservoir scheme in 1975. Since then, the Works contributed an average of 111,000 m3/day (PUB, 1975). There was also the realization that it was not possible to expand protected catchments (those that are left in their natural states as far as possible and development is not allowed) indefinitely. To obtain as much water as possible from national sources, the smaller streams and rivers were dammed up first, with big and highly polluted rivers left for later actions. Singapore had two motivations to clean up its rivers. First was the need to obtain as much water as possible from national sources. Second was that during British rule, areas inhabited by the colonial population were clean and beautiful but the remainder of the island was somewhat squalid, often with open sewers, squatters and very limited municipal facilities.

The idea of a 'clean and green Singapore' was born, and it became an integral component of the national strategy and the efforts for water self-sufficiency. Mr. Lee Kuan Yew became the only Prime Minister anywhere in the world in recent history taking special and continuing interest in water throughout the entire 31 years he was in office. During this period, he personally and regularly received all relevant water news, and the water situation was coordinated directly from his office. No ministry could make any decision that could in any way jeopardize the country's quest for water security: they were simply vetoed by the Prime Minister (personal interview with Lee Kuan Yew, 11–12 February 2009 in Tortajada et al., 2013).

Because of such consistent support from the highest political level, by the time Prime Minister Lee retired from office, the country had managed to put in place one of the most efficient and effective water and wastewater management systems in the world. It had the main objective to increase water supply by every means available, and whenever and wherever possible. By managing demand, Singapore ensured that the country made spectacular advances towards water security, in spite of curtailing demand being politically more difficult to attain than expanding water supply.

7. Water pricing

The increased focus on water demand management that began in the 1980s can be seen in terms of both pricing for cost-recovery and non-pricing measures. The Singapore government had repeatedly stated that water prices had to be increased to cover the cost of growing water demand, with the objective of higher tariffs being mostly for cost recovery. For instance, during the 1980s and 1990s, the cost of water supply and wastewater services represented less than 0.5 % of average household income, which meant that water pricing was not an incentive to reduce domestic water demand. The water tariffs during the 1980s and 1990s were decided primarily to ensure cost recovery.

Singapore, similar to other British colonies, had inherited the British water system of charging for water. As such, the challenge was not so much to charge for water but rather to get the population to accept increases in tariffs to assure cost recovery, as well as restructuring the tariffs so that the non-domestic sector would no longer subsidize the domestic sector. The latter objective was achieved in 1997.

In 1991, an explicit tax aimed at conserving water was put in place. While this marked a milestone in the use of water pricing to reduce water consumption, the basis for determining the tax quantum was not clear. In 1997, Singapore explicitly started to use economically efficient price signals to manage water demand. The consequent pricing revision was aimed at recovering the full cost of production and supply through the water tariff as well as to reflect the higher cost of alternative water supply sources through the water conservation tax. The revenues generated from this particular tax were not allocated to the PUB because the agency would be receiving funds it did not need for water production and supply. Instead, they were transferred to the consolidated fund of the government, which was managed by the Ministry of Finance (Tan et al., 2009).

While the water conservation tax has been levied to encourage water conservation, some other non-water related taxes have also been levied in terms of water price. One example is a statutory board tax that was introduced in 1969 to defray the increasing defence expenditure that was required to build up the Singaporean armed forces in response to the British announcement that all troops would be withdrawn from the island by 1971. This 10 % tax was levied from the total utility bill, which at that time comprised electricity, gas and water. From a policy point of view, this tax had no relation with water even though it may have had an impact on the consumers' behaviour since it affected their water bill.

Water price (water tariff and related taxes) were revised more than ten times between 1965 and 2012. As noted earlier, the initial price reviews were primarily motivated by the need to recover costs, rather than to encourage water conservation. During the 1960s, consumers were charged a flat volumetric rate with a fixed charge on meter rents and a turn-on fee. Non-domestic consumers were divided into three categories: shipping, consumers that processed water for sale, and others. In 1965, it became clear that the fuel oil tax increased fiscal contributions more considerably than property taxes and that the large capital investments required to meet increasing electricity, water and gas demands would necessitate a tariff revision for all services. Thus the first tariff revision since 1954 came into effect in November 1966 (PUB, 1966; The Straits Times, 22 October 1966).

As a result, the price of water per thousand gallons for domestic consumption increased from 60 cents to 80 cents, water supplied to ships increased from $3.75 to $4.00, and that to industries processing water for sale was revised from $2.00 to $2.50. For other trades and industries, the price increased from $1.30 to $1.50 per thousand gallons. For the government, the price was raised to $1.00 and for statutory boards and the foreign armed forces, it became $1.50 (PUB, 1966). The reasons behind the tariff raise were explained to the public over the mass media, using TV, radio and newspapers, and were generally accepted by all consumers (PUB, 1966).

Rates were revised so that increased costs for water services were spread across all consumers and to avoid imposing a burden on the industries that underpinned the economic development of the country (PUB, 1966). An additional reason was to ensure that, as far as possible, electricity, water and gas supplies were self-sufficient with their own generated revenues. When reporting the impacts of the 1966 tariff revision, the PUB emphasized that this measure had led to an increase in revenue, mentioning only in passing the impacts it had on managing water demands. This once again reinforced the notion that price adjustments served almost exclusively cost-recovery purposes and were not directly related to water conservation (PUB, 1967).

In 1973, Singapore modified the domestic water tariff structure from a flat volumetric rate to an increasing block tariff for the very first time. There was an escalating cost for every block of 25 m3 to 75 m3 with the aim of reducing water wastages in the domestic sector. Even when it was argued water conservation was the reason for changing the rate structure, cost recovery continued to be the main driver. The government also introduced three sets of tariffs for different household sizes living in one block unit so that large households with a higher consumption rate would not fall into higher tariff blocks. Block tariffs were established after analyzing the household average per capita water consumption so that a minimum necessary amount of water could be provided at low rates (PUB, 1973). Both the domestic and non-domestic water tariffs were revised again in 1975 due to the significant increase in water consumption and the accompanying growing capital and operating costs, as well as to encourage economic development (PUB, 1975). Tariff-generated revenue was necessary to pay for two major water supply projects that had an approximate total cost of $137.3 million, Upper Peirce Reservoir and Kranji-Pandan Reservoir scheme. Higher fees were also to cover the summing costs of treating raw water from the highly polluted Kranji-Pandan Dam (Hansard, 1976).

In 1981, several measures were introduced to encourage a more rational water use. The three sets of domestic water tariffs introduced in 1973 were eventually simplified and replaced by a single domestic tariff in 1981. Under the then regulations and at its discretion, the PUB could grant concessions to any premises where there were two or more households and where more than ten persons lived in the same place. The then four-tier domestic tariff was revised to three tiers. The nondomestic water tariff structure was also revised in 1981 from a flat volumetric rate to an increasing block rate where consumers with a water consumption exceeding 5,000 m^3/month had to pay a higher rate (PUB, 1981).

Subsequently, and as mentioned before, the water conservation tax was introduced in 1991 as a potential pricing tool to discourage excessive water consumption (Tan et al., 2009). Thereafter, water price has included both the tariff as well as the conservation tax. The tax was initially applied to domestic consumption above 20 m3 and to non-domestic consumption from the very first drop. In 1992, concerns regarding the development of strategies to reduce increasing water consumption were again expressed in the Parliament (Hansard, 1992). The need to promote higher GDP without necessarily using more water was discussed, especially as the resource was still mostly imported from Malaysia. The objective was that the economy could grow without concomitant higher water use. By then, and as part of this strategy, the water conservation tax had already been in place from the year before but even then water demand continued to soar. In fact, in 1991, domestic demand increased by 5.8 %, which was much higher than the annual average 3.8 % increase of the previous five years. The Parliament once again considered the desirability of elevating the water conservation tax even further.

Perhaps the most significant change in terms of water pricing policy occurred in 1997. This was the first time the government attempted to price water based on economic efficiency and aiming, in the long term, to restructure both the water tariffs and the conservation tax into uniform flat rates. As much as possible, the price per cubic metre of water was to be the same irrespective of the user (household, industry or a construction site), and regardless of the amount consumed (PUB, 1997a). Thus, several significant new changes were introduced. First, water price was pegged to the cost of desalinated water to reflect the higher cost of alternative supply sources. With this, Singapore became one of the pioneering countries introducing marginal cost pricing. Second, the water conservation tax was charged from the initial consumption, even for the domestic sector, to signal the importance of water as a strategic resource for the country (PUB, 1997b). Third, the lowest two domestic consumption tiers (0–20 m3 and 20–40 m3) were merged into one, domestic consumption above 40 m3 was charged a higher tariff and the non-domestic water price was made equivalent to the lower domestic consumption tier rate. Finally, the volumetric sewerage fees were also increased to link the fee charged with the volume of wastewater generated. To avoid drastic changes and confusion among consumers, this new pricing structure was gradually implemented over a period of four years, from 1997 to 2000. Since then, there have been no price increases, although in 2007, the government mentioned plans to introduce a single price for water supply and distribution and for wastewater collection, treatment and disposal. The government also announced the intention to remove the fixed sanitary appliance fee and thereby move to a fully volumetric charging mechanism for the waterborne fee that would be more equitable. The thinking was that the cost of used water treatment should be pegged to the volume of wastewater generated and not to the number of sanitation facilities installed.

The change in domestic consumption over time, indicating the years when pricing and non-pricing measures has been introduced, is shown in Figure 2. Table 2 show the several water tariffs based on consumption blocks, including water conservation tax, and water borne and sanitary appliance fees from July 2000. They all are valid at present. Tables 3 and 4 show NEW water tariffs from 2012 and industrial water tariffs from 2013.

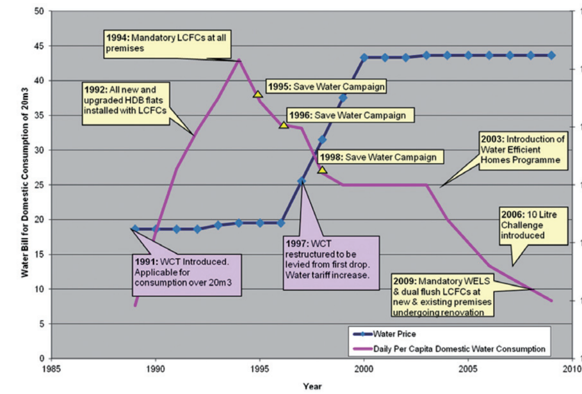

Figure 3. Change in domestic consumption and price and non-price conservation efforts (Source, PUB)

Table 2. Water Tariff since 1 July 2000

Tariff Category	Consumption Block (m3 per month)	Tariff($/m3) [before GST]	Water Conservation Tax (% of tariff) [before GST]
Domestic	0 to 40	1.1700	30
	Above 40	1.4000	45
Non-Domestic	All units	1.1700	30
Shipping	All units	1.9200	30

Tariff Category	Consump -tion Block (m^3 per month)	Water borne Fee ($/$m^3$) [before GST]	Water borne Fee ($/$m^3$)* [after GST]	Sanitary Appliance Fee [before GST]	Sanitary Appliance Fee * [after GST]
Domestic	All units	0.2803	0.30	$2.8037/ - per charge-able fitting per month	$3.00/ - per charge-able fitting per month
Non-Domestic	All units	0.5607	0.60		
Shipping	All units	0.5607	0.60		

Source: Public Utilities Board, http://www.pub.gov.sg/general/Pages/WaterTariff.aspx

Table 3. NEWater Tariff since 1 April 2012

Tariff Category	Consumption Block (m^3 per month)	Tariff ($/$m^3$) [before GST]	Tariff ($/$m^3$) [after GST]	WCT (% of tariff)	WBF ($/$m^3$) [before GST]	WBF ($/$m^3$) [after GST]
NEWater	All units	1.2200	1.3054	-	0.5607	0.6000

Source: Public Utilities Board, http://www.pub.gov.sg/general/Pages/WaterTariff.aspx

Table 4. Industrial Water Tariff since 1 Oct 2013

Tariff Category	Consumption Block (m^3 per month)	Tariff ($/$m^3$) [before GST]	Tariff ($/$m^3$) [after GST]	WCT (% of tariff)	WBF ($/$m^3$) [before GST]	WBF ($/$m^3$) [after GST]
Industrial Water	All units	0.6500	0.6955	-	0.5607	0.6000

Source: Public Utilities Board, http://www.pub.gov.sg/general/Pages/WaterTariff.aspx

Even with all of these positive developments and achievements, however, water conservation measures need to be given more thorough consideration for long-term.

8. Innovations

Long-term planning and visionary leadership in Singapore are characterized by innovation. PUB's planning, policy, management and development of water resources are clear examples of this, with technological development representing an extraordinary effort that is globally recognized. Thanks to visionary planning, strong leadership and also a touch of genius, Singapore has transformed its vulnerability to scarce water resources into a strength.

To meet the ever-increasing water needs for growth, development and quality of life of the population, PUB is constantly planning towards the future. The water catchment area of the city-state has been increased (to 67% at present) with the construction of the Marina, Punggol and Serangoon reservoirs. There are plans to increase it to 90% by 2060, which will make Singapore's water supply more resilient. According to PUB (2014), this will be achieved with the Variable Salinity Plant, a dual-function variable salinity plant that integrates desalination and NEWater treatment processes to treat water of varying salinity, allowing to source water from brackish streams and small rivers along the shoreline.

At present, NEWater covers 30% of the water needs of the city-state and is intended to cover up to 55% by 2060. This will be achieved with the construction of the NEWater plant in Tuas, and a second NEWater plant at Changi. In terms of desalination, a second desalination plant (Tuaspring) produces additional 70 mgd that, together with the 30 mgd produced by the first plant, contributes a total of 100 mgd. A third desalination plant with a capacity of 30 mgd is slated for completion by 2017. The objective is for desalinated water to cover up to 25% of future water demand by 2060.

The Tuaspring desalination plant built by Hyflux is designed to have a daily production capacity of 318,500 m^3 of water. PUB will purchase the water at the rate of SGD0.45 (USD0.35) per m^3 for the initial year. The company is carrying out construction work on a 411MW power plant in order to supply electricity to the desalination plant. Aside from Hyflux, Singapore-based utilities provider Sembcorp is also expanding its water treatment portfolio. In early July 2011, Sembcorp started construction work on a USD$40m integrated wastewater treatment plant in Jurong Island, the petrochemicals hub. The new plant will have the capacity to treat 9,600 m^3/d of complex industrial wastewater, nearly doubling Sembcorp's Singapore industrial wastewater treatment capacity on the island. Besides increasing water supply, the PUB is also expanding its superhighway for collecting and treating used water. In June 2014, the PUB awarded an engineering services contract to a JV between Black & Veatch and AECOM to shape the second phase of the Deep Tunnel Sewerage System (DTSS). This involves extending the tunnel system to the western side of Singapore via a 30km tunnel and construction of almost 71km of linked sewers and a 12km deepsea outfall. The entire system will reduce the land for used water infrastructure by 50%. Two water reclamation plants (Jurong and Ulu Pandan) will be closed eventually and domestic and industrial used water from the western part of Singapore will be treated at the new Tuas water reclamation plant (Business Monitor International, 2014; PUB, 2014a).

In 2006, the Environment and Water Industry (EWI) Programme Office was established to support the development of the local environment and water industry through research and development (R&D) and human resources development programmes, led by PUB, EWI seeks to provide overall direction and coordination in growing the water and environment industry through partnerships with, for instance, the Economic Development Board (EDB), International Enterprise Singapore (IE) and SPRING Singapore. The support it has received thus far from the National Research Foundation has been in the order of $470 million. As a result of these efforts, the contribution of the water sector to Singapore's economy is expected to grow to $1.7 billion by 2015 (PUB, 2014).

Singapore has also aimed at attracting a large number of water companies to establish themselves in the city-state to carry out their R&D, engineering, consultancy, manufacturing and headquarters operations. Results have been very positive with more than 150 international and local water companies and 26 research centres being set up in Singapore, including GE Water & Process Technologies, Black & Veatch, CH@MHILL, Siemens, Veolia and Nitto Denko (For information on the commercialization of new technologies, http://www.pub.gov.sg/mpublications/Documents/Water%20industry%20update%20-%20ANNEX%20B.pdf). For information on Singapore water-based companies that have positioned in the global market see also PUB Annual Report 2013/2014 (PUB, 2014b).

Last but not least, according to a 2013 ranking by Lux Research, the National University of Singapore (NUS) and the Nanyang Technological University (NTU) are the first and second top global water research institutes respectively in the world (see http://www.luxresearchinc.com/news-and-events/press-releases/read/singapore-universities-top-ranking-water-research-institutes). The work carried out by the 26 water R&D centres in Singapore will continue contributing to make the city-state a centre for research, development and innovation in the field of water technology

9. Looking towards the future

For Singapore, the biggest driver behind planning for the future is the consequences of resource scarcity, as opposed to, for instance, an overexploitation of natural resources of which Singapore has little, if any at all.

The continued availability of both water and energy in Singapore will be affected by the uncertain and unpredictable threat of climate change. Singapore is, arguably, more water- secure today than it has ever been in its short history. Its resilience to drought was affirmed in January 2014, during Singapore's worst and longest-ever drought, when lower water levels in reservoirs were adequately increased by water supplies from NEWater and desalination sources. However, Singapore's existing water supply capacities are already expected to come under mounting pressures in the near future due to intensifying demands for water – it has already been estimated that total water demand in Singapore is likely to rise to 760 Mgal/ day by 2060 (Tortajada, 2014) – about double the 2011 figure of 380 Mgal/day.

Population growth due to increasing urbanization is likely to inflate demand for more and better quality of water, as both domestic and industrial consumers and infrastructure needs, demand a steady supply of water to maintain a high quality of living. As an importer of both water (at least until 2061) and energy, the supply of both resources in Singapore is heavily dependent on the undisrupted availability of these resources elsewhere, a factor that may be beyond the control of Singapore. Furthermore, rising global prices of energy in particular may threaten the present affordability of energy imports, such that the financial sustainability of importing present amounts of energy may come into question. However, it is unlikely that Singapore will curb energy imports solely for cost reasons, given the indispensability of energy imports to the running of the entire economy. The changing climate also has a critical bearing on continued water and energy security. For instance, it may directly limit water supply by reducing the freshwater and seawater required for water treatment processes; it may also indirectly limit available energy imports from other countries by altering river flows in those countries in ways that obstruct the operations of power plants in river basins or hydroelectric dams. Given Singapore's vulnerability to both water and energy shortages, it is imperative that the policies in the water, energy and climate sectors (where relevant) are seen more comprehensively.

As a bustling city, Singapore experiences a high population density. It is not uncommon in ordinary discourse to hear of growing dissatisfaction amongst the population of increasing congestion in public spaces. As the population continues to grow, not only is demand for water and energy sources likely to rise, the proximity to which people, firms and infrastructure find each other is likely to narrow as well. As more congestion results, greater stress will be placed on the country's existing infrastructure, which may then need to be upgraded or retrofitted, with the consequence that more of both resources will be required. As Singapore's already-scarce land becomes more limited, options for the physical expansion of infrastructure development in the water, energy and climate change domains may also be severely reduced. Furthermore, as centre of economic growth and innovation, where traditional territorial boundaries of the economy have given way to global connectivity of capital, knowledge, ideas and a myriad of other flows, policy decisions in the several sectors will necessarily have additional implications for the connected, broader economy. Adverse consequences created in any one of the four sectors may have a knock-on impact on the provision of other forms of services and the overall quality of life (Tortajada, 2014). Given the Government's assurance of a better quality of life, these impacts may have consequences in the political space, where the Government may be held accountable for mismanagement or misgovernance. A more comprehensive approach is thus important in avoiding unnecessary costs arising from a parochial understanding of the cross-sectoral implications of policies, realizing instead the synergies between these sectors for economic growth.

Energy security also remains an enormous issue for Singapore. The city-state lacks natural energy resources and is entirely reliant on energy imports. This makes it a price taker and renders it highly vulnerable to risks of spikes in energy prices and disruptions in global energy supply. Furthermore, Singapore's energy mix is one of the least diversified in Southeast Asia (ESI, 2014).

In 2014, Singapore generated a record high of 95% of its electricity from natural gas (comprising piped natural gas and liquefied natural gas), 0.9% from petroleum products (mainly diesel and fuel oil), and 3.9% from other energy products (EMA, 2014). At the same time, Singapore lacks alternative energy sources – it is unable to harness hydroelectric power due to the lack of a major river system; it is unable to invest in geothermal energy due to the lack of volcanoes; and it is unable to invest in commercial wind turbines due to insignificant wind speeds and lack of land. Its small size, high population density and land scarcity limits its potential for sustainably grown domestic biomass (NCCS, 2013; MEWR, 2014). Existing nuclear energy technology was similarly determined to be unsuitable because of Singapore's high population density and small size (ESI, 2014). Although solar energy has been found to be a potential renewable energy option in Singapore – the city-state has a high average annual solar irradiation of about 1,500 sun hours per year – it faces challenges due to limited available land for the large scale deployment of solar panels, and potential intermittency from the presence of high cloud cover and urban shading (NCCS, 2013). It has been observed that even if solar panels are constructed on every single rooftop in Singapore, the energy generated will meet only 10 to 15% of the country's total energy needs (MEWR, 2014).

Given these vulnerabilities, the Government has made the diversification of energy sources and the improvement of energy efficiency to enhance energy security key strategies in Singapore's energy policy. At the same time, energy is promoted as a driver of economic growth, as seen through the National Energy Policy Report, titled Energy for Growth, which was prepared by an inter-ministerial group led by the Ministry of Trade and Industry (MTI, 2007). Broadly, governance of the energy sector is quite inter-disciplinary, with agencies, research institutions and think tanks being formed to address the linkages between energy and other policy issues in a whole-of-government approach. For instance, the Clean Energy Programme Office deals with the linkages between energy and clean energy as part of environmental sustainability strategies, while the Energy Research Institute takes an interdisciplinary approach to examining energy from the perspectives of security, economics and the environment, and climate change (ESI, 2014).

10. The Challenges ahead

Singapore is situated within Southeast Asia, which is a region that is highly vulnerable to climate change, such as intense rainfalls, dry spells, rising sea levels, rising temperatures and other extreme weather events (Bhullar, 2013). For instance, Singapore's annual mean surface temperature has increased by about 0.8°C since 1948 (NCCS, 2014). Its climate is characterized by relatively high but stable temperatures throughout the year due to its close proximity to the earth, with high humidity and abundant rainfall (Bhullar, 2013). As a low-lying coastal island, it is most vulnerable to rises in sea level. Most of Singapore is only 15 m above sea level; about 30% is less than 5 m above the sea level (NCCS, 2014). A number of essential infrastructure facilities are situated less than 2 m above sea level and on reclaimed land, such as the airport, ports, residential and commercial buildings and roads (Bhullar, 2013). It also has a relatively flat coastline of 180 km; given the land scarcity, the entire population lives within 100 km of the coast (NCCS, 2014). Thus, rises in sea level will increase the risks of flooding and infrastructure damage, amongst others.

Singapore's domestic and international climate change policies are coordinated across government agencies by the National Climate Change Secretariat (NCCS), which was established in 2010 under the Prime Minister's Office. The NSSC oversees an Inter-Ministerial Committee on Climate Change, which enhances the coordination of policies, plans and actions on climate change. Recognizing the dynamic nature of climate change, Singapore has engaged in a number of studies to continually improve its understanding of climate change impacts, review existing adaptation measures, and identify new ones (Bhullar, 2013).

Its domestic policies are outlined in its 2012 National Climate Change Strategy ("2012 NCCS report"), where a whole-of-government strategy is adopted to move towards a low carbon pathway. Its stated approach is four-fold: (1) reducing emissions across sectors, (2) building capabilities to adapt to the impact of climate change, (3) harnessing green growth opportunities, and (4) forging partnerships on climate change action (NCCS, 2012). At the international level, Singapore has expressed its commitment to combating climate change through active participation at the United Nations Framework Convention on Climate Change negotiations. In 2009, it voluntarily pledged to reduce emissions by 16% from the 2020 business-as-usual (BAU) level, and initiated measures to reduce emissions by 7% to 11% from the 2020 BAU level. Singapore has also ratified the Doha Amendment to the Kyoto Protocol.

With climate change, Singapore, as with the larger Southeast Asian region, is likely to see an increased frequency of precipitation extremes, including heavy rainfall and dry periods (Ziegler et al., 2014), a temperature increase of 4.2°C by 2100, and rises in sea levels of up to 0.65m (NCCS, 2007). These present a number of significant challenges. First, an increased frequency and severity of drought may lead to the evaporation of open water bodies, such as reservoirs, leading to reduced freshwater availability necessary for reused water. During the dry spell in January 2014, PUB had to pump more NEWater into the reservoirs in order to maintain water levels (Ee, 2014; Ziegler et al., 2014), which would have increased energy requirements for NEWater production, while local farmers had to resort to tap water to replenish their reservoirs (Cheong, 2014). Even though the occurrence of dry spells/droughts have been rare relative to its regional neighbours, the 2014 dry spell serves as a warning not to take history for granted. Second, and related to the first, higher annual temperatures may lead to heat stress as well as greater use of air-conditioning, increasing Singapore's energy demands (NCCS, 2014). Third, more frequent episodes of higher intensity rainfall during the monsoon season, as well as rises in sea levels, may place stress on existing water infrastructure and drainage systems, leading to flash floods. The most notable series of flash floods took place along the prime commercial belt of Orchard Road between 2010 and 2011, triggered primarily by an overwhelmed canal (MEWR, 2012). Furthermore, given the uncertainties of climate change, coupled with the capacity limits of existing infrastructure, close monitoring of climate trends and drainage systems must be carried out, and outdated infrastructure upgraded, to ensure the present and future needs of the urban system are met. This however is likely to further escalate the energy needs of the urban water system (Nair et al., 2014).

Clearly, a whole series of internal and external challenges lie ahead for the city-state. Given its focus on efficient resource use as a response to resource scarcity (which is also a characterization of its policies in general), it is in Singapore's interest to fully exploit these efficiency advantages. Given its track record of institutional, management and technological competencies, coupled with stellar leadership, the city-state is well placed to be a leader in setting best management and governance standards, not only in the water sector but also in exploring the interrelation among multiple sectors and make the best of them.

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