# Eco-innovation and its contribution to Quality of Life: Singapore

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*Can Singapore be considered a role-model in Eco-Innovation, considering its implemented policies and their effects on quality of life?*

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*“Come, we fellow Singaporeans*
***Let us progress towards happiness together**.”*
Singaporean national anthem.

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# 1. Introduction

## 1.1. Case study

In a time of unrestrained technological shifts, threats caused by climate change and widespread socio-economic crises, there is still a promising solution to help generate economic and social prosperity while safeguarding our planet and the well-being of its citizens: eco-innovation.

Eco-innovation is a dynamic process which can result from the activities of manifold players, ranging from governmental authorities to organizations and even private individuals. This paper examines the correlation between eco-innovation and its active contribution to the quality of life by presenting a practical case-study on the city-state of Singapore. The win-win narrative characterizing eco-innovation represents the underlying theme of the research, which ultimately aims at emphasizing the need for states to prioritize eco-innovative solutions in order to secure the future well-being of their citizens and of the environment.

The case-study at hand focuses primarily on the interventions of the Singaporean government in four specific policy domains, namely: solar energy, water, land use and transport. It will seek to determine whether Singapore can be considered a role-model which other countries should look upon and emulate for its capacity to use public policy as a driver for eco-innovation.

A consistent framework of analysis is applied throughout the sections of the paper: departing from some background information on the topic, the interventions of the Singaporean government in the respective policy area will be outlined, followed by an examination of the intended effects on the quality of life.

Section 2 considers Singapore's engagement to promote solar energy deployment at national level. Section 3 dwells on the importance of green buildings and green spaces in any urban reality. Section 4 explores the effective solutions adopted to deal with water scarcity in Singapore. Section 5 delves into the transportation field, considering the successful measures implemented to promote responsible car usage. Finally, section 6 draws the conclusion of the paper and presents the final findings of the research. Before moving on to the policy domains, a concise explanation of the concept of eco-innovation and the reasons for the choice to study Singapore are provided in the following sub-section.

### 1.2 Singapore and eco-innovation

Eco-innovation can be defined in numerous ways, depending on the types of eco-innovation at stake and the subject-matter under scrutiny (Kemp et al., 2019). An all-encompassing definition, however, was proposed in the 2018 Maastricht Manual: 'an eco-innovation is a new or improved product or practice of a unit that generates lower environmental impacts, compared to the unit's previous products or practices, and that has been made available to potential users or brought into use by the unit' (Kemp et al., 2019). A key factor leading to eco-innovation is thus the "the introduction of any new or significantly improved […] process, organizational change […] that reduces the use of natural resources (including […] energy, water and land) and decreases the release of harmful substances across the whole life-cycle" (Eco-innovation Observatory, 2016). For the purposes of the case-study at hand, said 'unit' is represented by the Singaporean government and the entities operating under its auspices.

The decision to circumscribe the research to Singapore and notably to these policy domains has a twofold explanation. On the one hand, these sectors were selected as being particularly promising in a forward-looking country like Singapore. Ever since its foundation, Singapore has always had the quality of life of its citizens in mind and the will to innovate, as seen from their national anthem. The first “Keep Singapore Clean” campaign was started in 1968 by Prime Minister Lee Kuan Yew and aimed to educate “Singaporeans on the importance of keeping shared public spaces clean”. Up until today, every Singaporean PM has attended the beginning of the yearly campaign now called “Clean and Green Singapore” - demonstrating the government’s will to effectively tackle environmental issues (Soon, 2015).

The positive results on quality of life achieved by the city-state of Singapore in these policy domains suggests that other cities and urban-like centers can successfully adopt Singapore’s approach to eco-innovation and equally secure eco-innovative outcomes in analogous sectors. All countries at national, regional and urban-level should strive for constructing systems founded on eco-innovation, for any alleged difficulty in creating such a system is fully offset by the benefits eco-innovation brings along in terms of well-being for its citizens and their quality of life.

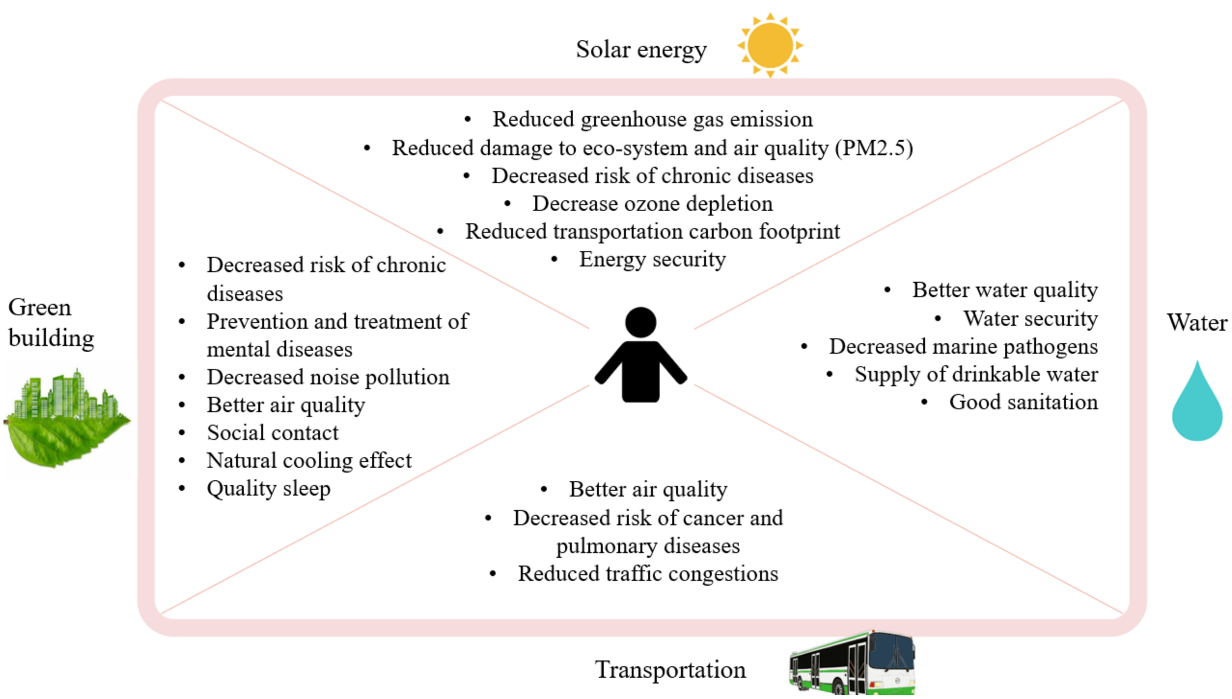

*Figure 1*. Summary of the intended impact of the four eco-innovative sectors on both the quality of life and the environment.

### 1.3 Limitations

This research faces limitations due to the lack of clear evidence of the link between the effect of eco-innovative policies, mental health and well-being. This is due to the presence of other factors impacting the health of citizens and the lack of clarity in quantifying non-physical health benefits.

Furthermore, Singapore being a city-state that has gained its independence relatively recently gives it an advantage in terms of policy-making, as there is more flexibility and different options to be explored. The city-state is, however, somewhat being pushed towards making these eco-innovative policies due to its geographical position - securing its water and energy source remains an important and crucial task of any state. These characteristics differentiate Singapore from other countries and showcase the importance of adapting the eco-innovative policies to the specific state and region concerned.

## 2. Solar Energy

### 2.1 Background

A fundamental principle to follow in order to succeed in a liberalized competitive market is to concentrate one's own resources in the field with most growth potential and with least difficulty in flourishing. Identifying this specific area represents a first crucial step to be taken in pursuit of this objective. Prioritizing and investing in this field accordingly should follow as second step, so as to ensure that such potential is effectively harnessed.

In order to develop a system which strives for sustainability while being economically and practically feasible to implement in the short-term, the Singaporean government has cooperated and consulted with many leading agencies, pooling the expertise of various relevant stakeholders. Singapore has focused its resources specifically on solar energy given its peculiar geographical exposure to the sun, which results in an average annual solar irradiance of 1,580 kWh $m^2$. The fact that other renewables are not as economically or commercially viable as solar energy has further supplemented this decision (Energy Market Authority [EMA], 2018a).

### *2.1.1 Key actors*

The main player within the energy sector is the Energy Market Authority of Singapore (EMA): it oversees Singapore's electricity and gas sectors, ensures a reliable and secure energy supply, and promotes effective competition in the energy market (Energy Market Authority of Singapore Act, 2001). For the purpose of advancing renewables and particularly solar energy, EMA works closely with the Economic Development Board (EDB) and with the Housing and Development Board (HDB). The EDB is a government agency subject to the Ministry of Trade and Industry, whereas the HDB manages housing for more than 80% of the population. These close collaborations aid the industry's development on promising renewable technologies in Singapore, as well as contribute to the adoption of integrated solar photovoltaics (PVs) systems in buildings.

Other leading stakeholders are, *inter alia*, the Solar Energy Research Institute of Singapore (SERIS), the Energy Research Institute @NTU (ERI@N), and REC solar, the main complex manufacturing solar complexes.

## 2.2 Government intervention

### *2.2.1 The promotion of solar as an overarching objective*

Since 2013 Singapore has started a process of comprehensive review of its renewable energy sector. In an effort to increase solar deployment across the country, Singapore promoted the adoption of solar photovoltaic systems by streamlining the commissioning procedures for PV installations, as well as reducing their pricing. PV installations are the most widely accessible and cost-efficient means to generate solar energy, even in private capacity. Compared to conventional generators, however, solar energy is considered an Intermittent Generation Source (IGS), as power output cannot be controlled or varied at will. In fact, it is contingent upon external environmental factors (i.e. weather conditions) and can easily result in shortfalls. This may lead to imbalances between supply and demand which, if not tackled adequately with sufficient back-up reserves, could lead to unpleasant situations, such as blackouts (SERIS, 2019). This is why EMA held a first official consultation to generate ideas on reforming the rules on intermittent generation sources, specifically for solar energy (EMA, 2013). This consultation culminated in a final determination paper providing various improvements to the regulatory framework of the national electricity market (EMA, 2014). Ever since, the Singaporean government has been streamlining existing processes, providing grants and funding for research, developing projects and implementing policies, all with the view to promoting the deployment of solar energy.

### *2.2.2 Projects, initiatives and implemented policies*

In 2014 the EDB and ERI@N introduced the Renewable Energy Integration Demonstrator – Singapore (REIDS) project, Southeast Asia’ first renewable energy integration demonstration microgrid testbed. REIDS provides the largest platform for researchers and industries to develop, test and demonstrate solar integration, as well as other renewables, on the landfill island of Singapore. REIDS collaborates closely with companies and public entities to provide them with insights into new developments of hybrid microgrids, which can be adopted at national level with the aim of integrating solar (REIDS, 2017).

In the same year the EDB also launched SolarNova, a government-led program aimed at increasing solar deployment by aggregating solar demand across government agencies. This is practically achieved by adopting solar leasing business models where private sector companies installing, owning and operating solar systems can sell electricity directly to government agencies through long-term power purchase agreements. Under SolarNova, HDB serves as the central procurement agency which, assisted by SERIS, conducts solar tenders for all other government institutions. The purpose is to increase the capabilities of Singapore-based solar enterprises, such as REC, and to encourage private adoption of solar energy (HDB, 2017).

Much in line with these previous efforts and objectives and within the framework of the 2030 Agenda for sustainable development, Singapore reiterated its pledge to continue its reform in the field of renewables, with the view of better achieving the SDGs. Looking beyond 2020, the country plans to further raise the adoption of solar to 1 gigawatt-peak (United Nations Sustainable Development Goals Knowledge Platform, 2018).

In order to achieve these targets and promote the objectives of SolarNova, the EMA engaged in further consultations, producing additional enhancements to the regulatory framework for IGS in the NEMS (EMA, 2017a).

Most importantly, in 2017 the Enhanced Central Intermediary Scheme (ECIS) was introduced (EMA, 2017b). The latter has at its core facilitations for embedded generation of IGS

– onsite generation of electricity for direct supply to a consumer's load facilities within its premises. Solar consumers at various levels (residential, SMEs, large businesses) have numerous benefits: after following the indicated procedures to install solar PVs, several options are given to decrease expenses and make profit. For instance, selling any excess solar generated electricity in the grid at the Singapore Wholesale Electricity Market is highly encouraged and rewarded by favorable payment schemes. Furthermore, ECIS lowered market participant requirements and allowed larger groups of consumers to undergo more convenient registrations processes. Additionally, the Solar Generation Profile arrangement offers consumers new possibilities to meet electrical metering requirements for small solar PV systems (EMA, 2018d). This *de facto* created a new class of market participants for solar installations below 10 MW for the purpose of self-consumption.

Last but not least, in 2016 the world's largest floating photovoltaic testbed on Tengah reservoir was launched. On top of that the EMA recently launched the Energy Storage System Test-bed under the Energy Storage Programme. Grid-level energy storage allows for development of technologies that will tackle the issue of stability and resilience of IGS for Singapore's power system (EMA, 2018d).

## 2.3 Intended outcomes and effects on well-being (quality of life)

### *2.3.1 Economic benefits*

Singapore's proactivity in developing a system that supports greater solar growth, while reducing regulatory burdens and maintaining principles of fair pricing epitomizes the idea underlying eco-innovation. The latter requires not only technological change but also institutional enablers in multiple sectors: Singapore is proving to be capable of operating on both fronts.

The Singaporean government is aware of the advantages of solar energy regarding electricity generation and acknowledges its intrinsic potential for a wider future deployment at national level. When considering energy production, solar energy is capable of better meeting demands at peak energy usage times, thereby decreasing pool prices. In terms of national economy, Singapore benefits through the deployment of solar energy as it requires no fuel import, limiting dependency on third states and strengthening the country's energy security (EMA, 2018b).

On the one hand, the policies that have been implemented resulted in significant progress towards the goal of sustainable development and a more efficient and responsible use of natural resources. Through cutting-edge technologies, new processes and facilitated services, solar energy deployment is in constant expansion. This is noticeable in the huge increase in number of PV installation (see figures below), resulting in a national gross Solar PVs output generation growing from 0.12% in 2016 to 0.35% in 2019 (EMA, 2019f). This positive trend marks the initial steps of the eco-innovative strategy by means of which Singapore aims to meet its pledge to reduce its emission intensity by 36% from 2005 levels by 2030.

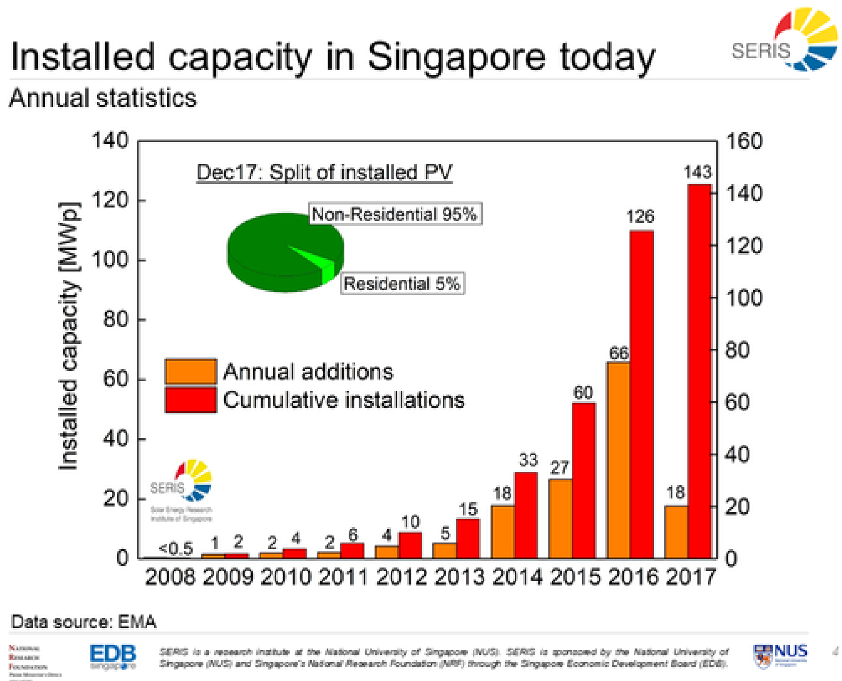


*Figure 2*. Installed capacity in Singapore today. Retrieved from https://www.solar-repository.sg/singapore-pv-market

| 2013 | | | | |
|---|---|---|---|---|
| **URA Planning Region** | **Residential Status** | **Number of Solar PV Installations** | **Installed Capacity (kWac)** | **Percentage Share (of Total Installed Capacity)** |
| **Overall** | Non-Residential | **270** | **10,902.2** | **92.7%** |
| | Residential | **118** | **853.8** | **7.3%** |
| | **Total** | **388** | **11,756.0** | **100.0%** |

| 2018 | | | | |
|---|---|---|---|---|
| **URA Planning Region** | **Residential Status** | **Number of Solar PV Installations** | **Installed Capacity (kWac)** | **Percentage Share (of Total Installed Capacity)** |
| **Overall** | **Non-Residential** | **1,786** | **149,317.2** | **95.4%** |
| | **Residential** | **926** | **7,131.6** | **4.6%** |
| | **Total** | **2,712** | **156,448.8** | **100.0%** |

*Table 1*. Statistics on the number of solar PV installations in Singapore. Retrieved from Energy Market Authority of Singapore website, https://www.ema.gov.sg/statistic.aspx?sta_sid=20140730ufXaHPgXpaY0.

On the other hand, the regulatory and market enhancements introduced (i.e. limiting burdens to enter the energy market for consumers and businesses, minimizing fees, introducing advantageous schemes for Singaporean community at large for PV solar usage) have succeeded in raising awareness on the need to opt for solar solutions and have contributed to making the business solar energy extremely attractive. This is especially so because solar energy is now at grid parity in Singapore, that is, the cost of generating solar energy is competitive with the cost of fossil fuel-derived electricity (Economic Development Board, 2017). Furthermore, the funding and grants allocated by the government to develop experimental micro-grid and storage testbeds such as REIDS created new growth opportunities for research, businesses and industries in Singapore (SERIS, 2018). Investment and demand continue to be catalyzed by Singapore's eco-innovative business approach to solar energy and public as well as private entities are eager to become greener. It is sufficient to think that Singapore became a solar hub for more than 50 top international solar companies across manufacturing, project development and financing (Economic Development Board, 2018). Ultimately, all of this evidence suggests that a country can maintain its economic stability and actually prosper when implementing forward-looking eco-innovative policies.

### *2.3.2 Quality of life*

#### 2.3.2.1 Health status and environmental quality

The positive impact of solar energy usage is not limited to the economic field. Producing electricity through solar energy also means cutting down on carbon emissions. Solar energy generates about one-tenth of carbon dioxide compared to oil-based energy (Parliamentary Office of Science and Technology, 2006), and reduction in carbon emission contributes greatly to environmental sustainability. Solar energy generation also reduces total produced amounts of other greenhouse gases, such as CFC, halons, sulfur oxides and nitrogen oxides.

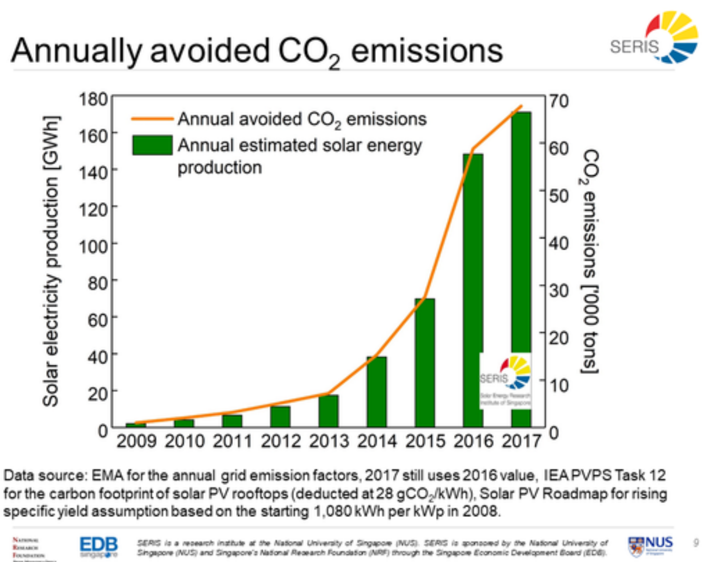


*Figure 3*. Annually avoided CO2 emissions in Singapore. Retrieved from https://www.solar-repository.sg/singapore-pv-market

There are several environmental benefits of using solar energy over conventional energy sources. For instance, with reduced sulfur dioxide and nitrogen oxide production, the acidity of rain would increase, lessening collateral damage to the ecosystem and decreasing air pollution. In addition, through decreased CFC and halogen production, the rate of ozone depletion would decelerate, protecting the earth from damaging ultraviolet radiation (Kalogirou, 2004). Furthermore, with solar energy, the import of fuels is greatly reduced, enhancing Singapore's energy security and lessening transportation carbon footprint (EMA, 2018c).

Lastly, reduced carbon emissions bring about several health benefits. Through improvements in air quality, particularly in the reduction of particulate matter (PM) 2.5., the risk of cardiovascular disease, chronic pulmonary diseases, and obesity related conditions are reduced (Health and Environment Alliance, 2012).

# 3. Green spaces and urban planning

## 3.1 Background

Since Singapore's independence in 1965, the city-state has known various economic booms that have enabled large changes in its infrastructure. Due to its limited land and low natural resource stock, Singapore was forced to develop a landscape of towering architecture. As the metropolis grew, designers kept incorporating nature into its new heights, whether through eco-friendly construction methods and materials themselves, or by physically incorporating greenery in facades like vertical gardens. Singapore's urban development agency places sustainable and livable systems at the core of its strategy (Kolczak, 2017).

## 3.2 Governmental intervention

### *3.2.1 Policies for implementation of green spaces*

Singapore is an advocate of international seminars searching for eco-friendly solutions. The city organized the Singapore Green Building Week of 2018, during which approximately 12,000 policy makers and professionals from over 30 countries gathered for the Build Eco Xpo. The goal of this event was to present solutions to help build urban areas in a way that enhances these buildings' coping abilities with today's climate challenges. These challenges range from congestion, to air pollution, rising temperatures, flooding and insecurity (International Green

Building Conference 2018, n.d.). A simultaneous goal is to incorporate ‘wellness designs’ in buildings so as to reach better environmental quality, both indoors and outdoors, that will promote occupant wellbeing (Phinyawatana, n.d.). The solutions explored during this event are later adapted to a panoply of building projects such as housing buildings, business buildings and even public places like malls or parks.

On top of seeking green solutions for buildings, organizations as well as the government play a key role in strengthening policies encouraging green principles. One of the most notable governmental institutions is the Building and Construction Authority (BCA) that started the Green Mark Scheme in 2005 as an initiative to drive Singapore's construction industry towards more environmentally friendly buildings. This scheme serves as a benchmarking tool to incorporate internationally recognized best practices in environmental design and performance. The Singaporean government launched the Green Mark Awards, along with three other awards, to recognize outstanding eco-friendly constructions. The BCA also provides incentive schemes to meet Green Mark requirements.

Another notable committee is the Inter-Ministerial Committee on Sustainable Development, that set a target for Singapore’s built environment, requiring 80% of the existing buildings in Singapore to meet the Green Mark certification rating by 2030. In terms of energy efficiency, the Committee set a target of 35% reduction from the 2005 level by 2030. Another incentive scheme is the MND Research Fund for the Built Environment. This fund focuses on the strategic areas of sustainable development. It consists of a $36.7 million USD funding initiative by the Ministry of National Development (MND) and managed by BCA. The objective of the fund is to “encourage and support applied R&D that will raise the quality of life and make Singapore a distinctive global city.” Under the MND Research Fund, some key focus areas include sustainable development projects, such as integrating solar technologies into building facades. The fund covers 30% to 75% of the qualifying cost of the project, subject to a cap of $15 million USD (BCA, n.d.).

#### *3.2.2 Green buildings as an eco-friendly solution*

Many policies encourage the construction of buildings to be environmentally friendly. Though standards for green buildings vary, they are generally designed to use less energy and water and improve the indoor environment, including air quality.

The Building Control Act of 2012 was updated to include legislation on the certification of buildings. Building owners were obliged to submit energy consumption data to the BCA in 2013. Additionally, they had to conduct energy audits, and achieve the minimum Green Mark certification when changing their cooling system. The most widely used certification for green buildings is called LEED (Leadership in Energy and Environmental Design) which is the U.S. Green Building Council rating tool. The use of this tool is expanding in Asia (Ives, 2013).

There have been many applications of green building methods throughout various industries. A factor that has made this possible is the Green Building Platinum Guidebook that contains a section on Building Planning and Massing. This guide provides information about green buildings, rooftop gardens, greenery on the sides of buildings, etc., which allows the Singaporean population to use the illustrated techniques in respective projects.

On top of this guidebook, the BCA Green Mark certification is used to measure the eco-friendliness of buildings. This tool supports green buildings movement and even encourages Super Low Energy Buildings and healthier workplaces (BCA, n.d.).

Designers and builders are incentivized to follow these procedures and implement solar panels, rooftop plantings, improved insulation, enhanced ventilation, modulate lightening based on natural light, water conservation, motion detection sensors control light, high-efficiency light fixtures as well as special building materials (International Green Building Conference 2018, n.d.).

### *3.2.3 Vertical gardens and farms*

Singapore is a leader in innovation in the vertical farm sector. Whilst not exactly a garden, Singapore has the world's first commercial vertical farm. Built by Sky Greens Farms, it helps the city-state grow more food locally and reduce dependence on imports. The farm produces 1 Ton of fresh vegetables every other day, which are then sold in local supermarkets such as FairPrice Finest. The vertical garden is made up of 120 aluminum towers that stretch up to nine meters, currently growing only three types of vegetables. Nonetheless, the farm is looking towards an expansion which would enable the inclusion of more varieties. Sky Greens is the world’s first low carbon, hydraulic driven vertical farm, using green urban solutions to achieve production of safe and fresh vegetables, using minimal land, water and energy resources (Sky Greens, n.d.). This is only one example of a vertical farm - there are many other vertical gardens that deliver significant environmental and health-related benefits at a limited cost.

### *3.2.4 Punggol case study*

The most renowned application of eco-friendly principles in land use in Singapore is Punggol. Punggol was selected by the HDB’s Research Institute to become the first eco-town in Singapore and was developed by Singapore’s Public Housing Authority. It is the first example of an ecoprecinct that aims to create a green living environment and increase awareness towards environment sustainability.

Strategically positioned to carry out large-scale experimentation and test-bedding of emerging green technologies and urban solutions, Punggol can be regarded as a sort of "integrated laboratory" for urban solutions in Singapore. The new green technologies applied there concern areas such as energy management, water management, resource and waste management, and maintenance optimization. Today, the Punggol Waterway and its Treelodge are successful and iconic developments that set Punggol apart from regular towns. It is the first sustainable town of the 21$^{st}$ century (HDB, 2019).

## 3.3. Intended outcomes and effects on well-being (quality of life)

### *3.3.1. Economic benefits of green buildings*

Initial costs of green buildings are higher than regular ones because the technology used is more complex and developed, and therefore more costly. Moreover, construction times are typically longer and generate costs. However, they demonstrate lower operating costs since the building is arranged to minimize energy use and maintenance. For example, green buildings certified by LEED demonstrate a high percentage of lower total utility, administrative, security, ground, repair and cleaning costs in comparison to the BOMA average (Arny & McCabe, 2009).

This means that green buildings provide a long-term return on investment and are not less advantageous economically than regular buildings. Green certified buildings who conform to BCA standards show a 20% drop in maintenance cost versus a traditional construction, as well as an occupancy rate 17% higher (Ries, Bilec, Gokhan & Needy, 2007). Moreover, with these eco-friendly buildings, economic value is created by the positive corporate image they transmit. This characteristic also has a positive effect on leasing and the resale value of the buildings. Indeed, it has been demonstrated that green buildings face a 7% increase in asset value compared to regular buildings (World Green Building Council, n.d.).

The use of the materials incentivized by the BCA create a panoply of positive environmental effects like reducing the storm runoff and helping mitigate the urban heat island effect. Energy efficiency is also boosted by reducing the amount of air that escapes. These materials encompass efficient plumbing fixtures, reuse waste water to reduce consumption and are aligned to the sun so as to maximize natural light and tend to reduce volatile organic compound emissions. Moreover, some buildings have smart heating and cooling systems and rainwater utilization systems. Efficiently designed green buildings consume less energy, conserve water, decrease per capita emissions, and generate less waste (International Green Building Conference 2018, n.d.).

### *3.3.2. Quality of life*

#### 3.3.2.1. Health status

Green spaces offer physical health benefits as the availability and quality of green spaces increase opportunities for the population to conduct physical activity, therefore rendering them healthier (Lee & Maheswaran, 2011). It is a well-known fact that exercising is essential in healthy weight loss and to prevent obesity. These sportive activities have also proved to reduce the risk of cardiovascular, cerebrovascular diseases, diabetes, colorectal cancer, osteoporosis and fall-related injuries as demonstrated by the MONICA/KORA Augsburg cohort study (Meisinger et al., 2007).

#### 3.3.2.2. Work-life balance, social connections, subjective well-being

Green buildings and sceneries give rise to better mental health. Indeed, when analyzing the case of green buildings, there is improved noise reduction. Productivity is improved in offices that use such building materials that reduce noise (Timur & Karaca, 2013). Moreover, the ventilation standards of green buildings have shown a positive effect on the productivity of workers and demonstrated that cognitive function doubles with enhanced ventilation. Green buildings are also constructed to allow the most amount of natural light possible. This has proved to help workers who sit near windows and get more light, as they sleep an extra 46 minutes at night – as light helps regulate sleep cycles (American Academy of Sleep Medicine, 2013). Within these green buildings and in the scenery around them, there are also fewer air pollutants, which reduces illnesses caused by air quality issues (National Geographic, 2017).

As mentioned previously, green sceneries allow for more physical activities outside. Increased physical activity has shown to reduce the risks of dementia and depression (Lawlor & Hopker, 2001). It improves mental functioning, mental health and the well-being entailed may have long-lasting psychological benefits (Karp et al., 2006). Indeed, green spaces may also influence social capital by providing a meeting place for people to develop social ties (Maas et al., 2009). This social contact contributes to their health by enhancing personal and communication skills of the people involved (Bedimo-Rung, Mowen & Cohen, 2005) Benefits on longevity have also been reported, as senior citizens who stroll through walkable green spaces have shown a positive longevity increase (Takano, Nakamura & Watanabe, 2002).

#### 3.3.2.3. Environmental quality

Green spaces benefit the environment because they are mostly constituted of trees, grass, allow evapotranspiration and provide shading, cooling down surrounding environments (Pérez, Coma, Martorell, Cabeza, 2014). This reduces reliance on technology such as air conditioning systems or fans, which consume large amounts of energy. It also decreases energy usage and greenhouses gas emissions, which contribute to a healthier environment. These green spaces also reduce the urban heat island effect, diminishing the trapping of greenhouse gases and therefore help prevent the production of more harmful secondary pollutants (Gago et al., 2013). Lastly, the trees in these green spaces also create dry areas and in the case of urban playgrounds, they create safe play-areas where children are less likely to be injured (Hunter et al., 2015).

In general, the introduction of extensive and vertical greenery solutions enables Singapore to achieve both an aesthetically pleasing environment and one that has a lower ambient temperature overall when compared with an estate that has not implemented such green solutions.

Regarding the environmental aspect, vertical gardens have the ability to absorb high quantities of $CO_2$ produced within cities, thus reducing air pollution and at the same time acting as carbon sinks. This makes Singapore more sustainable, by reducing its contribution to global greenhouse gas emissions. Furthermore, the installation of gardens in the facades of buildings has the potential to reduce energy demand by acting as thermo-regulating agents. Plants can easily reflect radiative heat during summer and can further insulate a building, reducing its heat loss during colder periods and therefore resulting in less need for air conditioning and heating for households and businesses (Timur & Karaca, 2013).

Further benefits arise from cities with vertical gardens, such as the increase in the local biodiversity (Timur & Karaca, 2013). Plants could potentially become a suitable ecosystem for multiple insects that feed on them and live within their soil. These gardens also offer the possibility of easily recycling the organic waste produced by the city inhabitants as well as the waste water: thanks to the cleansing properties of plants' roots, in fact, water can be recycled and reused by households (Masi et al., 2016).

# 4. Water

## 4.1 Background

Ever since its independence in 1965, Singapore has been preoccupied with its water supply. The city-state, covering a little over 700km$^2$, receives an average 2095mm of rainfall per year (Department of Statistics, 2018), yet is considered a water-scarce country (World Bank, 2006).

This is because the limited land area to catch and store rainwater for the 5.6 million people living in Singapore, as well as the lack of natural aquifers or groundwater, creates constraints for the densely populated country (Luan, 2010). Therefore, when it comes to water security, Singapore is essentially incentivized to pursue policies with long-term goals (Tortajada, 2006), which manifest themselves through technology R&D, policy research and innovation - all inputs to eco-innovation (Kemp et al., 2019).

As an example outcome indicator, Singapore has already managed to slow down and reduce the growth of its water demand through water conservation measures - so much that despite having a GDP twofold that of Kuala Lumpur's, the Singaporean water demand is still considerably lower (United Nations World Water Assessment Programme, 2014). This can be attributed in large part to the policies put in place by Singapore's government.

Currently, Singapore's water and sanitation policies are in the hands of the Ministry of the Environment and Water Resources (MEWR), with the Public Utilities Board (PUB) in charge of providing drinking water to Singaporeans as well as sanitation and storm water drainage.

PUB essentially manages the entire water cycle of Singapore, consequently facilitating comprehensive and holistic policy setting and implementation (Tortajada, 2006). Singapore's national water agency was recognized as a leader in water technology in 2007 with the Stockholm Industry Water Award due to its holistic approach (Stockholm International Water Institute, 2007).

Another statutory board under MEWR is the NEA, which monitors PUB's compliance with environmental and drinking water quality standards in accordance with the Environmental and Protection Management Act (Chapter 94A) and the Environmental Public Health Act (Chapter 95).

## 4.2 Government intervention

### *4.2.1. NEWater-related policies*

One of the most notable policies carried out by PUB is the diversification and expansion of Singapore's water sources, best illustrated by the "4 National Taps of Singapore" program. The 4 taps are (i) local water catchments, (ii) water imports from Malaysia, (iii) NEWater and (iv) desalinated water (PUB, 2018a). The first two taps have little to no eco-innovative aspects to them, so this section will concentrate on NEWater mainly, along with desalinated water.

Very early on, Singapore started looking into the possibility of reusing wastewater for indirect consumption (Goh, 2003). The first pilot water reclamation plant in 1974 was decommissioned after less than a year, as the technology was not developed enough to allow this option to be cost-effective. The Singaporean government was forced to wait until 1998 and 2000 respectively to set up a team to test the latest technology and commission a NEWater plant proving the economic viability of treating wastewater on a large scale (Yong Soon, Tung Jean &

Tan, 2008; PUB, 2018b). This came after the drafting and implementation of the Green Plan for Environmental Protection and Improvement in 1992, which also marked the beginning of the use of public consultations as an engagement tool in environmental issues (Ministry of the Environment, 1993; Tortajada & Joshi, 2014).

NEWater was launched to the Singaporean public in 2003, when the first two water recycling plants in Bedok and Kranji were completed. Overall, out of the five NEWater plants Singapore currently operates, only the first three were taken on entirely by PUB – after construction, companies in the private sector such as General Electric, Veolia and Siemens worked in collaboration with PUB to introduce innovative technologies. This approach, which falls in line with the government's 3P approach (involving People, Public, Private), helped build the private sector's trust and enthusiasm in wastewater reclamation. This meant that when the Singaporean government wanted to build a 4$^{th}$ NEWater plant in 2007, Keppel Seghers was willing to take on the commission and built the plant. The same pattern followed and in 2008 the fifth wastewater recycling plant was also commissioned and built by the private sector (Yong Soon et al., 2008).

### *4.2.1 R&D-related policies*

In 2006, environmental and water technologies were identified by the National Research Foundation (NRF) as an area of research to be supported and invested in, in order to create new industries and drive growth. The Environment and Water Industry Programme Office, an inter-agency body under PUB direction, was established to support a Strategic Research Programme on Clean Water through project funding (NRF, 2018).

As best exemplified with the restructuring of the Ministry of Environment and PUB in 2001, institutional capacity (to make eco-innovative policies) is a process that Singapore has also used to its advantage. Central coordination of the water cycle in Singapore was all brought under one umbrella once acknowledged that water catchments and supply system, drainage systems, water reclamation plants and sewerage systems were parts of a comprehensive water cycle. Thus, the national water agency PUB was born (Tortajada et al., 2014). This process of grouping the water cycle under one authority streamlines policy-making, while also allowing inter-ministry and private sector coordination and public consultations to be taken into account and valued – enabling Singapore to implement R&D innovations with relative ease.

Several funding schemes are available and allow PUB to collaborate with local and international companies to share the costs of R&D – which may lead to impactful and substantial innovations in the water sector (Bee Luan, 2010). Many companies and research institutes have already been attracted by Singapore's approach to the water sector (Ibrahim, 2009). The creation of collaboration opportunities and knowledge networks in Singapore is conducive to eco-innovation, and the Singaporean government appears to have understood and maximized the concept. One institute was created in Singapore itself in June 2008, under the Lee Kuan Yew School of Public Policy, part of the National University of Singapore. The Institute of Water Policy (IWP) undertakes research on water policy and management issues, as well as participating in consultancy projects with governments and institutions (e.g. World Bank).

Since 2006, USD 300 million have been invested in water technology R&D alone and this number has kept on growing - an additional USD 150 million over the next 5 years was pledged by the Prime Minister in 2016. In the same announcement, the critical issue of water supply was highlighted as strategic and high-priority. Financial support serves as an enabling factor and a policy instrument for eco-innovation (Kemp et al., 2019).

## 4.3 Intended outcomes and effects on well-being (quality of life)

### *4.3.1. Economic benefits*

PUB's innovative policy in its willingness to take on the burden of the demand and technology risks of building the first three plants paid off majorly, meanwhile also allowing them to have a good supervision and overview of all of the NEWater plants and collaborate with the private sector. This eco-innovative approach has given both public and private sectors the opportunities to work together, per contra to the approach of most other Asian national water agencies or their equivalent. PUB has made use of the public sector in situations where expertise, competence or competitive advantage were not certainly in their favor, as seen with the wastewater reclamation project. The outsourcing of specific activities to private sector companies is another aspect of this policy that contributes to rendering PUB's policies eco-innovative (Tortajada, 2006). Singapore has also put in place incentives for industry and private companies to recycle water themselves, in the form of liberal tax rebates for factories that install water-saving plants under the Economic Expansion Incentives Act (Goh, 2003).

Singapore's determination to achieve the lowest cost alternative is driven by the competing demands in the face of limited resources. PUB's environmentally friendly approach to policy making has necessarily taken economic considerations into account. The long-term cost effectiveness, timing and prices have all played a role in the setting out of the eco-innovative policies now in place in Singapore. When considering specifically the NEWater tap, Singapore's timing (waiting after the first 1974 trial) was also very beneficial and led to the present strong eco-innovative R&D work and partnership in the public and private sectors (Yong Soon et al., 2008).

Desalination plants were also not considered viable at first due to their cost but following pressure and the stress of water scarcity, PUB was given permission to source desalinated water from private companies developing desalination plants under the single wholesale buyer market structure in 2000 (Goh, 2003). The first desalinated water plant to integrate the water cycle in Singapore was in 2005.

Overall, the targets set by the Singaporean government for 2060 rely heavily on NEWater and desalination plants – 55% of the water demand is expected to be met by the NEWater factories (the goal is 50%) and another 30% is meant to be met by the two desalination plants. These high target numbers are partially due to the termination of the contract of water supply from Malaysia in 2061.

Furthermore, keeping in mind Singapore's tendency to develop environmental policies in line with economic considerations, the higher reliance on NEWater as opposed to desalinated water is understandable. NEWater is a more energy- and cost-efficient source of water because of the lower salt content of the wastewater, compared to seawater. "While desalination offers great potential to increase supply capacity in the long run, NEWater offers a more cost-effective solution to meet long-term water demand by lowering the quantity of desalinated water required to meet demand" (Lee & Tan, 2016).

### *4.3.2. Quality of life*

#### 4.3.2.1. Environmental quality

The development of systems which allow natural filtration of rain before joining the water-way system brought benefits to both the environment and human health in various ways. This system reduced the amount of pollutants, including microplastic and dioxin (Burkhardt-Holm, 2011), flow into the main water stream. This eventually decreases the accumulation and subsequent transfer of marine pathogens in the food chain and ultimately to human. These pollutants are dangerous as some of them are considered endocrine disruptors, which interferes with the normal hormone function which regulates various body systems (Royte, 2018). Accumulation of these pollutants may result in birth defect, cancer and developmental disorders (Safea, 2004). Reduction of the pollutants in the water source is beneficial to both the ecosystem and the human health.

In addition, due to extensive consumable supply-demand management, 100% of Singapore's population has access to drinking water and sanitation (Tortajada, 2006b). This suggests that the sense of water security of the Singaporeans is high, coinciding with the one of the criteria for OECD well-being framework (Durand, 2015).

## 5. Transportation System

### 5.1. Background

"The greenest car is one that does not exist" is the first sentence that can be read from the Singaporean Land Transport Authority (LTA) website under the "promoting clean and energy efficient vehicles" section (LTA, 2017). This statement captures fairly well the stance of the Singaporean government on land transport regulation. The country has developed a complex tax system with intertwined additional surcharges and rebates in order to discourage polluting car usage. As a consequence, the Singaporean market for cars is the most highly priced worldwide and has turned Singapore into the world’s priciest city since 2013 (Batarags, 2019). This is a direct consequence of the policies implemented by the Singaporean government.

## 5.2 Government intervention

### *5.2.1. Transportation tax in Singapore*

There are five factors determining the price of a car: its Open Market Value (OMV), an Additional Registration Fee (ARF), Excise Duty and Goods and Services Tax (GST), a mandatory Certificate of Entitlement (COE), and the local dealers’ margin. The OMV of a car refers to the car’s value under the competitive forces of demand and supply. On top of that value an ARF with a progressive rate (see Table 1) is applied, which increases the car’s value by more than double its OMV in most cases. Next comes the Excise Duty which amounts to 20% of the car’s OMV and the GST which levy another 7% on both the OMV and the Excise Duty amount. Finally, local dealers also add their profit margin.

Anyone who wishes to register a new vehicle in Singapore must obtain a COE which grants car ownership and road usage for 10 years (LTA, 2018). The use of mandatory certificates is a market-driven mechanism to increase prices in cases of high demand. COE prices nowadays range approximately between 19,000 and 28,000 USD (Automobile Association of Singapore, n.d.)

| Vehicle OMV | | ARF Payable (%) |
|---|---|---|
| SGD | USD | |
| First 20,000 | First 15,000 | **100%** |

| | | |
|---|---|---|
| Next 30,000 | Next 22,000 | **140%** |
| Above 50,000 | Above 37,000 | **180%** |

*Table 2*. Applicable ARF for a car in Singapore. Adapted from https://www.lta.gov.sg/content/ltaweb/en/roads-and-motoring/owning-a-vehicle/costs-of-owning-a-vehicle/tax-structure-for-cars.html

This complex tax system has been established in order to make the use of motor vehicles as unattractive as possible.

On the other hand, the LTA also promotes green vehicles with low emissions through a series of rebates. Since the beginning of 2018, LTA has established a new rebate scheme for car models with low carbon dioxide, hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter emissions on their Additional Registration Fee of up to 15,000 USD (LTA, 2017a). This new policy, the Vehicle Emissions Scheme (VES), has been implemented as an improved version of the Carbon Emissions-Based Vehicle Scheme (CEVS) that had been introduced in January 2013 (LTA, 2015). The CEVS was created to reduce the ARF payable for car models with low $CO_2$ emissions. Buyers could get up to 22,000 rebate or surcharge depending on their emission level. However, one crucial missing feature is that it did not take into account other pollutants. Therefore, the VES was implemented to remedy those limitations. Under this scheme, diesel cars have seen their prices rise tremendously. They also face an additional tax called the Special Tax (LTA, 2018).

This environmental tax system is characterized by its numerous positive effects and has positioned Singapore as one of the most eco-innovative states worldwide. As early as 2001, when most of the existing policies were not in place yet, Chia and Phang (2001) already recognized the positive effects of the Singaporean government's stance on environmental policy, mainly regarding double dividend and internalization of pollution externalities.

### *5.2.2. Fuel Economy Labeling Scheme*

In 2003, Singapore was the world leader in launching a voluntary Fuel Economy Labeling Scheme (International Renewable Energy Agency, 2018). This scheme aims to raise consumer awareness of vehicles energy fuel economy by placing FELS labels on vehicles displayed for sales (LTA, 2017a). It has been made more stringent since then. This policy underlines the intention of the Singaporean government to place consumers at the center of their environmental policy. They introduce consumer-driven incentives to render their city-state greener (IRENA, 2018).

### *5.2.3 Electronic Road Pricing system*

Despite all the regulations to make motor vehicles more expensive and the growing population density, owning a car is still regarded as a status symbol in Singapore. The city-state became a pioneer in managing road congestion with the introduction of the Area Licensing Scheme (ALS) in 1975. However, over the years, it became obvious that this system was too labor-intensive and impractical. As a consequence, the Singaporean government created the Electronic Road Pricing (ERP) system in 1998 (Development Asia, 2016).

According to the LTA (2019), the ERP system aims at reducing health externalities created by car usage, pollution and loss of productivity. The system charges motorists according to a pay-as-you-use system. Motorists are charged different prices depending on their vehicle type, average speed, whether they are driving during peak hours or in highly congested parts of the city. Singapore took about nine years to implement the ERP because it had to develop a complex pricing scheme that allowed for great flexibility in imposing road usage fees depending on actual traffic conditions. The current ERP system is able to directly diverge traffic from largely congested areas to more fluid ones (Development Asia, 2016).

### *5.2.4. Autonomous vehicles*

Another salient feature in Singapore's green future plan is the development and usage of autonomous vehicles (AVs). AVs have the potential to revolutionize the public and private transport systems (Lago & Trueman, 2019). In the 2019 KPMG Autonomous Vehicles Readiness Index, Singapore ranks second globally after the Netherlands, and first in Asia; it also occupies the first place regarding two out of four indicators: 'policy and regulation' and 'consumer acceptance'. The government is actively working to maintain its position as a leading center for development of AVs. In November 2017, it created the Centre of Excellence for Testing and Research of Autonomous Vehicles at Nanyang Technological University (CETRAN). This center includes an entire test-city to allow for the gathering of realistic data. The government has also announced the introduction of autonomous busses in some of its districts by 2022 (KPMG, 2019). Autonomous vehicles can lead to higher social inclusion by allowing elderly and disabled persons to access means of transports they otherwise would not have accessed or directly decrease environmental costs of car usage by managing congestion and air pollution (Lago & Trueman, 2019).

Using both disincentives for car ownership and car usage, Singapore has been able to keep a relatively low traffic congestion despite continuous growth in car population. Furthermore, the city-state has also developed a large network of public transport, which has become increasingly attractive over the years thanks to its development and due to the increased costs for cars (Development Asia, 2016). The latest household survey conducted in 2012 revealed that the share of travelers using public transport during peak hours increased from 59% in 2008 to 63% in 2012 (LTA, 2013). The MRT and LRT trains drive around three million passengers a day (LTA, 2017b).

## 5.3. Intended outcomes and effects on wellbeing (quality of life)

### *5.3.1. Health status and environmental quality*

There are various ways to measure the success of Singapore's transportation system - one of which is by looking at the changes in the overall amount of greenhouse gasses emitted by vehicles and the resulting alteration in the quality of air and hence its impact on human health.

The air quality of Singapore is measured in accordance to the 6 criteria of pollutants - namely PM10, sulfur dioxide, ozone, carbon monoxide, nitrogen dioxide and lead. The Pollutant Standard Index (PSI) is used to monitor the levels of these substances in the air. Singapore satisfies all the air quality standards set locally, as well as the criteria set by EPA and WHO - except for criterion PM2.5. PM2.5 substances include those emitted during the combustion of liquid fuels in vehicles (Velasco, 2012). The substances are small enough to diffuse into the bloodstream during the gaseous exchange in the alveoli, resulting in the accumulation of these toxic substances in various organs. They are known especially for increasing the risk of carcinogenic and pulmonary diseases (Riva et al., 2011).

However, the substances emitted by vehicles are not the only cause of toxic substances in the air. Despite the introduction of energy efficient vehicles and various measures to reduce emissions by cars, ischemic heart disease and lower respiratory infection still remain as the top causes of death in Singapore. The main reason for both causes is the accumulation of ultrafine particles in the lungs and cardiac blood vessels.

In addition, Singapore suffers from annual haze, which was linked with a 12% increase in the risk of upper respiratory tract illnesses, 19% increased risk of asthma and 26% increased risk of rhinitis (Institute for Health Metrics and Evaluation, 2017). Moreover, there are many other factors that affect the amount of pollutant in the air. The concentration of pollutants may differ according to the activity and the population density of the region. Thus, it is difficult to measure with exactitude the direct influence of the introduction of eco-innovative measurements and energy-efficient vehicles on the quality of air in Singapore (Velasco, 2012).

## 6. Conclusion

Through an analysis in the sectors of solar energy, urban planning, water security and transport system, this paper has highlighted the outstanding well-being improvements and quality of life impacts of Singapore's implemented eco-innovative policies. The positive results could not have been achieved without the active role taken by the Singaporean government. Not only has the government identified key sectors displaying high growth potential but it has also developed an extensive network of partners to support its efforts. The synergy among all relevant stakeholders, which include private and public sectors, has been a core enabler for Singapore to reach such high standards of quality of life through eco-innovation. Across all sectors analyzed, the role of the government has been notable and significant – turning limitations created by geography and environment, into strengths.

The multiple regulatory and market enhancements and the policy choices taken by the Singaporean government to harness the potential of the only economically-viable renewable energy option at the country's disposal, that is, solar energy, represent the paradigm of eco-innovation. The ongoing development in the field of solar shows how simple changes within the regulatory framework of a country, combined with efforts in correlated policy-areas (i.e. infrastructure), can make a difference in terms of sustainable growth and can be conducive to tangible economic, environmental and health benefits.

With regards to urban planning, the government closely collaborates with environmental organizations to ensure local adherence to eco-innovative practices. They do so by organizing events to discover eco-innovative solutions for construction and buildings. Policies implemented are aimed at improving efficiency such as increasing the amount of water, energy, light and waste that can be saved during building construction and maintenance. Green constructions thus reduce energy consumption and gas emissions, which ultimately improves air quality and lowers disease rates. This demonstrates eco-innovation's role in nourishing the community's well-being.

Comprehensive long-term planning is one of the eco-innovative characteristics of Singapore's policies which was highlighted in the water section. This encompasses, in all surveyed policy areas, the willingness of the government to invest financially, be it in R&D, in carrying the burden of risk at the beginning or through other means of funding or incentives. The institutional capacity of Singapore to shape itself in a streamlined and efficient manner also plays a large role in the drafting and successful implementation of eco-innovative policies.

Lastly, Singapore has been able to keep a relatively low traffic congestion, despite continuous growth in car population, by using both administrative and financial disincentives for car ownership and car usage. Meanwhile, the government is also investing in R&D for greener cars and has become a hot spot for autonomous vehicle testing – eco-innovative policies, for eco-innovative solutions.

In conclusion, the implemented policies and their intended impact on well-being and quality of life have proven to be significant indicators of eco-innovation in this case. The outcome indicators covering the intended economic, environmental and social impacts are the explicitly mentioned effects in each section of the paper and displayed in tables 3.1 and 3.2. These outcomes have both internal and external effects, for example guaranteeing clean water to an individual household, while at the same time ensuring water security for the entire Singaporean society. Some output indicators that substantiate the claim that Singapore is a role-model are the development and adoption of a complex vehicle tax system or the development and adoption of the NEWater and desalination plants.

Singapore can also be considered a role-model in eco-innovation by their implemented policies and effects, as it is clear that not only the government's approach to policy making and the policy characteristics themselves are eco-innovative, but the outcome results lead to innovative solutions that have an appreciable impact on the health and well-being of the citizens. Singapore has indeed already been recognized as high-standing in areas it has adopted an eco-innovative approach to: it has been advising and helping Australian states in managing its own water cycle since 2007, and Singapore also works with Malaysia to reduce the number of non-environmentally friendly cars (Yong Soon et al, 2008). Singapore is therefore a promising example for countries seeking to adjust their policies in order to transition to a more eco-innovative approach to governance.

| **OECD Selected criteria** | **Health status** | **Work-life balance** | **Social connections** | **Environmental quality** |
|---|---|---|---|---|
| Solar energy | ✔ | | | ✔ |

| | | | | |
|---|---|---|---|---|
| Green buildings | ✔ | ✔ | ✔ | ✔ |
| Water | ✔ | | | ✔ |
| Transportation system | ✔ | | ✔ | ✔ |

*Table 3.1.* Analysis of the impact of the four eco-innovative sectors on the quality of life of the residences in Singapore, in accordance to the OECD Quality of Life well-being index.

| **OECD Selected criteria** | **Personal security on resources** | **Subjective well-being** | **Economic benefits** |
|---|---|---|---|
| Solar energy | ✔ | ✔ | ✔ |
| Green buildings | | ✔ | ✔ |
| Water | ✔ | ✔ | ✔ |
| Transportation system | | ✔ | |

*Table 3.2.* Analysis of the impact of the four eco-innovative sectors on the quality of life of the residences in Singapore, in accordance to the OECD Quality of Life well-being index.

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8. List of Figures and Tables

**Figures**



**Tables**