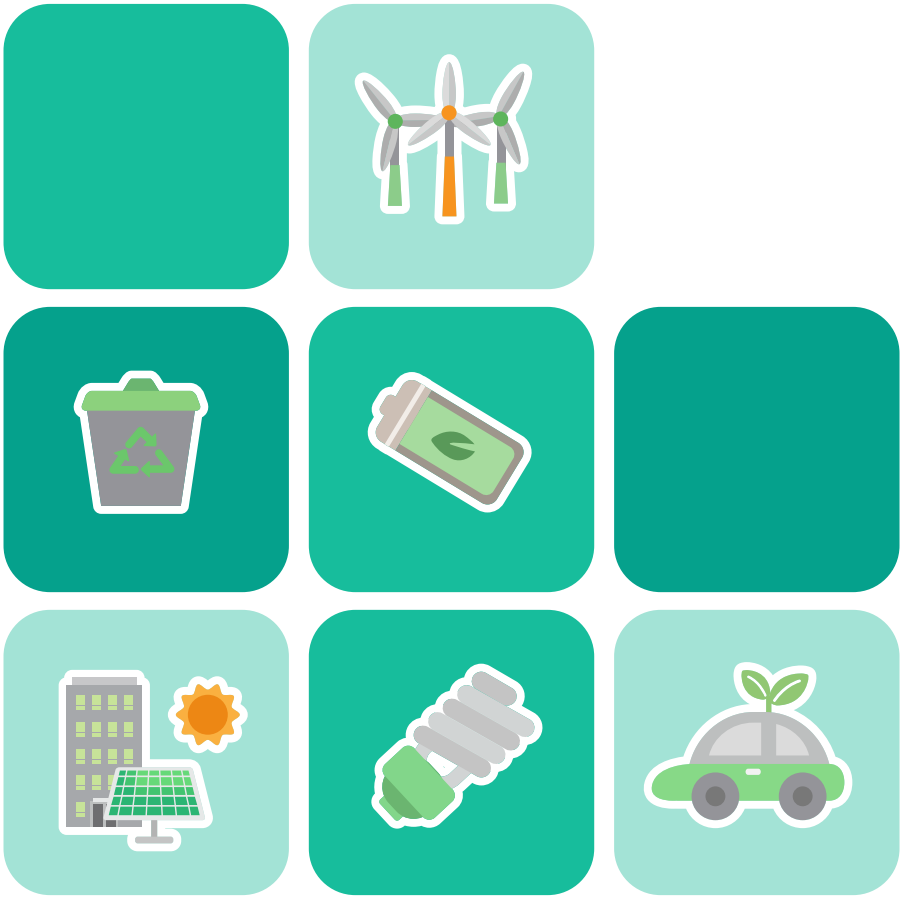
Leveraging Science, Technology and Innovation for Low Carbon and Resilient Cities



ESCAP 75 MOVING FORWARD TOGETHER

ICLEI Local Governments for Sustainability EAST ASIA

绿色创新发展中心
Innovative Green Development Program

Leveraging Science, Technology and Innovation for Low Carbon and Resilient Cities

ESCAP 75 MOVING FORWARD TOGETHER

ICLEI Local Governments for Sustainability EAST ASIA

绿色创新发展中心 Innovative Green Development Program

*The shaded areas of the map indicate ESCAP members and associate members.**

The Ecomomic and Social Commission for Asia and the Pacific (ESCAP) is the most inclusive intergovernmental platform in the Asia-Pacific region. The Commission promotes cooperation among its 53 member States and 9 associate members in pursuit of solutions to sustainable development challenges. ESCAP is one of the five regional commissions of the United Nations.

The ESCAP secretariat supports inclusive, resilient and sustainable development in the region by generating action-orriented knowledge, and by providing technical assistance and capacity-building services in support of national development objectives, regional agreements and the implementation of the 2030 Agenda for Sustainable Development.

*The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

United Nations publication

ST/ESCAP/2997

Please cite this publication as: United Nations, Economic and Social Commission for Asia and the Pacific (ESCAP) (2022). *Leveraging Science, Technology and Innovation for Low Carbon and Resilient Cities*.

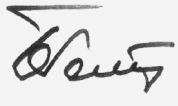
For further information on this publication, please contact:
East and North-East Asia Office
Economic and Social Commission for Asia and the Pacific
7th floor, G-Tower
175 Art center-daero, Songdo-dong,
Yeonsu-gu, Incheon 22004, Republic of Korea
escap-sroenea-registry@un.org

FOREWORD

The world's urbansation rate is rapidly increasing from 55% in 2018 to an estimated 65% by 2050. The East-Asia region is well ahead of this trend with the lowest urbanization rate of countries in this region already above 60% as at 2020 based on available World Bank data. The region also contains some of the most densely populated cities of the Asia-Pacific region, amplifying the importance of cities and built-up urban environments in the control of emissions. However of equal importance as we have seen through the COVID-19 crisis is the increasing need for urban resilience, not only against natural disasters but also a resilient social, economic and cultural fabric that makes cities liveable for its residents not only in the present but also the years to come.

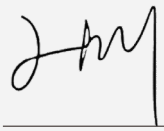
In this report, we aim to promote the integrated development of cities around the region, to not only deploy low carbon infrastructure in new build developments but to also retrofit existing buildings and infrastructure where possible. In addition to developing smarter urban planning, transport and awareness raising of climate actions through the adoption of modern information technology, we will also look at how cities are integrating micro-power sources such as rooftop solar and reducing their energy and water consumption through energy efficiency and water reuse projects, while delivering comfortable living in cities and reducing waste.

We hope that these case studies, will serve as an example and inform cities and towns of the paths and options they can take, as they seek to develop and renew their urban environments in light of the many challenges towards accomplishing the 17 SDG Goals. It also seeks to inspire planners to develop urban environments that are not solely designed for utilitarian economic purposes but to also reflect the rich natural environments and cultural history that each city represents.



Ganbold Baasanjav
Head of Office
UNESCAP – East and North East Asia Office

Shu Zhu
Regional Director and China Representative
ICLEI-Local Governments for Sustainability East Asia Secretariat



Min Hu
Principal & Co-Founder
innovative Green Development Program (iGDP)

ACKNOWLEDGEMENTS

This compendium report was prepared as part of the project "Leveraging Science, Technology and Innovation for Low Carbon and Resilient Cities" by the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) East and North-East Asia (ENEA) Office in collaboration with the International Council for Local Environmental Initiatives (ICLEI) - Local Governments for Sustainability of East Asia Office and the innovative Green Development Program (iGDP).

Under the overall direction and guidance of Ganbold Baasanjav, Head of the ESCAP ENEA Office and the supervision of Sangmin Nam, Deputy Head of the Office, Peter, Chin Tse Nam led drafting of the report and coordinated inputs from:

- ESCAP East and North-East Asia Office:
  Qian Cheng
  Yiran He
  Wai Kit Si Tou
  Minkyung Hong
  Alasdair Donald Cameron

- ICLEI East Asia Secretariat (ICLEI Beijing Office):
  Beatrice Sin Yi Chng
  Jinny Liu
  Yeajee Kim
  Kelly Dai
  Yujin Lee
  Merlin Lao

- innovative Green Development Program (iGDP):
  Jialing Hong
  Min Hu
  Diego Montero
  Yanhui Wang

Queries on the report may be directed to UNESCAP's registry at mail to: escap-sroenea-registry@un.org. Specific case study enquiries will be directed to the relevant partner for review and replies.

ABBREVIATIONS

AI	Artificial Intelligence
BCA	Building and Construction Authority
BIS	Bus Information System
BIT	Bus Information Terminal
BMS	Bus Management System
BOO	Build, Own and Operate
BRP	Building Retrofit Project
CCTV	Closed Circuit Television
CERC	Clean Energy Joint Research Center
CMA	Conference of the Parties serving as the meeting of the Parties to the Paris Agreement
CNY	Chinese Yuan
CO_2	Carbon Dioxide
COP	Conference of the Parties
CSCP	Civil Service Computerisation Programme
DGB	Digital Government Blueprint
ECMP	Energy Consumption Monitoring Platform
ESCAP	Economic and Social Commission for Asia and the Pacific
ESS	Energy Storage System
ETDZ	Economic and Technology Demonstration Zone
ETS	Emissions Trading System
EUETS	European Union Emissions Trading System
EVs	Electric Vehicles
FCEV	Fuel Cell Electric Vehicle (Hydrogen)
FEZ	Free Economic Zone
FIRR	Financial Internal Rate of Return
FTMS	Freeway Traffic Management System
GHG	Greenhouse Gas Emissions
GEF	Global Environment Fund
GFA	Gross Floor Area

GIS	Geographic Information Systems / Geospatial Integrated Systems
GLEES	Grid-level Large-scale Electrical Energy Storage
GPS	Global Positioning System
GTZ	Green Transport Zone
GW	Gigawatt
IAQ	Indoor Air Quality
ICT	Information and Communications Technology
ILUS	Integrated Land Use System
IOC	International Olympic Committee
IoT	Internet of Things
IMF	International Monetary Fund
iPLAN	Integrated Planning and Land Use System
Km^2	Square Kilometres
KRW	Korean Won
kW	Kilowatt
kWh	Kilowatt Hour
kWh/m^2	Kilowatt Hour per Metre Square
ITS	Intelligen Transport System
LID	Low Impact Development
LCD	Liquid Crystal Display
LCS	Lane Control System
LDH	Land Data Hub
LED	Light Emitting Diode
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
LTA	Land Transport Agency
M - Metres	
M^3	Cubic Metre
MCF	Mangrove Wetland Conservation Foundation
MoLIT	Ministry of Land, Infrastructure and Transportation
MoHURD	Ministry of Housing and Urban-Rural Development
MOH	Ministry of Health
MND	Ministry of National Development
MW	Megawatt
NDC	Nationally Determined Contributions
NFTs	Non-Fungible Tokens

NEASPEC	North-East Asian Subregional Programme for Environmental Cooperation
NRF	National Research Foudnation
NRW	North-Rhine Westphalia
NSDI	National Spatial Data Infrastructure
P2G	Power to Gas
PPP	Public-Private Partnership
QR	Quick Response
QUEST	Quantitative Urban Environment Simulation Tool
R&D	Research and Development
RFID	Radio Frequency Identification
SCP	Sponge City Programme
SMEs	Small and Medium Enterprises
SFC	Seoul Facilities Cooperation
SG-SPACE	Singapore GeoSpatial Collaborative Environment
SMG	Seoul Metropolitan Government
SNU	Seoul National university
STI	Science, Technology and Innovation
SUDS	Sustainable Urban Drainage System
SUETS	Social Urban Emissions Trading System
TCE	Tonnes of Coal Equivalent
TOD	Transit-Oriented Development
TOE	Tonnes of Oil Equivalent
TOPIS	Seoul Transport Operation and Information Service
TPES	Total Primary Energy Supply
UNFCCC	United Nations Framework Convention on Climate Change
UHI	Urban Heat Island
URA	Urban Redevelopment Agency
URLCPMC	Urban Renewal and Low Carbon Project Management Centre
UMG	Ulsan Metropolitan Government
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UPS	Uninterrupted Power Supply
USD	United States Dollar
VMS	Variable Message Signs
VOCs	Volatile Organic Compounds
WSUD	Water Sensitive Urban Design
ZEB	Zero Energy Building

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter I

Introduction

Leveraging Science, Technology and Innovation for Low Carbon and Resilient Cities

Chapter I. Introduction

"We cannot address climate change without technology."

United Nations Framework Convention on Climate Change

Developing low carbon and resilient cities serves as an important pathway for realizing national and local mitigation targets while assuring long-term economic growth and improving the quality of life.[1] Since the adoption of the Paris Agreement in 2015, there has been growing commitments to the transition to a low carbon economy, with more than 130 countries committed to achieving net-zero carbon emissions as of early 2022. In North-East Asia, Japan and the Republic of Korea have pledged to become carbon neutral by 2050, whereas China has committed to building an 'ecological civilization' with carbon emissions peaking before 2030 and achieving carbon neutrality before 2060. The Russian Federation also aims to achieve carbon neutrality by 2060 starting with transforming the fossil-fuel-rich Sakhalin Island into carbon neutral by 2025. Mongolia has also enhanced the target of its Nationally Determined Contribution (NDC) to achieve a 22.7% reduction in greenhouse gas (GHG) emissions from its business-as-usual scenario by 2030 through domestic efforts and to increase its reduction target to 27.2% with international support.[2]

These commitments are critical to address the threat of climate change and promote sustainable development. As the North-East Asian subregion accounts for more than one-third of the global GHG emissions[3], its efforts on GHG reduction play an important role in mitigating climate change. Moreover, the COVID-19 pandemic has provided a wake-up call to restore a sustainable relationship between human and nature. While returning to the status quo will only lead to another devastating blow from the next crisis, transformative changes that build back better and reorient traditional development pathways are needed. In this regard, **low carbon and resilient cities are a key element that must be incorporated into green recovery packages to build back better.** Cities account for 70% of global carbon dioxide (CO_2) emissions from energy use and are also the major ground of climate vulnerability with the heavy concentration of population and infrastructure. While being major

1 By 2050, approximately two-thirds of the global population will live in urban areas. Resilient and sustainable urban planning is needed to create compact, connected, and efficient cities to contend with rapid urbanization and a low carbon economy.

2 UNFCCC. NDC Registry. Mongolia National NDC. *Available Online*.

3 UNESCAP. 2020. Regional Power Grid Connectivity for Sustainable Development in North-East Asia. *Available Online*.

GHG emitters, cities are also a major driver of developing and deploying innovative solutions and a catalyst for disseminating proven solutions and practices within and beyond the country.

To achieve carbon neutrality and build resilient cities, business as usual will not work and innovative solutions are required to bring necessary changes in an efficient, cost-effective, and timely manner. Science, technology and innovation (STI) serve as a key means for transformative changes in the way of production and consumption required for accelerating GHG emission reduction towards carbon neutrality.

The objective of this report is to analyze the experiences of cities in and beyond North-East Asia in designing low carbon and resilient urban plans through STI in selected sectors, thereby supporting countries to utilize STI for the development of inclusive, sustainable, and resilient societies. Building on ESCAP's ongoing work on low carbon city development and STI policies, this report will offer technology solutions and innovative practices for collaborative action with the support of regional institutes, and city-based initiatives and programmes. **A strong emphasis is put on capacity building at the level of institutions and systems, and thus a thorough analysis of how STI works, the key constraints and supports, and lessons learned will be conducted for each case study in Chapter II.**

A. International Efforts to Tackle Climate Change with the Help of STI

The importance of STI in building low carbon and resilient cities has been stressed in various intergovernmental processes and international agreements. From the adaption of the United Nations Framework Convention on Climate Change (UNFCCC), the development and transfer of technologies to support national action on climate change has been an essential element of international climate action.4 The Convention includes specific provisions on technology i.e., Article [4], paragraph 1 mentions that "*All Parties…shall: (c) Promote and cooperate in the development, application and diffusion, including transfer, of technologies…that control, reduce or prevent anthropogenic emissions of greenhouse gases…*". Similar provisions were also included in the Kyoto Protocol.

Building upon these provisions, countries have stepped up their efforts by engaging in consultative processes on climate technology development and transfer, creating technology transfer frameworks, establishing export groups on technology transfer, and more.[5] One of the most significant works was the establishment of the Technology Mechanism in 2010, which aims to enhance climate technology development and transfer.

4 UNFCCC. Technology and the UNFCCC : Building the Foundation for Sustainable Development. *Available Online.*

5 UNFCCC. 2021. Compilation of good practices and lessons learned on international collaborative research, development and demonstration initiatives of climate technology. *Available Online.*

The Technology Mechanism consists of two bodies: the Technology Executive Committee and the Climate Technology Centre and Network. The Technology Executive Committee is the policy body that analyses climate technology issues and develops balanced policy recommendations, thereby supporting countries to accelerate action on climate change, whereas the Climate Technology Centre and Network is the implementation body that provides technology solutions and capacity building on policy, legal and regulatory frameworks tailored to the needs of individual countries.[6]

Furthermore, the Paris Agreement adopted in 2015 sets the stage for urgently needed climate technology development and transfer. For example, Article 10, paragraph 5 of the Paris Agreement states that "*accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and promoting economic growth and sustainable development*". More importantly, **the Paris Agreement defines a clear vision of fully realizing technology development and transfer for both improving resilience to climate change and reducing GHG emissions.** It also notes the importance of technology for the implementation of mitigation and adaptation actions. In addition, countries agreed to strengthen the Technology Mechanism, requesting further work on technology research, development, and demonstration, as well as endogenous capacities and technologies. A technology framework was created to provide overarching guidance to the work of the Technology Mechanism in promoting and facilitating enhanced action on technology development and transfer.[7]

As an ongoing process, governments periodically meet at the Conference of the Parties (COP) and Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) to discuss the opportunities and challenges regarding enhancing climate technology development and transfer.[8] The Glasgow Climate Pact adopted by the COP 26 in November 2021 underscore the significant role of technology in all pillars of the Paris Agreement and the need of strengthening cooperative action on technology development and transfer, including accelerating, encouraging and enabling innovation.

B. The Nexus Between STI and Low Carbon and Resilient City

Further to the international agreements on the importance of STI in strengthening low carbon resilience and combating climate emergency, various initiatives and researches including the study on low carbon city in China, Japan, and the Republic of Korea under the North-East Asian Subregional Programme for Environmental Cooperation (NEASPEC) [9], have shown the wealth of experiences and innovative solutions in reducing GHG emissions, and encompassing programmes and strategies addressing issues such as clean and sustainable

6 UNFCCC. UNFCCC Technology Mechanism. *Available Online.*

7 UNFCCC. 2015. Paris Agreement (English Version). *Available Online.*

8 UNFCCC. Information on Climate Technology Negotiations. *Available Online.*

9 Studies conducted as part of the North-East Asia Low Carbon City Platform (NEA-LCCP) under the North-East Asian Subregional Programme for Environmental Cooperation (NEASPEC).

energy supply, energy-efficient housing, and sustainable transport system. Many of these successful experiences highlight the key role of STI to facilitate and accelerate the efforts on building low carbon and resilient cities and communities.

Conceptually, STI is a broad term that encompasses three different domains – science, technology, and innovation. Science is the pursuit of knowledge through systematic studies of the structure and behavior of the physical and natural world and societies. It provides the necessary knowledge for the practical application for a given end (i.e., technology). The simplest form of technology is the development and use of basic tools (e.g., a wheel), while complex machines (e.g., a wind turbine) involve more complicated technology. As for innovation, it refers to a new way of producing, delivering, or using goods and services, based on new technology, or through new business models or forms of economic or social organization. While technology is often the focus of STI, innovation is equally important. It ranges from incremental process improvements to system innovation, involving better ways of managing the production or delivery of goods or services, new ways of organizing businesses, and changes in product-service systems.[10] In fact, technology and innovation usually go hand in hand. For example, organizational innovation is needed to work out suitable business models to make certain technology (e.g., solar panel) economically feasible considering the socio-economic profile of customers.

STI possesses a wide range of applications, from high-technology-based solutions requiring major infrastructure development to innovative approaches that employ more basic technologies or organizational designs, which could fit the distinct needs of cities with differing capacity and resource levels. While some situations require cutting-edge technologies, in other cases, simple innovative designs or inexpensive and readily available technologies may provide the best solution to solving urban problems.[11] The fit one is the right one. There needs to be an equal focus on both high-tech and low-tech application as well as technological and non-technological aspects of innovation.

Apart from being a direct technical solution that, for example, increases the cost-efficiency of renewable energy generation, enhances data processing capacity, or develops more eco-friendly infrastructure and equipment, **STI can be a means of implementation** that improves decision-making, strengthens governance and accountability,

10 The main faces of innovation summarized by the United Nations Inter-Agency Task Team on Science, Technology and Innovation for the SDGs include product and service innovation, organizational innovation, marketing innovation, business model innovation, pro-poor, inclusive and frugal innovation, grassroots innovation, social innovation, and system innovation. *Available Online*. In the context of low carbon resilience, for example, the 2050 Carbon Neutral Strategy of the Republic of Korea highlights the importance of policy innovation, social innovation, and technological innovation. *Available Online*.

11 M. Gulati et al. R. Becque, N. Godfrey, A. Akhmouch, A. Cartwright, J. Eis, S. Huq, M. Jacobs, R. King and P. Rode, Coalition for Urban Transitions. 2020. The Economic Case for Greening the Global Recovery Through Cities: Seven Priorities for National Governments. *Available Online*.

promotes inclusive multi-stakeholder engagement, and prompts a behavioral change.

As a practical reference material for cities to advance low carbon resilience, this report focuses on the technology and innovation dimensions of STI, covering both aspects of a direct technical solution and a means of implementation. A series of in-depth case studies on the applications of technology and innovation in the context of low carbon and resilient cities are provided.

The concept of low carbon resilience involves a systematic approach towards mitigation and adaptation.[12] Mitigation focuses on reducing GHG emissions and transformations towards low carbon and eventually net-zero development, while adaptation stresses the adjustments made for moderating the negative impacts of climate change. Advances in STI have enabled improved climate change mitigation strategies through a variety of methodologies – from innovative market mechanisms and regulation policies implemented by governments to progressive research and application of energy efficiency technologies.

Conversely, adaptation focuses on how climate change has already begun to trigger an increase in extreme weather events causing long-term changes to weather patterns, particularly affecting the well-being and livelihoods of vulnerable populations. STI can support adaptation policy and planning. For instance, STI can enable communities adapt at scale to climate change and increase their resilience to climate shocks and stresses. **STI can expand the availability and effectiveness of both mitigation and adaptation options, and more importantly, helps integrate the two approaches to maximize benefits and minimize conflicts for the development of low carbon and resilient societies.**[13] For example, advances in renewable energy have enabled the agricultural sector to adapt to increases in unpredictable seasons and weather, while delivering carbon emission reductions and agroforestry practices driven by STI co-deliver adaptation and mitigation objectives through providing ecosystem services and reducing human impacts on the environment.[14]

Mitigation and adaptation STI options also house a range of co-benefits, such as improved air quality, reduced fuel poverty, new jobs and better health. For example, STI can improve the efficiency and reliability of the public transportation system ,and decrease air pollution while reducing GHG emissions. It can also increase the resilience of infrastructure and buildings along with energy-efficient design.[15]

---

12 If the issues were handled separately, there could be problems such as mitigation approaches that are exposed to climate impacts and adaptation strategies that are highly emissions intensive. Integrating the two approaches can improve effectiveness and yield co-benefits. *Available Online*.

13 UNFCCC. Innovative Approaches to Accelerating and Scaling up Climate Technology Implementation for Mitigation and Adaptation. 2020. *Available Online*.

14 C. Mbow, P. Smith, D. Skole, L. Duguma and M. Bustamante. 2014. *Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa.* Science direct 6 2014 p.8-14. *Available Online*.

15 World Economic Forum. 2021.Net Zero Carbon Cities : An Integrated Approach. *Available Online*.

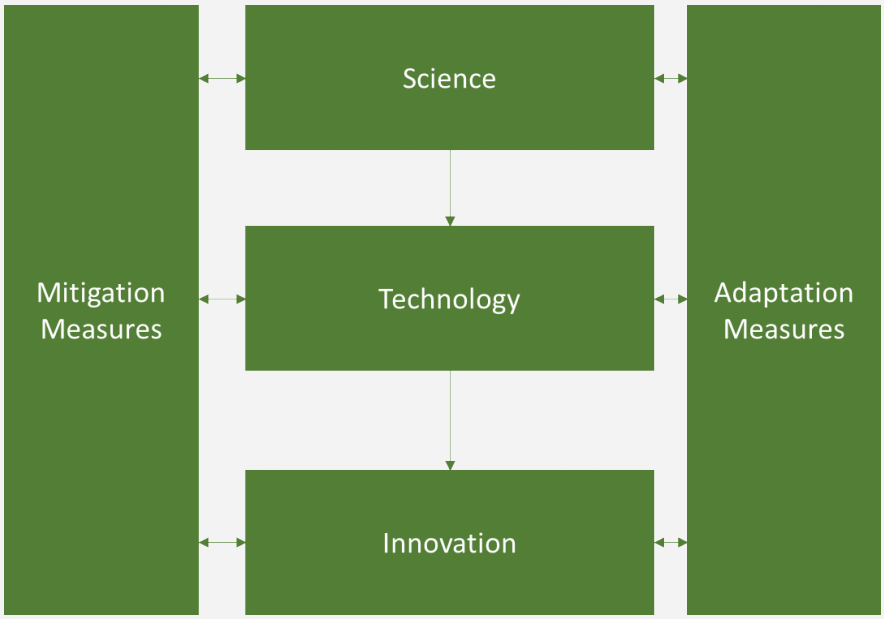


Figure 1 STI for Low Carbon and Resilient Cities

While low carbon choices between countries differ due to capacity limitations such as know-how, human resources and resource gaps, **these constraints can limit the ability to contend with the competing interests of rapid urbanization against accelerating the transformation towards carbon neutrality.** Moreover, a good response should be technically feasible but also aligns with the development objectives of the countries or cities, as well as being cost-effective and socially acceptable. **There is, therefore, a great need for further elaborating the concept and application of STI in the context of low carbon and resilient cities and analyzing cases to understand the role of STI to facilitate and accelerate efforts in the local context.**

As a non-exhaustive framework, the list below outlines six key areas STI operates in the context of low carbon and resilient cities. This is followed in Chapter II by examples of certain key technologies and innovations in the identified categories can reduce emissions and promote urban resilience, including some successful case studies. Chapter III will then conclude with some final reminders for the implementation of projects in the urban environment.

Information and communications technology (ICT)

Information and communications technology is a support field of STI in achieving low carbon and resilient cities, technologies such as artificial intelligence for analysis of data and computer aided design of goods and wireless networks like 5G for data transmission are powerful tools to obtain useful information from data collected via a variety of sensors to enable smarter decisions. However, ICT itself, as it substitutes and replaces many physical mediums and continues developing in utilization, also has its own emissions footprint, which is estimated to be

between 2.1% to 3.9% of global carbon emissions annually[16].

This estimate comprises of emissions from data centers, consumer electronics and devices. As ICT's annual emissions are closely linked to electricity usage, when not considering production, an energy transition to renewable energies will have an impact on reducing its projected emissions. ICT itself has also seen significant improvements in energy efficiencies with transistors, lighting displays and related technologies. Data center throughput has for example increased by 550% but with only a corresponding increase of power consumption from 194 to 205 TWh from 2010 to 2020[17]. However experts foresee a slight slowdown in efficiency improvements in certain segments of the ICT industry and its continued growth is likely to see increases in power consumption and emissions. ICT measures to improve emissions can largely be grouped into two categories optimization and digitalization.

1. ICT Optimization

Optimization is a mix of technology, and human capabilities to understand our world and that understanding is utilized to optimize real world processes and also serve as means of early warning and detection, thus lowering emissions and building resilience indirectly through such optimizations and anticipatory mechanisms. Examples include the various forms of automation such as turning on the heater when the sensor detects the temperature is at a certain threshold for example 60˚C and turning it off when it exceeds 70˚C.

2. ICT Digitalization

Digitalization is another key area by which ICT helps reduce consumption of selective resources but may result in an increase in emissions from digitalization. The conversion of once physical goods into data which is stored and accessed either at a local level or via a datacenter and accessed through the internet. Many physical goods have already undergone digitalization, examples being books, music, films and data recording such as business transactions have moved into the digital sphere, which makes it significantly easier to share data and also reduces the quantity of physical resources consumed such as paper. The emissions offset via digitalization may vary across a large range, depending on the frequency of sharing and access.

Sustainable mobility

Transport contributes up to 70% of urban pollution and approximately 20% of cities' carbon reduction potential.[18]

16 C. Freitag, M. Berners-Lee, K. Widdicks, B. Knowles, G. Blair and A. Friday. 2020. The climate impact of ICT: A review of estimates, trends and regulations, *Available Online*.

17 E. Masanet, A. Shehabi, N. Lei, S. Smith, and J. Koomey., 2020. Recalibrating global data center energy-use estimates. Science, 367(6481): p. 984-986. *Available Online*.

18 Coalition for Urban Transitions, 2019. Climate Emergency, Urban Opportunity. *Available Online*.

Through implementing a blend of policies and STI solutions, cities can benefit by not only adopting low carbon modes of transportation (e.g., electric vehicles or emissions and fuel efficiency standards) which can be quite competitively priced[19] over its lifetime ownership cost but also reducing health risks and potentially improve productivity by mitigating issues such as air pollution. There are two core areas of reducing emissions and building resilience under the sustainable mobility category, namely reducing or substitution of transportation demand as well as improving fuel efficiency and fuel replacements.

1. Reducing or Substituting Transport Demand

Reducing or substituting transportation demand can be done through several initiatives, such as the encouragement of walking, or personal mobility devices such as bicycles and kickscooters. The increase of telecommuting during the COVID-19 pandemic is also a means of substituting transportation demand. Mass transit such as buses and rail and similar high density transport options can reduce the number of vehicles on the road and potentially decrease overall per capita emissions when paired with good urban planning and scheduling.

2. Electrification, Fuel Efficiency and Fuel Replacements

Electrification of the vehicle fleet through the deployment of electric vehicles when paired with a renewable or low carbon energy source such as nuclear can significantly reduce the emissions footprint of the transport sector in cities. In areas, where deployments of such technologies may be difficult in the near term, fuel replacements with cleaner fuels such as hydrogen produced from electrolysis, the use of biofuels such as ethanol or the direct use of natural gas for combustion can act as a technological bridge to reduce emissions as infrastructure for long term electrification and a low carbon electric grid is implemented. Paired together with fuel efficiency regulations, planned obsolescence and vehicular policies to remove fuel inefficient vehicles or engines and encouraging regular upgrading and maintenance to reduce both fuel consumption and air pollution as well as emissions can be a path towards sustainable transportation.

Land use and nature-based solutions

As the climate changes, and as urban sprawl and the requirements for land to support society increases. The challenge of maintaining arable land for food production and desirable land for settlement comes into conflict with also maintaining ecosystems for wildlife to protect terrestrial biodiversity. Increasing the density of human activities performed within the same amount of land in a sustainable manner requires a rethink of land use and building designs. Much like how a forest serves as both a "farm" and residence for animals, urban and rural land usage needs to be addressed in a multi-disciplinary approach to ensure habitable living and work spaces. To that

19 Energy Transitions Commission, 2020. 7 priorities to help the global economy recover. *Available Online.*

end, encouraging residential areas to be closer to places of work and consumption, such as commercial and light industrial spaces, through the design of compact city also reduces transportation demand . Agriculture can also be brought into the city with urban farming techniques utilizing aeroponics, hydroponics or aquaponics, thus reducing the distance between where food is grown to where it is consumed. Urban environments would also need to carefully plan out water management and storage systems to promote urban resilience.

Clean energy [20]

The electrification in transport, industry, building and residential sectors together with increases in energy consumption continuously expand global electricity demand.[21] With solar photovoltaic and offshore wind power now becoming more economically competitive against various sources of electricity power supply, clean energy technologies are increasingly becoming a cost-effective means for cities to move towards a net neutral or net positive in carbon emissions. Two key areas in the energy sector for reducing emissions are in clean energy generation and energy storage.

1. Clean Energy Generation Technologies

Clean energy in the urban environment relies not only on importing electricity from power plants but also increasingly generating electricity at the micro-grid level from sources such as micro-hydro, solar and wind where available. Building Integrated Photovoltaics (BIPV) are also an interesting upcoming option for newer structures or retrofitted ones to provide both energy generation and shading. Newer developments in thin films and selective wavelength absorptions also allow for photovoltaic skylights, functioning as both a "window" for visible light while absorbing energy in other spectrums such as ultraviolet light. Grid operations need to be able to take into account these power sources and legislative and regulatory enhancements also need to factor in grid stability and micro-generation feeds together with energy storage.

2. Energy Storage Technologies

Grid-level large-scale electrical energy storage (GLEES) is an essential approach for balancing the supply–demand of electricity generation, distribution and usage. Activities include peak shaving and load leveling, voltage and frequency regulation and emergency response. However, a core problem for current mixed and fully renewable based grids is the fluctuations in power supply throughout the day, thereby requiring active management of the power supply depending on its composition. This is where energy storage would come into play, passively or actively automated to discharge and absorb power from the grid to maintain a supply balance to fluctuations in demand. With sufficient energy storage built, a larger share of the grid supply could be converted to intermittent renewable sources without requiring corresponding increases in the number of peaker power plants to act as a

20 REN21. Renewables in Cities 2021 Global Status Report. 2021. *Available Online.*

21 Energy Transitions Commission, 2020. 7 priorities to help the global economy recover. *Available Online.*

regulation mechanism, thus further reducing emissions.

Sustainable waste management

Cities are the main source of waste, in terms of solid, liquid or air. Managing waste often brings to mind the 3Rs (Reduce, Reuse and Recycle). However, as knowledge and technology develop, increasingly there is a push to move towards a circular economy, **where a waste product feeds as a raw material into another product and to ensure that the resources used are constantly being recycled in some form or the other to minimize extractive activities from the natural environment and ensuring that as much of the resources are renewable.** Some example cases of new uses for what historically waste products would be utilizing coal fly ash from power plants to produce concrete, turning waste plastic and organics such as tyres into chemicals and fuels.

1. Waste Management

With the development of low power sensors, transmitters as well as machine intelligence, sorting of waste and fleet management for waste collection has improved. Urban data on waste levels and locations can help operators to plan fleet collection routes more optimally to ensure waste clearance around the city is maintained in good order and that the various streams of waste ranging from compostables, recyclables and general waste can also be sorted more carefully for various waste processing streams.

2. Circular Economy

As cities increasingly are setup for recycling of most solid mono-material consumer goods such as paper, plastics, aluminium and metals. The recycling of more complicated products which have multiple material types going into a products makeup also needs to be given more attention. Examples such as tertrapaks with plastic nozzles, which may seem easily recyclable on first glance but by mixing plastic with paper, additional steps need to be made to separate the various materials from the products first.

To that end, governments, cities and the private sector need to work together in terms of product design, regulatory frameworks and infrastructure to ensure that products are designed in such a way that minimizes the waste of resources over its life cycle while also ensuring that certain design principles such as the design for disassembly, recycling or repair frameworks are adopted. Depending on the product type, it may also be expedient to shift consumer behaviors towards using reusable consumer products such as glass bottles and that the municipality has the right infrastructure to facilitate such reuse, or where possible to have a product repaired or upgraded based on specific parts rather than a complete replacement, thus saving resources.

Building energy efficiency

Buildings worldwide account for 40% of CO_2 emissions from energy use[22] but offer the greatest and lowest cost potential for emission reductions at 6 Gt CO_2e per year. It is estimated that heating, cooling and lighting in residential and commercial buildings consume more than half of a building's energy use, with lighting alone consuming approximately 11% of the energy. The remainder, being a combination of outdoor lighting, computers and other building equipment. **As the urban environment centers around buildings, ensuring that buildings are designed to be fit-for-purpose and integrated into district level utilities such as heating and cooling, as well as retrofitting older buildings to improve their efficiencies via insulation are key methods to reducing emissions.**

1. Energy Efficiency

In terms of direct energy efficiency savings, installation of light emitting diode (LED) type lighting and energy efficient electrical appliances within a building are achievable through regulation and other energy efficiency programs. However, in some cases, if a building has its own power production capability through solar or wind, a battery system together with smart grid devices could reduce the need for energy from the grid, potentially reducing emissions if a grid is reliant on the utilization of fossil fuels for power.

2. Thermal Efficiency

Thermal efficiency reflects the amount of energy required for a building to maintain a desired temperature level and is often affected by two core means, insulation to prevent thermal losses of the building environment to the external environment as well as energy efficient heating and cooling solutions such as heat pumps. Minimized heat losses as well as energy efficient district heating and cooling can reduce emissions over traditional building envelopes and thermal control technologies.

22 B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds.). IPCC, 2007. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York. *Available Online*.

Chapter II

Case studies

Leveraging Science, Technology and Innovation for Low Carbon and Resilient Cities

A. Information and Communications Technology (ICT)

B. Sustainable mobility

C. Land use and nature-based solutions

D. Clean energy

E. Sustainable waste management

F. Building energy efficiency

Chapter II : Case studies

This chapter looks at the six areas presented in Chapter I at some of the technology and innovative areas to reduce carbon emissions and promote urban resilience followed by examples of successful case studies.

A. Information and Communications Technology (ICT)

Introduced in Chapter I, ICT can be grouped into two main areas of classifications, optimization technologies and digitalization. Here we will provide a list of areas where ICT can reduce emissions or build resilience, as well as three case studies on successful implementations.

Digitalization Type Technologies

Digital Currencies / Tokens

Rewards points, time banks, non-fungible tokens (NFTs) or currencies are an extension of record keeping of ownership towards items of tangible value, usually a national currency or physical good or product for redemption or exchange. Systems can be designed around such currencies or tokens to reward behavioural changes such as recycling, healthy lifestyles or consumption patterns,

Media and Record Keeping

Record keeping or accounting has been facilitated by the use of computers and spreadsheet software. The categorization of income and expenses for digital display has also faciliatated decision making and deeper insights into operations. Historical analysis of records can provide insights into patterns or trends, which can be useful to understand the development of urban areas.

Consultative and Telecommuting

Work, Health and Education consultation are now capable of being delivered remotely, which is made possible through relatively cheap and fast internet access. It is a continued outgrowth of the initial consolidation of document and media digitalization process and remote database accesses and has potential to reduce commuting, as well as to reduce physical resources consumed such as paper records.

Geographic Systems

Interactive map systems which can be updated more quickly and with real time reporting functions are now ubiquitous in navigation software on phones and vehicles, replacing old physical maps, transport timetables and even tourist maps into a single adjustable map or applications.

Optimization Type Technologies

Iterative Computer Aided Design / Artificial Intelligence (AI)

Machine intelligence creates designs or optimisations based on certain set criteria to maximize performance with the least amounts of resources. Simulation processes can also be used for example in evaluating insulation and thermal flows and computer aided design allows for flexible modifications to architecture and simulations to verify design changes.

"Smart" Building Management / Interiors

Heating / cooling with heat pumps when combined with thermal storage of water / air when energy prices are at their lowest to provide economic thermal management. Motion sensor activated lights, sensor activated blinds or smart windows can also be used to control internal lighting.

Disaster Warning and Coordination

Utilizing GIS, weather forecasting and sensor data can be analysed to anticipate floods, earthquakes, wildfires and evacaution plans enacted where required

Urban Planning

Utilizing GIS, pollution, census, traffic and population flows can be used to optimize the design of cities by knowing where and why people are moving, allowing for better layout of infrastructure such as roads, public transport, services and urban districts.

Geographic Information Systems (GIS)

Such Systems tend to combine data from various sources, such as satellites, cameras, sensors or even mobile phones to provide a data map which is transposed on a physical map. Weather, traffic, emissions, resources, public transit, utilities and population census can be mapped and combined in many ways for planning.

Landscape / Agriculture

Plants whether in landscape or agricultural purposes, needs nutrients and water. ICT can be utilized to monitor needs for either alerting human personnel or automatic application of it through connected watering and nutrient apparatus.

Route Optimization

Utilizing GIS, real time traffic data and available routes and destinations can be used to program the fastest or most efficient routes and is useful for both transportation and logistics.

Robotics / Automation

Robotics and automation are capable of performing repetitive tasks at increasingly consistent quality levels. This results in lower material and energy waste in correcting product or service errors during manufacturing and assembly and utilisation.

CASE STUDY A1:
TAN PUHUI CARBON OFFSETTING MECHANISM - CATALYSING INDIVIDUAL LOW CARBON BEHAVIOURS

Tan Puhui is a carbon offset mechanism that rewards carbon credits to low-carbon actions of small and micro enterprises (SMEs), communities, households and individuals. It aims to promote low-carbon knowledge, low-carbon lifestyle and low-carbon consumption patterns, as well as the use of low-carbon products and technologies. Guangdong Province's Tan Puhui Programme rolled out the pilot programs in Guangzhou, Zhongshan, Dongguan, Shaoguan, Heyuan and Huizhou in 2016. Users can log in to the Tan Puhui Account through the Tan Puhui website, mobile application, WeChat official account, and exchange carbon coins gained from their low-carbon behaviours for corresponding products and discounts. With more than 20,000 members, Tan Puhui mitigated a total of 16,976.75 tonnes of CO_2.

WHY HAS THE CITY TAKEN ACTION

With the rapid development of urbanisation and the continuous improvement of the living standards of residents, carbon emissions per capita are increasing at a rapid speed. Small and medium enterprises (SMEs) and residents' living and consumption areas have become the main cause of the increasing energy consumption and carbon emissions. Therefore, China recognised the need to nudge the public and encourage behavioural change towards low-carbon consumption and production (Guangdong Low-Carbon Development Promotion Association, 2017).

GOALS AND OBJECTIVES

In 2012, in the 18th National Congress of the Communist Party of China report, the strategic vision of "promoting the construction of ecological civilisation vigorously", as well as guiding principles of "promoting green, circular, and low-carbon development", were promulgated. In 2015, in order to make the strategic vision a reality, the State Council issued the *Opinion on Accelerating the Construction of Ecological Civilization*, which includes "advocating diligence and frugality, green and low-carbon, civilised and healthy lifestyles and consumption patterns" as part of the guiding principles. The Opinion also pointed out the imperative to "accelerate the transformation to green and low-carbon lifestyles in sectors including clothing, food, housing, transportation, and travel", emphasising action plans such as promoting energy-saving and low-carbon products, green travelling, and anti-food waste actions. This laid the political foundation for the promotion of low-carbon consumption nationwide (NRDC, 2021).

In response to the national policy, Guangdong province has decided to establish a voluntary emission reduction program, namely Tan(carbon) Puhui, to promote low carbon development production and lifestyle, and to encourage public participation in mitigation. As of 2015, Guangdong has released *The Implementation Plan of the*

Guangdong Province Carbon Generalized System of Preferences Pilot which sets the objectives and tasks of the pilot programme.

PROJECT IMPLEMENTATION

By January 2016, six pilot cities were selected as the first batch, including Guangzhou, Dongguan, Zhongshan, Huizhou, Shaoguan, and Heyuan (Guangdong Low-Carbon Development Promotion Association, 2017). By 2018, based on pilot cities' experience and models, a sound, standardised, and well-functioning Tan Puhui had been established province-wide; By 2020, with the continuous improvement of Tan Puhui platform, efforts were refocused on raising green and low-carbon awareness, by encouraging enterprises and the general public to practice low-carbon production patterns and lifestyles, contributing to the national low-carbon development agenda and provide useful experiences for voluntary emission reduction and emission trading.

In the Tan Puhui Pilot Programme, Guangdong Province clarified the responsibilities at the provincial and municipal levels for the implementation. The provincial authorities are responsible for formulating the overall plan for Tan Puhui Pilot Programme, including establishing a provincial-level Tan Puhui promotion platform, and setting up the provincial certification emission reduction trading and supplement mechanism for Tan Puhui, as well as guiding the pilot work. On the basis of the provincial guidance for the Tan Puhui pilot, each city selects areas that have the potential to reduce carbon emissions and can be replicated and promoted to carry out the pilot work in accordance with the local context. (Liu & Zheng, 2018).

In 2016, the Guangdong Province Tan Puhui Innovation Development Centre was established and approved by the Guangdong Provincial Development and Reform Commission. It is responsible for operating as well as providing technical support to the Tan Puhui programme. To be more specific, the centre constructs and maintains the Tan Puhui platforms, coordinates the research, operation and promotion of Tan Puhui, whilst also promoting and implementing new pilots and coordinating the exchange of best practice information accumulated through the pilot exercises.

Determining the scope of low-carbon actions: In accordance with *Guangdong's Tan Puhui Pilot Guideline*, pilot cities can choose the scope of the pilot. It can be at the community-level (neighbourhoods), public transportation areas, tourist attractions, amongst others. The different emission reduction calculations and incentive mechanisms are formulated according to the different scopes shown in Table 1 below.

ICT technology: The Tan Puhui platforms : Upon determination of the scope and identifying the low carbon actions at the resident or SMEs, the carbon credit system is enabled by different digital platforms. These digital platforms, such as the Tan Puhui website (www.tanph.cn), the mobile App, and WeChat account, users can register and use Tan Puhui core functions, which are:

Table 1 Tan Puhui Pilot Models (Liu & Zheng, 2018).

Scopes	Mechanism	Source of low carbon behaviour data
Communities (neighbourhoods)	Target: Household Low-carbon behaviours: Reducing consumption of electricity, water, and gas; reducing travel by private cars; separating and recycling waste	Electricity usage: Power Supply Bureau of the district Water usage: Water company Gas usage: Gas company Private car travel: Property management office generated from vehicle entry and exit records Garbage classification data: Residents' garbage sorting cards issued by the community (neighbourhoods)
Public transportation	Target: Resident or individual-level public transport choice Low-carbon behaviours: riding BRT, public bicycles, clean energy buses, subways	Passengers' travel data: bus companies, transportation card issuing companies, transportation operation companies, or transportation data centres
Tourist attractions	Target: Tourists Low-carbon behaviours: take environmentally friendly vehicles (boats), purchase electronic tickets etc.	Electronic tickets purchase and eco-friendly vehicles (boats) riding: Quick Response (QR) codes printed on the tickets Plant adoption: Tourist Attraction Management Office

- Record and calculate the users' carbon reduction activities: By comparing individual low-carbon behaviour trajectories with service providers', such as public transportation and shared bicycles, Tan Puhui digital platforms can calculate the amount of carbon reductions and convert them into carbon coins issued to the users.
- Redeem the carbon coins: Users can redeem the carbon coins in their accounts in exchange for products offered on the Tan Puhui platforms. They can also opt to invest their carbon coins on the carbon emission trading market or donate into the charities of their choice.

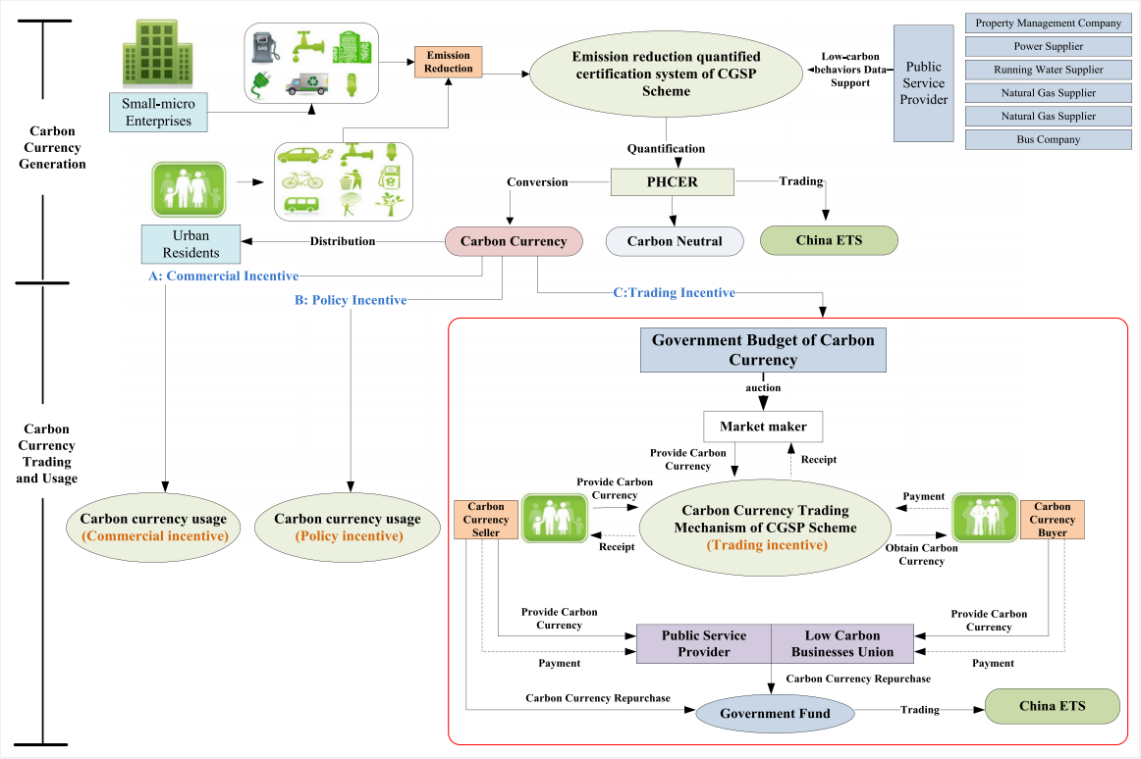


Figure 2 Tan Puhui Mechanism *(Source: Tian, Wang & Zaidi, 2019)*

IMPACTS

Guangdong has developed three Tan Puhui platforms, one of which is on WeChat. By October 2020, the number of followers of the Tan Puhui WeChat account reached 188,000 people, and the platform provides a total of about 220 kinds of products. 290,000 carbon coins have been redeemed out of a total of 2.5 million carbon coins have been issued to which an estimated reduction of 16976.75 tonnes of CO_2 is calculated to have been achieved.

FACTORS FOR SUCCESS

- **Common System and platform:** The establishment of Tan Puhui, an institutional system that encourages the public and SMEs to participate in carbon emission reduction through a regulatory framework supported by the policy documents and Tan Puhui Guidelines and a data-sharing system to allow for data collection and quantification of the low-carbon actions.
- **Promotion and Incentives:** The common platform provides a standardised promotion and publicity mechanism which has contributed to the raising of awareness in terms of low-carbon and green consumption, which is complemented with incentives to promote low-carbon behaviours carried out by the residents such as public utility rebates.

LESSONS LEARNED

Data sharing and integration is not an issue for public transportation, and utilities (water, gas, electricity), which the government has direct authority. Therefore, residents' accounts in these areas can be directly connected to Tan Puhui accounts. However, apart from that, private companies possess users' data, which is usually valued as an important business asset, thus reluctant to share their data to the Tan Puhui platform. In this case, for low-carbon actions carried out within the scopes of the private sectors, users are required to upload the corresponding records as a proof of their low-carbon actions, which can then be converted to carbon emission reductions. However, the products or gifts available for redemption are not attractive enough for users to go through the hassle. Thus, the Tan Puhui platform is being connected to other carbon markets to allow trading of the carbon coins and enhance the platforms attractiveness and broaden customer and service access.

CASE STUDY A2:
TRANSCITY - A CROSS DISTRICT EMISSION TRADING SCHEME IN ESSEN, GERMANY

The TRANSCITY project established a cross-district emissions trading scheme between two districts of the city of Essen (Altenessen and Werden), as an instrument to spur climate protection from a socio-spatial inclusion perspective. The participating neighbourhoods represent very different socio-economic structures and milieus. Based on concrete indicators, an emissions trading scheme (ETS) has been set up with the emission certificates budgeted, distributed, and traded between the districts.

The financial resources activated in the process are reinvested in social and ecological climate protection projects in the neighbourhoods. In addition to supporting the City of Essen in advancing municipal climate protection goals from a social perspective, TRANSCITY contributes to raising socio-ecological awareness and translating that into concrete inner-city cooperation. (City of Essen, 2021a)

WHY HAS THE CITY TAKEN ACTION

Social inequality between the south and north of Essen. The northern part of Essen is relatively poorer, more densely populated with fewer green areas, and more polluted compared to the south, creating a 'north-south' divide (Kerr, 2017). The south of Essen benefitted from coal mining and industrialisation in the eighteenth and nineteenth centuries. The technological advancement, such as steam pumps and electricity, made it possible for miners to get into deeper depths of the coal mine. Therefore, the coal-centred economic development of Essen moved from the Ruhr River in the south to the Emscher river in the north. As the coal mining activities shifted north, the urban regeneration process and economic shift began in the south. Moreover, when the main supporting industries became obsolete, the north part of Essen suffered from economic depression, high unemployment rates, deserted buildings, and air pollution. The different development trajectories in the north and south of Essen led to distinct socio-economic disparity.

The city also needs to tackle the climate change challenge in an inclusive and just manner. As Essen intends to reduce CO_2 emissions by 40% by 2020 (UNFCCC, 2017), the challenge is how to realise a just and inclusive transition engaging the two districts. Therefore, the boundaries of the city districts need to be opened up, and residents should be made aware of the social imbalances in conjunction with climate protection measures (RheinMain University of Applied Sciences, 2021). In addition to reducing carbon emissions and achieving its climate goals, TRANSCITY will create a newly flourishing exchange between two very different social milieus that overcome the challenges.

GOALS AND OBJECTIVES

The city aims to address both carbon reduction and inclusive transition through multilateral collaboration and create public awareness to social imbalances in climate protection issues through investment at the local level (Bundesnetzwerk Verbraucherforschung, 2021). Some of the more concrete goals include:

- Reduce greenhouse gas emissions
- Raise socio-ecological awareness
- Enhance inner-city cooperation and exchange
- Invigorating climate-sensitive urban publics
- Desegregation of districts
- Encourage other cities to participate

PROJECT IMPLEMENTATION

Against this background, the TRANSCITY project creates a Social Urban Emissions Trading System (SUETS), which enables residents in the north and south of Essen to participate in the district development while protecting the climate in the process. The focus of the ETS is at the district-level, and not at the European level or city-level. Compared to the European Union Emissions Trading System (EU ETS), which is too abstract for residents to comprehend, the SUETS is a concrete and tangible trading scheme with ecological and social components (Thiesen & Fischedick, 2020). The two districts of Werden and Altenessen were selected due to the drastic difference in the social structure (income and education levels, unemployment rate, etc.).

The approach of SUETS taps on the emission reduction potential of the inner city area, where the wealthy usually reside, as well as the underprivileged districts. The assumption is that economically weaker residents are involuntarily practicing a low-carbon lifestyle due to low consumption patterns and purchasing power. On the other hand, the richer and more environmentally conscious district residents can actively participate in the carbon market and lead the transformation process (Thiesen, 2016).

The project was initiated as a research project. During the project term, the Wuppertal Institute takes a leading role in evaluating the technical implementation process of the certificate trading and provides the necessary data, while the RheinMain University of Applied Sciences takes a leading role in evaluating the participation process in the districts (City of Essen, 2021b). The City of Essen provides staff and organisational support on site and funding of 250,000 euros was provided by the Mercator Foundation (Clemens, 2021).

The backbone of the SUETS is the emission trading empowered by a smartphone application. With the help of an easy-to-use App, the municipality of Essen first determines the "ecological footprint" of the two urban districts. Based on this, the city sets the spatial climate protection targets and distributes the emission in both parts of the city, which can be traded on a virtual "emission exchange". The certificates have the character of a "voucher",

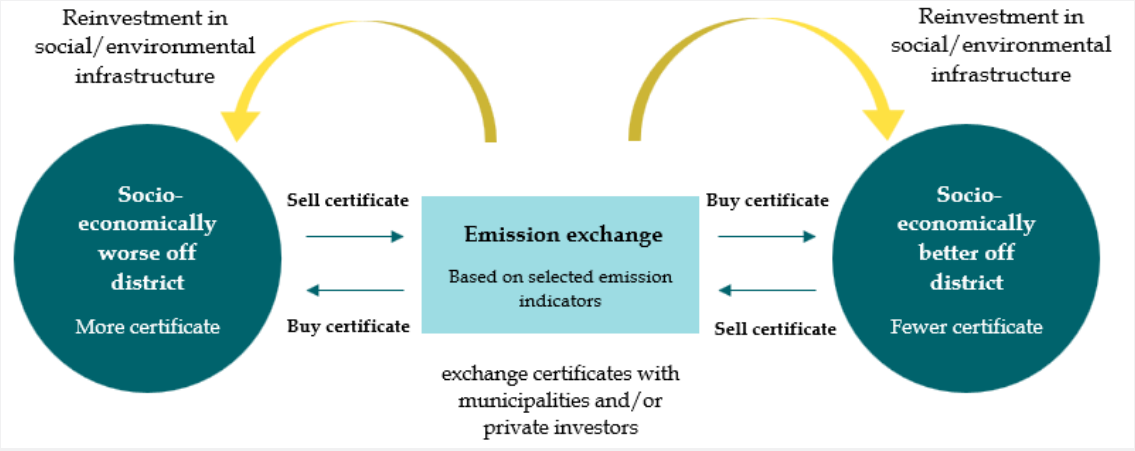


Figure 3 The mechanism of SUETS *(Source: Thiesen, Steizer, & Weber, 2021)*

which can be sold on the emission exchange, thus giving the districts incentives to reduce emissions (City of Essen, 2021c).

Each participating district has a set climate target by the municipality. If the districts do not meet the climate protection requirements, they will voluntarily compensate and pay to the municipal budget. As the wealthier district presumably has a higher carbon footprint, more certificates will be needed to meet the climate target, which they can purchase and trade from socio-economically weaker districts. At the same time, both districts can sell their certificates to the municipality and private investors for investments.

Figure 4 Essen City with Altenessen and Werden districts marked (Adapted from: Wikimedia Comms)

The investment incentivisation mechanism makes SUETS even more attractive because it gives the districts a variety of choices and thus, prevents the certificates from being "hoarded" and incentivises climate-friendly practices. The more residents participate in the two districts, the greater the climate impacts. The proceeds from the local emissions trading will be channelled into sustainable, social and ecological projects in

both neighbourhoods (City of Essen, 2021a). Figure 3 shows that the basis of SUETS is the exchange of emission certificates between the two urban districts with different social structures.

The participating districts are Altenessen and Werden as shown in Figure 4. Altenessen is located in the north of the city with 44,000 residents (City of Essen, 2021b) taking much stronger hit from the coal industry phased out and therefore more economically disadvantaged. Meanwhile, the historical district, Werden, is located in the south of the city. Unemployment rate is 10% in Altenessen, while the rate is only 2.8% in Werden, showing the significant difference in the socio-economic structure.

IMPACTS

The project contributes to the greenhouse gas emission reduction by encouraging residents from both districts to adopt a low carbon lifestyle. In addition, the proceeds received from the ETS will flow into social and environmental projects that involve both districts, as illustrated in Table 2 below.

Table 2 Social and environmental projects and their climate protection contributions (Source: Thiesen, Steizer, & Weber, 2021)

Projects Climate Protection Contribution	Short-term	Medium-term	Long-term
Replacement of inefficient devices	Reducing electricity bills		
Renovation of buildings without adequate insulation		Measurable increase in building energy efficiency and living quality	
Targeted empowerment of energy awareness	Reducing electricity bills		Consumer behaviour
Workshops and labs for cross-milieu capability building	Breaking cultural barriers through the establishment of small workshops, such as repair cafés		
Expansion of pedestrian and bike lanes network		Reduction of CO_2 emissions through curbing traffic	

In addition to the environmental benefits of emissions reductions, social equity is also an important component for the SUETS system design, the socio-economic benefits achieved are:

- A sustainable form of inner-city competition motivates city dwellers across the city, to change their climate and cultural practices;
- In the mid-term, with socio-economic and socio-ecological added value for the municipality;
- Change the overall view and perception of disadvantaged neighbourhoods as a result of dis stigmatisation

FACTORS FOR SUCCESS

Instead of taking the common approach of making the analysis of climate change's social impacts, the project takes the social perspective into account and intelligently leverages on the differences when considering the climate protection efforts. It considers the social aspect as the actual prerequisite for effective climate actions.

Increasing awareness, openness and willingness of urban climate for the residents to cooperate and engage in climate actions. In addition, the project also creates financial incentives for sustainable development projects that improve the overall quality of life.

LESSONS LEARNED

It is crucial that the project continues to receive support from the local government, both politically and in terms of human resources. In addition, the establishment of a working alliance or group joined by academia and think tanks are also significant to support in the technical emissions. In TRANSCITY's case, the RheinMain University of Applied Sciences and the Wuppertal Institute contributed to the success of the project. Furthermore, SUETS system design is transferable to other cities or regions where at least one or more better-off neighbourhoods or districts are ready to take on the role of a "net payer". For this reason, it is preferred that the neighbourhood partnerships are established based on a voluntary basis and legal mechanisms to facilitate such projects' need to be considered locally.

CASE STUDY A3:
DATA-DRIVEN URBAN PLANNING IN SINGAPORE

Urban resilience is pivotal for Singapore and it goes beyond just the ability to bounce back from shocks and crises. As the city-state is small with limited natural resources and heavily reliant on trade and human talent, enhancing urban resilience is about integrated and long-term planning as well as good urban governance, to allow Singapore to adapt and thrive in the threat of climate change and demographic change. ICT enables the planning agencies to anticipate, forecast, and balance the socio-economic demands for a better land use planning process.

Over the last couple of decades, Singapore has seized unprecedented opportunities in harnessing ICT and geospatial data to reduce vulnerability through risk-informed decision making, create economic opportunities, improve urban liveability, and build closer communities in its transformation towards a smart nation. Data-driven urban planning enables Singapore to prioritise investments in building resilient and sustainable cities. Singapore has grown into a geo-powering city that harnesses the use of the geospatial data to create meaningful information for the decision makers to make evidence-based decisions. The geospatial integrated system and the "Whole-of-Government" approach has helped Singapore to move away from sectoral egos and towards an ecosystem approach, where the identification of risks and solutions are performed in a collaborative manner, complemented with science, innovation, technology, capacity, and regulation. Through an interactive and coherent ecosystem, they strengthen evidence-based urban planning, together, they create a more resilient and people-centred Singapore.

WHY HAS THE CITY TAKEN ACTION

The challenge of balancing a multitude of needs in a small area: Singapore is a small island that houses all the needs of an entire city-state. Beyond housing, transport, greenery and parks, culture and heritage, the city-state also has to find space for other needs, such as seaport, defence and water catchment, all of which has to fit into a land area of 721 square kilometres (278 square miles) (Huang, 2018), which is about half the size of London. Therefore, in order to balance economic, social and environmental needs and goals, the planners in Singapore require a powerful geospatial integrated system and planning tools for a flexible and resilient urban design.

Singapore is vulnerable to climate change impacts: Addressing climate resilience is essential as Singapore is already experiencing the impacts of climate change as temperature rose by 0.25℃ per decade (1948 to 2016) and the sea level rose by 1.2 millimetre (mm) to 1.7 mm per year. By 2100, it is projected that the temperature of Singapore will rise by 1.4℃ to 4.6℃ with sea levels rising up to 1 meter (m) (URA, 2021). Warm nights, urban heat island effects, strong monsoon seasons and heavy rainfall seasons are more pronounced. Furthermore, Singapore will continue to rapidly develop the new housing estates and growth areas to meet the population demands and

economic goals by 2030, thus better planning of the built environment and climate-responsive urban planning is a critical challenge for Singapore.

Changing demographics and ageing population presents a key challenge as Singapore heavily relies on human talents: As an open hub for international talents, the city-state has attracted people from all around the world. Despite that, Singapore's population is ageing, with an estimation of around 900,000 residents aged 65 and above by 2030, which will have an impact on both the economy and society. The demographic shift with a sizable non-resident and elderly population will require good urban and land-use planning for the future. (CLC, 2018a).

Limitations in traditional urban planning tools: Land use planning requires a comprehensive understanding of the ecosystem of the constant-changing environment. Before the adoption of ICT, urban planning was largely based on manual tools, such as paper records, hand drawings, and land surveys. Therefore, the data were often out-of-date, laborious and limited in functionality (e.g. generate conceptual presentations and real-time descriptive analysis). It also failed to produce in-depth planning analysis and keep up with the rapid development and planning requirements (GPSC, 2017). Therefore, the planners were in urgent need of current, accurate, and readily available information so as to make informed decisions on land use planning.

GOALS AND OBJECTIVES

Establish a cross-agency collaborative approach: Data sharing, especially geospatial data, can be an issue. The spatial planning agency in the city might be reluctant to share sensitive data (e.g., disaster risk data) to other public works agencies. The lack of data sharing protocols, data custodianship agreement or mandate prevents agencies from seamless data sharing, efficient and risk-informed decision making. In Singapore's case, the culture of an open, collaborative data-sharing culture is cultivated in line with the wider Whole-of-Government approach in the delivery of public services.

Stay ahead of the curve by leveraging geospatial and data analytics: Through advanced ICT and data analytics, planners are able to identify potential gaps and opportunities to plan for the future infrastructure and amenities to ensure that sufficient resources and forward-looking policies are in place to address the needs of the local communities, particularly addressing the demographic shift issue.

PROJECT IMPLEMENTATION

From 1980 till this day, multiple national Infocomm Master Plans and e-Government Master Plans have been implemented so far, which not only set the tone and direction for ICT advancements, but also fasten the pace of incorporation of ICT into Singapore's governance (CLC, 2018b):

- *Civil Service Computerisation Programme (CSCP, 1980-1999)* which raises public service efficiency through the

effective use of ICT. The Programme started from automating work functions and reducing paperwork, then it involved digital conversion of data. By the early 1990s, the focus shifted to consolidation of computing resources into the form of a shared data centre and a civil service-wide network.

- *Infocomm 21 (2000-2003)* that establishes Infocomm as a key sector of growth, boost competitiveness of businesses and enhance the quality of life through infocomm
- *e-Government Action Plan I & II* that drove public service excellence by deploying 1,600 e-services and developing integrated services.
- *iGov2010 (2006-2010)* that promoted Whole-of-Government (WOG) integration including the integration of data, processes, and systems for government agencies.
- *eGove2015 (2011-2015)* that focuses on collaboration within and outside the government
- *Digital Government Blueprint (2018-2023)* that aims to build common digital and data platforms for the WOG; strengthen policy, operations and technology integration; and raise digital capabilities to pursue innovation, amongst others.

Established in 1989, the Land Data Hub (LDH) brings agencies including the Land Office, Urban Redevelopment Agency (URA), Land Transport Authority (LTA), JTC corporation, Building & Construction Authority (BCA), and Housing & Development Board among others, together and acts as the intermediary to exchange and translate data to fit the needs of each agency. The development of LDH also realised the standardisation and sharing of land data across government agencies and reduced duplication of efforts in data collection and creation (CLC, 2018b).

In April 2008, Singapore's National Spatial Data Infrastructure (NSDI) and Singapore GeoSpatial Collaborative Environment (SG-SPACE) was launched. SG-SPACE creates linkages between the Land Data Hub and other national data hubs for people, business and security respectively. The initiative has facilitated informed decision-making and development monitoring by coordinating the use of geospatial information across the public sector

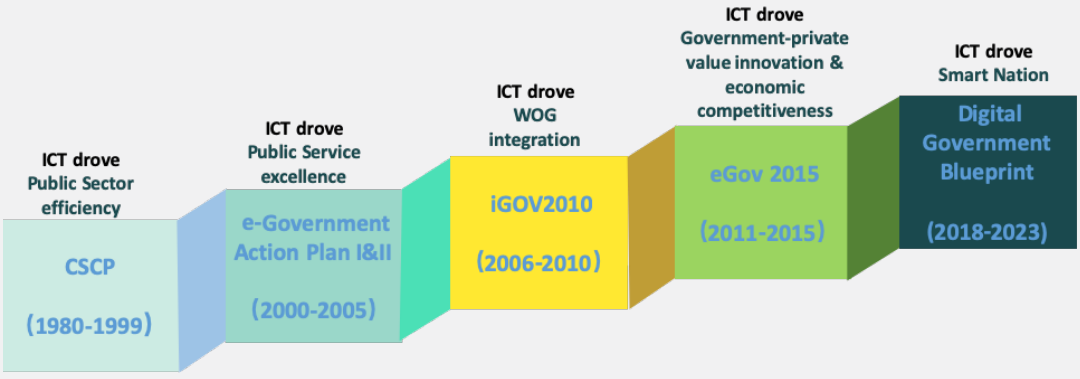


Figure 5 eGovernment Masterplans, 1980-2025 *(Source: CLC, 2018)*

(CLC, 2018a). Such infrastructure and data connectivity allowed comprehensive big data collection through real-live and actual user interaction. Figure 5 below shows eGovernment Masterplans that cultivate data-informed decision making governance.

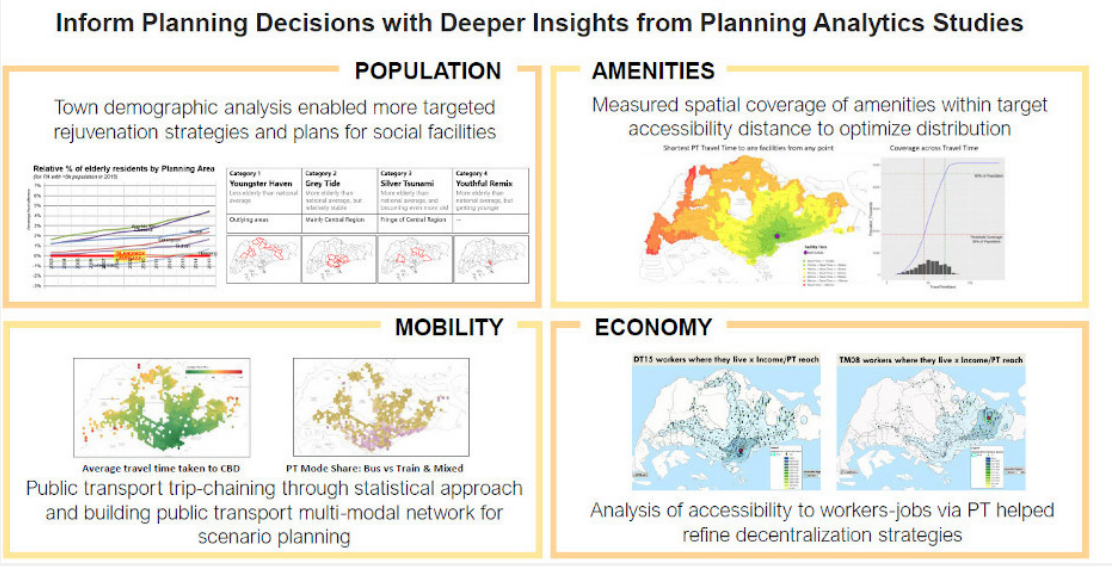


Figure 6 Inform planning decisions with deeper insights from planning analytics studies *(Source: URA)*

Innovative urban planning process: The advanced ICT enables the planning agencies to anticipate, forecast, and balance the demand of a growing population and the limited land area without compromising the requirements for economic and development objectives, and the good quality of life, and hence, further address the resilience challenges (GPSC, 2017).

Singapore' urban planning processes have been systemic. The city-state's planners are among one of the first movers in using planning technologies ever since the 1960s (Huang, 2021). In the 1980-90s, the city-state began integrating computing technology for urban planning, adopting computerisation and geospatial integrated systems (GIS). The use of ICT in urban planning helps urban planners to address increasingly complex urban issues, as well as carry out integrated, future-oriented, and comprehensive land use planning.

The URA, the national urban planning authority of Singapore under the Ministry of National Development has been adopting the GIS system for land use planning since 1995, from Integrated Land Use System (ILUS) and Integrated Planning and Land Use system (iPLAN) to ePlanners, integrated quantitative urban environment simulation tool (QUEST) and 3D simulations. For instance, the GIS system provides critical tools that enable URA to integrate all available data into a single platform to analyse spatial and temporal patterns at a glance and understand the interdependencies and flows within the dynamic urban system (URA, 2021b).

Building on that, the URA coordinates with partner agencies in different urban subsystems for cohesive planning. In order to gain deeper insights into how the city and each of its subsystems work, the URA has been working closely with partner agencies, including planning for social facilities, such as eldercare, health care, child care, schools, parks, sports and recreation. The URA has been building up geospatial and data analytics capabilities with these agencies to enable the planners to study the usage patterns of various amenities, better identify and prioritise areas for intervention, and evaluable choices and trade-offs.

Figure 6 illustrates how planners use data analytics and geospatial technologies to gain deeper insights and make more informed decisions in land use, amenities and infrastructure planning so as to address the challenges, thus Singapore's long-term planning needs are met through digitalisation.

The set-up of URA's Digital Planning Lab in 2013 brings together planners and data specialists to use digital tools to improve planning processes and outcomes. The approach is holistic, with different professions working together to combine insights (Morwenj, 2020). The mission of the Digital Planning Lab is to incubate skills and ideas, to accelerate insights and transformation, and to inspire, through innovation and partnerships. There is a strong focus on building skills and capabilities within government, with the Lab running a data analytics immersion programme twice a year, to train cohorts of government staff on how data can be used in their work (Morwenj, 2020).

ePlanner: ePlanner is a one-stop multi-platform geospatial urban planning tool. ePlanner allows the planners to perform advanced spatial visualisation and analyse various land use planning information on a single platform. It also provides planners in URA and other over 50 agencies across Singapore quantitative and qualitative insights of each area. With easy and quick access to such information, planners are able to anticipate changes, and coordinate with relevant agencies to facilitate integrated planning (URA, 2021c). Figure 7 below shows a snapshot of the tool.

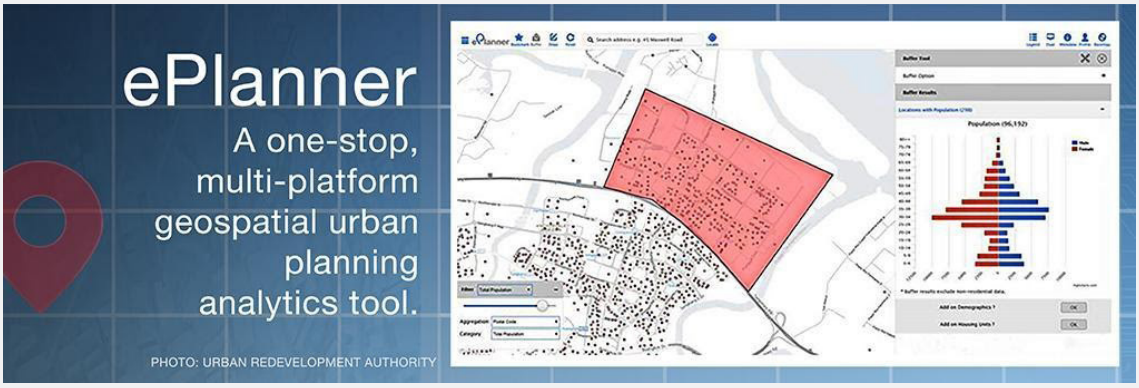


Figure 7 A snapshot of the ePlanner multi-platform geospatial urban planning analytics tool *(Source: URA)*

Care for the ageing population using the geospatial tool ePlanner: URA has been collaborating with the Ministry of Health (MOH) in the development of a comprehensive social-health database for the ageing population. This is built upon the planning and development data on ePlanner. Before this project, data on the seniors was fragmented. Most agencies did not have insights on where the vulnerable elderly reside and if their needs were met by healthcare services and social programmes. The joint database contains MOH's data on the seniors, data from partner agencies such as the Ministry of Social Family Development and Silver Generation Office, as well as URA's planning and development data (Huang, 2018).

By utilising ePlanner, MOH can not only visualise the ageing population "hotspots", but also make analysis on the accessibility of healthcare facilities. MOH can thus identify and fill the gaps working with healthcare service providers and community-level organisations to plan health and social programmes for the seniors more precisely (Tay, 2021). Hence, the service planning and development of new healthcare and eldercare facilities and services is much more data-driven (Huang, 2018). It is found out that a larger portion of the ageing population lives in the east and northeast regions, and that most of the seniors are residing within 1.5 km of their nearest polyclinic. With this knowledge, the authorities can allocate more healthcare facilities in areas where the ageing population is living and anticipated demand is (URA, 2021b).

Quantitative urban environment simulation tool (QUEST): QUEST is a tool to stimulate micro-climate and thermal comfort that change with future urban development and climate change. It can be used by planners, architects, and engineers for building analysis and to integrate appropriate urban heat island (UHI) effect mitigation

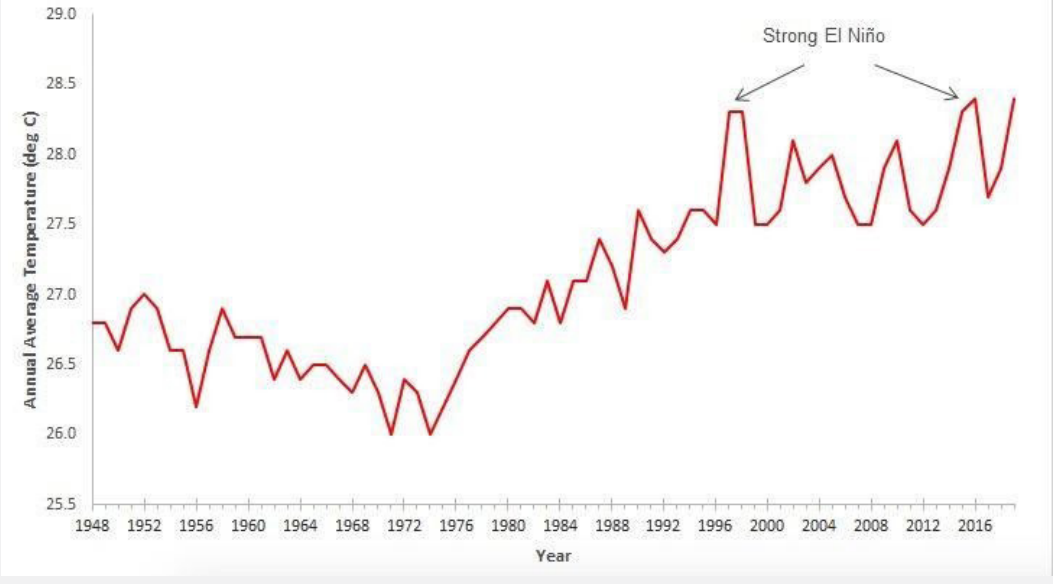


Figure 8 Annual mean temperature in Singapore from 1948 to 2019 *(Source: Meteorological Service Singapore)*

measures upfront in the upcoming land use and urban development plans (Lim, Rajabifard, Khoo, Sabri, & Chen, 2020; URA, 2017; Lim, Ignatius, Miguel, Wong, & Juang, 2017). Hence, QUEST can help with combating the combined impacts of global warming induced rising temperatures and UHI phenomenon. The application of QUEST involves cross agencies and institution collaborations, including URA, National Environment Agency, Singapore Land Authority, Building Control Authority, National Parks Board, and the Agency for Science, Technology and Research, among others, showing the WOG approach (Lim, Ignatius, Miguel, Wong, & Juang, 2017).

Combating UHI phenomenon using QUEST: As shown in Figure 8, Singapore has been getting hotter and hotter through the years. Therefore, coping with the UHI effect will compound warming brought by climate change and ensuring thermal comfort for the residents has been one of Singapore's climate-change-adaptive undertakings.

With the support of the Ministry of National Development (MND) and National Research Foundation (NRF) under the Land and Liveability National Innovation Challenge, QUEST combines high-resolution atmospheric modelling

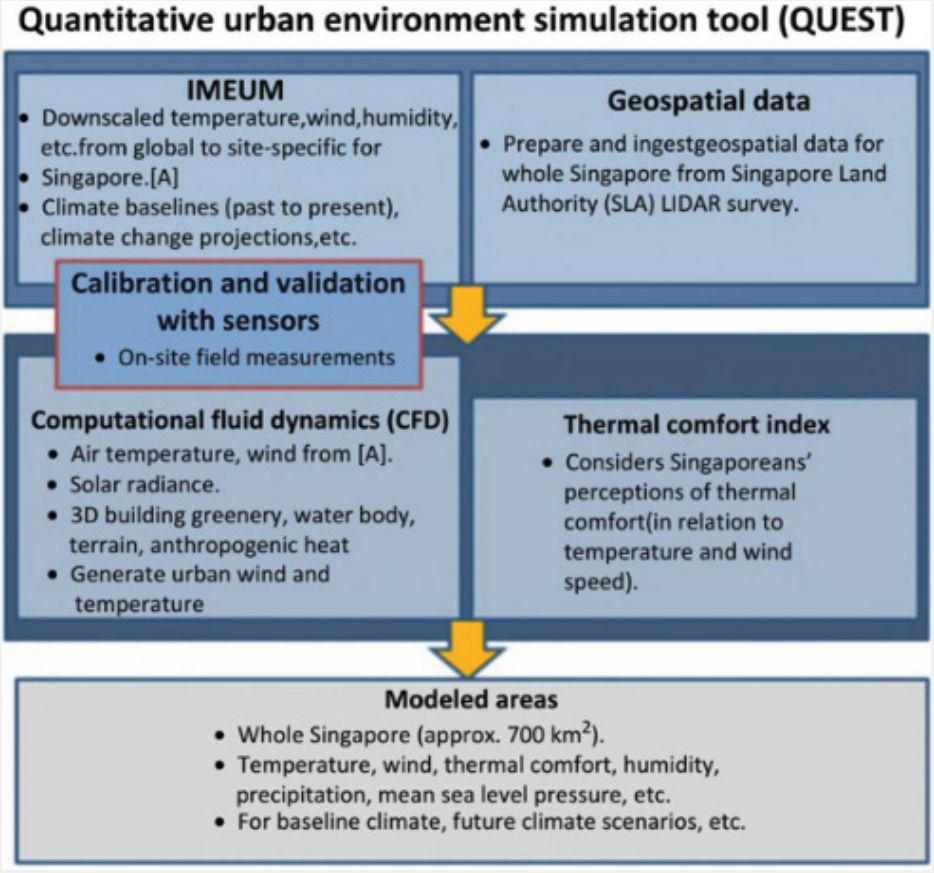


Figure 9 QUEST's work packages and components *(Source: Lim, Rajabifard, Khoo, Sabri, & Chen, 2020)*

with urban-scale computational fluid dynamics modelling to generate various parameters, namely wind, temperature and thermal comfort index at multiple urban scales. QUEST allows planners to visualise how the new addition to the built environment will affect people's thermal comfort levels as well as test the effectiveness of various intervention strategies, such as increasing greenery and adjusting building orientation and massing for shading and good wind flow.

Users can obtain results and outputs from an island-wise scale to a district, neighbourhood, or even a building-level scale to support urban design to mitigate UHI effect and growing temperatures due to global warming. (Lim, Rajabifard, Khoo, Sabri, & Chen, 2020; URA, 2017). Figure 9 illustrates the different components and work packages that consist of QUEST.

ePlanner and QUEST demonstrate how Singapore has been able to stay ahead of the development curve by leveraging ICT and smart technologies in urban planning processes, and providing planners with a more holistic understanding of the urban ecosystem. Therefore, the city-state is planning with higher granularity to create a more resilient and liveable environment (URA, 2017).

IMPACTS

Digitalisation supports planners to apply data analytics and ICT tools to support data-informed, climate-responsive urban design, thus helping form communities to the whole city-state to adapt to the impacts of climate change as well as reduce the GHG emissions that resulting from climate change.

FACTORS FOR SUCCESS

One of the main key factors for success has been political consistency, which ensures the continuity of policies that advance ICT development and its integration into governance. This allows for longer term phased implementation of the whole of government approach towards streamlined cross-agency governance and sharing of data. Furthermore, efforts to continuously evolve digitisation technologies and tools that allow urban planners to perform a more climate-sensitive and adaptive urban design and the institutional capacities and networks to test the accuracy of such tools allows for further refinement of the overall digital system.

LESSONS LEARNED

In order to cope with the rapid pace of development, aging population and uncertainties brought by climate change, Singapore plans to become more data-informed by initiating the whole-of-nation *Smart Nation* initiative in 2014. It consists of three pillars: Digital Government, Digital Economy, and Digital Society. With digitalisation being a key pillar of the Government's public service transformation efforts. The release of Digital Government Blueprint (DGB) is a statement of Singapore's ambition to better harness data and new technologies in support of Smart Nation.

When it comes to digitalisation in urban planning, a good foundation has been laid by previous efforts of digital data integration, and data science tools and advanced GIS capabilities development. URA is now pushing the frontier of digital toolkits such as AI solutions for optimal data-informed urban planning. AI tools are enabling URA to optimise land use, improve citizens' accessibility to services and amenities, and manage utilisation of infrastructure. In the long-run, this allows the planners to plan in a more anticipatory and agile manner to ensure that the plans stay relevant and cater to the changing needs of the residents in the post-pandemic era, although many issues still surround the data ecosystem as will be explored further.

The complexity of city's eco-system: A city is a system within a system, with many interacting parts that come together to create different outcomes under different conditions. Cities vary due to differences in social and economic dynamics, in physical and digital infrastructure, as well as in governance frameworks. Each will have a unique set of priorities and will need tailored solutions. How to simulate them into a digital tool is always a challenging process that requires reiteration, data analytics and simulation.

Maintain the continuity of innovation: Urban planning in the last five decades has been a series of innovations in planning strategy, policy and methodology—the only way to respond to the city-state's changing needs. In this digital age, the ability to harness geospatial and data analytics to strengthen urban planning is important. Hence, URA has equipped the planners with the tools and capabilities to build up their digital competencies in order to transform urban planning practices.

The negligence towards valuable data sets: Many Smart Cities Initiatives, despite the potential, largely focused on Apps development and applications, rather than evidence-driven planning and urban management. Although data is collected, they seldom feed into long-term planning. Therefore, the policy makers tend to overlook the city's long-term spatial, and socio-economic development plans, and instead focus on complaints received from apps, which undermines data-driven, risk-informed planning as a result.

Data sharing itself can be an issue, especially for the geospatial data: The urban planning agencies might not be willing to share the data with the public works or the disaster risk agency. In addition, the lack of data sharing protocols, data custodianship agreement or mandate that enables agencies to seamlessly share data, and the absence of integrated data platforms that host the data and update the data periodically often results in data duplications across different agencies and inefficient planning and development plans.

Another situation is that the data is shared among agencies, but none of these agencies talk to each other, hence, the information stays fragmented. Information in silos also results in duplication in data sets, inefficiency and poor planning in terms of addressing risks.

Mindful for data security: Smart city systems tend to generate a large volume of data, including sensitive data including personal information of citizens like the case of Singapore. As such, appropriate measures must be taken to ensure that collected data are secured and protected by law, to thwart misuse of information and unauthorised access.

B. Sustainable mobility

Introduced in Chapter I, sustainable mobility improvements on urban resilience and emissions can be grouped into two main areas of reducing or substituting transportation, improving fuel efficiency or fuel replacements. Here we will provide a list of areas where sustainable mobility improvements can reduce emissions or build resilience, as well as three case studies examples on successful implementations.

Personal, Mass Transportation and Substitution

Personal Mobility Devices

Bicycles, kickscooters are some of the transportation devices that could help to replace personal cars in urban settings, especially where careful urban planning and transport systems could encourage the use of such devices for last mile coverage such as from a subway station to place of work or home.

Bus Transit

Buses are a flexible option for use in either long range or short range transportation, utilising existing road and highway networks shared with motor vehicles. In some cases, buses act as part of an integrated spoke and wheel model when integrated with rail systems, functioning as the last mile transport option.

Rail Transit

Various rail transit modes exist and are generally capable of high passenger traffic, depending on the load capacity of the designed rail system. Light rail such as trams and subways are often used for intracity transportation. Whereas heavy or high-speed rail is usually used for intercity transportation, although there may be exceptions depending on the required capacity. As rails often do not intermingle with personal transport vehicles such as cars, it is often seen as a means to provide effective transportation in urban environments and a means to assist in the reduction of road congestion.

Vehicle and Ride Sharing

Ride sharing vehicles can also help to contribute to emissions reductions by increasing the passenger density of passenger vehicles such as cars. Vehicle sharing could also to some extent help to reduce overall emissions by reducing production emissions costs by reducing overall numbers of cars if shared among a large number of users.

Fuel Efficiency and Fuel Replacements

Improved Combustion Engines and Fuels

Fuel efficiency policies, emissions checks, taxes on high emitters as well as upgrading and planned obsolescence strategies can help to reduce emissions by the replacement of polluting engines with low fuel efficiencies with newer engines that are fuel efficient and also help to encourage a migration towards renewable and clean fuels. It may also function as an interim transitory measure towards electrification to reduce emissions.

Electrification

Electric motor vehicles are a potential system to replace internal combustion engines as the overall system efficiency of an electric drive in vehicles is above 80%. However, it is also dependent on the fuel source producing the electricity and in some instances, such as where an electric grid has low efficiency and polluting power plants, the effect of electrification may have a reduced impact. Where range is needed and the charging time is insufficient, battery swap vehicle designs may be utilised to overcome some of the shortcomings of the extended charging cycle.

Synthetic and Renewable Fuels

Synthetic diesel and gasoline, ethanol, butanol as well as hydrogen are some of the synthetic and renewable fuels that are thought of having the potential to eventually be part of a carbon capture, reuse and recycling loop, utilising catalytic reactions or fermentation processes to produce fuels directly from captured carbon dioxide or through food and agricultural waste.

Fuel Cells / Hybrid Drive Trains

Fuel cells can take in a variety of fuels depending on the construction and operating parameters, although the commonly known type is the hydrogen fuel cell. Utilising hydrogen to produce electricity, it can be considered as a type of hybrid drive train which consumes fuels to produce electricity and drive an electric motor for the vehicle. The overall system efficiency is between a fully electrified vehicle and a standard combustion engine and is a potential measure to reduce emissions in regions where the infrastructure supporting electrification is being developed.

CASE STUDY B1:
THE SEOUL TRANSPORT OPERATION AND INFORMATION SERVICE (TOPIS)

The Seoul TOPIS (Seoul Transport Operation and Information Service) is Seoul Metropolitan's digital brain that gathers and processes real-time road and public transport traffic information to enable the city to effectively manage the different transportation modes to alleviate road congestion, respond to emergencies, and support in informed-decision making while developing public transportation policies. While TOPIS is an Intelligent Transport System (ITS) and functions as an integrated traffic management centre in the control room, its functionality is beyond the platform or advanced Information Communication and Technology (ICT) system. Another core component is the functional organisation that facilitates data sharing and collaboration from the different transport entities and modes (bus, subway, carsharing and bike-sharing information). The successful implementation of TOPIS not only increased Seoul's public transport ridership satisfaction and transport planning process, but it is also replicated and localised in other international cities.

WHY HAS THE CITY TAKEN ACTION

Increasing automobile ownership leading to traffic congestion: Along with the breakneck economic growth of Seoul is the car ownership boom. Between 1980 and 2009, car ownership staggeringly increased by 1,341% in Seoul and 2,907% in the metropolitan area. By 2014, vehicles on the road dramatically increased by 130 times, although the road network expanded only 1.2 times in the same period, leading to severe traffic congestion and the social cost of traffic is estimated to be United States Dollar (USD) 7 billion in 2009. Besides, it is also closely associated with other urban challenges, including air pollution, inefficient use of public space, and declining use of public buses.

Unattractive public transportation system: Public transport ridership declined, particularly public buses, due to the competition with cars and subways (the first subway, Line 1, was introduced in 1974). Traffic congestion also led to unreliable public bus arrival times, while the private bus operators were only serving lucrative routes, making the public transportation services very unreliable and unattractive.

Lack of comprehensive traffic management system: Prior to the introduction of TOPIS, there was no central system managing the road traffic and public transportation system, including illegal parking, penalties and fines, traffic control, emergency response, amongst others. Private and public traffic information was scattered without a systematic way of analysis and management. Furthermore, the coordination between transport stakeholders was mainly ad-hoc, leading to piecemeal policies and interventions with minimal impact. For example, the Seoul Municipal Government, the Traffic Broadcasting System, and the Korean Expressway Corporation operated their respective systems. There was a need for a coordinated and systematic way of managing traffic data for enhanced decision-making through stakeholder collaboration in emergency response and long-term urban transportation

policymaking.

GOALS AND OBJECTIVES

As part of the rehaul of the public transportation system to combat traffic congestion, Seoul began to introduce the ITS system in 1998 with limited use at specific stretches of the city and gradually led to the first official introduction of the Seoul TOPIS in 2005. As a result, there are different functionalities of the Seoul TOPIS, which gradually evolved and developed over the years. Nonetheless, the overall goals for the Seoul TOPIS are:

- ***Public transportation management systems***, including the bus routes, bus operation intervals, smart transport cards, arrival and departure information, ridership, and others
- Provision of a scientific and data-based ***traffic administration support***
- ***Real-time communication and management of the road traffic control***, including automatic illegal parking control systems, traffic violation control, unmanned traffic control system, traffic flow control and traffic signals management
- ***Integral to emergency response management***, traffic accidents, security, natural disasters, or even war-time response to strengthen urban resilience and disaster response
- ***Better informed transportation policy making*** based on big-data analysis

Ultimately, the TOPIS is a means to support Seoul's Transportation Vision 2030, which envisions a Liveable Seoul – without relying on cars, anchoring on three main pillars: (1) human-centric; (2) sharing; and (3) environment.

Seoul Transport Vision 2030

Seoul implements a consistent and strategic transport planning paradigm with a clear vision of minimising private vehicle use and maximising multimodal transportation to build a "Liveable Seoul – without relying on cars," as stipulated in the Seoul Transport Vision 2030. Seoul's Masterplan listed the Seoul Urban Planning Charter in 2014 for the development in the next century as the foundation for urban planning administration and also included consistent messaging and strategies for the transport sector. The Seoul Transport Vision 2030 listed six principles for implementation to achieve human-oriented, shared, and environmentally-friendly mobility, in which technology is one of it. The mobility plan frames the implementation actions in the long-term to achieve the "Triple 30" goals:

- 30% increase in the use of active and public transportation;
- 30% reduction of personal vehicle use; and
- 30% reduction in public transport commuting time.

Technology is recognised as one of the key pillars that enable the city to manage traffic better. As described in the sections above, the core Seoul TOPIS's functionalities are customised to boost public transportation use and smooth traffic flow, consistent with the Seoul Transport Vision 2030.

PROJECT IMPLEMENTATION

A progressive approach in ITS implementation

Seoul developed a keen interest in developing ITS to promote efficient traffic management at a reasonable cost since the late 1980s with traffic congestion. At the same time, the Korean national government also invested in ITS research and development programs in the 1990s, leading to the first introduction of ITS to detect private cars driving illegally on exclusive bus lanes in 1995. Another key milestone is the first Freeway Traffic Management System (FTMS) in Seoul by piloting at the 18-kilometres stretch along the Olympic Expressway in 1997 (Lee, et al., 2014). The FTMS is an integral part of the Seoul TOPIS by collecting, analysing, and managing traffic data focused on the urban expressway to relieve traffic congestion and improve traffic management. It is operated by the Seoul Metropolitan Police Agency, the Seoul Metropolitan Government, and the Seoul Metropolitan Facilities Management Corporation (Seoul Solution, 2017). In this period, Seoul developed the Comprehensive Plan for Seoul's ITS Projects in 2000 by identifying 16 ITS projects encompassing: traffic information, public transportation, road and traffic maintenance, traffic management, and the pedestrian safety system. Today, the ITS evolved to an integrated approach to manage the entire transportation ecosystem with a functioning organisational structure to fulfil the Seoul Transport Vision 2030.

A comprehensive public transportation system reform, particularly the public buses, was undertaken in 2004 as traffic congestion worsened and public bus ridership drastically reduced. Before the extensive public bus reform in 2004, bus operators were only serving profitable routes, resulting in poor public bus services, although the metro system had a competitive edge in reliability. The public transport reform in 2004 led to a semi-public bus management system so that the Seoul Metropolitan Government (SMG) could better manage and control the operation and service management. Furthermore, integration of the subway and public bus services reduced inter-modal competition and enhanced public transport services. The public transportation information system (Bus Information System, BIS or Bus Management System, BMS), smart transport card, and exclusive bus lane were among the measures gradually introduced and are integral to the Seoul TOPIS.

The Seoul TOPIS can also be perceived as an institution that plans, develops, and operates an intelligent traffic system because the successful software use hinges upon a functioning institutional setup that enables collaboration. The institutional arrangement involves 13 parties, as illustrated below in , joining forces in terms of data sharing, response team, maintenance, information processing, and information communication. While private sectors are not actively involved, they also use the Seoul TOPIS data to create online map services for traffic forecasting and live traffic updates in smartphone apps. The overall institutional setup and components of TOPIS are shown in Figure 10 below.

Figure 10 Institutional setup of the Seoul TOPIS *(Source: https://topis.seoul.go.kr/eng/page/service_1.jsp)*

As Seoul TOPIS is more than just the platform or the control centre, it enables collaborative city management involving the Seoul Police Agency, Seoul Traffic Broadcasting, Korea Meteorological Administration, Regional Construction and Management Administration, and the Korea Expressway Corporation. Predicting and forecasting prompts science-based judgments and translates into real-time responses by mobilising the necessary responses or parties on-ground. In 2019, SMG also announced the Information Strategy Plan (ISP) to connect the entire Seoul with the Internet of Things (IoT) sensors and set up smart poles in downtown Seoul. The Smart Pole is a combination of streetlight or traffic signals equipped with Wi-Fi, Closed Circuit Television (CCTV), IoT sensor or display, facilitating live updates of the public internet services, public security and environmental information.

Complementing that, SMG is actively working on the IoT-based city data management system by creating a joint public-private big data platform as part of the smart city project. As a pilot project, SMG collaborates with two districts to set up ten smart poles with a Korean Won (KRW) 600 million investment (USD 507,000) (Korea IT News, 2020). Once successful, this will be the pioneer of the Seoul TOPIS Portal, which SMG plans to launch in November 2021. The Seoul TOPIS Portal is a comprehensive big data open platform for integrated transport data disclosure, sharing, and utilisation in real-time with data from both the public and private sectors to provide a one-stop service and real-time utilisation (Seoul Metropolitan Government, 2020). The continuous investments reflect SMG's political commitment to continuously upgrade the smart city management system to address transportation issues in an integrated manner.

Seoul TOPIS is a real-time and round-the-clock traffic information and communication system to provide science-based traffic administration support. It collects traffic information from the BMS, the Smart Transportation Card System, the unmanned surveillance system, and traffic authorities and institutions. Operated by four teams and 150 employees, the TOPIS system underwent three main phases of upgrading, from "cutting-edge" era (TOPIS 1.0) to "Openness" (TOPIS 2.0), to what Seoul operates today under "Collaboration" (TOPIS 3.0) with more specifications continuously enhanced:

1. 2005: Establish the Traffic Information Integration system to connect the traffic information control centre to manage the general traffic situation
2. 2006 – 2007: Expand the TOPIS support system for strategic decision-making process by integrating the operating system for subway and public bus services, connecting the traffic signal systems, and expansion of public services
3. 2008 – 2009: Enhance the TOPIS system to be an intelligent metropolitan management hub for transportation, disasters and security-related incidences, also known as TOPIS 3.0
4. The core of the Seoul TOPIS processes can be summarised as data collection, data processing, and information provision through various communication channels and responses with different functionalities.

An overview of how the Seoul TOPIS system works with its core functions is illustrated in Figure 11 below.

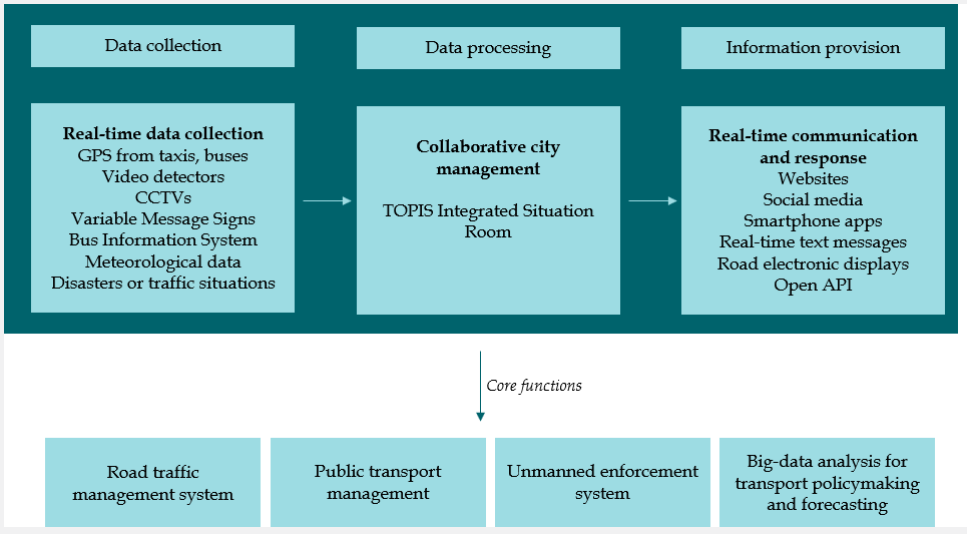


Figure 11 How the Seoul TOPIS work and the core functions

Road Traffic Management System

Data collection: Basically, the transportation information system collects data from the smart transportation card, the Global Positioning System (GPS) of buses and 70,000 taxis, 1,955 video detectors, 849 CCTVs, 341 Variable Message Signs (VMS), bus information system to process the data and information in the TOPIS

Integrated Situation room or the control centre located at the Seoul City Hall. The #5 Lane Control System (LCS) is also operated at 95 locations. Information about the speeds, locations of buses, taxis, subways, traffic volume and flow, meteorological conditions, unexpected situations, and others are all part of the collection system. The GPS installed in taxis collects real-time information to calculate travel speed, collected through wireless communication between the GPS in vehicles, wireless communication devices, and road-side monitoring and detection systems (Lee, 2017). The vehicle detection systems are installed every 200 to 500 metres (m) on highways, such as loop and video detectors, to collect the traffic volume. Coupled with surveillance cameras and the meteorological information system, the system collects integrated climate information, the state of the road, temperature, and visibility from the National Police Agency, the Meteorological Administration, and civilians.

The metropolitan smart transportation card is another vital data source, which is made possible through the Metropolitan Unity Fare System, which allows commuters to pay on a distance basis, covering Gyeonggi Province and Incheon Metropolitan City. Two of these neighbouring Province and Metropolitan City are crucial sources of incoming and outgoing traffic, therefore the data is also essential for intercity travel.

Information provision: Communication and response: Seoul TOPIS conducts big data analysis at the control centre through a series of information analysis, processing and diagramming to provide an operations plan and prompts responses based on predictions and extensive data analysis, which enable the prevention of transportation issues on-site before they occur.

The resulting information and decisions are communicated and illustrated through websites, social media, smartphone applications, real-time text messages, electronic displays on the roads, and open API. Through a

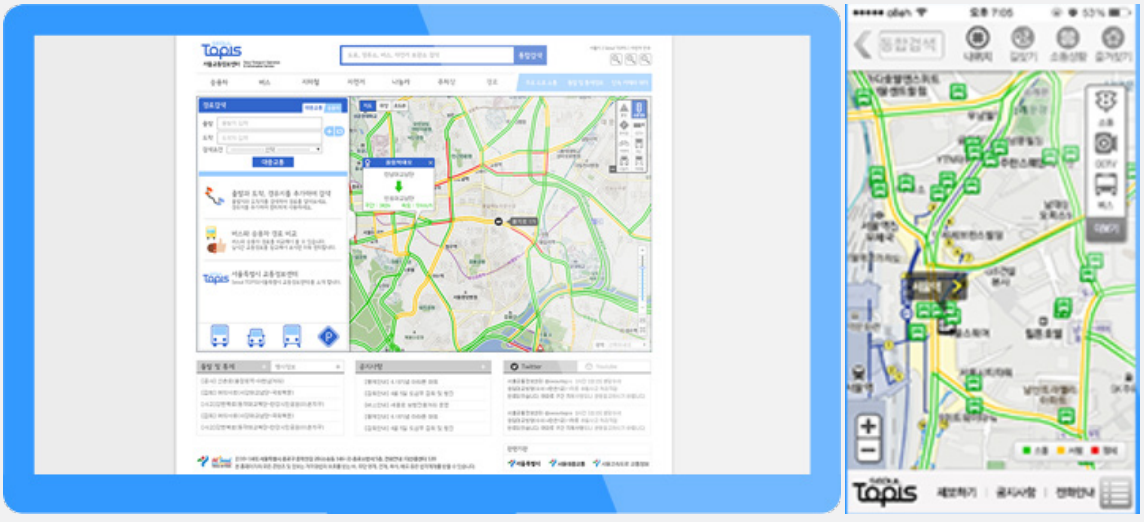


Figure 12 TOPIS System service display on the website and mobile phone (Photo: topis.seoul.go.kr)

real-time and interactive display of traffic information, road users are able to select alternative routes or transport modes. In the event that an unexpected road situation occurs, it will be automatically detected through video or detector and displayed electronically in the control room. The road control system will be activated to redirect traffic flows through bypass roads or orienteering the traffic signal control system to adjust the duration of traffic signals. Users can also go to the Seoul TOPIS website or the smartphone application to get real-time information on road transport, public transport, car- and bike-sharing systems, as seen in Figure 12.

Public transport management: As part of the Seoul TOPIS, the BMS has a two-fold function:

- ***Enhance the policymaking process*** by evaluating the public transportation companies' operation and passenger travel information to optimise the bus and subway routes, bus stop location and overall service quality.
- ***Manage bus operation information in real-time*** Bus Information Terminal (BIT) to improve the service quality of public transportation.

The city installed the BIT at 78.2% of all bus stops to provide commuters with real-time bus location information, arrival and departure time, seat availability, and bus route information. In the event of congestion, the system also recommends commuters a detour to enhance the commuting experience. In addition, bus arrival information is installed in all the buses with an accuracy level of 99% and a satisfaction level of 96% (Seoul Solution, 2021).

In addition to the BMS, the carsharing and bike-sharing systems provided by the Seoul Metropolitan Government are centrally managed through Seoul TOPIS by providing users with essential information, such as docking stations and availability in real-time. However, the city has yet to leverage the city bikes and spatial data collection to optimise bike routes, a potential area to enhance cyclability.

Unmanned Enforcement System: Seoul TOPIS operates about 336 unmanned enforcement systems to strengthen enforcement in road traffic regulation violations. The system detects the number plates of the cars at the no-parking or no-car lanes and automatically searches the car owner's details and address through the Vehicle Registration Management System of the Ministry of Land, Infrastructure and Transport to issue the electronic fine physical photographic evidence via the Post Office. From detection to the ticket issuance process, the entire process takes only two to three days, making Seoul one of the fastest enforcement systems.

Similarly, the Seoul TOPIS also automatically detects and imposes fines on Grade 5 vehicles that should not be in the Green Transport Zone (GTZ). The GTZ is a low-emission zone, whereby Grade 5 vehicles are prohibited from driving, except for emergency vehicles, vehicles for people with reduced mobility (PRM), and other exceptional cases. Again, Seoul enforces it for real-time monitoring and notification.

Big data analysis for transport policymaking and forecasting: Around 100 million road and public transportation traffic data is collected daily. Smart transportation cards (known as T-money transport cards) are used about 13.9 million times each day, transacting about KRW 225.2 billion of transportation fares in buses (98.7%), subways (100%) and taxis (67.4%). The smart transportation card is another big data source, with about 85 million transportation card data collected daily, of which are approximately 26 million real-time data from operations (speed and locations) of buses, taxis, and subways. Coupled with socioeconomic indicators (e.g., automobile ownership trend, land use), a large amount of big data is used to diagnose bottlenecks in congested areas and optimise public transportation services or create new services. For example, adjusting the bus route or the subway time interval based on commuters' travel patterns or creating the night bus routes (Seoul Solution, 2021).

IMPACTS

Based on the FTMS Phase 1 implementation between 2003 and 2007, the social benefits were obvious: 176,189 million KRW saved from reduction in travel time; 38.383 million KRW reduction of energy consumption from operational costs; and 3,829 million KRW of air quality improvement were seen because of the drop in vehicle-kilometres travelled (VKT) by private vehicles.

While it may be difficult to attribute the introduction of Seoul TOPIS directly reduced carbon emissions from transport, the Seoul TOPIS system increased public transportation efficiency and better planning of private vehicle journeys and trips by managing congestion. Therefore, it is a means to reduce the VKT by private vehicles, which results in the reduction in energy consumption in the transport sector, as presented in Figure 13. Based on the figure, the use of petroleum in the transport sector has been decreasing since 2010. In 2017, the energy consumption for Seoul's transportation sector is 4,150,000 tonne-of-oil-equivalent (TOE), of which 89% is powered by fossil-based, and the remaining 11% is powered by city gas (7%), electricity (3%) and renewables (1%) (SMG and Seoul Institute, 2020).

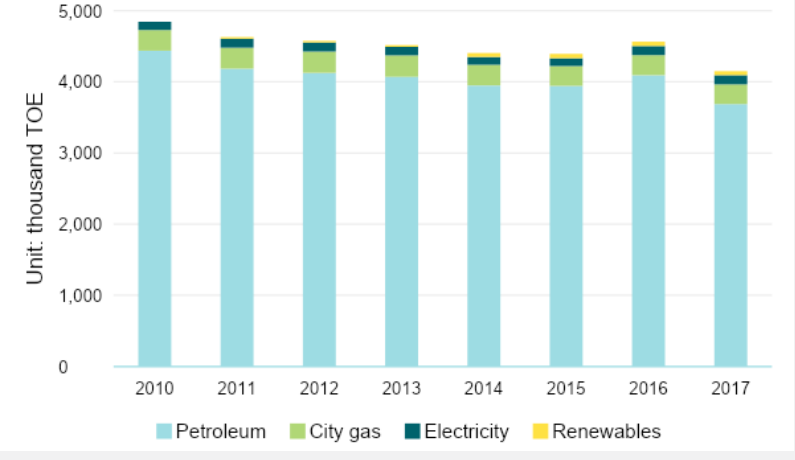


Figure 13 Energy consumption in the transport sector of Seoul (Data source: SMG and Seoul Institute, 2020)

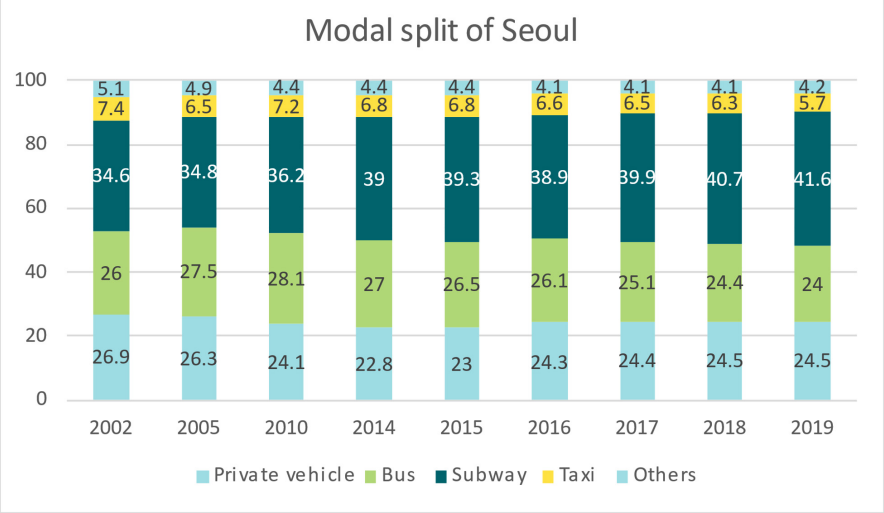


Figure 14 Trend in public-private transportation modal share (SMG, 2021)

Introducing the Seoul TOPIS is not just about an ITS system, it also catalysed innovation in line with the digital revolution, in connection with autonomous driving, connected vehicles, 5G-infrastructure, and digitalisation. This positions Seoul as the world forerunner in advanced technology and attracted various start-ups and funding in new mobility ecosystems, spurring innovation, employment, and high-end specialised industries. The increase in public transport usage and reduction in private transport usage can be observed over the years as shown in Figure 14 below.

The Seoul TOPIS collects data from about 70,000 taxis and 1,955 video detectors in real-time to effectively provide immediate response and policymaking due to the amount of big data available. As a result, the bus arrival information and bus service operations boast an accuracy of 99% and 96% satisfaction rate, respectively.

The continuous upgrading of the system reflects the interests and demand from the users, the commuters themselves. Since December 2020, the Seoul TOPIS has also provided the MyData service, a customised travel service that analyses individual travel behaviour through AI technology. Once the user agrees to collect personal information, the AI analyses the commuter's travel patterns across the public and shared transportation services (e.g., bus, shared bikes) paid by a credit card. This will customise and recommend the best route in real-time based on transport forecasting, e.g., traffic, weather situations, demonstration activities, and others. During the COVID-19 pandemic, MyData also shows travel routes of confirmed COVID-19 patients to avoid travel overlap with any patients. In the future, it is expected that the role of big data will be more prominent in customising the travel of each individual and for policy making.

FACTORS FOR SUCCESS

The factors for success are:

- The determination of SMG in reforming the urban mobility system and consistent strategies and interventions allowed the Seoul TOPIS to function well and meet the intended goals
- The phased approach to progressively introduce and upgrade the software and hardware of the Seoul TOPIS over the years
- The sustainable financing and innovative investment from the municipal budget and support from the national government
- Strategically leveraged on the public bus reform to maximise its impacts by complementing the software with effective institutional setup, bus-route negotiations with the private bus operators, and other municipal departments and agencies
- All transport policies and strategies are well aligned and led by the SMG Transportation Bureau, enabling a unified approach in fare collection, data collection, information processing and policymaking
- Korea has a vibrant and advanced technology, including ITS, IoT, ICT, with active participation and investment into innovation and research and development (R&D) by private companies
- A series of negotiations and collaboration with the taxi companies, bus operators, and multi-stakeholders, including the police authorities, fire stations, and others, to reach a consensus to set up a central transportation management system and the response structure.

LESSONS LEARNED

While the software system can be easily replicated, the core of the successful implementation is the institutional setup, consistent transport strategy that prioritises public transport over private vehicles, and financial resources for public transportation. Some of the short-term opportunities for cities are:

- Begin with a pilot to collect data, preferably public transportation data, through a smart card system
- Agree with an institutional setup involving the relevant stakeholders for data-sharing
- Adjust the traffic signal system also to ensure that the time priority is given to public buses or pedestrians
- Identify opportunities to enhance the public bus system and services by working on the Bus Management System or Bus Information System, which are essential to an ITS that favours public transportation
- Leverage on existing public transportation improvement or reform efforts to use technology as a means to support the reform goals
- Work with the existing data and resources, whether it is a formal or informal transportation services

In the medium-to-long term, a sustainable financing model is necessary to ensure continuation. This can also be complemented by better public transport infrastructure, e.g., building exclusive bus-only lanes, upgrading public bus stops, creating a Mobility-as-a-Service application, expanding public transportation, and sharing mobility services to enable multimodal transportation.

In the long-term, SMG plans to tap upon the digital revolution in transportation by connecting with the automated driving industry and 5G-based connected cars. It is envisaged that by upgrading the system to high-tech road infrastructure, such as blind-spot and accident hotspot surveillance, traffic accidents can be reduced by over 30%.

One of the core elements of this system is data collection, which is evolving to be more customised and individualised. Users or commuters need to agree that such personal data collection, cyber security risks, and confidentiality are essential considerations for the city and the users. Currently, the regulations for cyber security are relatively weak in many countries and cities. At the same time, many daily users may not be skilled to understand the intricacies of the data exposure, technological systems, and regulations, making them vulnerable to such risks. Therefore, the regulatory systems need to also be more progressive in line with the rapid pace of technological development.

CASE STUDY B2:
THE TTAREUNGYI PUBLIC BIKE SHARING SYSTEM IN SEOUL

The Seoul Metropolitan Government (SMG) introduced 'Ttareungyi' in 2015 as a main public bicycle rental service shown in Figure 15, to reduce road traffic as well as GHG emissions. Ttareungyi's cumulative membership exceeded three million in May 2021, meaning that one in every three Seoul residents has a Ttarengyi membership. Operating in 25 autonomous districts in Seoul, the shared-bike system has brought convenience to its residents, while also contributing to the city's carbon reduction.

It is found that the Ttareungyi is most frequently used during weekdays as a first- and last-mile transport mode after using other public transportation, such as buses and subways (Seoul Metropolitan Government, 2021a). According to the "Seoul Transportation Data Report 2020" published by SMG in March 2021, the number of public transportation users has dropped 26% in 2020 compared to 2019 due to COVID-19 outbreak, while the number of Ttareungyi users has increased 25% in 2020, compared to the year of 2019 (Seoul Metropolitan Government, 2021b). By September 2021, the cumulated number of public bicycles users reached more than double the number of 2019 users, reflecting the great potential of Ttareungyi in leading a sustainable mobility system in Seoul.

Figure 15 Ttareungyi *(Source: Seoul Bike Main Website)*

WHY HAS THE CITY TAKEN ACTION

Urbanisation and traffic congestion issues: Seoul has experienced rapid economic and population growth between the 1960s and 1980s. With an increase in income, the number of vehicles has increased sharply since 1980. Increased use of private cars has thus led to serious traffic congestion, where average roadway speeds were only 20 kilometres per hour (km/hr). This was followed by high levels of air pollution, noise, and traffic accidents. While Seoul's public transportation system is extensive and well-developed with buses and subways, first- and

last-mile journeys are filled by taxis, shared cars (Namun car) or by walking. Shared bicycles can bridge the gap to existing transport networks.

Climate change and the warming city: In 2020, Seoul's annual mean temperature reached 13.2°C, which is 2.4°C higher than in 1980 (Seoul Metropolitan Government Weather Statistics, 2021). Due to the overcrowded characteristics of the city along with high population density, Seoul is situated in a highly vulnerable situation where population, facilities, and natural environments can be severely affected by global warming, urban heat island effect, and extreme climate conditions.

GOALS AND OBJECTIVES

In 2013, the SMG announced its Seoul Transportation Vision 2030, which serves as a root plan for the city's entire spectrum of traffic policies by 2030. The Transportation Vision 2030 Plan is built upon three core values of 'People, Sharing, and Environment', seeking to shift the city's heavy dependence on private cars to a more sustainable, shared, human-oriented paradigm. With such expectation, the slogan "Livable Seoul without relying on cars" has been adopted, followed by 11 specific promises targeting three core values. Through this Vision 2030 and 11 promises, the city plans to achieve 'Triple 30' goals by 2030: reduce car traffic by 30%, shorten the average commuting time by 30%, and expand the use of different modes of green transportation by 30%. In managing the transportation demand, the city aims to lower unnecessary movement and minimise the need to travel by implementing different strategies to foster a "low mobility society". In managing transport supply, the city will also work toward shifting from energy-consuming transport modes to environmentally-friendly modes. The Ttareungyi project as part of this strategy aims to:

- Promote bicycles as one of the main transportation in Seoul
- Reduce GHG emissions by increasing cycling's modal share
- Improve residents' health through daily use of bicycles

PROJECT IMPLEMENTATION

Ttareungyi system is a dockless bike-sharing system. However, unlike the dockless bike-sharing system in other international cities like Beijing, Singapore, the Ttareungyi dockless bike-sharing system requires the cyclists to return the bicycles to designated stations to better organise the city space and prevent bike theft. The dockless bike-sharing system is supported by a combination of a bike-sharing network plan and an innovative application.

According to a report released by the SMG Urban Transportation Department, the total number of Ttareungyi operated in the city was 37,500 by 2020. In response to a growing demand for public bicycles since COVID-19 and to manage transportation supply, the city plans to operate a total of 40,500 bicycles by the end of 2021. SMG will further introduce 3,000 new bicycles next year, making the total number of bicycles 43,500 by the end of 2022 (Seoul Metropolitan Government, 2021). Its goal is to ensure people have access to bicycles within a walking

distance. Through this policy, Seoul aims to achieve its goal of 2,300,000 cycling transit per day, as well as the expansion of main bike roads by the year of 2025. The total budget in 2021 for shared bicycles is approximately 30 billion KRW (25.1 million USD) (2021 Seoul Metropolitan Government Transportation Office Report, 2021) The budget has been expanding every year since the first year of operation in 2015 as can be seen in Table 3 below.

Table 3 Budget for Ttareungyi service (unit: 1 million KRW) (Source: SMG Transport Division)

		2015	2016	2017	2018	2019	2020	2021	Total
Expenditure	Construction	964	2,485	14,395	7,132	9,928	10,047	26,280	71,231
	Operation	1,096	3,421	6,985	11,979	18,013	21,730	6,042	69,266
	Sum	2,060	5,906	21,380	19,111	27,941	31,777	32,322	140,497
Income		N/A	895	2,889	5,130	9,051	11,832	7,730	37,527

Ttareungyi application : Since 2020 March, Seoul Facilities Corporation (SFC), the facility-specialised public corporation responsible for managing major infrastructure in Seoul, introduced shared bicycles with QR code scanning function installed (Seoul Metropolitan Government, 2021). The users can easily unlock the bicycle by scanning the QR code attached to the bicycle, via the Ttareungyi application. This QR-code-attached-Ttareungyi is an upgraded version from the previous Liquid Crystal Display (LCD)-Ttaruengyi, which had durability issues, operated only through wifi installed in the rental centre and were vulnerable to weather. Since the upgraded QR code Ttareungyi is operated through Bluetooth installed in the rental station, bicycle and smartphone, users can easily find the location of the bicycles using the Ttareungyi application and unlock them easily. According to the Ttareungyi system general manager, Sangsun Kim, such Internet of Things (IoT) technology is one of the unique features of the upgraded Ttareungyi and the Ttareungyi application. The application also allows the users to check the accumulated amount of carbon reduced by the total travelling distance using a bicycle, strengthening the image of eco-friendly low-carbon transportation of Ttareungyi.

Management of Ttareungyi: The Public Bicycle Team under the Transportation Department in SMG is responsible for the construction of bicycle lanes and relevant infrastructure. Since March 2016, the SFC has been contracted by SMG serving as an implementation agency of the Ttareungyi initiative. Currently the contract is until 2025, however it is likely that SFC will continue serving as a main operating agency for Ttareungyi. The Public Bicycle Management Office within SFC is currently (end of Sep, 2021) divided into four teams: operation, system management, general management, and maintenance team as seen in Figure 16 below. The operation team is in charge of managing the budget and revenue, as well as promoting Ttareungyi. The customer call centre consisted of 45 employees working directly under this operation team, responding to Ttareungyi users' concerns and suggestions. The system management team is responsible for the Ttareungyi application and unmanned rental and return system. The general management team is responsible for the general maintenance of the whole

Ttareungyi system while managing two management offices: Gangbuk (the metropolitan district north of the Han River) and Gangnam (the metropolitan district south of the Han River). The maintenance team is responsible for general maintenance of bicycles. Currently, there are six maintenance centres in Seoul, located at Sangam, Isu, Yeongnam, Gaehwa, Jungnang, and Training Centre.

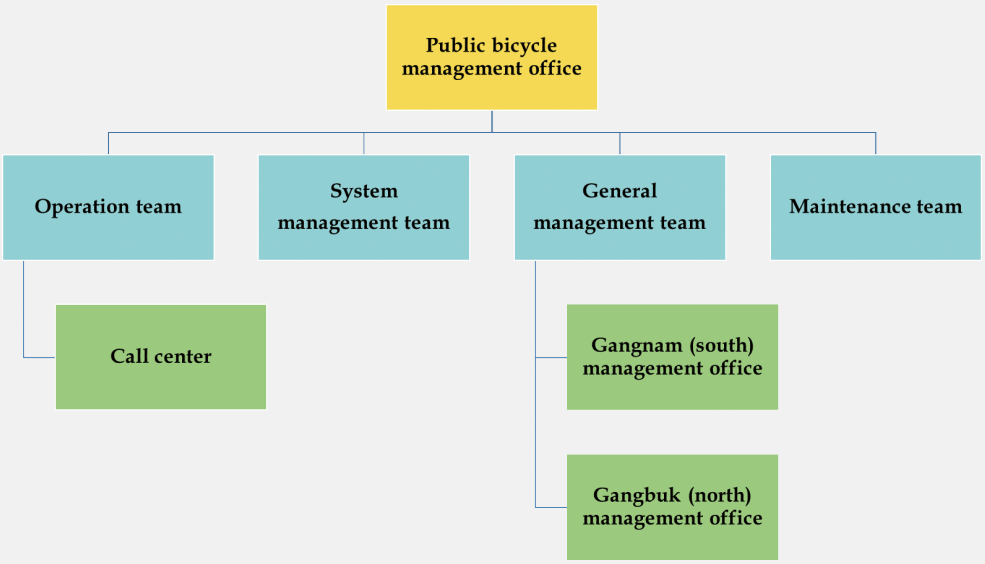


Figure 16 Seoul Facilities Corporation Public Bicycle Management Office organisational chart (by Sep, 2021)

Expansion of Ttareungyi: To accelerate expansion of the programme, the SFC accepts requests for constructing the Ttareungyi bike stations via its main Ttareungyi website. A rental centre is largely composed of bicycles and bicycle racks, and can only be installed in areas with a sidewalk width of 3.5 metres (m) or more and a length of 5 m or more. Moreover, there has to be no interference with raised blocks for the visually impaired or with nearby facilities, such as fire hydrants. The location has to be considered as well, as there should be no difficulty in delivering bicycles, meaning that the bicycle rental centres cannot be constructed in a congested area or a spatially small area. If a requester wants the centre to be installed on a private land, the consent of the property holder is required. In the case of apartments, tenants' and owners' consent are required. Similarly, for the centres to be installed within the university campus, an official request by the university is required. If a store owner applies for a rental centre in front of the owner's store, the bike-sharing station can be named after the store name .

Bicycle lanes: Bicycle lanes are essential infrastructure needed for the effective operation of Ttareungyi rental service. The total length of bicycle lanes has expanded from 674 km in 2012 to 941 km in 2019, allowing the percentage of bicycle lanes to increase by 3.2% in the same period as can be seen in table 4 below.

Table 4 The percentage of bicycle lanes in Seoul (%) (Source: SMG Transport Division)

	2012	2013	2014	2015	2016	2017	2018	2019
Regular roads (km)	8,174	8,197	8,214	8,215	8,241	8,243	8,246	8,282
Bicycle lanes (km)	674	708	725	779	869	889	916	941
The percentage of bicycle lanes (%)	8.2	8.6	8.8	9.5	10.5	10.8	11.1	11.4

Bicycle Maintenance: As the number of bicycles in circulation expands, so too does the need for maintenance and repair. Broken shared bicycles are however backlogged due to insufficient manpower. Aimed at improving the efficiency of maintenance as well as revitalising alley business districts, the SFC announced on 30 March 2019 that it will start the "Ttareungyipo" project, in which the SFC will collaborate with local bicycle agencies in carrying out repairs and maintenance of public bicycles (Seoul Facilities Corporation, 2019) The SFC publicly recruited private bicycle dealerships wishing to participate in the Ttareungyipo project from 20-28 February 2019 through which 42 agencies were selected initially. According to the "2021 Ttareungyipo Operation Plan" released in January 2021, 100 to 150 local agencies will work together with SFC between March 2021 and November 2021, followed by the evaluation in December 2021. The SFC will first handover the broken bicycles to individual stores for repair, then rearrange them to public bicycle rental centres. The 2021 Ttareungyipo plan is also aimed at providing support to small businesses during the COVID-19 epidemic, by establishing a public-private maintenance cooperation system (Seoul Facilities Corporation, 2021). Thus, the Ttaruengyipo project is a great example of sustainable operation of shared public bicycles, as it allows more bicycles available to residents with faster repair processing and better quality of maintenance service.

"Bicycle riding ability certification": In order to foster safe bike riding culture, SMG has implemented a "bicycle riding ability certification" system in which the city provides financial benefits to people who successfully acquired certification after completing the safety education. People with the certification could receive a maximum of 30% deduction in the shared bicycles daily usage fee for two years, which is expected to encourage more people to use shared bicycles. Safety education is divided into two parts: online education via Google Meet and offline practical training, which can be registered at the Seoul Lifelong portal to acquire the certification (Seoul Metropolitan Government, 2021).

Shared bicycle safety training centre in metaverse platform "Roblox": Targeting teenagers and the younger generations, SMG is planning to introduce a shared bicycle safety training centre in the metaverse platform "Roblox", where participants can learn about traffic regulations and experience virtual bicycle riding by using avatars. The bicycle track in Roblox is designed similar to the real bicycle lanes used in the "bicycle riding ability certificate" examination, allowing young people to effectively prepare for the test. SMG aims to strengthen the safe bicycle riding culture, as teenagers' usage of Ttareungi increased by 8% between 2020 (Jan - July) and 2021 (Jan - July) (Seoul Metropolitan Government, 2021).

IMPACTS

The existence of the Ttareungyi rental service before the COVID-19 pandemic has reflected the city's resilience, as a number of people chose bicycles as a safe alternative transportation mode. Public transportation in Seoul is usually very crowded, especially during rush hours; therefore, many residents have voluntarily chosen to commute using the public bicycles to practice social distancing. According to "Seoul transportation 2020" published by SMG in March 2021, the number of public transportation users has dropped 26% from 2019 due to COVID-19 outbreak, while the number of Ttareungyi users has increased 25% in 2020, compared to the year of 2019.

The shared-bike system in Seoul has created job opportunities, especially during COVID-19 era. The SMG Job Policy Division is operating a "Ttareungyi Quarantine Team," which mainly consists of middle-aged people in their fifties and sixties. The team is responsible for sterilising bicycles and bicycle rental centres, as well as managing hand sanitisers for commuters. This Quarantine Team is evaluated as an exemplary case for local government job projects targeting socially vulnerable groups. A total of 200 workers were recruited in 2021, with 100 workers for the first half of the year and 100 for the second half. More specifically, 50 people were allocated to the metropolitan district south of the Han River and the other 50 in the metropolitan district north of the Han River (Seoul Facilities Corporation, 2021).

According to the SMG, the total amount of CO_2 reduced through using Ttareungyi is 55,472 tonnes, which was calculated based on the total distance travelled by Ttaruengyi (239,099,326,863 km) by a total number of 61,324,770 people. The fuel efficiency of a normal car is used based on the assumption that each bicycle trip replaces a car trip. In order to calculate the reduced amount of CO_2 (kg) per kilometre through use of Ttareungyi, the kilometre-travelled for Ttareungyi is multiplied by the fuel efficiency of a passenger vehicle.

FACTORS FOR SUCCESS

The management of bicycles through GPS and security system: In order to prevent bicycles from being stolen and to manage the operation of Seoul bicycles, SMG collects personal location information through the terminal attached to bicycles. Such security technology allows the city to operate Ttareungyi rental service in a more efficient way by making sure that bicycles are available for the wider public and not being used for an individual's personal use. This system thus allows Ttaruengyi to be managed effectively as an environmentally friendly public transportation.

User-friendly Ttareungyi application & QR code model bicycle: Ttareungyi application has allowed users to easily rent bicycles through its reservation system and QR code system. The users can first check out bicycles located nearby and make a reservation via the Ttareungyi application or the Ttaruengyi website. Moreover, the QR code model bicycle allows users to easily unlock bicycles just by scanning the QR code, attracting many users due to the ease of use and convenience.

LESSONS LEARNED

To stabilise the financial situation and allow the system to eventually self-fund itself without need for public funding, there is a possibility that Ttareungyi will run with the paid advertisements starting next year to compensate for the deficit of approximately 20 billion KRW (16.8 million USD). Even though this is not confirmed fully, there has been news reporting regarding this possibility since October 2021 (Huh, 2021). Although Ttareungyi, as a public service, is not fundamentally set up for gaining profits, the city has been exploring effective ways to cover some of the deficits. By upgrading the bicycles to QR model, the city has improved operational efficiency. According to the explanation material provided by SMG (Seoul Metropolitan Government, 2019), the city has aimed to save approximately 10 billion KRW (8.4 million USD) of operational and repair costs by replacing the terminals of Ttareungyi from LCD to QR. However, it may be challenging for elderlies to use the bicycles as it requires using smartphone technology such as scanning QR code via the Ttareungyi application.

In addition, the construction of the bicycle lanes is raised as one of the main challenges for expanding the shared bike system in Seoul, as many existing roads are constructed for private cars and buses. Building completely new bicycle lanes requires a huge finance budget, which is difficult to secure, especially with the deficit occurring in the operation of Ttareungyi service. Furthermore, there has been increasing concern on the issue of bicycles being parked everywhere - not in the designated returning spots. Although users can still find the location of bicycles via the Ttareungyi application, this will cause huge inconvenience for residents when walking and driving. Due to the reservation system in Ttareungyi application, there have been conflicts between users. There have been cases where a person has been waiting in the rental centre to rent a bicycle but it is no longer available because the other person has already booked it.

Additionally in 2019, a controversy was raised regarding the use of Ttareungyi as a means of transportation for the delivery business. According to the delivery industry, many couriers did not own any means of transportation often used Ttareungyi in operating delivery service, due to its low cost (Yim, 2019). The SFC, however, after receiving such feedback from users via the Ttareungyi application, put a brake on such business activities. According to the SFC, the use of Ttareungyi for profit or commercial purpose is prohibited based on Article 16 of Terms and Conditions of Use of Ttareungyi ("User's duties and responsibilities") (Seoul Bike Main Website, 2018). Based on these terms and conditions, the corporation sent requests to "refrain from using Ttareungyi for-profit" to several delivery agencies. There have been mixed reactions from the public towards SFC's action. While some have argued that it is necessary to prohibit the use of Ttareungyi for commercial purposes, others criticised that the prohibition is not justified and SFC has to consider couriers' situations better. Furthermore, commuting to work can be perceived as a commercial means to earn income. Despite the debate, SFC and SMG maintain the stance that the Ttareungyi bikes should not be used for commercial and delivery purposes as they are public property.

CASE STUDY B3:
PATHWAY TO FULL E-MOBILITY IN JEJU ISLAND

Since announcing the first comprehensive plan to expand the Electric Vehicles (EVs) in Jeju Special Self-Governing Province in 2015, Jeju has been actively working on navigating clean mobility and the long-term development of renewable energies. Jeju released its second and the third plan in 2018 and 2020 respectively to strengthen electric mobility implementation for both private and public vehicles and of 2020 achieved a EV share of 4.69% of registered vehicles about 4 times the national average. Today, more than 30% of electricity supply in Jeju is generated from renewable energy energies (Korea Trade-Investment Promotion Agency, 2021b). It is expected that the island will be powered by 100% renewable energy by the year 2030, which also enables the EV system to be net-zero carbon.

WHY HAS THE CITY TAKEN ACTION

Transportation is one of the key sectors with high greenhouse gas emissions, while also becoming the core to achieve the energy transition target. As a popular tourist destination,most tourists in Jeju use rental cars, as high as 65%, with a low share of public transportation use as the public transport system is not extensive. Proactive actions are required to decarbonise Jeju's development in the long run and electric mobility is identified as a strategic sector to drive clean mobility and renewable energy transition.

The renewable energy and mobility transition requires localised experience and business models. To engage the public and the private sector into this transition, Jeju has a series of uncertainties and concerns, such as how to plan for the transition, how to cope with electric mobility demand, and how to maintain the market while providing affordable choices for consumers. All of these all require long-term strategic planning and immediate responses to keep up with the changing market.

GOALS AND OBJECTIVES

Initiated in May 2012, the Carbon-Free Island 2030 Project in Jeju outlined Jeju's goal in energy transformation, committing to 100% renewable energy by 2030. It includes the following objectives (Korea Trade-Investment Promotion Agency, n.d.):

- Promote electric vehicles as the main transport vehicles to reduce greenhouse gas emissions;
- Adopt new technology and engage multiple stakeholders to achieve the transformation;
- Achieve energy self-sufficiency through renewable energy usage;
- Become the first city in the Republic of Korea to achieve a carbon-free and green growth model.

In August 2015, Jeju was elected to be the first province in the country to start the comprehensive plan for electric vehicles. By March 2020, Jeju released *the Third Mid- and Long-term Comprehensive Plan on Electric Vehicles*.

Together with the private companies, the city gradually phased out diesel vehicles and replaced them with electric buses.

PROJECT IMPLEMENTATION

Systematic planning is the core for Jeju's electric mobility development. To promote the usage of EVs, the Jeju Government provided an electric mobility ecosystem by integrating urban planning, transport planning, financial mechanisms and incentives, and stakeholder collaboration. The planning process also leveraged on close private sector involvement to build charging infrastructure, provide EV diagnostic services, and build advanced Energy Storage Systems.

- As of December 2018, there were 16,352 EVs registered in Jeju, which is up more than one-third of all Korean's. By December 2019, this number increased to 18,178 cars, 20.2% of the Korea EV fleet; while the ratio of EVs registered in Jeju is up to 4.69%, more than ten times the national level (Korea Trade-Investment Promotion Agency, 2021a).
- As at March 2020, there are 118 electronic buses operating in Jeju Province, used as public transportation accounting for 13.8% of the total 852 regular-route buses (Son, 2020b).

The same year, a survey on correlations between incentives and people's willingness to pay for the EVs, showed that incentive policies in Jeju encouraged people to purchase EVs (Kwon et al. 2018). It is estimated that 75% of existing vehicles will be replaced by electric ones by 2030, and greenhouse gas emissions will be reduced by 43% (Korea Trade-Investment Promotion Agency, n.d.). The new electric buses are also universally designed for people with reduced mobility, such as low-floor buses supporting the *Plan to Promote the Mobility of Vulnerable Transportation Users* for more inclusive and convenient public transportation.

Charging and Battery Swap Infrastructure: For private EVs, charging is the main part that science and technologies need to secure for their functions. Jeju EV Battery Industrialisation Centre is the one launched in June 2019, manages the whole process of the battery system (Korea Trade-Investment Promotion Agency, 2021a):

> *from warehousing of retrieved batteries to inspection, rating, and disposal—using blockchain technologies, which has laid the foundation for standardising battery performance testing. Such efforts are expected to help mitigate environmental degradation resulting from the disposal of used batteries, and identify new industry business opportunities using big data on EV batteries.*

Initially implemented as a public service by the local government, the high-speed chargers were insufficient to meet the rising demand due to the increase in electric vehicles within a short period of time as shown in Figure 17 and a survey showed that around 35% drivers had to wait for 10 to 30 mins to be able to charge

their vehicles. (Son, 2020a). To manage the lack of charging infrastructure, close collaboration with multiple stakeholders was key to the commercialisation process to attract investments from private companies. As the public charging infrastructure developed, paid chargers were also established in 2019 and the smartphone app 'Sky Blue' was introduced to the market. Users can gain points when charging their EVs through the public chargers based on their electricity usage and the points can be traded for local currency. Moreover, Jeju was demarcated as a regulation-free special zone for EV charging services in November 2019, which sparked another wave of investment from various enterprises (Korea Trade-Investment Promotion Agency, 2021).

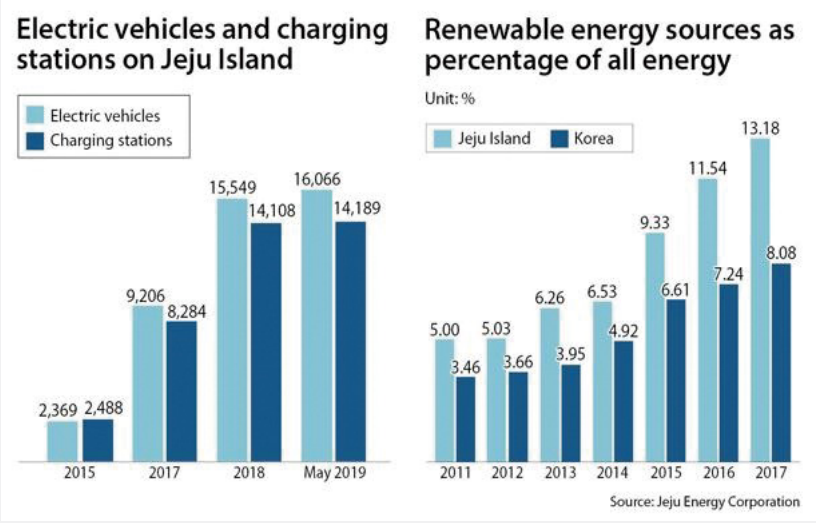


Figure 17 The development of Jeju's Electric Vehicles and renewable energy source, 2015-2019
(Source: Korea JoongAng Daily, 2019)

For public transportation, battery stations are designed to be located at the same location as the bus stops, where mid-to-long distance buses can get their batteries swapped. Supported by the battery-leasing program in Jeju, the battery replacement stations are installed at four bus stops across the island so that buses in the middle of operation can quickly replace their batteries with a fully charged battery. Since the battery is attached to the roof of the buses through a plug-in technology, it can be easily swapped in a short-time.

FACTORS FOR SUCCESS

The following factors are important for Jeju's successful electric mobility transformation (Jeju Self-Governing Province & Jeju Research Institute, 2018):

- High EV subsidy and tax incentives
- Reinforce dissemination of EVs for the public sector and businesses
- Expande the charging infrastructure in response to the increase of EVs
- Improve the convenience of using EVs through the charging call centre and safety education

- Allow EV users' to participate in the policy and incentive program
- Link the EV dissemination policies with Jeju's energy and environment plans
- Provide diverse opportunities to experience EVs and testrun, even hosting the annual Electric Mobility Expo
- Establish mid- and long-term EV plans with strong implementation.

LESSONS LEARNED

To provide systematic service to the EV system, Jeju Special Self-Governing Province's EV Battery Commercialisation Center was established in 2019 to strengthen the safety and security of the EV infrastructure and explore innovative technology for Jeju. Collaborating with other R&D institutions and private companies, the Center successfully developed the Energy Storage System (ESS) and a series of commercialisation pilots. In terms of waste management and recycling, batteries are either discarded, scrapped or reused as ESS units after performance examination and residual valuation.

C. Land use and nature-based solutions

Introduced in Chapter I, land use and nature-based solutions can through careful urban planning and design result in resilient cities with a lowered ecological and carbon footprint. In this section, we will provide a list of areas in which urban emissions could be reduced and resilience improved. In addition, nine successful case studies will be presented on achieving urban emissions reductions and resilience improvements.

Sustainable Urban Design and Planning

Mixing commercial, residential, public amenities and industrial places together in easily accessible transportation formats such as walking, cycling or public transport can greatly reduce emissions resulting from mobility required to access work and entertainment while park spaces provide green spaces as well as pollution and emissions control zones. Buildings where planned for long term habitation and conversion can also reduce total life cycle costs to the environment.

Urban Farming

Hydroponics, aeroponics or aquaponics when paired with LED lighting or natural sunlight on urban roof spaces can shorten the logistics of food to table distances from conventional agricultural farms and potentially result in reduced emissions, while also increasing urban resilience by bringing certain food sources closer to where they are consumed and reducing supply chain risks.

Constructed Wetlands

A means to deal with partially or treated sewage by reintroducing the water back into the natural environment to be evaporated and recirculated as rain again is constructed wetlands, which can also act as carbon sinks through the growth of plants.

Water Conservation and Management

Whether conserving water resources through collection of rainwater and mitigation of evaporation of reservoirs will build urban resilience to drought. In dry coastal environments, these measures can reduce the need for desalination. Proper water control measures can also mitigate flood damage due to sudden excess rainfall.

CASE STUDY C1:
TRANSFORMING A FORMER LANDFILL SITE TO AN ECOLOGICAL PARK - NANJIDO ECOLOGICAL PARK RESTORATION

Features of Nanjido, a small island home to various plants and animals, have been transformed in recent decades along with the paradigm shift towards environmental protection and conservation. When the environment was given less priority compared to social and economic growth in the 1970s and 1980s, Seoul city chose the island as a waste disposal site. Garbage dumping and landfilling continued for 15 years until two 100m-high garbage heaps were built up and consequent soil and water pollution worsened in 1993. Coupled with the economic recession in 1997 and the international movement to green sports events, the national and local governments began to view the island as a resource for a sustainable future. As a result, the Seoul Metropolitan Government (SMG) overcame economic, social, and environmental challenges by turning the landfill site into the World Cup Park with five thematic parks (Seoul Institute, 2014).

WHY HAS THE CITY TAKEN ACTION

Increased environmental awareness and international trends: With severe criticisms of environmental destruction caused by the 1992 Albertville Winter Olympics, the International Olympic Committee (IOC) introduced a theme of Environmental Olympics; since then, the Olympics safeguarded the environmental value to international sports competitions. Korea also joined this international movement, consequently facilitating the restoration of Nanjido (Korea Environmental Industry and Technology Institute, 2018; Seoul Institute, 2014).

A solution to overcome the economic crisis

In 1997, Korea faced a severe economic crisis. Upon receiving assistance from the International Monetary Fund (IMF), the whole nation was united in paying off the country's debt by launching the gold-collected campaign. People donated personal gold treasures to help the country out of its economic crisis (BBC, 1998).

As a part of efforts to handle the economic crisis, the transformation of Nanjido from a waste landfill site to an ecological park was perceived as an economic breakthrough in two ways: the creation of environmental conditions suitable for a stadium for the World Cup game; and developing the Sangam New Millennium Town as a new sub-center of the city (Seoul Institute, 2014).

GOALS AND OBJECTIVES

The continuous practice of waste landfilling on Nanjido island worsened its environmental condition and led to serious contamination. The need for improving the waste landfill management system arose and led to the revision of *the Waste Management Act* in 1996, obligating a need to review landfills for construction and closure. Furthermore, Seoul city envisioned the transformation of Nanjido into an ecological park by announcing three

plans.

First, in 1992, the basic master plan of the 'Seoul, Capitalization 600 Years-old capital city project' to celebrate the 600 anniversary of the capital suggested strategic development of five areas of the city including Sangam area (Seoul Metropolitan Government, 2015b). Second, the 'Sangam New Millennium New Town Basic Plan' carried out from August 1998 to May 2000 laid the administrative foundation for initiating the restoration of the Nanjido landfill site (Seoul Institute, 2014). Third, in 1999, the New Seoul Our Han River Master Plan released a development plan for changing three areas along the Han River - including Nanjido - to eco-friendly places to rest for citizens (G. Lee & Seo, 1999), leading to the goals:

- Recovering the environmental value of the island
- Follow the international trend in hosting sports games
- Contribute to overcoming the national economic crisis and developing a new sustainable city model

PROJECT IMPLEMENTATION

The 'Sangam New Millennium New Town Basic Plan' was carried out from August 1998 to May 2000. This plan was designed to develop a city model where the ecosystem for digital media industry, the work-life balanced environment, and urban environment restoration in an eco-friendly manner would be (Seoul Metropolitan Government, 2015a). The plan laid the administrative foundation for the transformation of Nanjido from the waste landfill site to an ecological park within the frame of urban planning. The Nanjido project contributed to the success of the 2002 World Cup and the development of the Digital Media City (DMC) of today and its reputation.

The planning for landfill stabilisation of the Nanjido was made from 1991 to 1996. With an international symposium in December 1999 as a beginning, four stakeholder workshops for constructing the World Cup Park on the island were held in the year 2000. The Cleaning Project Headquarter and Environment Management Headquarter of the local government monitored the development of landfill stabilisation basic plan and construction plan. Moreover, monitoring and managing the park after the restoration work needed continuous engagement of multiple stakeholders: 65 public officials, a civic organisation, and citizen volunteers (Seoul Institute, 2014; Seoul Metropolitan Government, 2015b).

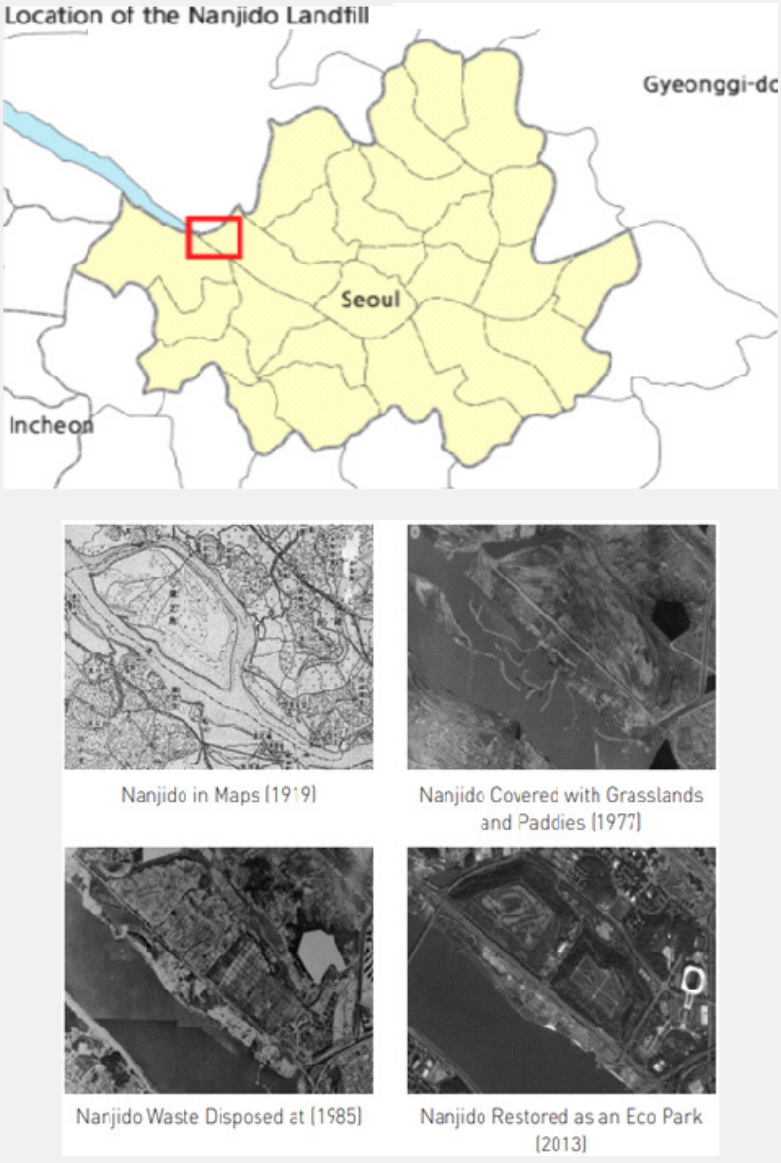


Figure 18 Location of Nanjido Landfill and the progression of the restoration project
(Source: 2014 Modularization of Korea's Development Experience: Nanjido Eco Park Restoration from Waste Dumping Site by the Seoul Institute)

A total of 235 million USD was spent in the implementation: 140.5 million USD for landfill stabilisation and 94.5 million USD for the construction of five thematic parks (Seoul Metropolitan Government, 2014).

In the World Cup Park construction process, five thematic ecological parks – Pyeonghwa Park, Haneul Park, Noeul Park, Nanjicheon Park, and Nanji-Han River Park – were constructed (Seoul Institute, 2014; Seoul Metropolitan Government, 2014, 2015b), shown in Figure 19 below.

Figure 19 Pyeonghwa Park (Top Left), Haneul Park (Top Middle), Noeul Park (Bottom Left), Nanjicheon Park (Bottom Middle), Nanji-Han River Park (Right)

The restoration work was implemented in two phases: landfill stabilisation and construction of theme parks. As the plan was to restore the ecosystem without removing the existing garbage on-site, landfill stabilisation was an important process and fell into four categories. First, in terms of the treatment of leachate, a shielding wall was installed under the ground to prevent leakage of leachate from the dump site; 31 leachate collection wells were installed on the inside of the shielding wall to collect the leachate amounting to about 1,860 tonnes a day; the leachates sent to the treatment facility for purification. Second, in terms of the collection and treatment of landfill gas, the 106 landfill gas collection wells were installed on the upper part and sides of the landfill to extract landfill gas from waste heaps; landfill gas was collected and sent to the treatment facility through a 14,050m-long gas pipe; the landfill gas was used as fuel for a regional heating system. Third, in terms of the construction of grassland, multiple layers of soil and vegetation with a water shield layer (HDPE) were installed to not only prevent rainwater penetration and underground water pollution but also create environmental conditions favourable to restore vegetation. Fourth, in terms of slope stabilisation, slope safety devices were installed to prevent slope collapse and scouring (Seoul Institute, 2014; Seoul Metropolitan Government, 2015b). An overview of the stabilised landfill site is shown in Figure 20 below.

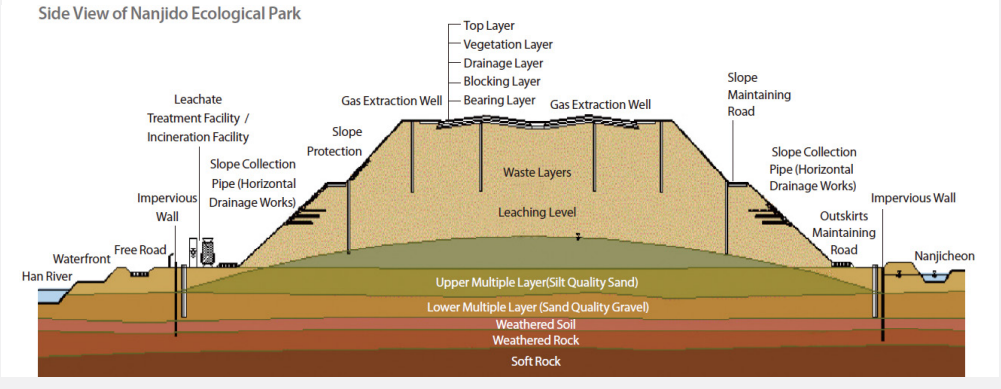


Figure 20 Side View of Nanjido Ecological Park *(Source: Seoul Metropolitan Government, 2015b)*

IMPACTS

Carbon reductions: Methane, one of the major gases generated from the landfill site, was no longer emitted into the air. Instead, it was collected into methane gas extraction wells under the ground and used as a fuel to provide heating for three public sites, 40 office buildings, and 16,335 households in the surrounding residential areas. Methane decreased from 8,523 tonnes in 2002 to 3,601 tonnes in 2013. Between 2002 and 2014, methane generated from the site provided 43,851,787m^3 of heating leading to a financial benefit amounting to 8.77 million USD (73,089 USD per year) (Seoul Metropolitan Government, 2015b).

Recovery of ecosystem: The leakage of leachate from the site decreased from 164.13 tonnes in 2004 to 70.99 tonnes in 2013. The alleviation of water and soil pollution led to enhanced urban biodiversity of both plants and animals. The number of species doubled within 13 years, from 438 species inhabited in 2000 to 1,092 species inhabited in 2013 (Seoul Metropolitan Government, 2014).

Tourist attraction: The World Cup Park has become one of the tourist attractions in Seoul city. For the past twelve years after its opening in 2002, 91 million visitors visited the place that tells a unique story of the successful transformation from waste-to-resource for a sustainable future and of the 2002 FIFA World Cup (Lim, 2014). In addition, the World Cup Park took up a new challenge beyond a simple tourist attraction. Connected to the digital media industry in the neighbouring area, the rich realm of species from plants to animals attracted public attention as a centre of the north-western region of the city (Park, 2020).

FACTORS FOR SUCCESS

Aligning with urban development plans proposed by the local government

Urban development plans presented by the local government helped the restoration project of Nanjido to be implemented in a systematic and inclusive manner. The engagement of the local government through three regional development plans between 1992 and 2000 led the project implementation to be aligned with a vision for a sustainable city and harmonised with the neighbouring areas.

Hosting the 2002 FIFA World Cup

The 2002 FIFA World Cup accelerated the project implementation in a short period and provided stronger incentive and justification for the national and local governments to invest in the transformation of Nanjido to an eco-friendly and cultural place. Thus, two approaches – landfill stabilisation and World Cup Park construction – were taken together to complete the project in a limited time.

CASE STUDY C2:
URBAN AGRICULTURE - SEOUL CIRCULAR FOOD CITY

As the capital of the Republic of Korea, Seoul city has experienced rapid urbanisation with characteristics of the modern society of today. However, the degraded urban ecosystem and weakened urban circular system are laid behind. They pose serious risks to the urban ecosystem and the physical and mental health of residents. In this context, Seoul city suggested urban agriculture as an inclusive solution to the challenges brought by climate change and urbanisation and began a journey to making the urban environment sustainable by transforming its resource consumption model from linear to circular. Since 2012, the city has laid the foundation for the urban agriculture initiative and promoted its practices through three phases. As of 2020, the city achieved remarkable progress: the development of three master plans; the adoption of 19 ordinances (19 times more than the level of 2011); the increase in farming sites to 202 hectares (ha) (6.9 times more than the level of 2011); the increase in the number of participating private organisations and cooperatives to 201 (100 times more than the level of 2011); the increase in the number of participating residents to 0.64 million (14 times more than the level of 2011); the increase in the number of activities to 44 (22 times more than the level of 2011); the increase in the annual budget to 13.7 million USD (19 times more than the level of 2011) (Economic Policy Office, 2020).

WHY HAS THE CITY TAKEN ACTION

A warming city with a lack of green urban spaces: Seoul city experiences warming from climate change. With green areas less than one-third of the total urban areas excluding streams and swamps (Seoul Institute, 2018), the urban environment covered by buildings and impermeable pavements makes the city vulnerable to adverse impacts including heat waves. For example, between 1960 and 2020, the annual mean temperature of the city gradually increased by more than one degree Celsius (Korea Meteorological Administration, n.d.). The number of days with daily maximum temperature exceeding 25 degrees Celsius and of tropical nights also increased with projections of long-term warming trajectories. The rise of average temperature in the urban centre was greater than that in urban areas near mountains (Cho et al., 2017).

Adverse impacts of urbanisation: Urbanisation level and growing urban pressures bring about societal and economic problems, such as the linear model of urban economy and resource consumption, economic polarisation, high unemployment rate, mental and physical health of residents, less interaction between generations, and an ageing society (Economic Policy Office, 2020). For instance, the linear urban economy shows a lack of a sustainable management system for urban resources. The city needs an innovative approach to bringing resources consumed in the city into a circular cycle locally while providing a comprehensive and durable approach to engaging residents in handling the challenges brought by rapid urbanisation while making a balance between economic, social, and environmental aspects.

The international trend of urban agriculture: From New York City to Berlin and London, the rise of urban agriculture and farming practices have grown in popularity, driven by the increasing awareness in the transformation into a liveable city with social inclusion. New York City has promulgated the legislative framework for urban agriculture with the scale of 550 Green Sun Farm, while Berlin operates urban farming projects in 6,700 *Kleingartens* (known as small gardens) and mandates new building projects development to allocate urban farming space. Meanwhile, London runs 763 allotments and 14% of local residents engage in urban farming (Economic Policy Office, 2020). Although South Korea has one of the highest food safety standards in the world, heightened consciousness on health, nutrition, and food safety drove the market demand for organic farming, permaculture, and sustainable practices instead of a commercialised food distribution network. This niche demand can be served by urban agriculture.

GOALS AND OBJECTIVES

- To contribute to the transformation into a circular, liveable, and climate-resilient city
- To tackle socio-economic problems brought by urbanisation from a holistic perspective

The Ministry of Agriculture, Food and Rural Affairs released the *Second Five-Year Plan for Urban Agriculture Development (2018-2022)*. It sets a vision of a happy life for both residents and farmers. The plan aims to lay the foundation for mutually beneficial relationships between urban and rural areas by introducing the concept of urban agriculture in a broader context and integrating environment, culture, and welfare dimensions into its practices (Ministry of Agriculture, Food and Rural Affairs, n.d.). The Seoul Metropolitan Governance (SMG) also released the *Seoul Urban Agriculture 3.0 Master Plan (2020-2024)* in 2020.

The plan visions a healthy city with one million urban farmers. The plan sets three strategies: site securing, engagement of local communities, and value promotion. With a 251.4 million USD of budget, the city will carry out nine tasks consisting of 27 projects by 2024 (Economic Policy Office, 2020). The Urban Farming Division is in charge of the promotion of urban agriculture in the city by developing master plans, implementing and monitoring projects, organising international events, managing memberships, and an online platform. Accordingly, the local government provides the administrative and financial frameworks for scaling up urban agriculture throughout the city (Seoul Metropolitan Government, n.d.).

There are different types of urban agriculture or small-scale gardening activities in Seoul with some examples shown in Figure 21:

- *Jaturi* (Spare space) gardens: where individuals grow food in spare spaces in the national land, public land, city land
- Rooftop gardens: where individuals grow food in rooftops at public buildings, housings, private buildings, religious facilities, universities

- *Sangja* (Box) gardens: where individuals grow food using boxes without space constraints
- *Singsing* gardens: where individuals grow food in rooftops and spare spaces at social welfare facilities with help from horticultural therapists and urban farming experts
- School gardens: where students grow food in spare spaces at schools and universities
- *Together-Seoul Eco-farms*: where individuals grow food in plots owned and provided by farmers in the suburbs of Seoul
- Urban agriculture complex centres: where individuals experience urban agriculture activities including farming, cooking, learning
- Smart-farm: where agencies grow food in spare spaces at their buildings with the application of Information and Communication Technologies (ICTs)
- Emotional support plants: where the elderly grow plants with help from horticultural therapists

Figure 21 Jaturi Gardens (Left) *(Source: (Shim, 2021)*, Rooftop Gardens (Middle) *(Source: Seoul Metropolitan Government, 2020b)*, Sangja Gardens (Right) *(Source: Seoul Metropolitan Government, 2019a)*

Composting - Turning food waste into natural fertiliser: Urban farmers grow vegetables and fruits in their farms using natural fertiliser. In the case of resource circulation farming as one of urban agriculture practices taken in a housing complex, food waste from households is sent to the composting equipment installed in the complex. Then, food waste is separated into liquid and solid waste. Effluent is sent to a wastewater treatment plant, while about 80% of solid waste turns into fertiliser. As a result, food waste is put back into the urban circular system as resources (Yang et al., 2021).

Hydroponics: Another unique technology used for urban agriculture is a smart metro farm. Unused spaces at the subway stations are converted into smart farms to grow easily grown vegetables, such as European lettuce, using the hydroponics system to reduce competition with local farmers. Special LED lighting, hydroponic growing trays, and smart control equipment are installed to monitor temperature, humidity, CO_2 level, and the lighting duration. By creating a favourable environment, hydroponics fosters vegetables growth at a shorter period compared to traditional farming practices that are land-based. Furthermore, locally produced vegetables are also fresher as they have shorter supply chain and transport duration. Such practice boosts local production and consumption patterns and, thus, reduces the food mileage and carbon footprint (Yang et al., 2021). A vertical indoor metro-farm using such principles is pictured in Figure 22.

Figure 22 Metro-farm at Sangdo subway station *(Source: Seoul Metropolitan Government, 2019b)*

IMPACTS

Carbon reductions: Urban agriculture contributes to the reduction of carbon footprint by promoting the consumption of local produce and, consequently, increasing food self-sufficiency of the city. Given that transportation accounted for around 19% of greenhouse gas emitted from the energy sector in the city in recent years, urban agriculture reduces the food mileage and carbon footprint (Climate and Environment Headquarters, 2021).

The healthy mind of residents and community bonding: According to the research conducted by the Rural Development Administration, urban agriculture has contributed to youth's physical and mental health and character building. For instance, improvement of dietary life increased to 66%, while aggression and hostility reduced by 20% and 18% respectively. Even amongst adults, urban agriculture fostered a better lifestyle and thus, reduced stress and depression by 56.5% and 20.9% respectively (Economic Policy Office, 2020).

Restoration of urban circular economy in terms of food: Urban agriculture increases resource efficiency by utilising untapped resources: unused lands, rainwater, and food waste. The spare spaces or lands around the housing complexes are reused as urban farming sites; harvested rainwater collected in the underground storage tank is used to water the urban gardens; and composted food waste are used as the natural fertiliser for the plants (Economic Policy Office, 2020; Seoul Metropolitan Government, 2020; Yang et al., 2021).

FACTORS FOR SUCCESS

Aligning with the national and local policies and plans: With support from the national and local governments,

urban agriculture in the city has been developed and expanded in a systematic way. The governments enacted laws and regulations; provided online and offline platforms engaging multiple stakeholders; and provided financial support to promote urban farming in the city (Economic Policy Office, 2020; Seoul Metropolitan Government, 2020). Under the legislative, administrative and financial frameworks set by the governments, the urban agriculture initiative has been expanded consistently and efficiently.

Engaging local communities: The residents' sense of ownership in urban agriculture is important to make the practices sustainable in the long term. In the process, the residents act as actors and implementers – more than beneficiaries. Residents have been engaged throughout the development and implementation phases to strengthen local networks. They raised their voices and consequently turned the governmental ideas and plans into practice in an effective way; thereby they have also contributed to the implementation of urban agriculture for the past ten years (Economic Policy Office, 2020; Seoul Metropolitan Government, 2020).

Comprehensive approach: It is noteworthy that urban agriculture takes into account multiple dimensions. Aside from the environmental considerations including the expansion of urban green spaces and the restoration of the urban ecosystem, urban agriculture tackles social and economic challenges simultaneously. First, urban agriculture promotes the paradigm shift from a linear urban economy to a circular one. Second, it contributes to residents' health by relieving stress and improving community fellowship. Third, it contributes to job creations (Economic Policy Office, 2020).

LESSONS LEARNED

Securing space for urban agriculture within space limits is a challenge. About 24 ha per annum of urban space in the city was changed to urban farm between 2011 and 2018. However, only five ha of urban space was allocated in 2019. Considering that about 0.75 million residents aged between 55 and 59 who would be interested to join urban agriculture will retire in the next five years, the existing farming spaces are not able to meet the upcoming demand. Thus, apart from utilising spare spaces, it is important that the local government takes such demand into account in land use planning (Economic Policy Office, 2020).

Furthermore, the limited capacity of organisations acting as a bridge between the local government and residents is another challenge. These centres bridge the gap between the local government and residents while providing practical support from education to the deployment of equipment (Economic Policy Office, 2020). Although the number of relevant private organisations and cooperatives dramatically increased from two in 2011 to 201 in 2019, most of them are new entrants. The limits exist in financial and personnel aspects and pose a challenge for them to initiate projects based on their own resources. In addition, the current five centres are insufficient to support the 0.64 million urban farmers.

CASE STUDY C3:
FROM GREY TO GREEN TRANSITION - ESSEN'S EUROPEAN GREEN CAPITAL PROGRAMME

Essen, a city of 590,000 people, is located in the North-Rhine Westphalia (NRW), Germany. In the heart of the Ruhr metropolis of 5.1 million residents, Essen has developed from its history as an industrial city of coal production and steel manufacturing into a green and vibrant metropolis. In the late twentieth century, with the decline of local steel and coal industries, the city needed a structural change, which was done successfully through a series of strategic vision and implementation plans. Essen won the title of European Green Capital of 2017 for its successful transformation from a grey city of coal and steel to the third greenest city in Germany (Early, 2018).

Essen closed its last coal mine in 1986. The city's economy underwent a transformation from coal and steel based to focus on service and finance, the latter providing 86% of the city's employment in 2014. In the grey to green transition, Essen now has extensive walkways and cycleways, over 20 of re-naturalised streams and rivers, and green areas that cover over 50% of the Metropolitan area, showing the city's ambition for a sustainable future (European Union, 2017).

WHY HAS THE CITY TAKEN ACTION

The need for structural repositioning to achieve economic prosperity and sustainability: The German Ruhr area, where Essen is located, used to be an industrial powerhouse of the German national economy in the early nineteenth century. However, in the 1970s, cheaper coal imports began to outcompete German production and drive down the price of domestic coal. The region took a deep dive economically due to the decline of its signature mining industry. At the same time, the region recognised the need for green development, as the residents have been long suffering from pollution due to heavy manufacturing. Moreover, the region suffered from degraded environmental quality and natural resources (Ramon, 2019; Bryce, 2017).

The people and leadership of the Ruhr Metropolis soon took action. The "Structural Change" approach jointly led by municipal and state leadership recognised the need to re-orientate the economic model in an environmentally friendly and people-centred way. This programme stimulated investments in education and infrastructure but more importantly in environmental protection programmes and urban renewal projects (Ramon, 2019). Ever since the reorientation, Essen rose to become a key leader in innovative sustainability strategies development and implementation and has also turned its industrial legacy into future opportunities.

GOALS AND OBJECTIVES

As the European Green Capital, in 2017, Essen initiated the European Green Capital programme to trigger sustainable processes and developments that will continuously secure, or even further improve the quality of life

in the city (Kufen, 2017). The goal of the programme is to eventually achieve:

- A model split of 25% (25% bicycle, 25% car, 25% public transport, 25% pedestrian) by 2025
- 20,000 green jobs by 2025
- Residents can have access to the nearest park within 500 meters (m) by 2020
- Reduction of CO_2 output by 40% by 2020, and 95% by 2050

PROJECT IMPLEMENTATION

The programme includes 453 projects and events, divided into five thematic clusters (city of Essen, 2017):

1. "**My paths**" describes all sustainable topics regarding mobility including, e.g., cycling, car-sharing, and public transport
2. "**My rivers**" focuses on the conversion of the Emscher system and of the project "ESSEN. New Ways to the Water" as well as the green and blue infrastructures associated therewith
3. "**My green spaces**" connects to a range of projects including public parks and green spaces and to the services they provide
4. "**My shopping**" encompasses the sustainable consumption lifestyle, including food production, fair trading, building materials, waste and recycling
5. "**My Future**" refers to new jobs, training and education associated with environmental topics and sustainability.

Of these projects, the city implemented 187 of its own projects, with 210 citizen projects and 56 conventions and conferences with more than 12,000 participants in total.

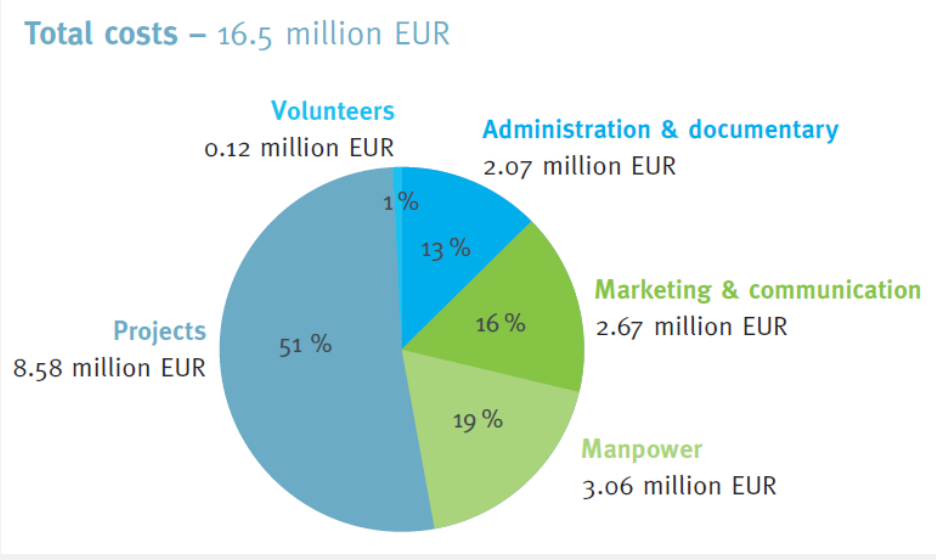


Figure 23 Total costs of Green Capital programme (Source: European Union, 2017)

As shown in Figure 23 below, the total budget of Green Capital of Europe – Essen 2017 is 16.5 million euros with over 50% spent directly on the projects. As for public sponsors, the Federal Government provided 4 million euros in funding and the State of North Rhine-Westphalia provided a further 6 million euros in funding. A total of 1.5 million euros from sponsors boosted the budget (city of Essen , 2018).

Moreover, the European Green Capital – Essen 2017 also gained support from more than 50 partners and sponsors at the regional and local levels. Their way of participation was diverse, including sponsorship provision in the form of financial or material resources, among others. A large crowd of supporters also contributed with their own programmes and projects to the Green Capital or are involved content-wise. Additionally, the project office generated significant media reach (European Union, 2017).

Through the year of 2017, support was obtained from three main sponsors, two premium sponsors, six co-sponsors, seven further sponsors, two foundations and 14 project sponsors. A total of 2.8 million euros were benefits in kind containing additional services, and 1.5 million euros in funding. Owing to general and project-specific sponsorships, numerous projects were made possible (European Union, 2017).

1. My paths – mobility for the future

The Ruhr Area region is characterised by cars, meaning the greatest potential for cutting down CO_2 emissions lie within the area. Essen used the Green Capital year to initiate a transport transition. By 2035, the city plans to achieve the modal split of: 25% of transport users travel by bicycle, 25% by public transport, 25% by foot, and 25% by car (Sustain Europe, 2017).

The city of Essen has been promoting sustainable mobility, showing from its hundreds of kilometres of cycle paths, a network of bike and car sharing stations with rising number of electric vehicles charging stations, and a well-developed public transport system. Residents are offered a variety of alternatives to their private cars (European Union, 2017).

Pedestrians: To raise the number of pedestrians in the city, walks for senior citizens have been held weekly in 34 city districts since 2012. In 2017, these also inspired other Green Capital in Europe. The initiative is known as "Let's take a walk" and is operated by the Senior Citizens' Advisory Board, the Senior Citizens' Department and the Health Conference. This initiative was repeated in 2018.

Bicycle Transport: Essen's cyclist commuters can access the Ruhr Bike Expressway RS1, Germany's first fast cycle path. In the city, the cycleway connects various tourist attractions, including the notable area such as the Krupp Belt housing major regeneration projects and is three times the size of the city centre. The cycle highway is expected to cover a distance of 101 km connecting 10 cities in total located in the Ruhr metropolitan area,from

Duisburg in the west to Hamm in the east (European Union, 2017). When completed in 2020, RS1 is expected to obviate 52,000 car journeys per day, and thus saving 16,000 tonnes of CO_2 per year (Sustain Europe, 2017).

Public Transport: With 590,000 residents, 140,000 commuters and a steady increasing number of visitors on business or pleasure trips, the city has been actively finding its solutions. While bicycles may well be the most ideal form of sustainable transport, Essen has invested in a variety of complementary approaches (European Union, 2017). In 2017, the region also opened two mobility stations, acting as central hubs connecting not only local public transport, but also other transport options such as car-sharing, taxis, and rental bicycles in a single location. The station also expanded its fleet to have the lowest exhaust gas emissions in the Ruhr Region. Other sustainable mobility initiatives, include the "Essen Mobil" app, which offers users intermodal navigation amongst other things, and the "GreenTicket", which is a monthly ticket subsidised by the European Green Capital and includes discounts by car and bike sharing.

2. My rivers – between the Emscher and Ruhr

Essen is a city of two rivers, Emscher and the Ruhr, as shown in Figure 24. The two rivers have shaped life in the city for decades. In the industrialisation era, the rivers were abused as sewerages. Therefore, an important part of Essen's green transition is actually blue infrastructure expansion projects that connect the Emscher and Ruhr Valley, with a focus on the two rivers and their local tributaries, their health and service to the community (city of Essen, 2017).

Figure 24 A visual representation of Essen and the two rivers *(Source: City of Essen, 2015)*

Emscher River Restoration: The rise of steel production and coal mining industry in the Ruhr area in the tenth century was a key contributor to the increased pollution level in the region, affecting the nearby Emscher River the most. Not too long after that, the 865 square kilometres (km^2) of the river basin became a dumping ground filled with wastewater from factories, slaughterhouses, mines, and local residents. More than a century later, the river was ultimately transformed into one of Germany's most polluted rivers that even destroyed the surrounding ecosystems (AFRY, NA).

In Essen, two-thirds of the wastewater is disposed of through the Emscher system. Due to coal and steel production, untreated wastewater was still being dumped into the Emscher until the 1990s. With the ambition to improve the water systems around the area and to restore the ecology of Emscher, the public water management association, Emschergenossenshaft, was founded in the 1990s and the conversion project commenced in 1992. For many years, the area around Emscher has been restricted from the public. The project's objective is to build underground wastewater systems as well as restore nature and increase biodiversity above ground.

The key project of the Emscher conversion is "ESSEN. New ways to water", which has been reflected in over 500 projects since 2005. By 2017, the city has re-naturalised 26 streams, and a few measures will be continued to be implemented till 2021. The idea is to connect the Ruhr and Emscher river valleys with a system of green belts and waterways, which is also shown in the logo of Green Capital City of Essen. The conversion of the Emscher River has played a major part in the city of Essen's green urban development over the past few years (AFRY, NA). Throughout the entire Ruhr region, 400 kilometres (km) of new sewers have been laid underground, 45 kilometres of which is within the Essen municipal area (Sustain Europe, 2017). The natural environment streams above ground have thus been re-naturalised and become free of wastewater and demonstrates the significance of modern water management infrastructure.

Restoring Activities to the Ruhr River: The Ruhr river has been closed to swimmers since the early 1960s (Early, 2018). However, for many local residents, the highlight of 2017 was the pleasure of swimming in Lake Baldeney, where a total of 7,000 visitors enjoyed the cold waters over the course of 47 days in the Seaside Beach swimming spot. In 2018, it is planned that the Ruhrverband, the Water management association responsible for Lake Baldeney, will optimise the early warning system allowing more swimming days in 2018. The project acts as an enlightenment for the entire region: the cities of Mülheim an der Ruhr and Bochum are making plans for their own river bathing areas, while the District Administration (Ruhr Peninsula) is considering making a bathing area at the Kampmannbrücke bridge.

3. My green

As the third greenest city in Germany and the first in North Rhine-Westphalia, the city of Essen has over 3,100 hectares of green areas and woodlands. The city is green throughout, with more than half of the municipal area

consisting of green areas and open spaces, such as water, fields, woodlands, and urban greens. With diverse parks and green areas, the city is unique in Germany (Sustain Europe, 2017; city of Essen , 2018).

Green urban development has been the driver of urban development in general over the last ten years. The creation and expansion of green spaces, water parks, footpaths, and cycle paths connected district areas and regions, thus laying the foundation for successful urban development of larger areas, and has served as a strategy of integrated adaptation to climate change (Sustain Europe, 2017). The municipal action programme, "ESSEN. New ways to the water", has created a total of 150 km of footpaths and cycleways between the Emscher Valley in the north and the Ruhr Valley in the south, erasing the urban separation between the north and the south in the Essen municipal area (Sustain Europe, 2017).

There are two parks in the city that also symbolise the city's structural change and adaptation to climate change through sustainable architecture, landscaping, and water management. From 2007 to 2012, a park was built on the location of the Krupp cast steel factory. The park has become a recreational space for local residents located at the edge of the city centre. The rainwater from the roofs of the ThyssenKrupp headquarters is collected to feed the lake in the park. The other is the Zollverein UNESCO World Heritage Site. Being a former coal mine, nature has reclaimed the areas. The diversity of species in the Zollverein Park is unique and astounding: 540 kinds of ferns and flowering plants, 100 kinds of lichen, and around 60 kinds of birds, 20 kinds of butterflies and 6 kinds of amphibians. A part of the resident species is also not original from the area owing to the transport of goods from around the globe resulting in rare plants settling on the grounds (Sustain Europe, 2017).

4. My shopping

In 2017, as the title holder, Essen is utilising the opportunity to shift the residents' expenditure into a more sustainable pattern. Essen has been promoting nutritious, sustainable and locally grown produce for consumption . A diverse range of associations, initiatives, and service providers in the city have long been promoting healthy diet, saving electricity, and making sustainable use of resources. Essen has long been acting as a role model for urban gardeners, with 9,000 allotment holders, 17 community gardens, and 14 farm shops (city of Essen , 2018). With fair trade products being readily available, Essen received certification as a Fair Trade Town in 2013 (European Union, 2017).

Events and Festivals for Awareness: As one of the several projects that fall under "My shopping", Essen organised a one-day event – **Day of Good Food** – in each of the seasons of spring, summer and autumn, to explore sustainable production and consumption of local food. Farmers, community gardens, allotments and other local producers were being encouraged to show their work, and cycle tours were scheduled along the line with the city's green corridors that connect the main sites on urban food routes (European Union, 2017).

Promoted under the joint title of "Sow, harvest, eat", each of the three seasonal events has a slightly different emphasis. In spring, the programme contains activities dedicated to sowing and gardening, while in summer, the programme offers an open-air party with cultural programmes. The event in autumn is flanked by an exhibition highlighting aspects of food production and nature conservation (European Union, 2017). Around 70 farmers cultivated a total of 3,000 hectares in Essen. Many products can be bought directly in the farm shops on-site.

Food Guide Awareness Raising: Essen's food guide, the "Good food in Essen" first published in 2015, has served as an inspiration for residents who are keen to explore new sources of home-grown produce. The new edition of the guide has been updated in 2017 (European Union, 2017). The guide outlines information on various aspects ranging from traditional and organic agriculture, climate change and natural resources preservation, as well as packaging and waste. Other contents include urban gardening, fair trade, and main logos that identify organic produce (European Union, 2017).

The second part shows a variety of businesses in Essen from farms and community gardens to shops and restaurants that fulfil the guide's criteria. The objective is to highlight suppliers of organic, seasonal produce grown in and around the city, prioritising artisanal manufacturing over industrial processing where applicable. Fair trade shops are also included, widening the scope to source imported products with more sustainability (European Union, 2017).

Incentivisation for Behaviour Change: The city has been promoting the **"greenApes" app** since 2017, an application for sharing information on ways to adopt a sustainable lifestyle. Commuting by bike, buying "local root" products or recycling, is rewarded with points redeemable in several shops (European Union, 2017).

5. My future

Jobs of the Future: The structural change in Essen has also brought about new, green opportunities for the city's residents. The city is fostering green jobs, education, and training that ties with sustainability. By 2025, it is expected that the number of green jobs in Essen will grow from 13,000 by the end of 2017 to 20,000.

The old industries jobs have been replaced by new green jobs that have strong ties to sustainability. It is worth noting that green jobs have been created in the energy sector, where major providers based in Essen are pursuing innovative production. A plenty of small and medium-sized enterprises specialise in environmental technologies, and further activity focus on resource efficiency. Moreover, training and education are readily available for green careers in a diverse range of additional areas, such as water resource management, hydraulic engineering, and horticulture (European Union, 2017).

Underground Sewer System: The unstable soil and high risk of subsidence caused by mining is one of the

technological challenges that the construction of the new underground wastewater system has been dealing with. The sewage system is built using pipe jacking at 40 metres deep under the ground, which in turn, created a need for renovation and modernisation of the existing wastewater treatment plants. Previously, the plants processed and purified the water from Emscher, handling about 30 cubic metres (m^3) of water per second. Now, only the wastewater is collected and channelled to the treatment plants with the new sewage system, making the plants more efficient (handling 15 m^3 of water per second) (AFRY, NA).

The Emscher wastewater sewer was designed as an armoured concrete sewer. The future wastewater will stress the sewer to a high degree so that clear answers had to be found as early as the planning phase for material questions, questions of corrosion, aeration and ventilation as well as for health and safety issues. For the Emscher wastewater sewer a minimum utilisation period of 100 years was established.

With regards to the system and operating reliability of the Emscher wastewater sewer designed as a mono-pipe sewer, Emschergenossenschaft has come up with a special solution. If a section of the sewer failed, the wastewater would be passed on by means of pumps and of temporarily installed pressure pipelines. The limits for this solution are a delivery rate of $3m^3$ of water per second and a depth position of 25m. Where these limits need to be exceeded, even today the Emscher wastewater sewer is already built as a dual pipe sewer.

Behavioural Change: The sustainability focus is reflected in various activities that Essen is advancing as a part of its Green Capital programme, in the form of a number of projects dedicated to the theme "My future". Initiatives and projects involving kindergartens, schools, associations, and business, along with the general public, are helping to cultivate a new green mindset.

Environmental education starts at a very young age. A wide range of kindergartens, child day-care facilities and schools was immensely committed in 2017. Children participated in activities to raise beds, plant colourful gardens or learn about the method of waste avoidance and separation.

ICT Technologies: An integral part of the transition to a greener, cleaner lifestyle is to inventorise carbon emissions at the consumer level. The GreenApes has developed a game that allows consumers to earn points called BankoNuts throughout the day for engaging in behaviours that are considered low-carbon (e.g., carpooling, using green energy, biking or buying organic products). The Apps focus mostly on what consumer level actions contribute to the transition to a low carbon society.

IMPACTS

Tourism in 2017:

- 500,000 additional visits to Essen motivated by business and tourism

- 1.1 million people visited the green oasis in the city centre, an increase of 7.5% compared to 2016
- The number of overnight stays increased by 6.9%
- Growth of 8% in available tours and participants

Biodiversity:

- 100,000 flower bulbs and 50,000 perennials were planted along the main traffic arteries of the city to promote biodiversity.
- More than 1,100 trees were planted
- More than 800 species were counted at Zollverein Park

Water supply:

- A total of 26 re-naturalised streams and rivers.

FACTORS FOR SUCCESS

The deep involvement and commitment of the municipal authorities, from the Youth Welfare Office, the Schools Administration Office to the Building Administration Office and the Environmental Office, are the driving force for the project. Close collaboration with Essen's residents, the businesses, scientists, industries on the projects and activities also built collective buy-in efforts that helped to push the naturalisation and rectification efforts.

In total through the programme, a total of 158 volunteers came to provide assistance, with 30 sponsors in the main sponsors, premium sponsors, co-sponsors, patrons, and project sponsors categories supporting the Green Capital programme with funding and benefits in-kind.

LESSONS LEARNED

After the conclusion of Green Capital year 2017, the city of Essen continues to pursue its goals. The Green Capital experience will be brought into the newly founded "Green Capital Agency". The aim of the establishment is to design strategic measures for the long-term goal and achievement of the targets developed in the application. The successful projects from 2017 still persists, including resident's initiatives, the volunteer network, the "green islands" in the city centre, participation in European Mobility Week, and environmental education in the Nature School. Engaging in important networks and the implementation of technical events are also planned to further promote regional and international communication (Green Capital Essen Project Office, 2018).

The European Green Capital 2017 marks the opening of a green decade throughout the entire Ruhr area. Coal mining ended in 2018 and the Emscher conversion will be completed in 2020, the results presentation of the KilmaExpo.NRW and the Climate Metropolis Ruhr will take place in 2022. Ambitious targets have been set by the Ruhr metropolis, and the successful transition, which has earned the recognition of the EU Commission, will continue. The city of Essen will continue to develop itself to be a more climate-friendly, low carbon and resilient city which provides a high quality of life for its residents (Sustain Europe, 2017; European Union, 2017).

CASE STUDY C4:
RAIN CITY INITIATIVE - SUWON WATER RESOURCES MANAGEMENT

The name of Suwon city literally means "water source", derived from the characteristics of the local environment with abundant water sources. However, contrary to the city's name, Suwon city faced a major challenge of inefficient water resources management due to rapid urbanisation. The city uses approximately 120 million tonnes of water every year. The annual precipitation in the city amounts to approximately 160 million tonnes. However, the city exhibits high dependency on external water resources, given that the city procured 90% of water resources from other cities and failed to utilise even 1% of rainwater resources. Poor water management also had an important implication of the risk of flooding and drought posed to the city (Han, 2009; Korea Water Resources Corporation, n.d.). The need for sustainable water resources management led the city to draw a blueprint for Rain City in 2009 and begin its journey to restore a water resources circulation system (Suwon City Government, 2009). Essentially, the Rain City Initiative of the city sets a policy framework and establishes green rainwater infrastructure. It also develops an urban model shown in Figure 25 below to strengthen water security and climate resilience by restoring the urban water circulation system which was damaged by rapid urbanisation and climate change.

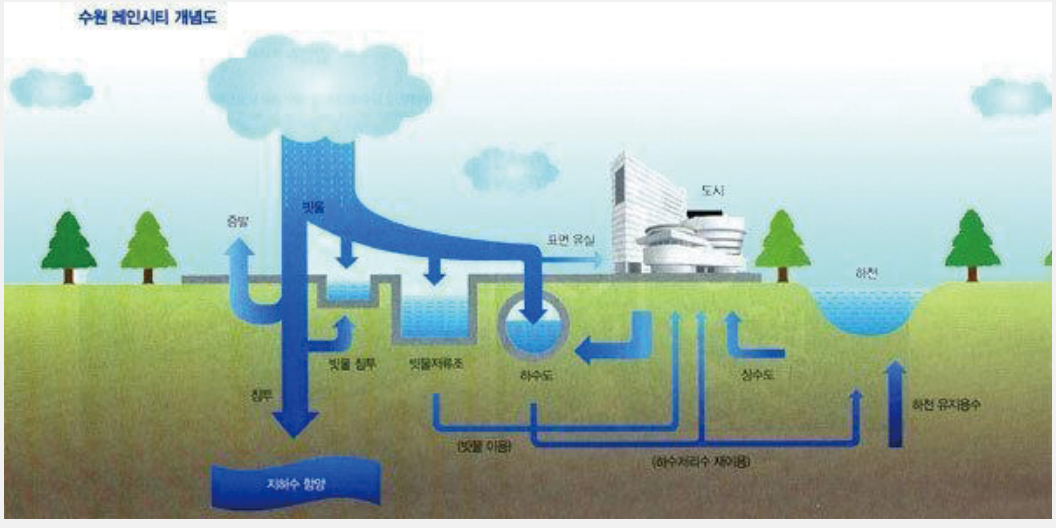


Figure 25 The Concept of Rain City Initiative *(Source: Han, 2009)*

WHY HAS THE CITY TAKEN ACTION

Water security and urbanisation: Urban sealing results in the increase of impermeable surfaces, which can change the hydrological cycle. The rate of runoff over the sealed surface in urban areas increases and occasionally overburdens the urban drainage system that potentially causes urban flooding. During droughts and periods with no rainfall, the city is also vulnerable to water shortage in terms of quantity and quality. Given this, the city

has made a strategic decision to combat the climate crisis by restoring the water circulation system to create a more climate resilient and sustainable environment (Korea Water Resources Corporation, n.d.; Suwon City Government, 2009).

GOALS AND OBJECTIVES

The national government introduced the Korean *New Deal* consisting of the *Digital New Deal* and *Green New Deal,* which *set the country's sustainable development agenda*. According to the Ministry of Environment, Green New Deal regards an integrated management system for water security as one of three initiatives for Green Transition of Infrastructure (Ministry of Environment, 2020). Aligning with the national agenda, Suwon city set an ambitious vision on moving towards a sustainable city. Since the city declared itself as the Eco-Capital in 2011 – an initiative led by the local government, city council, and civic organisation, the city has embarked on a journey on green transition in terms of urban planning, policy and governance, and residents' lifestyle.

The establishment of the Climate and Atmosphere Department reflects the city's determination to address sustainability and climate change issues (Suwon City Government, 2020a). The city has identified ten goals for sustainable development and one of the goals is to transform itself into a circular water city through management of water ecosystem, improvement of water quality, increase of water self-sufficiency, water saving, and public engagement (Suwon City Government, 2020a). Every ten years, pursuant to *Ordinance on Integrated Water Resources Management, t*he city develops a Basic Plan for Integrated Water Resources Management. The basic plan released in 2013 envisions a healthy water ecosystem of the city and outlines plans to develop initiatives in water management, water supply, river, swamp and lake management, and public engagement (Suwon City Government, n.d.c), these are primarily to:

- Restore water resources circulation system of the city
- Ensure urban environment is sustainable and resilient to the changing climate

PROJECT IMPLEMENTATION

The innovative component involves both the policy and regulation combined with the technology to restore a water circulation system where people, water and nature co-exists together. These can be broken up into three phases of implementation shown in Table 5 below.

Data on the total budget for the first phase of the project is not available. In the second phase of the project, a total of two million USD (0.6 million USD from the city and 1.4 million USD from Gyeonggi-province) was invested in the application of Low Impact Development (LID) technology to rainwater utilisation infrastructure, including porous parking lots and paving blocks, and permeable ditch, and rainwater garden, to reduce rainwater runoff and nonpoint pollutant (Suwon City Government, 2016).

Table 5 Rain City Initiative Progression

	Regulations and policies	Innovative approach
Phase 1 (2009-2014)	• Ordinance on Water Circulation • Ordinance on Integrated Water Management	• Install a road-spraying and de-icing system utilising rainwater • Install rainwater collection containers • Build infrastructure to save 77,000 tonnes of rainwater across the city by connecting rainwater to wastewater reuse system
Phase 2 (2015-2021)		• Expand rainwater utilisation and storage facilities • Porous pavement at parking lots, rainwater runoff barriers, infiltration trenches, and rain gardens
Phase 3 (2022 onwards)		• Plan to cultivate residents who recognise the importance of utilising rainwater and creating a city-wide rain culture

In the first phase of the project between 2009 and 2014, Suwon city laid the administrative and regulatory frameworks for restoring the water resources circulation system. In addition to the declaration of Rain city in 2009, the city conducted basic research in cooperation with Seoul University and Korea Rural Community Cooperation to reflect findings from the research into urban planning; organised international events to identify the international trend; adopted *Ordinance on Water Resources Circulation* and *Ordinance on Integrated Management System of Water Resources*; established infrastructure to save 77,000 tonnes of rainwater across the city with connecting rainwater to wastewater reuse system (J. Kim, 2021; Suwon City Government, 2009, 2016).

In the second phase of the project between 2015 and 2021, Suwon city expanded the rainwater harvesting and storage facilities across the city including parking lots, paving blocks, and ditch with the permeability of rainwater, and rainwater gardens by using Low Impact Development (LID) technology to reduce rainwater runoff and nonpoint pollutant. At SIWI World Water Week 2021, Suwon city declared the Rain City Initiative to encourage a global paradigm shift in rainwater management and also revealed a plan to implement the third round of the project by launching a Youth network on rainwater (J. Kim, 2021; Suwon City Government, 2016, 2020b).

In addition, this initiative of Suwon city for restoring the urban water circulation system has been recognised in the country and abroad. The initiative received an award for the excellent practice of green development and the best policy for water management in the country. The initiative also received an award at the Green World Award in 2018 and 2018 Energy Globe Award. The initiative was recently introduced at SIWI World Water Week 2021 (ICLEI Korea, 2016; J. Kim, 2021; Suwon City Government, 2020b).

Low Impact Development (LID) technology: The Rain City Initiative is a classic example of the application of LID technology in water resources management. The city focuses on the increase in permeable urban areas through the expansion of rainwater collectors and facilities to accelerate its transformation into the Rain City. According to an expert from Korea Land and Housing (LH) Corporation, the decrease in permeable urban areas due to urban

development leads to an increase in risks of water pollution especially through non-point source pollution. The rainwater infrastructure - such as permeable roads and ditches, rainwater gardens, and rainwater collectors which LID technology is applied to - helps to restore the urban water circulation system and to reduce rainwater runoff and nonpoint source pollution (Suwon City Government, 2017).

The rainwater collector: A rainwater collector invented by a Suwon City Government official is a classic example of the application of Low Impact Development (LID) technology. The collector improves the efficiency of rainwater harvesting (T. Kang, 2014; Suwon City Government, 2017). The collector is used to harvest clean rainwater separately from one with pollutants. With a simple structure, the collector does not require power or generate any noise during operation. It can be installed anywhere without particular spatial requirements. It also has eco-friendly features. For example, the collector reuses unused water tanks on building roofs or helps to water plants next to it (Park & Ha, 2013), as shown in Figure 26.

Figure 26 The rainwater collector *(Source: (T. Kang, 2014))*

An automatic road-spraying and anti-icing system using rainwater: Suwon city was the first in Korea to install a road-spraying and anti-icing system utilising rainwater. Remotely controlled by a smartphone, the system automatically operates every day at dawn except winter and rainy seasons. Sprinklers spray water on the roads to

reduce mid-summer heat and wash away fine dust. Rainwater used to clean roads is filtered through nonpoint pollutant treatment facilities before channeling into the rivers. Sprinklers also help to cope with heat waves in summer through automation, when the temperature reaches above 30 degrees Celsius in summer, sprinklers are activated to spray rainwater over roads to reduce surface temperatures via evaporation. In winter, sprinklers spray eco-friendly liquid deicers, which can work well in minus 40 degrees Celsius over roads to remove ice and snow (C. Kang, 2013; Suwon City Government, 2013), the systems are shown in action in Figure 27 below.

Figure 27 An automatic road-spraying and anti-icing system using rainwater *(Source: Suwon City Government, 2013)*

IMPACTS

Carbon Reductions: In 2016, rainwater collectors installed in public buildings – including the Jangan District Office, Suwon World Cup Stadium, and Suwon City Hall – collected 85,254 tonnes of rainwater and collectively offset 35,651kg of CO_2 (S. Kang, 2017).

In addition, the rainwater collectors, rainwater gardens, and porous pavement at parking lots, rainwater runoff barriers, and infiltration trenches contribute to the restoration of water circulation and, thus, enhance climate resilience in events of floods, droughts, and heat waves. According to a local government official, the rainwater collector installed at the Sports stadium in Songjuk-dong helps to prevent Seo-ho stream in the neighbourhood from drying up. During heavy rainfall events, they also help to reduce the risk of flooding, thus preventing loss and damage in Songjuk-dong (Gyeonggi Urban Innovation Corporation, 2013). Moreover, the Rain City initiative project in Suwon received recognition for its ability to enhance climate resilience at the SIWI World Water Week 2021 (Song, 2021). However, it is difficult to find statistics for enhancing climate resilience.

Pollution Reduction and Cooling Effects: Rainwater collected by the city combated the heat island phenomenon during summer. In 2018, the local government sprayed 618 tonnes of water including treated water and rainwater over 176 km of 62 roads in the city. Spraying water over roads lowered the road temperature and the surrounding areas by two to three degrees Celsius, reduced the heat island effect, prevented roads from being deformed, and cleared fine dust in the air (B. Kim, 2018).

Rainwater infrastructure built in areas belonging to Suwon City Hall and Suwon City Council also contributed to reducing water pollution. The application of LID technology to the rainwater infrastructure lead to the decrease in Biochemical Oxygen Demand (BOD) by 27.8%, Total Nitrogen (TN) by 28.1%, Total Phosphorus (T-P) by 28.6% (S. Kang, 2017).

Water-saving and self-sufficiency: In 2016, rainwater collectors installed at the public buildings – for instance, Jangan District Office, Suwon World Cup Stadium, and Suwon City Hall – saved 85,254 tonnes of rainwater, while 22,132 tonnes of rainwater was channelled underground. Rainwater harvesting saved 214,000 USD, an equivalent of two USD per tonne (S. Kang, 2017). Another example is the rainwater collector installed at the Suwon World Cup Stadium with a capacity to store 22,000 tonnes of rainwater. Rainwater collected at the storage was used to water grass in the stadium and to spray over roads in the city. As a result, the rainwater harvesting reused 18,000 tonnes of rainwater every year, saving water equivalent to 25 million KRW. Through the Rain City Initiative, the city increased the water self-sufficiency rate from 11% in 2009 to 35% in 2021. The city plans to increase the rate up to 50% by 2030 (National Assembly Water Forum, 2021).

FACTORS FOR SUCCESS

A strong political will of the local government to transform the city into the Eco-Capital with a healthy water ecosystem is a crucial factor for success. The Mayor is a former environmental activist who proposed the Eco-Capital (Suwon City Government, 2020a). Under the leadership of the Mayor, the local government embarked on a journey to recover its reputation as a city of water by promoting rainwater utilisation beyond rainwater harvesting.

At the local level, the city developed a plan to reuse rainwater in cooperation with Seoul National University (SNU) Rainwater Research Centre; adopted ordinances and regulations designed to promote the restoration of the water circulation system; raised public awareness of the importance of water circulation to promote public engagement. More importantly, water circulation areas are taken into consideration in urban management (Lee et al., 2014; Suwon City Government, 2009). At the national level, the city carried out projects in collaboration with the national government. For instance, the Green Rainwater Infrastructure Establishment Demonstration Project in collaboration with the Ministry of Environment in 2014 (Suwon City Government, 2020b). At the international level, the city joined international events and introduced its Rain City Initiatives to the international society (J. Kim,

2021; Suwon City Government, 2021).

LESSONS LEARNED

As an overarching framework at the national level, Acts on urban water circulation need to be adopted by the national government. Regulatory frameworks for water resources built by the national and local governments have laid the groundwork for the implementation of current policies and initiatives. However, the national government takes a broad approach to the water environment rather than narrows the scope down to water resources circulation. The existing water management system under the laws focuses on non-point source pollution and, consequently, has limits to restore water circulation of cities. Therefore, from a comprehensive perspective, laws on water circulation which stand above the *Ordinance on Water Resources Circulation* adopted by Suwon city are necessary to exercise enforcement power effectively (Byun, 2021).

To increase the effectiveness of water circulation as a means to promote sustainable cities, the urban water circulation system needs to be advanced as follows: it set indicators and goals for multi-purpose; it manages green and grey infrastructure in an integrated manner; it includes land use plans and urban design; it identifies strengthened responsibility of the local government and enterprises to manage water circulation; it develops a cost-sharing system charging those who discharge sewage and run rainwater off the land surface, and the public (Byun, 2021).

CASE STUDY C5:
SUSTAINABLE WALKING TRAIL AND TOUR - JEJU OLLE

Jeju Special Self-Governing Province is one of the major tourist destinations in the Republic of Korea. According to the 2015 Regional Area Input-Output Table published by the Bank of Korea, Jeju Province is heavily dependent on the service industry, accounting for 67.1% of local industries, followed by the construction industry (13.4%). This is the highest level in comparison to other cities in the county. From a value-added perspective, the service industry accounts for 74.6% of the local industries, followed by the construction industry (11.3%) (Kim, T., 2020), showing Jeju's reliance on the service industry and tourism.

Against this backdrop, Jeju promotes ecological tourism as a means of decarbonising the local tourism industry and making the island climate resilient. As the classic example of ecological tourism, Jeju Olle is a trail stretching across 425 km with 26 courses (Jeju Olle Trail, n.d.). Originating from an individual's idea, today, Jeju Olle prides itself as one of the successful pioneers of ecological tourism in the country and expands the network at domestic and international levels. It received many national and international awards (Jeju Olle Foundation, n.d.c). It also built networks with domestic and overseas local communities in the name of friendship and sister trails (Jeju Olle Foundation, n.d.d). Despite COVID-19 pandemic, 469,000 visitors visited the trail, an increase of 10% from 2020 (Kim, G., 2021). The trails are illustrated in Figure 28 below.

Figure 28 Jeju Olle Map *(Source: Jeju Olle Trail website)*

WHY HAS THE CITY TAKEN ACTION

Carbon-intensive Island tour practices: According to the mid-term plan (2019-2023) for urban traffic

improvement of Jeju, the modal share of public transport in 2017 was 14.7%, the lowest level in the country, while the share of rental cars accounted for 65%. Seven out of ten visitors used rental car service (Yoo, H., 2019). Jeju pointed out that rental cars used by visitors are a cause of traffic congestion and illegal parking. In this regard, Jeju suggested a cap on rental cars operating in the province (Oh, J., 2020). Although the province is active in promoting the transition to clean vehicles, such as electric vehicles, a bold action to control the number of vehicles is necessary to make the tourism industry decarbonised and sustainable.

Environmental degradation accelerated by urban development: Jeju faces a challenge of environmental degradation due to urban development. The Bank of Korea highlighted that the construction industry represented the second-largest share to the economic structure of the province from both economic output and value-added perspectives in 2015 (Kim, T., 2020). In 2017, the construction industry drove a high economic growth of the province with a high contribution rate amounting to 27.4%. The construction and property boom was driven by popular housing demand, population influx, foreign investment, but it affected the natural environment of the island (Lee, D., 2020). For example, a construction of a naval base and a construction plan for Songaksan mountain area near Jeju Olle courses meet with harsh criticism from local communities and Jeju Olle supporters (Heo, H., 2011; Hwang, K., n.d.).

GOALS AND OBJECTIVES

A bottom-up approach placing local communities and tourists at the centre in promoting ecological tourism makes Jeju Olle innovative and sustainable. The founder of Jeju Olle first brought to life the idea for the ecological walking tour. A few years later, the local government began to be engaged in managing Jeju Olle. In 2012, the local government provided supplementary aid to preserve the value of connecting tourists, local communities, and the natural environment in the manner proposed by the founder (Jeon, J., 2012). At the national level, governmental support for trail tours is more challenging as only subordinate regulations adopted by the different agencies are available without any overarching laws (Kim, D., 2012). Therefore, no overarching governmental frameworks at the national and local levels, such as law, regulations, and policies are available to lay the foundation for developing Jeju Olle. The need for more discussion and social consensus arose to support the local governments to take a systematic approach to promote ecological tourism, while creating synergistic effects with local communities and tourists. Within this context, there is a strong need in innovating the island's tourism practice through ecotourism to achieve the following objectives:

- To introduce ecological tourism practice to green the tourism industry
- To contribute to achieving the 2050 carbon neutrality target at the local level
- To enhance climate resilience of the island with environmental restoration

PROJECT IMPLEMENTATION

Jeju Olle is a paradigm shift in tourism practiced in the island, bringing tourists, local communities, and the natural

environment into a circular loop and widening the horizon of the ecosystem of the tourism industry.
First, Jeju Olle changed tour practices from spot-oriented to linear-oriented (Kim, D., 2012). The 26 courses as shown previously in Figure 28 above, conform to the shape of the island and are connected to each other. This linear-oriented tour practice provides opportunities to appreciate the beauty of the natural environment of the province in an ecological continuum compared to the spot-oriented tours. Tourists no longer spend more time taking a car to travel between tourist attractions that are located far away from each other. Instead, they can immerse themselves in appreciating the natural environment at a leisurely pace and enjoy different features of the ecosystem in the province and the overall mindset shift is pictured in Figure 29 below.

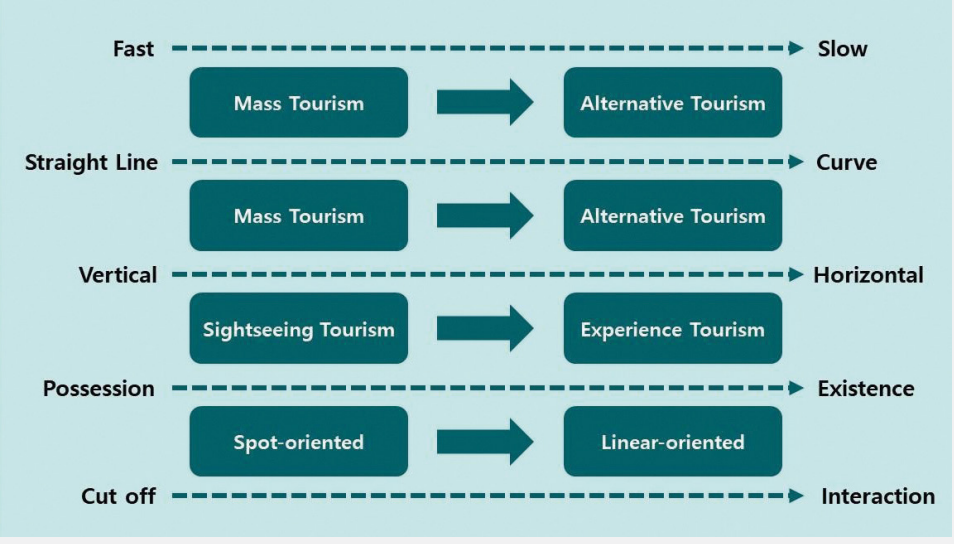


Figure 29 Paradigm shift in culture and tourism *(Source: 'Current Status of trail tour projects and improvement plan' published by Korea Research Institute For Local Administration)*

Second, Jeju Olle promotes the interaction between tourists and local communities due to the linear-oriented tour practice. Every course passes through at least three local villages. Local villages provide tourist opportunities to experience local streets, storytelling, cultural activities, and local products in cooperation with Jeju Olle Foundation (Jeju Olle Foundation, n.d.b). Local residents can be a service provider such as accommodation and also be represented as an honorary ambassador to the villages or a travelling companion while spurring local economies of the villages. Moreover, Jeju Olle further develops a new business model by connecting local villages to domestic corporations. Consequently, local villages reach out to different groups of people beyond the tourists through the village-corporate partnership platform and generate more income (Jeju Olle Foundation, n.d.b).

Third, Jeju Olle greens the tourism industry and the province. The magnificent scenery and cultural heritage of the island is the major social overhead capital and an engine for sustainable development of the province (Jejunews, 2010). For instance, Jeju province received a triple crown from the United Nations Educational, Scientific and

Cultural Organisation (UNESCO) as a National Biosphere Conservation area in 2002, a World Natural Heritage site in 2007, and a certified Global Geopark Network in 2010 (Jeju Special Self-Governing Province, n.d.). Jeju Olle shed light on green practices – trail repair by hand, nature rest system, a plogging campaign (a combination of jogging with picking up litter) – to make the trail tour greener and more sustainable (Jeju Olle Foundation, n.d.b).

Jeju Olle leverages the engagement of multi-stakeholder to make the trail tour sustainable. First, four volunteer groups including those received training and finished 26 courses of the trail assist in repairing the trail, walking on the trail with visitors, and operating programs and activities. Second, partner companies give one-time or monthly donations and support local campaigns (Jeju Olle Foundation, n.d.a). This enables Jeju Olle to operate without collecting entrance fees and minimise financial assistance from the local government. For example, the luxury brand, Burberry Korea Ltd., will donate for the next five years to help its trail repairment and the plogging campaign (Hong, J., 2021).

Financially, about 500,000 USD is spent annually in the trail repairs and the production of promotional materials exempt of labour cost (Byun, J., 2017). Between 2009 and 2013, Jeju Olle received subsidies (about 5,500,000 USD) from Jeju Special Self-Governing Province, Jeju city, and Seogwipo city for supporting volunteers, promotion, and facility establishment (Lee, S., 2014).

IMPACTS

Carbon Reductions: There is no research on carbon reductions from the trail tour such as Jeju Olle. However, Jeju Olle may help to reduce carbon emissions to a considerable level considering its contribution to encouraging tourists to switch from vehicle tours to walking tours. Rental car services are very common amongst tourists with seven out of ten visitors using the service (Yoo, H., 2019). According to recent research on estimating CO_2 emissions from ecotourism in the island, rental cars are the largest CO_2 emitter (0.363 kg per person) among means of transportation (Lee, W., et al., 2019). Given that 469,000 visitors joined the trail tour in 2020 (Kim, G., 2021), Jeju Olle might help to reduce 170,247 kg of CO_2.

Trail Restoration: A major management strategy of Jeju Olle is to restore local roads where residents have walked for a long time and minimise causing harm to the natural environment (Jeju Olle Foundation, n.d.c). Although there is no research on the contribution of the trail to climate-resilience of the island, eco-friendly practices taken to manage Jeju Olle may contribute to restoration of the natural environment and make the island climate-resilient.

Economic benefit for local villages: Jeju Olle promotes the active engagement of local villages in operating the programs and activities, which leads to profit-making opportunities for local villages. For example, it develops new business models which help economic activities of local villages; its village-corporate partnership platform

helps fourteen villages to seize the opportunity to cooperate with the private sector; its craft workshop producing souvenirs provides jobs to local women; it launches many local eco-friendly brands using local products (Jeju Olle Foundation, n.d.b). However, there is no data measuring the scale of economic benefit provided to the local villages.

FACTORS FOR SUCCESS

Local communities and tourists-driven management: Jeju Olle actively brings local communities and tourists who are potential loyal supporters and volunteers into managing the trail and operating relevant programs and activities. Both local communities and tourists interact in a circular loop beyond a relationship between a service provider and a customer. Their interaction based on the diverse programs and activities enable Jeju Olle to be sustainable and independent from governmental support, and preserve the value of connecting people (residents and visitors) and the natural environment.

Multi-layered networks: Jeju Olle expands its network and reaches out to domestic and overseas partners. Knowledge exchange and constructive discussion with the Korean Trails Association, Asia Trails Network, and World Trails Network helps to advance an ecological tourism model more comprehensive and transferable. Also, the Friendship Trail project provides Jeju Olle the opportunity for international promotion of its trail – especially, its one course paired with trails in Canada, England, Switzerland, Lebanon, Turkey, Japan, Taiwan, Greece, and Australia (Jeju Olle Foundation, n.d.d).

LESSONS LEARNED

Lack of Impact Assessment Index: The difficulties of assessing the impact of Jeju Olle is a major challenge. Although Jeju Olle has noble vision and people-driven strategies as the engine for its sustainability, there is a lack of science-based research and data for presenting its effectiveness in terms of climate actions (low carbon emission and climate-resilience) and economic benefit. Therefore, it is necessary to conduct more in-depth research on and produce statistics for identifying the relationship between the trail tour, low carbon emissions, restoration of the natural environment, and economic profit of local communities.

Need for Policy-based and Regulatory support from the Local Government: Although the initiation and management of Jeju Olle is deeply rooted in people-driven and bottom-up approaches, governmental support is necessary to make it sustainable in a longer term. The policy-based and regulative frameworks set by the local government will contribute to making the approaches adopted by people and the private sector in a more comprehensive and systematic manner and expanding the opportunity to make synergy effects between the approaches. Local communities and people (volunteers and supporters) may need to have a series of consultations with the local government on how the local government better devise policies and regulations favourable to their policies.

CASE STUDY C6:
THE SPONGE CITY PROJECT - INTEGRATED WATER MANAGEMENT APPROACH IN SHENZHEN, CHINA

China initiated the *Sponge City Programme* (SCP) in 2014 to address urban water management and resilience in China and to support ecological civilisation implementation. The Ministry of Housing and Urban-Rural Development (MoHURD) selected 30 pilot cities to implement sustainable urban water management approaches to resolve urban waterlogging, water storage and discharge, water quality, and urban heat island effects. A national technical guidance was also released by MoHURD to guide the implementation and facilitate localisation as the pilot cities create the technical guidelines and evaluation criterias. As the SCP matures, the pilot cities even incorporate sponge city planning approaches into the long-term urban and sustainable development plans.

Shenzhen is a coastal megacity with 24 million population located in South China along the Pearl River Delta. The economic powerhouse has been selected as one of the Phase 2 pilot cities for SCP in 2016 and the city's SCP design and experience highlighted the innovative 'Shenzhen approach' in localising and implementing SCP, with successful results. The key elements included in Shenzhen's SCP include: 1) detailed pre-assessments of its natural resources, hydrological characteristics, and climatological elements for spatial planning; 2) integrated water management plan ; 3) customised design according to the living environment and ecological conditions.

The SCP brings nature back to cities by applying blue-green design concepts which have been successfully mainstreamed as part of the city's spatial planning and urban design, changing the "concrete urbanisation" paradigm in China. These blue-green infrastructures, also known as Nature-based Solutions (NbS), are effective responses to the myriad urbanisation problems, ranging from surface water and stormwater management, to air purification, urban noise cancelling, and carbon sinking. Shenzhen's phased-approach in application of such infrastructure, lends to a continuous learning cycle, strengthening the institutional capacity by building upon technical expertise and awareness raising, as well as practical experimentation and correction of any weaknesses in future implementations of similar projects.

WHY HAS THE CITY TAKEN ACTION

Urban flooding risk is increasing in frequency and intensity: In the past 40 years, Shenzhen turned from a laid-back fishing village to a spectacular economic centre in southern China. However, rapid urbanisation comes at a cost. The naturally marshy environment exacerbated by land cover change, population density and local climate change directly influenced urban surface runoff and urban flooding. According to the national and municipal flooding disaster assessment in 2016, there were 446 flooding points in Shenzhen, with a maximum flooding area of 500,000 square metres (m^2), a maximum flooding depth of 2.5m, and a maximum flooding duration of four hours (Zhang et al., 2016).

Water pollution has been a serious problem in Shenzhen Bay and the Pearl River Delta: As the frontier of international trade, Shenzhen hosts numerous factories with serious negative environmental impacts, such as textile and IT manufacturing. However, the lack of environmental regulation back in the early 21st century resulted in severe pollution in the water bodies. Pollution source control is worsened by incomprehensive sewage management.

Water security and limited drinkable water resources in Shenzhen: Shenzhen's per capita access to water resources is 154.54 cubic metres (m^3), one-thirteen of the nationwide average, making it one of the top ten water-scarce cities in China (World Water Atlas, n.d.). In comparison, the United Nations' definition of absolute scarcity threshold is 500 m^3. It is estimated that Shenzhen will face water shortages of 690 and 890 million m^3 by 2020 and 2030 respectively (International Water Association, n.d.). Meanwhile, water conservation has been a core environmental conservation practice in China, which is embedded in national development strategies, such as non-renewable energy conservation and low-carbon development (Sun, 2017).

GOALS AND OBJECTIVES

Under the *Guiding Opinions on the Construction of Sponge Cities* in 2015, China's State Council set an ambitious national target for Chinese cities to transform the urban areas to absorb, retain and reuse 70% of the rainwater. Political commitment and national support serve as a significant factor for Shenzhen's achievement for the SCP. Prior to the SCP, the LID has already raised cross-departmental awareness on the necessity to enhance and engage in urban resilience. Therefore, Shenzhen, especially Guangming District, was more equipped and fully prepared for the SCP implementation. Shenzhen responded rapidly after being selected as a SCP pilot by formulating comprehensive, stage-by-stage planning and technical instructions. There were also supporting policies at municipal level, such as financing and budgeting that were officially approved in early 2018.

The Sponge City concept is a paradigm shift from the traditional grey infrastructure approach of steel and pipes to green and natural infrastructure, such as rain gardens to restore natural habitat and functions. Using this paradigm, Shenzhen aims to have more than 20% and 80% of the built-up areas to meet the standards of a sponge city by 2020 and 2030 respectively.

The SCP is a city-wide programme, covering the entire Shenzhen. The implementation is multifaceted at each zone. According to the *Shenzhen's SCP planning and action plan (2016)*, the city is categorised into six sponge zones: ecological conservation zone, ecological containment zone, ecological buffer zone, function enhancement zone (on built-up sponge areas), function improvement zone (on environmental restoration areas), and function optimisation zone. Based on the categorisation, the plan recommends distinguished lists of elements for residential areas, public spaces, factorial and storing areas, paveways, urban renewal areas, water bodies, and parks and green spaces. Each project site contextualises the design for application.

Objectives:

- **Water security:** effective prevention of urban flooding disasters
- **Water environment:** water treatment on polluting sources, to ensure the improvement of water quality
- **Water ecology:** ensure the volume capture ratio of annual rainfall exceeds 70%
- **Water resources:** effective use of rainfall, recycled water, seawater and other non-conventional water resources
- **Institutional setting:** Development of sponge city planning & construction control framework, technical specifications and standards, investment and financing mechanism, performance assessments and incentive mechanism.

PROJECT IMPLEMENTATION

The SCP is an integrated urban water management approach to address urban surface runoff, water pollution, and flooding risks. It is a holistic planning mechanism which intends to mobilise water spatially and temporally, it shares similarities with other urban water governance concepts, such as Low Impact Development (LID), Sustainable Urban Drainage System (SUDS), and Water Sensitive Urban Design (WSUD). Prior to the SCP pilot, Shenzhen started the LID experiment in Guangming New Area (now Guangming District), back in 2004 (Shenzhen Government Online, 2017). The LID sought to address urban surface runoffs during heavy rainfall episodes through LID construction elements, to allow water infiltration, retention, and storage. In Guangming, the new areas provided the possibility to test out a variety of LID designs:

Guangming has 26 LID projects incorporated within the new developments, residential and industrial areas, parks, and roads. For example, Guangming People's Sports Centre has been built with green roofs, rain gardens and porous pavements, which have a capacity to capture more than 60% of annual rainfall. New roads include sunken green spaces, permeable driveways, bicycle paths, and sidewalks (International Water Association, n.d.).

The previous LID projects at Guangming District laid the foundation for the SCP implementation at the city-scale. Instead of ad-hoc LID projects and in-situ solutions, the SCP is seen as a comprehensive masterplan to accelerate the city's actions in sustainable development and urban resilience. The grey, green, and blue infrastructure are designed systematically to foster their social-ecological functions. For example, green infrastructure (e.g., greenbelt) is integrated into grey infrastructure (e.g., paveways), functioning in different stages of water catchment, purification and storage.

Bioretention catchment and greenbelt for stormwater management

The technical guidelines developed by the MoHURD provided a list of approaches qualified as 'sponge infrastructure'. As flood risk and the experience gained from the Guangming LID design reinforced Shenzhen's priority to address stormwater management through the SCP design.

Bioretention catchment and greenbelt are mandatory for the newly constructed driveways in Guangming District. Rainwater can be channelled or stored at catchment zones via permeable pavements, as shown in Figure 30.

Figure 30 The design of bioretention catchment and greenbelt next to driveways
(Source: Shenzhen Sponge City Construction Office, 2017)

The directional arrows show that the gradient and slope of the greenbelt allow stormwater to seep and enter the greenbelt through small channels and permeable pavements. The greenbelt consists of vegetations and materials of different permeability, including vegetations, tree barks, claies, and limestones. They all function together to purify and infiltrate underground for water retention and storage. The gradients and the materials of the driveways allow rainwater to flow through the greenbelt and feed to the greenbelt through the small channels. The greenbelt consists of multiple layers, consisting of plantations, tree barks, claies, and limestones, to store and purify rainwater, and thereby channelling the purified and infiltrated water through the pipes. The underground pipe network channels water towards a storage pond or a nearby sink. Examples of greenbelt designs are shown in Figure 31 below.

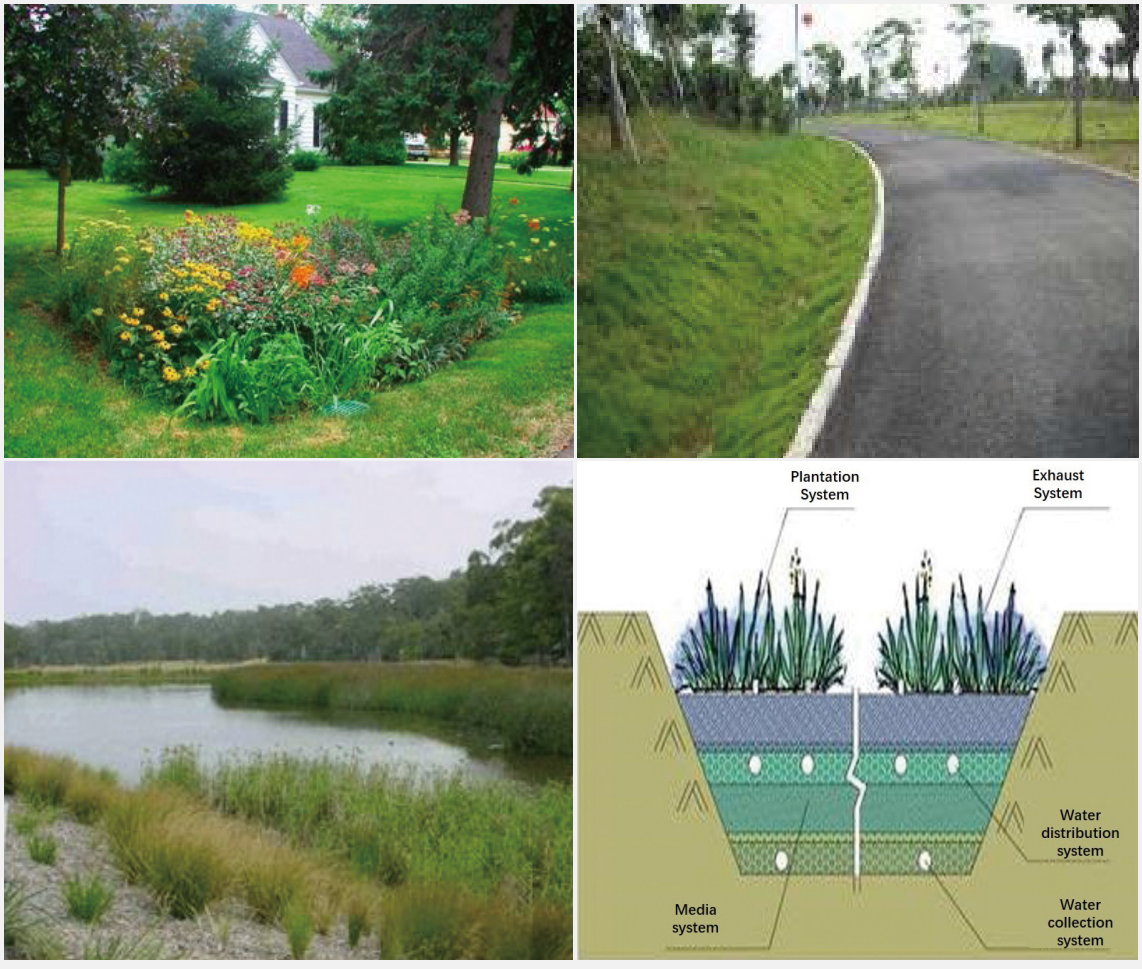


Figure 31 Different types of bioretention catchment, including the rain garden, grass swale, bioretention bond, and bioretention catchment layers according to clockwise direction
(Source: Office of the Leading Group for the Implementation of Sponge City Construction in Guangming District, 2017)

The bioretention catchment is customised and applied according to the different natural environment and needs. For example, the rain garden is usually applied in small parks or residential areas. If there is a large area of grassland, grass swale is a feasible approach with small construction efforts, while bioretention ponds are very useful for water circulation at parks and restoration of micro-scale wetland ecosystems.

Permeable pavements

Permeable pavement is seen as 'the lungs of cities', which allows rainwater to seep through immediately, reducing surface runoffs, particularly during heavy rainfalls. They are widely applied at sidewalks, cycling paths, and even roadways in Figure 32. The structural layers are made out of different sizes of rocks, stones, and gravels, mimicking the natural soil layers for natural seeping and channelling of surface water. Without permeable

pavements, rainwater is inundated at low-lying areas, causing "urban flood-prone points" or waterlogged areas. The permeable pavements effectively reduce the speed of rainwater and release pressures on the soil layers. Moreover, permeable pavements also generate additional benefits, such as water purification and reducing underground water pollution.

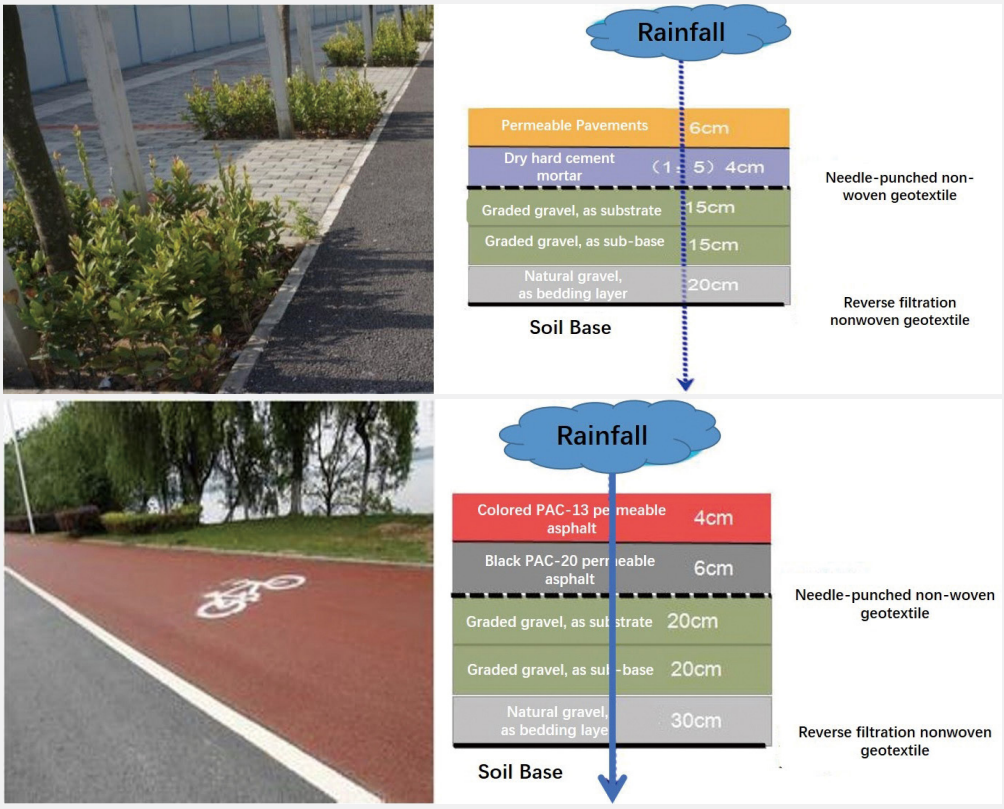


Figure 32 Permeable pavements used for sideways (above) and cycling paths (below) applied in Guangming District
(Source: Office of the Leading Group for the Implementation of Sponge City Construction in Guangming District, 2017)

There are significant achievements for No.38 roadway, as the 'fully-sponged' one: the overall volume ratio of rainfall annually is up to 60%; half of the pollutants brough by rainwater can be reduced by more than half; and there is also 15% reduction of water consumption (Crystal News, 2016).

Cross-departmental task force teams have been set up at both municipal and district levels. At the municipal level, Shenzhen Sponge City Construction Office takes responsibility in planning and coordination, while at the district level, District Sponge City Construction Offices are established. Considering the SCP implementation in Shenzhen synergises with water environmental restoration, the Water Affairs Bureau at municipal and district levels also play a core role.

The financing and budgeting plan plan of 2018 provides guidelines for Shenzhen's SCP implementation. It mainly consists of two sources: public funding and private investments. The governmental budget is mainly used for core projects like water management and restoration, incentivising SCP-related research, and infrastructure construction. To engage the private sector into SCP construction work, the Public-Private Partnership (PPP) model is incentivised, especially on sponge infrastructure and restoration projects. SCP application and technical research institutes can be partly funded. Green building standards initiated by Shenzhen also encouraged several private companies to select green and nature-based materials for building upgradation.

For urban water resilience, (Wang et al., 2021) identify Shenzhen's SCP has a full inclusion of most categories, especially increased water resilience around overall runoff control and comprehensive rainfall runoff coefficient. Compared to other SCP cities, Shenzhen has a consistent monitoring and accumulation of SCP's potential to urban heat island mitigation. Moreover, from an ecological and biological perspective, reintroduction of riparian plantations can gradually increase urban biodiversity. This process can further contribute to ecological restoration, recovering the completion of the ecosystem. These long-term impacts and indicators might not be included in the initial design of the program but can be monitored to enhance the comprehensive benefits of ongoing programs.

IMPACTS

The SCP implementation in Shenzhen happened in parallel to the environmental restoration and ecological civilization agendas that are prioritised by both the national and local governments. It facilitated a more holistic and integrated approach to urban water management. Shenzhen applied a cluster of ambitious actions towards green development. For instance, the implementation of *Shenzhen water quality improvement work plan (2015-2020)* (Shenzhen Water Quality Control Command, 2015) improved the water quality at the beginning stage, and gradually restored the whole water-based ecosystems. From January to September in 2021, eight rivers in the core urban districts met Level IV-II of the national surface water standards. The water quality is now even suitable habitat for fishes and other aquatic animals (Environmental quality standards for surface water, 2002; Shenzhen Water Affairs Bureau, 2021). Other practices such as offshore environmental protection and conservation, large-scale ecological buffers, management on local and invasive species were undertaken. These interlinking projects and actions together contribute to the overall environment improvement.

Flood Management: The SCP significantly supported urban water management and enhanced urban resilience by reducing the impact of flooding and improving water quality and its ecosystem services. By 2020, Shenzhen met the ambitious goal to transform 20% of the urban area by 2020 to meet the Sponge City requirements, which is about 312.7 km^2 of total area. The goal is to achieve 80% by 2030. These improved areas absorb and use 70% of the local rainfall, significantly strengthening Shenzhen's adaptive capacity towards urban flooding (Xu et al., 2020). Since Guangming District is at a more mature implementation stage, the volume capture ratio of

annual rainfall is up to 72%, implying that more than half of the stormwater is infiltrated and stored for different purposes, such as garden irrigation (Guangming Government Online, n.d.).

The improved environmental and ecological performances create a more sustainable, livable and resilient space for residents and local communities. The 'flooding points' used to occur frequently in residential areas when there were heavy rains, are reduced, decreasing the likelihood of waterborne diseases and providing safer living environments, in addition to improving commutes. The expanded green space and landscaping in core urban areas and cleaner water quality allows local residents to enjoy nature and public space during the COVID-19 period, as part of enhancing social resilience, from an individual- to community-level.

FACTORS FOR SUCCESS

The previous experience of Guangming LID provided the experience necessary for Shenzhen to pursue integrated water management frameworks and approaches to the project, ensuring that surface water management, sewage treatment, and risk management of urban flooding are supporting each other. In addition, the SCP is approached in terms of a public and private partnership with not only funds and actions from the government, but incentive mechanisms to maximise the participation of private sector and research institutes, with customised solutions of varying scales to support hundreds of projects.

LESSONS LEARNED

Capitalising on the national commitment and political opportunity, Shenzhen maximised its impacts through a series of supporting actions, including scaling-up district-level practices and working with different actors and private sectors. For example, Shenzhen worked with The Nature Conservancy (TNC) to engage private and public sectors in creating rooftop gardens, greening sidewalks and parks. Rooftop gardens were especially popular among communities and attracted companies to also pilot and transform their buildings (The Nature Conservancy, 2018).

To achieve scalability, the SCP concept should go beyond city-level initiatives in managing surface rainfall and water bodies by engaging more private sectors or local communities. In doing so, Shenzhen also published *Promoting Green Buildings in Shenzhen* (2013). It is to introduce SCP concepts to inspire and guide individual actors in terms of material choice, roof design and water circulation principles. For example, the Public Art Centre in Bao'an District in Figure 33 below, also known as the 'rain box', successfully integrates rainwater harvesting as part of its architecture design. Rainwater from the rooftop is collected, purified and channelled through the glass building frame to the artificial terraces and rain gardens underneath.

Figure 33 Rain Box, the Public Art Centre of Bao'an District, Shenzhen *(Source: Turenscape, 2018)*

CASE STUDY C7: ENHANCING ECOSYSTEM SERVICES THROUGH PUBLIC-PRIVATE-PARTNERSHIPS IN SHENZHEN, CHINA

Since the Chinese government designated Shenzhen as the Special Economic Zone in the 1980s, the city has undergone fast urbanisation, changing the ecosystem of Shenzhen Bay to a huge degree. To restore the coastal ecosystem and maximise its ecosystem services, Shenzhen Mangrove Wetland Conservation Foundation (MCF) initiated cooperation with the Shenzhen Municipal Government and Guangdong Provincial Government in 2015. Under the five-year partnership agreement, MCF will manage the Futian Mangrove Conservation Area pictured in Figure 34, which faces the Mai Po Natural Reserve of Hong Kong Special Administrative Region across the sea. This innovative governance mechanism has been able to address the coastal environmental issues, multi-stakeholder engagement from the early-stage research, assessments, and work plan formulation, to the long-term monitoring, in-situ planting, and platform establishment for professional training and public education.

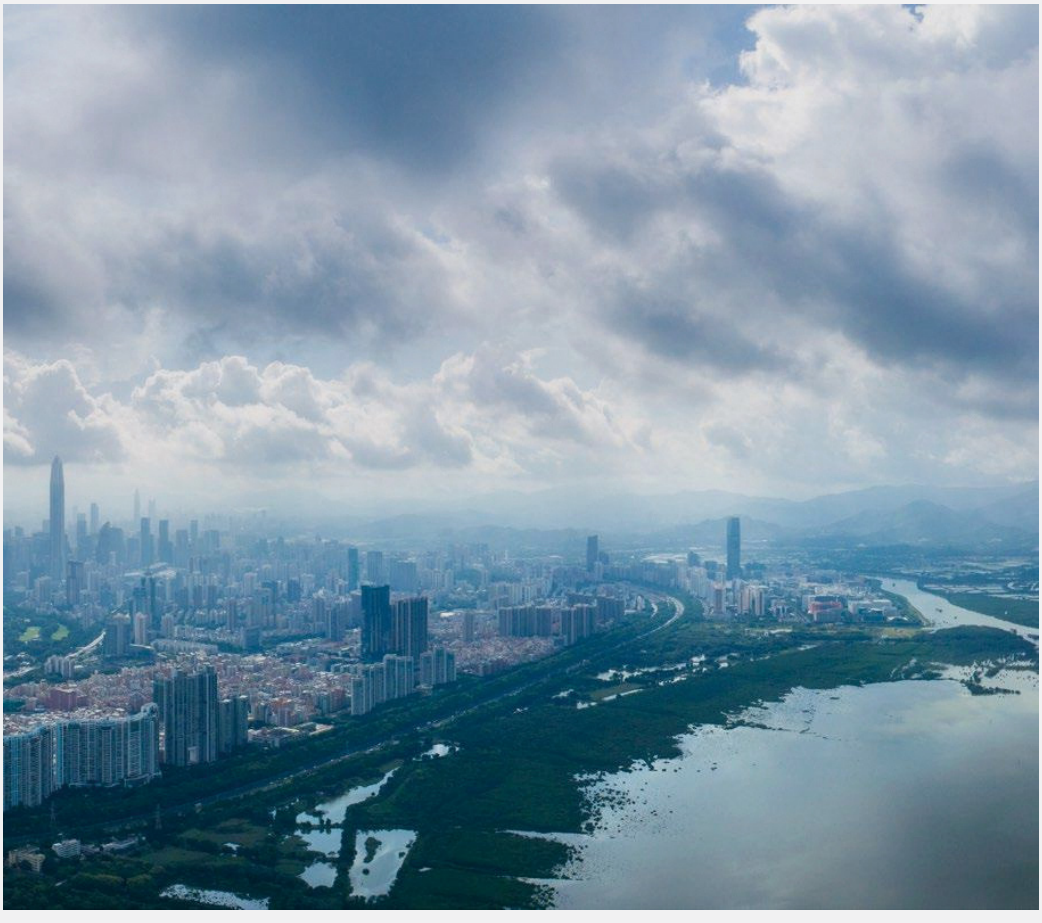


Figure 34 The Futian Mangrove Area and Shenzhen city *(source: MCF, 2016)*

WHY HAS THE CITY TAKEN ACTION

Ecosystem Loss: Large-scale urbanisation in Shenzhen Bay has a significant impact on the coastal environment. It is estimated that the majority of 10 square kilometres (km^2) mangrove areas in Shenzhen Bay were lost between the 1970s and 1980s due to wetland reclamation. (Wang, 1998) The loss of mangrove areas changed the water environment due to increased sedimentation, weakened water purification abilities, and has caused damages to the city's capacity in dealing with sea surges. The damaged ecosystem also led to dramatic biodiversity loss (Han et al., 2006) as the density of terrestrial birds dropped by 39% from 1993 to 1998; and several native vegetation became endangered species.

Push for Sustainable Development: Environmental degradation and changing climate risks have become priority issues that Shenzhen must address. However, how to navigate the way towards sustainable development is a huge challenge for Shenzhen. For the past decade, this megacity with steady population growth had to explore solutions for better river management, marking ecological baselines to maintain different types of ecosystems, and enhancing offshore seawater quality. The restoration of mangrove ecosystems is an integrated approach to achieve the goals.

GOALS AND OBJECTIVES

Legislated in 2015, the agreement among Shenzhen and Guangdong administrations and the MCF is to restore the mangrove ecosystem alongside the seashore of Futian District. It consists of two areas, the natural reserve area and the EcoPark. Based on the baseline mapping, there are two priority measures identified as follows:

- **To conduct a comprehensive baseline assessment to understand and restore the native ecosystem of the natural reserve area.** Based on the comprehensive local biodiversity baseline survey, the task force manages the natural reserve according to the ecological landscapes; management of the invasive species, and carry out long-term monitoring to protect the environment from seawater intrusion, pollution, noise and light pollution;
- **To designate the EcoPark as an open park for professional training and public education.** MCF builds the EcoPark as a platform for knowledge-sharing and recreational use, as well as leading localised research and developing systematic educational materials.

In recent years, China has paid special attention to mangrove ecosystem protection and restoration. In 2019, the Ministry of Natural Resources and National Forestry and Grassland Administration jointly conducted a comprehensive and detailed inventory of mangrove forests and coastal areas suitable for mangrove restoration. A comprehensive *Overall Plan for the Protection and Restoration of Important Ecosystems (2020-35)* was also released. One of the targets is to safeguard at least 35% of the country's natural coastlines and protect the marine ecological condition, including protection and restoration of mangrove ecosystems. The Shenzhen case in the mangrove ecosystem protection provides grounded knowledge for nationwide planning and actions.

PROJECT IMPLEMENTATION

Innovative governance suggests the participatory process where actors can play a variety of roles. How non-governmental players are engaged in the management of public natural resources is an ongoing experiment worldwide. The practice for Futian wetland ecosystems combines most strengths from different sectors. Firstly, the government identified the necessity of environmental restoration and maximised the ecosystem services. Due to limits of management mechanisms, cross-departmental collaboration on protected areas might not be sufficient enough to bring systematic solutions. On the other hand, NGOs are generally more flexible on mobilising resources and organising the work force accordingly. The common interests create room for these two key players to find approaches towards effective ecosystem management.

The Futian case presents the 'co-management' model, which is knowledge-informed and pioneer to similar practice in China. The MCF is the core executor on setting up working plans, organising task-oriented professional teams, as well as fundraising. The governmental actors ensure that the conservation activities correspond to regulations and long-term development agendas, via regular evaluations of the process.

- In 2015, the Urban Management Bureau of Shenzhen and MCF signed the agreement of *The Cooperation Framework of Natural Conservation of Funtian Mangroves*, addressing MCF's role in drafting overall plans, biodiversity survey, ecosystem management, and public education;
- In 2016, the MCF developed a five-year management plan, stated the establishment of Mangrove EcoPark, and education projects;
- From 2017 to 2018, the MCF conducted a comprehensive survey of the Futian mangrove ecosystem. Several ecological restoration projects on fish ponds and water birds habitats were conducted. Public education in the EcoPark involved with the Project WET nature education and some preliminary schools were on trial;
- Since 2019, the EcoGallery has opened to the public, while the education centre has been under planning and enhanced with more courses.

Public education is another breakthrough throughout the Futian case. Compared to other countries, nature education in China is emerging for only a small group of families and schools. The Futian EcoPark's central location in Shenzhen creates an opportunity to provide accessible and localised nature education resources and environment. Since 2017, the task force has been developing educational materials for different age groups and actively cooperating with primary and secondary schools in Shenzhen, encouraging the public to immerse and learn about nature in their daily life. In recent years, the involvement of nature education in the national curriculum has opened up more opportunities for the Futian mangrove ecosystem and the EcoPark (MCF, 2018) (MCF, 2019). Providing localised knowledge and linking the local conservation practice to a bigger context shapes the new roadmap for them to move forwards.

Ecosystem management is the science-based method taken in Futian practice. From a systematic perspective,

balancing conservation and economic development has always been a discussion since the very beginning. Fish-pond-based agriculture as seen in Figure 35 below, is the traditional to the Guangdong Province with fragmented water bodies and arable land collectively used for both aquaculture and agriculture and nutrition flow is circulated internally. After the baseline survey, the task force identified that several ponds transformed from mangrove forests into a healthy ecosystem, which provides habitats for small animals and birds as well as purification and sedimentation functions. Thus, these micro-ecosystems are conserved, instead of destroying the native species, which would take years to restore a functioning ecosystem.

Figure 35 Fish Pond inside of the Futian Mangrove Conservation Area *(Source: MCF, 2015)*

Grounded surveys maintain the accuracy and completeness of the baseline assessment. Site-by-site plans are made to achieve collective effectiveness, while sustaining the diversity of ecosystems. The main types of micro-ecosystems are fish ponds, rain gardens, floating islands, habitat zones, bird watching and vinery zones. These micro-ecosystems have distinguished purposes, ensuring a habitable environment for bird species without human disturbance, while well-planned routes can connect people with the EcoPark.

IMPACTS

Carbon Reductions: Mangrove ecosystem has incredible performance as carbon storage and sequestration. As a complete blue carbon ecosystem, mangroves and seaweeds have high carbon removal potential. The Global Mangrove Alliance estimates that mangrove forests can convert carbon dioxide to organic carbon at higher rates

than almost any other habitat on earth, therefore the 'blue carbon' can be both stored in the living plants and in their thick peaty soils, for centuries. Due to the lack of data, exact carbon reduction is not presented.

Environmental Education: Education and the development of nature education for schools are extended branches from the ecosystem management tree. Nature and cities did not coexist. As soon as Futian redesigned EcoPark and opened the educational galleries and museums, the local communities lived with nature. Parallel to the reform of the education policies and plans from national and local levels, the EcoPark increased in popularity for on-site nature education.

FACTORS FOR SUCCESS

One of the reasons for the success of the project is pursuing a realistic action plan based on local context, conducted by a cross-sectoral professional team. Primarily, the use of the PPP model as an innovative governance approach, which utilises the advantages of different stakeholders. Furthermore, with the political and community commitments towards the project, continuity of action plans and adaptive planning methods based on information, contributes to positive results.

LESSONS LEARNED

The 'Government + NGO + Professional management committee' model is innovative. For a long time, the engagement of the private sector and NGOs on environmental and ecological protection have been uncommon in China. Even for Shenzhen and the Guangdong Province, known as 'the hotspot of NGOs', NGOs took on advisory, execution or inspection roles for many social governance programs. This 'co-management' model is certainly a success. Considering the MCF is the core actor in this program, it also shows interest in supporting similar grassroots organisations through multiple paths. In 2017, the MCF proposed a fund targeting other educational organisations working in coastal areas (MCF, 2017). A peer-learning platform is also built through close collaboration with other environment foundations.

The MCF with a clear vision on mangrove ecosystem protection guarantees sustainable funding investing in research, ecological restoration, long-term monitoring, and the establishment of educational resources, substantially contributing to meeting the data gap, while navigating appropriate management approaches. Locally, the ecosystem area in Futian gets managed in a professional manner, which is also partly open as a new recreational site for citizens. For other coastal areas in China, it provides an example of how to restore, manage, and develop important ecosystems. The wetland education centre is also certified by the Ramsar CEPA framework (MCF, 2019).

CASE STUDY C8:
BRINGING THE RIVER BACK TO URBAN LIFE - ENVIRONMENTAL RESTORATION OF THE SUZHOU CREEK IN SHANGHAI

Suzhou Creek runs through all of Shanghai's old towns as seen in Figure 36 below, starting from the Tai Lake in the northeastern, flowing towards the East along the Qingpu, Jiading, Minhang, Changning, Putuo, Jing'an, Huangpu, and Hongkou districts. The river is significant in Shanghai's growth and development dating back to 1,300 years as a main transportation route. However, the rapid industrialization and urbanisation in the twentieth century damaged the Suzhou Creek as a water system, making it known as 'smelly and black water'.

Figure 36 Suzhou Creek and core districts in Shanghai
(Source: Shanghai Planning and Natural Resources Administration, 2020)

In 1996, the Shanghai municipal government started to address river pollution, especially for Suzhou Creek. The restoration of the Suzhou Creek and the riparian areas cost 14 billion Chinese Yuan (CNY), approximately 2.2 billion USD, implemented in three phases between 1998 and 2011. The costly yet successful restoration brought the river back to life. The fourth phase of restoration in 2017 sets a bigger vision with a financial budget of 25.45 billion CNY (3.99 billion USD), covering most regions along the Suzhou Creek surface system, accounting for 855 km^2. This stage emphasises the function of rivers from the ecological, environmental, and social perspectives. In recent years, more projects are implemented around the river with the aim of embedding and further integrating the river to the residents' life, by creating walking and cycling networks, public spaces and greening the areas to mitigate urban heat effects.

WHY HAS THE CITY TAKEN ACTION

Rapid industrialisation and lack of environmental regulations severely polluted the Suzhou Creek: Suzhou Creek has been absent from Shanghai life for decades as it is known as the "black lace" of the city. During most of the twentieth century, untreated sewage mixed with hundred years of sludge, totally destroyed the water ecosystem of Suzhou Creek.

Environmental restoration became the first task for the Shanghai municipal government in 1998: As this was a gargantuan task for a relatively inexperienced municipality back then, the city experimented with different strategies and adapted accordingly. This adds to another layer of challenge to the environment issue itself, which is how to set practical goals, and dividing them into approachable steps.

Shanghai 2035 Agenda aims to create Shanghai as a global metropolis that is innovative and prosperous, while maintaining the historical, cultural and ecological elements. The Suzhou Creek and the Huangpu River are recognized as the most important waterfront areas connecting most districts of Shanghai, thus the *Shanghai 2035 Agenda* will continue to improve the interface landscapes along the rivers (Shanghai Planning and Land Resource Administration, 2018).

GOALS AND OBJECTIVES

The project is along the 21 km Suzhou Creek, totalling to 42 km for both riversides. The restoration and design of the Suzhou includes three layers of perspectives and functionalities:

- Creating clean, enjoyable and accessible water body, watercourse and green space
- Creating interactive and functional elements for people to walk, such as bridges, small art galleries, historical buildings
- Integrating the Suzhou Creek landscape with the overall cityscape with a chic combination of historical and modern flair

PROJECT IMPLEMENTATION

Instead of viewing the river as a singular and linear ecosystem, the reclamation of the river is based upon creating a vibrant urban frontage that dynamically engages the surrounding neighbourhoods, architecture and green space while retaining its existing character. The entire restoration process can be broken down into four distinct phases, each phase consists of differentiated goals, which are:

- Phase 1 (1998-2002): Comprehensive environmental restoration, focusing on pollutant removal, sewage interception and treatment, sediment dredging [6.89 Billion CNY]
- Phase 2 (2003-2005): Water quality improvement and overall environmental upgrade, including enhancing the tributaries, upgrading the rivers' capacity on flood control, and the overall landscape design and walking infrastructure for recreational use. [3.77 Billion CNY]
- Phase 3 (2006-2011): Advanced restoration and upgrade, expending the restoration projects from the core districts to suburban areas, including a series of riverbank hardening, sediment dredging, and relocation of sewage and sanitation treatment centres [3.14 Billion CNY]

The fourth phase consisting of the *Suzhou Creek Waterfront Area Construction Plan* (2020) officially sets its timespan from 2018 to 2035, which is a comprehensive plan focusing on the whole 'Suzhou Creek Waterfront'

area, a total of 855 km^2. The goal of *the fourth phase of Suzhou Creek program (2018-2035)* is set as a demonstration to create a liveable and vibrant area in the megacity. Considering there are different types of industries alongside the whole river, there are three main targets:

- **Vibrant zones with multiple functions:** Meeting the residential, working, leisure needs
- **Historical and cultural zones in a 'lagom' size:** Historical blocks and buildings can be re-innovated as public space for outdoor recreation
- **Maximise ecosystem benefits through large-scale green infrastructure:** Integrating the river ecosystem and use as part of the residents' daily life, as an easily accessible area with restored ecosystem.

As the fourth phase of the project extends to conservation and upgrading of historical buildings, the city also engages diverse stakeholders, such as real estate companies, commercial centre developers, restaurants, community centres, in the renewal, operation, and maintenance works. The downtown segment with a higher density of human activities is designed to be more walkable, recreational and integrated with the residential and commercial areas. The part outside of the Outer Ring will be ecology-based, which includes multiple eco-corridors and natural parks for ecological conservation and recreational use. This split is illustrated in Figure 37 below.

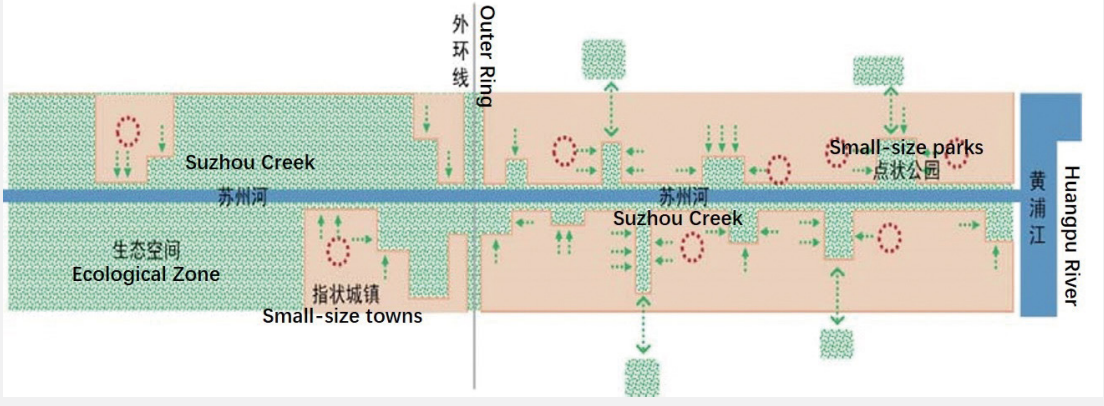


Figure 37 The design of Suzhou Creek Green Spaces
(Source: Shanghai Planning and Natural Resources Administration, 2020)

Most of the Outer Ring will be used as ecological zones for parks and natural conservations, where small-scale towns are embedded. For the downtown areas, besides connected green infrastructure all the way through riverbanks, several medium-size parks may also be linked as a system. Most areas are about commercial zones, residential communities, and public spaces and shopping centres. The design of green-blue infrastructure takes explicit consideration of multiple perspectives to create a liveable and inclusive city by emphasising on network connectivity and accessibility. The Suzhou Creek meanders along old communities, lanes and alleys, which might be less accessible by public transportation.

By incorporating Transit-Oriented Development (TOD) design, the river-side infrastructure connects the neighbouring communities and riversides with good walking and cycling infrastructure, as a low-carbon and convenient mobility alternative. Moreover, through the 'paths-with-a-view' concept, the landscape creates a continuous water and wetland landscape. The plan in the fourth phase is also to maintain consistent distance between the bridges. The bridges located at the Outer Ring and Inner Ring are around 500 to 800 metres (m) apart, since it is less populated. For the residential segment, the distance is about 300 to 500 m, while the high density commercial and shopping areas are about 150 and 250 m apart to control the crowd present for recreational and sightseeing purposes. The proposed bridge placements are seen in Figure 38.

Figure 38 The planning of bridges crossing Suzhou Creek (Shanghai Planning and Land Resource Administration, 2018)

Furthermore, the project also diverted sewage and installed a wastewater treatment plant with a capacity of 400,000 m^3 a day and solid waste collection wharves to flush and cleanse the creek. A barge that supports reoxygenating the creek was also built to restore aquatic life. Digital platforms are used for daily monitoring on water quality of the Suzhou Creek, especially the All-in-one-Net service delivery platform. The data collected are transferred to water affairs departments and community committees for the city to analyse. (China Economic Net, 2021).

To allow more mobile species to move through the unconnected areas of semi-natural habitat close to ecological corridors, ecological steppingstone is adopted as a cross-boundary design during the fourth phase of the Suzhou Creek Program. Originating from the landscape ecology subject, ecological steppingstone is one of the approaches to increase 'ecological points' for better connectivity for both people and small urban animals. This is implemented through installing small-sized green infrastructure and spaces at localised spots to create ecological corridors for animals and enhance walkability for people. The restored ecosystem and surrounding enhancements in addition to serving in risk reduction roles (eg. urban heat island effect mitigation, and flooding

control) also function as social centers (eg. recreational purpose and educational spaces).

Holistic approaches are also applied at historical buildings with cultural importance. As a core part for the fourth phase, the riverside area has been designated as a protected heritage zone. Through the classification of all historical buildings along the Suzhou Creek, five building types are identified: factories and warehouses; lanes and alleys; public buildings; special architecture, including the historical park (Zhongshan Park); and university facilities (such as the mansion-like former Saint John University building). Since old factories and warehouses occupy the most land space and have the highest potential for public use, most of the regeneration works are focused on the factory space. For example, the former Fuxin flour factory, which consists of several buildings, will be repurposed and transformed into a museum, a fashion and art gallery, and an indoor restaurant, contributing to Shanghai's flourishing art scene. Figure 39 below, shows an example of a proposed renovation of historical building spaces, such as the old flour factory.

Figure 39 Renovation design of Fuxin Flour Factory and the old picture
(Source: Shanghai Design and Promotion Centre for Urban Public Space, 2020)

IMPACTS

Water Management: The better stormwater and sewage management and remarkably improved flood control. The Suzhou Creek program reconnects most tributaries, which substantially reduces flooding risks, and creates ecological corridors through the whole water system.

Through improved water quality and sanitary conditions, the Suzhou Creek is no longer a health hazard, thus benefiting the three million residents living on the bank (Asian Development Bank, 2017).
Some of the other co-benefits include:

- Improved water quality at the Level V national standard with 45 fish species found in 2012, a significant increase from 2000 where only several fish and shellfishes were found
- As of 2021, Shanghai can treat 8.4 million m^3 sewage per day (China Economic Net, 2021), and in Phase 2, 1.3 million m^3 of sludge was removed. After separating solid waste and sludge, the sludge is used as soil bases for planting (China Environment News, 2018).

Social Benefits: Shanghai's Pudong area is the trademark of Shanghai, whereby the Suzhou Creek is the main character. The blend of modern and historical landscape along the waterfront continues to attract many tourists. Phase Four restoration works envisage increasing watercourse activities for tourists, including boating, cycling, and walking through better connectivity.

Social resilience is thus improved by reconnecting busy urbanites to 'blue nature'. The restoration of Suzhou Creek brings a lot of convenience for people to live a life within walking distance, and provides a cluster of public spaces. By 2021, the majority of Suzhou Creek Waterfront was built, accounting for 42 km in total (Dong, 2020). There are also 650,000 m^2 green spaces for the public, which makes the gathering and meeting much easier than before (Chen, 2018). The connectivity through the 42 km riverbanks enhances accessibility and walkability, which will be further strengthened in the fourth phase of the project.

FACTORS FOR SUCCESS

The consistency of policies and action plans: As presented in this case study, the environmental restoration process of Suzhou Creek has lasted for two decades, and still to be continued with the upgradation actions.

Learning by doing: Back in 1998, the government settled its action plan based on numbers of tests, since there was no clue on how the water pollution happened. Years of experience enabled comprehensive governance in the urban environment.

LESSONS LEARNED

Urban river pollution is a very common issue for cities in developing countries, and which is to be tackled for creating a much more liveable and sustainable environment. Suzhou Creek's decades of experience has three key take-aways:

- **Systematic and scientific thinking.** When Shanghai started its Suzhou Creek environmental restoration, there were many uncertainties, such as pollutant types and origins. However, after several experiments, the target pollutants were identified and included into the action plan.
- **Step-by-step action plan.** This is a long way from 'black-smelly river' to a growing, vibrant, and rich ecosystem. Even back in the 90s, the 'liveability' and 'human-nature interaction' were not in the consideration and planning of the Suzhou Creek program, the follow-up action on ecosystem restoration is certainly based on the former achievements. Through the first three phases, this improved environment offers adequate space for ecosystem service design.
- **Combination of scaling-up and scaling-down.** As introduced in previous sessions, this program has different scoping from one to another - mainly according to the phase duration and explicit targets. Appropriate scale setting adds more co-benefits, which can also provide suitable information for next-step planning and working.

CASE STUDY C9:
URBAN RENEWAL WITH GREEN BASIS IN CHENGDU, CHINA

As one of the major cities in southwestern China and the capital of Sichuan Province, Chengdu prides itself with its rich historical and cultural diversity dating back to at least 2,000 years ago. The long history of Chengdu's old towns, combined with the rapid industrialisation, meant that Chengdu had to strategically work on urban planning and regeneration for sustainable and balanced development. Chengdu has been doing extraordinary work on urban renewal practices. Similar to other rapidly developing cities, Chengdu started the urban design, restructuring and planning process in the mid-1990s.

The first city masterplan instituted in 1994 focused on industry relocation to suburban areas and expanded to the development of several new districts and towns in 2011 to cope with new growth opportunities. The second master plan targeted the renewal of the North Town, developing several programs, including redeveloping shanty towns around the railway station; relocating industries to designated industrial zones; and enhancing the functions of commercial centres and tourist sites, including historical heritage and traditional communities. The current urban renewal focus on developing the city into a "Park City". The timelines of the urban renewal plans can be seen in Figure 40 below.

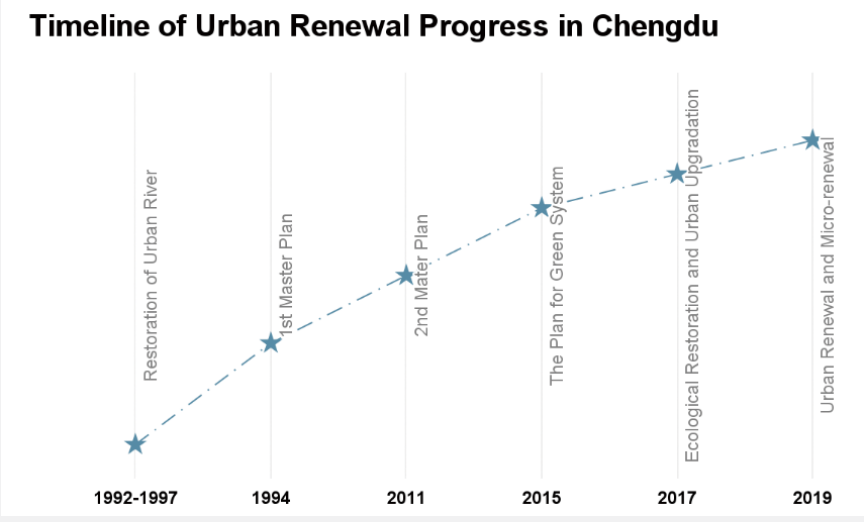


Figure 40 The timeline of the urban renewal process in Chengdu

Chengdu residents have been biggest beneficiary of the urban renewal program, seeing improved living conditions as upgrades provide better housing conditions and living environment. Consequently, the development plans have also seen new industries and businesses enter the communities, attracting new business opportunities from small companies to international multinationals.

WHY HAS THE CITY TAKEN ACTION

Ageing and dilapidated old residential areas and public settlements have been one of the obstacles for urban development and liveability. Since old infrastructure and urban services could no longer meet the current needs given the rapid economic and population growth in Chengdu as one of the most populated cities in China. Therefore, the city hopes to reimagine the existing public space to make it more liveable.

Rapid and uncoordinated city development led to urban sprawl and brought challenges to the core city districts and overall better planning. Urban sprawl induced travel demand, particularly by private automobiles, making high automobile ownership and traffic congestion another critical issue for Chengdu. While the newly built districts have clearer plans on their urban functions and zoning, the lack of coordination with the existing and older urban districts in terms of transportation corridors, satellite cities and inclusive social services. The challenge for Chengdu is merging the old and new development through a coordinated and coherent urban plan.

GOALS AND OBJECTIVES

Decades of experience on integrating ecological and natural capitals into urban development, brings Chengdu creative strategic planning. The Park City development strategy is an integrated, coherent and synchronised urban development and regeneration plan.

Harmonising nature with the built urban environment: Instead of addressing issues in silos at the sectoral or local-levels, Chengdu aims to harmonise the urban and natural environments emphasising Chengdu's character and ideology, also known as the "Green basis". For instance, rivers were excluded from the city masterplan in the past, but they are now considered as part of Chengdu's sustainable development. Hence, multiple approaches, like restoring river landscape, and improving water quality are undertaken. The 'liveability' of the city is integrated by upgrading the riparian ecosystem as part of its effort to enhance urban resilience

Turning Chengdu into a Park City: Chengdu aims to 'build a city within a park', as envisioned in the Park City long-term development agenda, emphasising on urban resilience, liveability and collaborative socio-ecological sustainability. The integrated plan coordinates the different urban districts within Chengdu in implementation. The key objectives of the Park City plan are: 1) value and incorporate the natural capital and ecosystem services into sustainable urban development; 2) achieve restoration of natural assets, such as water and green networks; 3) apply people-centred design and incorporate green-blue infrastructure; and 4) transform the industrial and manufacturing practices to achieve carbon neutrality and climate resilience .

PROJECT IMPLEMENTATION

Since early 2000s, Chengdu started a serial of policies and strategic plans on

- Historical community preservation (since 2003);
- Urban renewal (since 2011);
- Old neighbourhood preservation and regeneration through better infrastructure and service (since 2016);
- Revitalise old communities' by introducing different types of recreational activities and collective workplaces (since 2018);
- Urban 'micro-renewal' (since 2019); and
- 'Organic renewal' under the 'Park City' plan (from 2020).

The Decision on accelerating building a beautiful and liveable Park City, the Chengdu Beautiful and liveable Park City Planning (2018-2035), the Decarbonising Chengdu Strategy, are regarded as the green dimension of the city's Urban Development Plan (2016-2035). The political commitment of the Park City urban development is clear through the establishment of Park City Construction Bureau to implement a comprehensive, integrated, sustainable and innovative urban development plan. The whole urban renewal process is highly reliant on the cross-departmental incorporation, while the Park City Construction Bureau is the nexus in mainstreaming this concept into urban development. However, a key feature is the community planner mechanism, which has been unique to Chengdu utilises existing urban settings, community needs, and revitalisation strategies to make 'the local community alive again', hundreds of communities in Chengdu are regenerated in various new elements. These innovative solutions support residents to participate in the urban transformation, as well as create possibilities for new industries.

Urban renewal can be performed in various ways. Chengdu creatively applies it in multiple spatial dimensions. Firstly, micro-renewal is the essential approach used. The 'embroidery needles' metaphor indicates it is a way to upgrade communities without large-scale replanning and rebuilding but in-situ solutions, while the needs of residents are carefully considered. Similar concepts are also applied in other mega-cities in China, such as Guangzhou and Shenzhen with high migrant flow. Micro-renewal refers to small and localised solutions to meet the diverse living and housing requirements of local communities. For example, traditional houses are upgraded to meet the accessibility needs for the young children and the elderly. Furthermore, the surrounding neighbourhood is also equipped with community gardens and social gathering places for the senior citizens. The design and planning of the overall living environment are well thought of to cater for the young and old to live, work, study and play (He & Wang, 2016).

Following that, a niche vocation also began, known as community planners. These planners specialise in creating inclusive urban design and regeneration for different age groups at the community-level. In Yit's interviews (Yit, 2021), new public settings are introduced by community planners, such as Cafe, a place not within the typical

activity range of the senior residents' but a common meet-up place for the young. However, the community planners seek out micro-renewal opportunities to design inclusive cafes in the community. It considers the original environment into design, such as trees, sheds, benches, while building more accessible infrastructure to support people with reduced mobility. The Cafe is also used as a community gallery where grassroot works are revitalised. The café is picture in Figure 41 below.

Figure 41 An inclusive community Cafe in Chengdu *(Source: Yit, 2021)*

As part of the ***Smart City Design***, Chengdu also embeds ICT in urban design and planning as a systematic means to digitise community management and engagement. The direct application of the ICT is transportation infrastructure design and improvement. It is now being piloted at the Tianfu New Town. Through ICT and application of big data systems, all data resources for local administration could be gathered into one platform, for better monitoring and planning (Fan, 2016). By dividing Chengdu into 1,814 transportation units, the system analyses the carrying capacity of the road network and needs based on present and future demands to avoid rebuilding and redesign in the near future. Based on the analysis, the planners can decide the suitable number of parking units, road width and length in Tianfu New Town (Chu et al., 2020).

Inclusive design is another major component. People-oriented mobility planning is also adapted, a paradigm shift from the previous road-vehicle-focused transport planning. Instead, small paths, safe crossroads, and sidewalks between building blocks are created to enhance walkability, safety, and the overall urban landscape. Wang (Wang, 2016) conducted an analysis on the design of different intersections for pedestrians and the density of small paths. With this, a detailed plan for the road network in Tianfu is developed, as an inclusive approach to 'bring people back to the streets. Building on this practice, slow-traffic systems in old town areas were improved, taking walkability, unique landscapes, and tourist sites into account (Li et al., 2020). Children are especially prioritised in Chengdu's spatial planning, institutional design and social service provision. For instance, through participatory policymaking, the needs for children are also considered for business and urban development needs, from

medical and children welfare, to child-friendly infrastructure at the neighbourhood, district and city-levels.(Zeng et al., 2020).

IMPACTS

Chengdu's experience shows several dimensions of urban resilience. Besides disaster risk reduction and climate adaptation through better blue-green infrastructure and planning, the renewal plan also brought socio-economic benefits. This renewal program consists of systematic design, where there are several possibilities under the 'urban setting'. Many regenerated communities include shared workspace for small enterprises that are affordable, centred, and flexible. The urban regeneration concept balanced the old and the new by avoiding total makeover and reconstruction that wiped off the rich history and at the same time, not overly conservative that the old neighbourhoods do not allow for contemporary development and ideas. This attracts Chengdu's younger workforce to stay and work at the city instead of migrating to the more developed cities on the East coast.

FACTORS FOR SUCCESS

- **Strategic Commitment and Evaluation:** With a strategic political commitment and vision to build "a city within a park" under the overarching Park City development plan, there was strong support from the municipal government by establishing the Park City Construction Bureau to coordinate and implement the spatial plans. Part of this effort, involved the development of an ecosystem service valuation monitoring framework, which promotes investments into natural environments by accounting for natural capital.
- **Ensuring Community Acceptance:** Building on Chengdu's experience in urban regeneration and renewal in a phased approach, community and local experts were engaged to redesign and renew the urban areas, through the utilization of community planners, reflecting neighbourhood cultures and uniqueness and resident needs.

LESSONS LEARNED

Urban renewal is a long-term and continuous process, which aims to meet the existing demands that come with city development and also create possibilities for people to co-design the future of the city. The PPP experience in Chengdu invites private partners and individual planners (such as the community planners), into the program design, management and development of historical community development projects has shown that vibrant community life in old districts and people-centred new district design, are two compelling outcomes that are possible.

Chengdu's experience can be easily transferred to other cities, particularly the inclusive design aspects, micro-renewal, community planner. This will be very relevant for both old communities and newly developed or developing communities. It creates a more transboundary and solution-oriented working method on dealing with urban issues.

D. Clean energy

Introduced in Chapter I, clean energy in the urban environment revolves around two key areas, clean energy generation, as well as energy storage technologies. Introduced below are some of the key technology areas to reduce emissions and build upon urban resilience. In this section, we will also introduce three case studies of successful implementations of clean energy.

Energy Technologies

Photovoltaics and Solar Power

Solar panels can be used to provide electricity or the thermal energy may be collected in solar heaters to provide warm/hot water as well to reduce the need for electric or fuel based heating. Batteries can in tandem provide electricity during the night. The stored and converted energy could also reduce the need for heating or cooling.

Geothermal

While the conventional idea of geothermal power is in the use of steam for power generation. The temperature differences can also be used for warming water or for cooling as well as underground temperatures due to the thermal mass tend to maintain temperature within a certain range more effectively.

Ionic Differential Power

Specific to city geographies near river mouths connecting to the ocean or a saltwater body. This technology relies on the osmotic effects of salts migrating from higher to lower concentrations to provide power.

Wind Turbines

While the rotary horizontal wind turbines are more commonly seen as the image of wind turbines, the lower wind speeds that are most likely to be found in urban environments can also be utilised by vertical wind turbines with its compact frames to provide small amounts of power in urban settings to smaller individual low-rise buildings.

Hydro (Rivers and Dams)

Waterwheels, low-head micro hydro and turbulent turbines may be used on a smaller scale to provide electricity that feeds into the grid a consistent amount of power provided by flowing rivers. However, such projects may interfere with other river activities such as tourism or boats for transport.

Carbon Capture and Storage and Reuse / Recycle

Carbon dioxide from factories or power plants are captured and reused by pumping into underground reserves to aid in liquid or gas extraction. Alternatively, the direct conversion of carbon dioxide into gaseous (Carbon Monoxide or hydrocarbon gases) or liquid (Hydrocarbons and alcohols) fuels through catalytic chemical reactions.

Energy Storage Technologies

Mechanical Flywheels

In energy storage, the inertial rotation of a flywheel is used to store excess energy and discharged into the motor/generator when needed. Flywheels can charge and discharge rapidly, although frictional and mechanical losses have to be accounted for as well as service life, when comparing to competing technologies such as capacitors or batteries depending on the load use case.

Compressed Gas Storage

Atmospheric air is compressed when excess power is available and released through a turbine to generate power when it is required, more complex mechanisms of thermal recovery or combination with other mechanisms such as district heating and cooling or thermal storage may be used to increase the overall system energy efficiency.

Batteries (Passive)

Lead-acid, metal hydride are commercially well implemented and recycled batteries with Li-Ion batteries now becoming a mainstay due to its adoption in portable consumer electronics and electric vehicles. Research is ongoing in mitigating battery performance degradation in existing battery types, as well as different chemical compositions for batteries with higher energy densities and safety against fire and explosions.

Supercapacitors

A design that has the benefits and drawbacks of both batteries and capacitors. The fast discharge response of a capacitor and energy storage almost reaching that of commercial batteries, is deemed as a positive trait for a load-balancing device in electrical grid applications or as an uninterrupted power supply setting when paired together with batteries or other longer term energy storage devices.

Thermal Storage

Storing thermal Energy either at supercritical levels of steam or liquid nitrogen as an example. Such gases are then processed to run through turbines to extract power from gas expansion similar to compressed gas storage. As an alternative for building heating and cooling, hot or cold water may be stored and used to regulate a buildings thermal envelope and charged when excess electricity to power a heat pump is available.

Flow Batteries

Flow batteries are actively pumped liquid solutions that allows reactant solutions to interact across a membrane which prevents direct mixing. The reactions produce a charge similar to normal batteries and stops providing power when the active reactants are used. Unlike batteries that are widely used and known in commercial applications, that act passively in a circuit to provide power, flow battery systems requires intervention to operate.

CASE STUDY D1:
NEAR-ZERO ENERGY BUILDING - XINGYE RENEWABLE ENERGY INDUSTRY PARK R&D BUILDING IN ZHUHAI

The R&D building of Xingye Renewable Energy Industry Park in Zhuhai shown in Figure 42 below, has been initiated as a demonstration project of the China-US Clean Energy Joint Research Center (CERC) Building Energy Efficiency Program. As China's first green building showcasing near-zero energy technologies in a climate zone that experiences both hot summers and warm winters ('hot summer and warm winter' climate zone), the R&D building obtained China's Three-star Green Building and Leed Platinum Certification by the United States Green Building Council.

In addition to extensive use of solar technologies such as photovoltaics, the building also makes extensive use of solar thermal technology to provide hot water. The combined panel and shading effects serve not only to cool the solar panel but also serve to control lighting and thermal envelopes of the building, which is also bolstered by the use of insulating windows with thermal conduction breaks and low-E insulating glass. The enterprise China Shuifa Singyes Energy Holdings Limited self-raised main part of the fund and received additional funding from the Ministry of Science and Technology of China for the building project, which covers a total construction area of 23546m^2 and is 17 floors tall.

Figure 42 Landscape View of the Xingye industry park and research building. *(Source: Constructions21.org)*

WHY HAS THE CITY TAKEN ACTION

Continuous growth of energy consumption in the building sector: By 2020, the total existing building area of Zhuhai City was estimated at approximately 210 million square meters. The total building energy consumption accounts for 30% of the city's total energy consumption. With the continuous development of the city and the ongoing population growth, the overall building area and energy consumption will increase year by year.

Therefore, it is crucial to reduce building energy consumption and promote green, near/net-zero energy buildings for Zhuhai to transit to low-carbon development.

Necessity for innovative technologies for the 'hot summer and warm winter' climate zone: Zhuhai's 'hot summer and warm winter' climate zone is known for its high temperatures and humidity. Therefore, it is essential to develop innovative and optimised building technologies in line with local climate characteristics to achieve the maximum amount of energy-saving from building operations.

GOALS AND OBJECTIVES

Zhuhai issued and implemented the "Thirteenth Five-Year Plan for Building Energy Efficiency and Green Buildings" and "Special Plan for Green Building Development in Zhuhai City", setting up the goals and implementation steps for green building development and proposing a 100% compliance rate for new buildings in terms of green and energy-efficiency requirements, setting obligatory targets such as achieving more than 50% of green buildings with a rating of two stars or more, and predictive targets such as achieving cumulative building energy savings and carbon dioxide emission reductions to promote the overall development of green buildings.

- Demonstrate near-zero energy technologies for buildings for this climate zone that can be replicated and promoted in other localities with this climate
- Reduce energy consumption and greenhouse gas emissions caused by low energy-efficient buildings and enhance the overall building energy efficiency in Zhuhai
- Promote the low-carbon transition of Zhuhai city and contribute to China's 2050 carbon neutrality target at local level

PROJECT IMPLEMENTATION

New S&T approaches: The technology is developed by the China-US CERC Building Energy Efficiency Program. The project adopted a technical route to improve energy efficiency, i.e., it prioritised the use of passive technologies and further optimised the energy system using active technologies in order to meet energy demand. An innovative, combined technology system was developed in this project that integrates two major passive technologies of "ventilation and shading" and two major active technologies of "personalised intelligent control and renewable energy utilisation" to demonstrate the feasibility of cost-effective, near-zero energy-consumption buildings in a climate zone with high temperature and humidity in summer and relatively high temperature in winter. In addition, solar thermal is used to provide the building with a source of hot water.

Multifunctional photovoltaic curtain wall that integrates ventilation, shading, and power generation: This wall design shown in Figure 43, cools photovoltaic modules and passages in the building, provides natural ventilation of indoor spaces at night and also serves to cool the rear face of the installed solar panels. It has high

shading performance reducing the thermal transfer of heat into rooms, reducing the need for air conditioning or heating making it suitable to use in the climate zone across seasons.

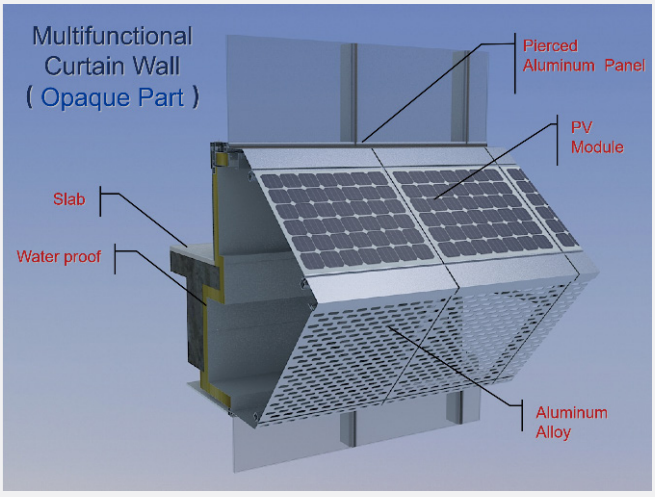


Figure 43 The controllable multi-functional photovoltaic curtain wall integrating ventilation, shading and power generation

Smart microgrid technology based on office buildings' main load: After matching the building's photovoltaic system with grid power and diesel engines, the operation will run in an energy-efficient and economical way through smart management systems. The installed photovoltaic capacity is 122 KiloWatt (kW) and is connected to two 50kW energy inverters set in parallel to form a two-way system and a 80 KiloWatt-Hour (kWh) lithium battery supply. The redundant backup power supply is utilised when grid energy is not available. The system functions as a traditional uninterrupted power supply (UPS) system for the building and balances power discharge and charging cycles across day/night cycles as well as seasonal loading differences with grid charging.

Building an energy management system: This system utilises radio frequency identification (RFID) and other positioning technologies to run climate and energy control systems according to the presence of people, which is adjustable according to personal preferences and can go into a hibernation mode during night-time to conserve power when everyone has left the building.

IMPACTS

The annual operation energy consumption of this building is 40.53 kWh/m^2. The net energy consumption of the building after deducting solar power generation and energy consumption of the data center is 23.65 kWh/m^2, which is only 23.4% of the energy consumption for large public buildings in Guangdong Province. The project saves about 312,200 kWh of electricity and 2,689 tons of water each year; therefore it qualifies as a near-zero energy consumption building.

National and international recognition and application: proof of successful application of R&D to improve energy efficiency and green energy production can be emulated in China and abroad in South-East Asia in places that face similar climates.

Flourishing communities: there is an increase in comfort and living conditions for occupants of the building which can lead to increased health, working productivity, and life satisfaction. On the city level, this construction and further expansion of these technologies can also lead to reduced costs for maintenance and operation due to the usage of advanced technologies of high quality and higher asset values for homeowners for inhabitants of Zhuhai.

Decrease in carbon emissions and related pollution: due to the reduced energy consumption, carbon emissions in the city are lowered, leading to a reduction in pollution and an increase in public health in the Zhuhai area.

LESSONS LEARNED

The further improvement of building performance and the application of scientific and technological innovations will lead to increasing costs, which is one of the challenges of future project replication and promotion. However, some of the nearly zero energy building technologies demonstrated in Zhuhai's project have been replicated to other buildings in Zhuhai, and other cities such as Yan'an, Guiyang, Datong.

There is however, a shortage of talent engaged in design, construction, inspection, supervision, and management related to high-performance buildings such as near-zero energy buildings. For example, designers are not familiar with new design theories and calculation methods and lack experience in refined and accurate designs; most construction personnel is not trained to handle refined construction and lack knowledge of new technology theory and practice. Significant education and research studies need to be conducted to build competence in reproducing and developing low energy or zero energy structure designs as well as computer design programs and simulations for such activities.

CASE STUDY D2: ENERGY SELF-SUFFICIENCY VILLAGE - CLEAN ENERGY TRANSITION WITH PUBLIC ENGAGEMENT IN SEOUL

Seoul metropolitan is home to about 10 million residents. In 2018, the energy consumption of the city accounted for 6.3% of the total energy consumption of the country. Residential and industrial sectors are the largest energy users, accounting for 57% of the total energy consumption of the city (Climate and Environment Headquarters, 2020). Furthermore, energy security and safety are also topics of high prominence and interest from the local communities and citizens as nuclear safety is a continuous debate due to the Fukushima incident in the neighbouring country, Japan (Seoul Institute, 2016).

Against this background, the Seoul Metropolitan Government (SMG) engaged its communities to fight against climate change and energy crisis by launching the Energy Self-Sufficiency Village project in 2012 under the slogan "citizens are energy". This concept heavily involves community participation beyond their role as energy consumers and aims to increase energy independence through decentralised solar power generation and consumption at each village, which in turn will support Seoul's overall energy independence. Local stakeholders and communities are able to directly contribute to the energy crisis through energy saving, energy efficiency, and further energy generation by using solar panels (Climate and Environment Headquarters, 2019). An example of the solar panel project is shown in Figure 44 below.

Figure 44 Mini solar panels installed in Sibjaseong Energy Self-Sufficiency Village
(Source: Seoul Metropolitan Government, 2017)

WHY HAS THE CITY TAKEN ACTION

Energy transition goal set by Seoul Metropolitan Government

The urban village model of energy self-sufficiency has been developed and promoted under the One

Less Nuclear Power Plant policy, a classic example of the energy transition policy of Seoul city (Climate and Environment Headquarters, 2019). The Fukushima nuclear accident stirred governmental and public attention to the risks of nuclear power plants and facilitated increasing public consensus about a transition into safe and clean energy (Seoul Institute, 2016).

A large share of residential sector in energy consumption and GHG emissions

In 2018, the energy consumption of Seoul city accounted for 6.3% of the total energy consumption of the country. Residential and industry sectors were the largest energy consumers, amounting to 57% of the total energy consumption of the city (Climate and Environment Headquarters, 2019). Moreover, when looking into the GHG emissions inventory by sectors in 2018, energy demand accounted for 92.2% of GHG emissions of the city; residential buildings from energy demand emitted 27.9% of GHG emissions from the energy sector (Climate and Environment Headquarters, 2021). In this regard, energy demand control and energy efficiency with public engagement were suggested as a solution to Seoul city, because of the large volume of the energy demand of about 10 million residents with a high level of dependence on external energy sources.

GOALS AND OBJECTIVES

The local/national government's policy targets, goals, and strategies

The Korean Government aims to transition to sustainable and clean energy by announcing the Green New Deal and 2050 Carbon Neutral Strategy in July 2020. Korea is highly dependent on energy imports, accounting for 94% of the total energy supply in 2017. Furthermore, its Total Primary Energy Supply (TPES) is also highly dependent on fossil fuels and nuclear energy sources (94.2%) compared to the TPES at the international level, with the following breakdown: Oil (39.5%), Coal (28.5%), Natural Gas (15.7%), and Nuclear Energy (10.5%) (Climate and Environment Headquarters, 2020; Seoul Institute, 2020). Thus, the central government set a goal of increasing renewable energy sources to 30~35% by 2040 (Ministry of Trade, Industry, and Energy, 2019).

Aligning with the national approach to the energy transition, the SMG implemented energy management and transition initiatives. SMG launched the first phase of the One Less Nuclear Power Plant in 2012 and its second phase in 2014, with a stronger narrative for public engagement (Seoul Metropolitan Government., n.d.a). Moreover, SMG initiated the 'Solar City, Seoul' project with a focus on deploying solar panels generating one gigawatt (GW) energy by 2022 (Seoul Metropolitan Government., n.d.b). These results in the following core goals for the project:

- To enhance the energy independence of the city to be less reliant on imported energy outside of the city
- To contribute to the transition into safe and clean energy

PROJECT IMPLEMENTATION

The SMG set up the Citizen's Environmental Cooperation Division under the Climate and Environment

Headquarters which monitors and scales up the project and the institutional setup is shown in Figure 45:

- The Citizens' Energy Cooperation Division of SMG managed the project by providing financial support and supervising the project implementation. Today, the Energy Transition Cooperation Team under the Citizens' Environmental Cooperation Division monitors and promotes the village model.
- The district office connects the project with other existing projects in the respective local areas, including setting up a consultation group for knowledge sharing between the environment agencies and the villages.
- Community service centers, which are set up by the local governments, directly communicate with the villages and contribute to the promotion of the project and public cooperation.
- Consultation agencies communicate with the villages and design programs and a vision for the community.
- The local residents play a major role in carrying out the project with enhancing sustainability.
- Steering committees support the project implementation at the municipal level, including the project screening and selection, problem consultation, vision casting, and strategy setting processes. Inputs received from the local communities are incorporated and reflected in the policies and action plans

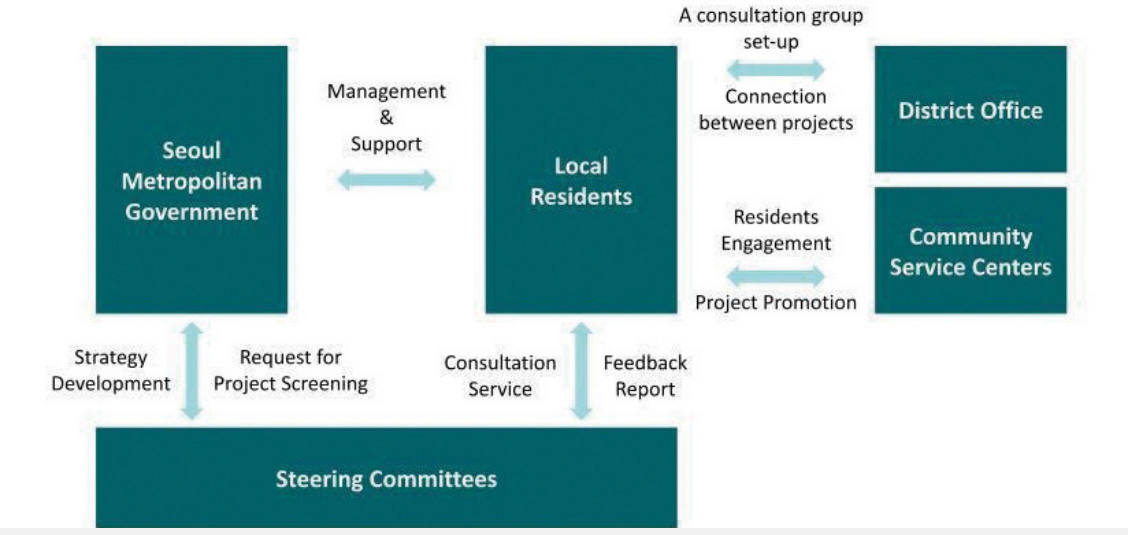


Figure 45 Energy Governance of Energy Self-Sufficiency Villages *(Source: Seoul Energy Self-Sufficiency Village White Paper)*

The project has been developed in two phases. Between 2012 and 2018, the Energy Self-Sufficiency Village 1.0 project was designed and implemented to stabilise the concept of the villages, i.e., minimising villages' demand for external energy sources and enhancing the capacity to be self-sufficient in energy generation and consumption. The number of villages increased from seven in 2012 to 100 in 2018 with various features. In 2019, the Energy Self-Sufficiency Village 2.0 project consequently followed to develop a profitable, standard, urban model and expanded the scope from village to district with the creation of an urban ecosystem for economic benefits from energy self-sufficiency. The second phase continues to set up 300 villages, 10 energy living LABs,

and four energy self-sufficient and innovative districts using ICT by 2022 (Climate and Environment Headquarters, 2019).

The technology used in the first phase of the project focuses on energy generation and energy efficiency. Firstly, in terms of energy generation, 3kWh and 250W solar power generators are installed in the villages depending on the housing types, such as detached housing, housing complex, and community building. In general, solar panels are equipped on roofs of detached housing to generate 3kWh energy (Lee, J., 2017). For example, Seongdaegol Energy Self-Sufficiency Village joined a village-living-LAB project with the Korea Institute of Energy Technology Evaluation and Planning to develop a DIY kit for small-sized solar power generators that can be easily installed compared to those on the market (Climate and Environment Headquarters, 2019). The solar panels are also equipped in balconies of housing complexes, such as apartments with limited space, to generate 250W energy. In terms of energy efficiency, low energy-efficient light bulbs are replaced with LED lights for both detached houses and housing complexes. Building Retrofit Project (BRP) was also implemented but limited to community facilities in some villages due to high cost (Lee, J., 2017). For instance, Seongdaegol Energy Self-Sufficiency Village carried out BRP to minimise energy loss at the senior citizen community centre through building insulation, deployment of LED, installation of energy-efficient equipment for windows, and deployment of micro heat combined boilers (Energy and Climate Policy Research Institute & Seoul National University, 2017). More advanced technologies include Intelligent Communication Technology (ICT) for collecting and analysing energy data will be applied to the second phase of the project to be completed by 2022.

Approximately 0.3 Million USD was spent on the Energy Self-Sufficiency Village project between 2012 and 2019. Subsidy varied according to the sub-project tailored to the local villages and the project plan's assessment results. Villages received around 10,000 USD a year on average. Villages take responsibility for the project and, in this regard, bear 10% of the project cost.

IMPACTS

Carbon Reductions: The amount of GHG emissions reduction achieved from only the Energy Self-Sufficiency Village project is not available. However, it is assumed to contribute to the achievement of One Less Nuclear Plant – that is, 14.50 million tonnes of carbon emissions reduction of the city between May 2012 and December 2018 – together with 5.18 Million tonnes of oil equivalent (Mtoe) of energy generation and strengthened electricity self-independence capacity of the city up to 20% (Climate and Environment Headquarters, 2019).

Thirty villages participated in the project between 2012 and 2015, saving about three times more energy than ordinary villages in the city within the same period. In 2015, thirty villages consumed 649 kWh less external energy sources and reduced 12.2% total energy use compared to 2012. Moreover, the average ratio of energy reduction to governmental financing of the 30 villages between 2014 and 2016 was 2.9 kWh per 1,000 KRW (2.9

kWh/0.85 USD). The highest ratio was 33.6 kWh per 1,000 KRW (33.6 kWh/ 0.85 USD). On the other hand, ordinary villages consumed 108 kWh less external energy in 2014 compared to the 2012 level; and reduced 3.4% of energy use compared to the level of 2012 (Lee, J., 2017).

Energy Welfare

Profits from energy saving of the villages are used to support those who have less energy access. For example, the Energy Self-Sufficiency Village housing complex in Seongbuk-district is a classic example of energy welfare. Profits from the "3+1 Energy Saving Campaign" were used to guarantee employment of 30 security guards of the housing complex with increased salary by 19% and to install a small-sized solar energy generator in their office. Later, SMG deployed solar energy generators for more security guards (Climate and Environment Headquarters, 2019).

Job creation

The village model contributes to job creation in the energy sector. For instance, Seongdaegol Energy Self-Sufficiency Village launched a market shown in Figure 46 below, for selling eco-friendly heat-insulating materials, high-efficiency LED light bulbs, chargers using solar energy. The village also launched an online pop-up store selling eco-friendly products and providing consultation services for energy training, home renovation, and solar panels (Climate and Environment Headquarters, 2019).

Figure 46 Energy Supermarket in Seongdaegol Energy Self-Sufficiency Village *(Source: Seongdaegol People, n.d.)*

FACTORS FOR SUCCESS

Compared to the previous initiatives for enhancing energy self-sufficiency of villages, *the Energy Self-Sufficiency Village project* in Seoul city purposefully engages governments at the city and district levels in launching the project. Multilateral collaboration has the significance of laying the administrative, regulatory, and financial frameworks necessary to facilitate project management. While SMG provides administrative support in setting up the villages through the Citizens and Environment Cooperation Division, the district provides more practical support tailored to the conditions of the villages by keeping continuous and close communication with local residents (Climate and Environment Headquarters, 2019).

Aligning with the context of energy policies adopted by SMG, *the Energy Self-Sufficiency Village project* promotes energy governance as a means of enhancing its sustainability. Energy governance adopts a public and private partnership to find solutions to challenges faced by the villages. In particular, public engagement plays a crucial role in making the project sustainable and effective. Local residents contribute to project design, considering the local context, capacity, and challenges, in cooperation with experts and local governments. To do this, governments at the city and district levels help communities to enhance knowledge through education, awareness-raising, training provided through energy campaign promotion centres and by the internal and external experts, and on-the-ground energy consultation services (Lee, Y., 2017; Climate and Environment Headquarters, 2019).

LESSONS LEARNED

The project, from a practical perspective, is to present the political will of SMG to improve the energy supply capacity of the local community. Although the project technically promotes the urban village model of self-sufficiency in energy with three key focus areas - energy saving, energy efficiency, and energy generation using solar panels, it is challenging that the scope of the project limits electricity independence capacity. Firstly, the Seoul metropolitan area has a limited capacity to generate clean energy, which is essential to achieve self-sufficiency in energy, due to the climate, geography, and economic conditions. Secondly, the city cannot be self-sufficient in utilising diverse sources and usages of energy, such as urban gas and heat for heating and cooling, water energy, and petroleum for transportation. Lastly, considering project implementation under the scheme of One Less Nuclear Power Plant, it is clear that its inclination to be self-sufficient in electricity rather than energy.

The project lacks reliable indicators to evaluate how self-sufficient the local community is in terms of energy. First, project evaluation leans toward reports submitted by participating residents without a system of verifying the data. Furthermore, there is a perspective gap between common understanding of energy independence ratio – the ratio of demand to production – and indicators of reduction ratio of external energy demand compared to a previous year set by SMG. Precise and sound indicators from both quantitative and qualitative perspectives are required to improve the objectivity and reliability of project evaluation.

CASE STUDY D3:
HYDROGEN TOWN - ULSAN ENERGY TRANSITION THROUGH THE PROMOTION OF HYDROGEN

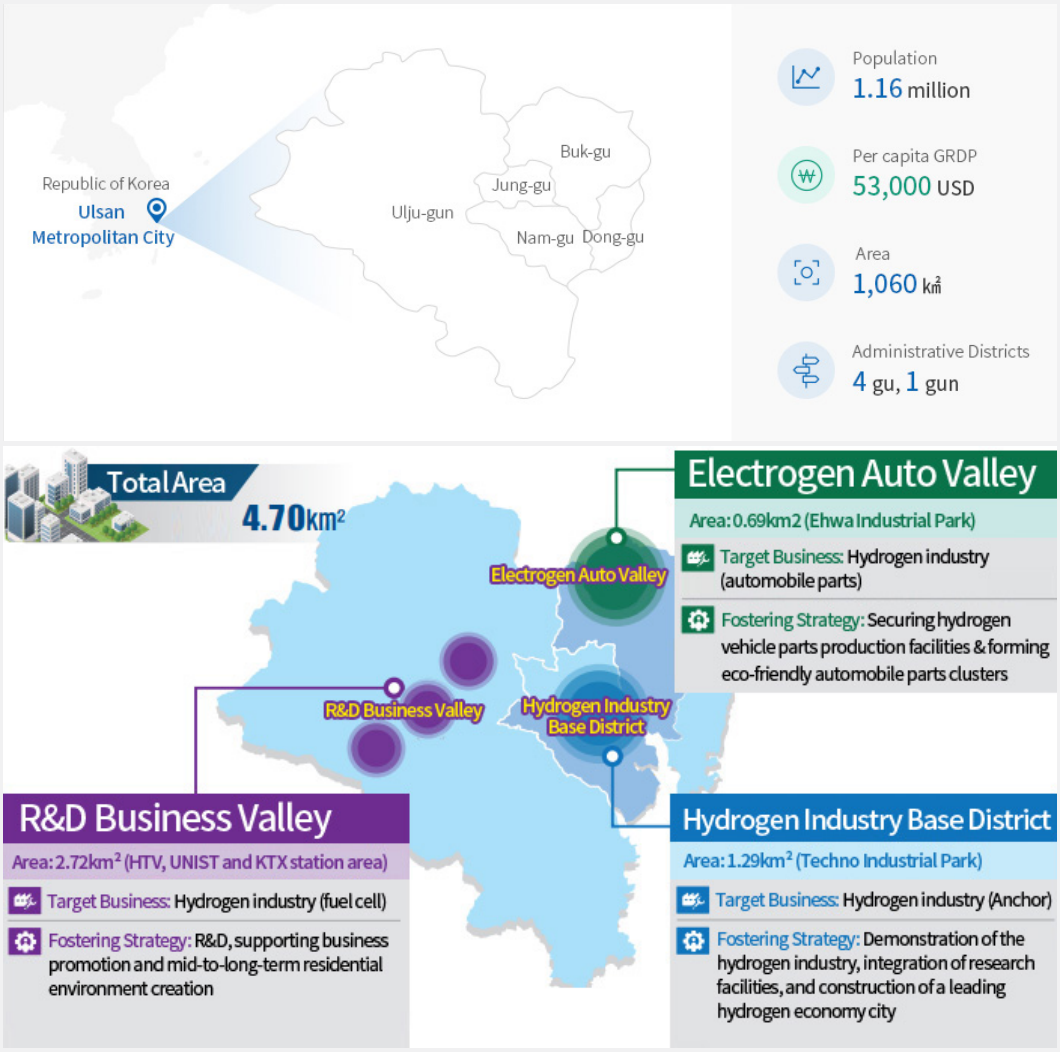


Figure 47 Ulsan City at a galance *(Source: Investkorea.org)*

Ulsan city as shown in Figure 47 above, is a representative city for heavy and chemicals industries where a large number of oil-refining, petrochemical, automobile, and shipbuilding businesses are located. Due to a high volume of fossil-based energy consumption for industrial use, energy use per capita of the city set a record in the Republic of Korea in 2013. In response to surging demand for climate actions and move toward sustainable energy at international, national and local levels, Ulsan Metropolitan Government (UMG) formulates strategies to use hydrogen as an engine to fuel sustainable development (Woo, 2014).

The local government makes efforts to establish hydrogen infrastructure and launch demonstration projects in the fuel cell battery and the transportation sector. According to a publication by Korea Development Institute, the city lays the groundwork for hydrogen ecosystem by producing 820,000 tonnes of by-product hydrogen accounting for 50% of a total hydrogen production at the national level, installing 120 kilometres (km) pipeline accounting for 60% of a total hydrogen pipelines of the country, and building a hydrogen station in urban area connected with the pipeline – which is the third urban hydrogen station in the world and the first in Republic of Korea (In, 2021).

Between August 2012 and April 2018, the city also implemented a demonstration project for the world's largest hydrogen town. This hydrogen town project was designed for developing a new market model for hydrogen fuel cells for building by using hydrogen produced from industries. The project mainly focused on the establishment of hydrogen infrastructure and, on a bigger scale, a whole town powered by hydrogen fuel cells. As a testbed for hydrogen economy, the project contributed to raise public awareness and collect information and data to develop the second phase of the project (Woo, 2014).

Together with the hydrogen town project, the city expanded hydrogen energy through demonstration projects for hydrogen fuel cells for industry and mobility use, and Power to Gas (P2G) micro grid development. The city also joins hydrogen projects led by ministries, developing the roadmap for hydrogen development with ten major projects (In, 2021). The city further has been designated as a Free Economic Zone (FEZ) boosting its competitiveness as a global hydrogen city (Choi, 2020).

WHY HAS THE CITY TAKEN ACTION

A breakthrough in sustainable urban development: Local economic depression and surging demand for climate actions give Ulsan city the task of seeking an important breakthrough in urban development by strengthening the social, economic, and environmental dimensions. Given this, the city uses hydrogen as a new growth engine for urban development. The city devises strategies to create opportunities to reactivate infrastructure that was once occupied by heavy and chemicals industries since the 1970s. The engagement of the local industries in the promotion of sustainable energy transition and consequently adds values of sustainability and environment to the industries (Lee, 2020).

Roadmap for Hydrogen Economy: Ulsan city's focus on the promotion of hydrogen aligns with policy directions at the national and local levels. In response to a growing need for sustainable and clean energy on the national move toward carbon neutrality, the Korean government unveiled the Hydrogen Economy Roadmap in 2019. The roadmap envisions an industrial ecosystem for hydrogen economy consisting of two pillars: a hydrogen fuel cell and hydrogen mobility (Ministry of Trade, Industry, and Energy, 2019). Ulsan city government also presents a vision for a global hydrogen city by 2030 to revitalise the local economic slump while meeting the growing need

for taking climate actions. The city's roadmap for hydrogen development identifies ten major initiatives with targets including the provision of 67,000 hydrogen mobility; provision of 60 hydrogen power stations; installation of more than 200km hydrogen pipelines; manufacture of 500,000 hydrogen vehicles; and deployment of 250MW hydrogen fuel cells (In, 2021).

GOALS AND OBJECTIVES

Targets set by the local and national governments

The national and local governments identify targets for promoting the hydrogen ecosystem through the roadmap for the hydrogen economy. According to the national roadmap, the national government plans to cumulatively produce 6.2 million hydrogen fuel cell vehicles by 2040 and be a global market leader in hydrogen vehicles; to generate over 15 GW energy by 2040 through hydrogen fuel cells for industrial use; to facilitate a paradigm shift in hydrogen production from grey hydrogen to green hydrogen; to develop safe and cost-effective storage and distribution system for hydrogen; and to develop a hydrogen industry ecosystem with safety management throughout the life cycle (Ministry of Trade, Industry, and Energy, 2019).

With the vision of becoming a global hydrogen city by 2030, the local government has set the targets of distribution of 67,000 hydrogen fuel cell vehicles (FCEVs), deployment of 60 hydrogen stations, manufacture of 500,000 FCEVs by 2030 with ten major initiatives to consolidate the groundwork for hydrogen industry and economy. The local government also lowers technical and regulative barriers through the implementation of three projects – a model city for hydrogen led by the Ministry of Land, Infrastructure, and Transport; a regulation-free special zone for green mobility led by the Ministry of SMEs and Startups; a hydrogen mobility complex led by the Ministry of Trade and Industry – and transformation into FEZ in cooperation with the national government (Choi, 2020; In, 2021).

- To revitalise the local economy by promoting hydrogen
- To stabilise the local industrial ecosystem for hydrogen
- To contribute to the 2030 target of becoming a global hydrogen city

PROJECT IMPLEMENTATION

The advanced technology is used for a hydrogen fuel cell. An ordinary hydrogen fuel cell generates electricity and heat from chemical reactions between oxygen and hydrogen which is extracted from Liquefied Natural Gas (LNG) or Liquefied Petroleum Gas (LPG) (SK Gas, n.d.). Importing LNG from overseas and processing it emits GHG. This feature draws criticism of the production of hydrogen – more precisely the grey hydrogen – from environmental activists.

However, hydrogen fuel cells deployed in Deoksin Village, in Ulsan city use by-product hydrogen produced from private enterprises – SPG Corporation and Samsung BP Chemical – rather than LNG imported from overseas

(Cryogenic Industrial Gases Magazine, 2013). As a part of the demonstration project, 140 hydrogen fuel cells with 1 kW generation capacity were deployed at 140 housings of LS Nikko Copper Inc.; nine hydrogen fuel cells with 5 kW generation capacity were installed at public institutions and facilities; one hydrogen fuel cell with 10 kW generation capacity was installed at a public gym. Hydrogen power produced from local industrial zones is transmitted through pipelines – a newly installed 7 km pipeline connected to existing pipelines of Ulsan-Mipo Industrial Complex and Samsung BP Chemicals. Channeling the hydrogen through pipelines, different sizes of hydrogen fuel cells provided electricity to residents. The heat from producing electricity heated up water (Woo, 2014). Illustrations of the project are seen from Figure 48, showing the source of hydrogen, Figure 49 on the village layout and Figure 50 shows installation of the hydrogen pipes to individual housing units.

The total project budget was 8.775 million USD. In terms of sources, 5.2 million USD was subsidies from the national government; 3.575 million USD was funded by the local government and the private sector. In terms of a budget allocation, 7.033 million USD was for hydrogen fuel cells; 1.742 million USD was for infrastructure (Woo, 2014).

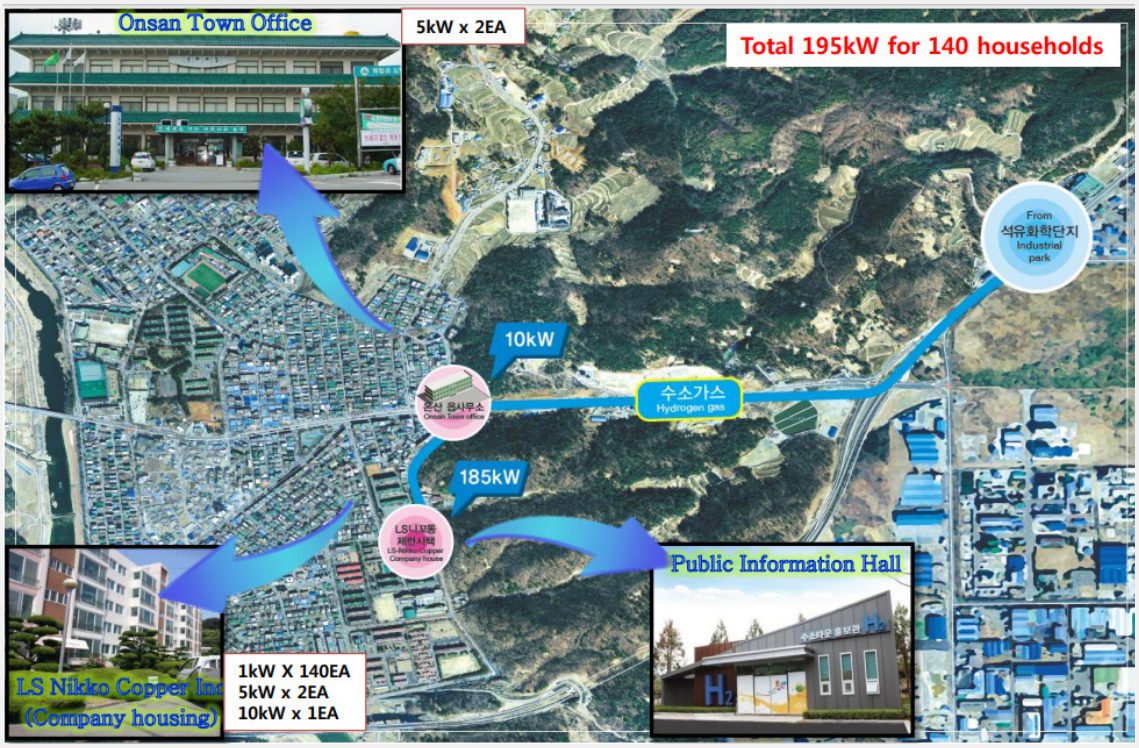


Figure 48 Ulsan hydrogen town *(Source: Ulsan Metropolitan Government, 2013)*

Figure 49 Ulsan hydrogen town *(Source: Ulsan Metropolitan Government, 2013)*

Figure 50 Hydrogen pipelines (red) installed on the external wall of the apartment (Shin, 2014)

IMPACTS

Energy, Heat production and Carbon Reductions: The outcome expected from the project was a total energy generation of 2,637,033 kWh per year including 1,622,790 kWh of electricity and 1,014,243 kWh of heat respectively. This equals to fossil energy replacement of 331.4 tonnes of oil equivalent (toe) per year and thus a GHG emissions reduction of 991 tons of CO_2 (Woo, 2014). According to Ulsan Research Institute, the hydrogen town generated a total of 1,000,600 kWh of power and reduced GHG emissions by 451.98 tonnes after five years of operation from April 2013 to December 2018 (Kim, 2020).

Energy Bill Savings: Electricity production from hydrogen fuel cells led to cutting down electricity bills. A total of 120,000 USD of energy was saved and consequently, an individual household has saved 14 USD every month (Kim, 2020).

FACTORS FOR SUCCESS

The public-private partnerships contributed to the successful implementation of the project. Ulsan Metropolitan Government provided administrative and regulative support; the public enterprise (Ulsan Technopark) promoted the hydrogen town to the public; private enterprises provided technical support including supplying hydrogen energy, manufacturing hydrogen fuel cells, constructing the pipelines and facilities, and managing safety (Woo, 2014).

Public and Private Partnership: The public and private partnership is a remarkably successful factor of the project. A different approach taken by public and private sectors in making contributions to the project produced synergy effects and provided an opportunity for the city to develop advanced measures to transform itself into a representative hydrogen city. In terms of the public sector, the local government provided administrative and regulative support. Ulsan Technopark as a public enterprise also helped to raise public awareness of the project through project promotion at international events. In terms of the private sector, private enterprises largely contributed to project implementation in a cost-effective manner. They provided by-product hydrogen generated from activities of oil-refining, petrochemical, automobile, and shipbuilding businesses, hydrogen pipelines, and housings where hydrogen fuel cells were installed at.

Utilisation of existing infrastructure: In order to transform into a future-oriented hydrogen city, Ulsan engages the local heavy and chemicals industries in the promotion of hydrogen energy. This approach is to maximise the efficiency of local resources which contributes to the successful implementation of the hydrogen town demonstration project in two ways. First, utilisation of local resources helps to save the budget for project implementation. A conceptual shift in using infrastructure in local industrial zones helps to not only secure energy sources for electricity and heat supply with the lowered cost compared to importing LNG from overseas but also save cost for constructing pipelines to convey hydrogen. Second, utilisation of local resources helps

to prevent disrupting the local economy. The heavy and chemical industries in the city were the engine for the economic growth of the city. Thus, Ulsan city creates an alternative opportunity to utilise existing local industrial infrastructure on its move toward sustainable energy rather than abandoning it. This contributes to alleviating risks and challenges to the urban economy in the process of transformation into an eco-friendly city.

LESSONS LEARNED

Given that a demonstration project is mainly designed to test a model, outcomes and effectiveness of the hydrogen town project need to be better assessed in a systematic and well-organised manner. Ulsan city launched the project as a part of developing a global hydrogen city. The city utilised the public-private partnership to increase the efficiency and effectiveness of project implementation and promoted the project to draw attention from the public and international society. However, compared to visions and expectations of the project easily found on the internet, it is challenging to access statistics on the effectiveness of the project after the demonstration. If the project engages with academia or research centre to take the lead in monitoring the hydrogen town and analysing energy supply and demand of individual housings for different periods, it would be easily measured how effective the project was and what challenges may need to be handled for the next round of the project.

Considering Ulsan city heavily relies on the heavy and chemical industries, this hydrogen town model showcases a sustainable transition pathway for similar cities. For example, the national government presented the vision for a hydrogen economy as a part of its move toward sustainable energy. Some cities, Samcheok city in Gangwon province and Yeosu city in South Jeolla province, join this movement toward the promotion of hydrogen energy and build a partnership with the private sector. Moreover, the hydrogen town model can be applied to cities in Japan, China, and Australia making an investment in the hydrogen industry.

E. Sustainable waste management

Introduced in Chapter I, sustainable waste management technologies can broadly be categorised under two categories, waste management and the circular economy and some key technology areas are introduced. Three case studies of successful implementation of waste management and circular economy will also be presented.

Waste Management

Automated Sorting

Automated sorting is the combination of improved sensor technology, machine intelligence and mechanical automation. Sensors are used in capturing the type of material indicated on manufactured products and sorting them to their types for recycling. This speeds up the sorting process, which would otherwise have to be done manually.

Smart Waste Bins

Smart waste bins are essentially waste bins fitted with low power sensors and transmission capabilities to let municipality trash network operators know the fill status of the bin and when it needs to be cleared. It can be combined with a fleet management system to better calculate household or business level trash generation and pricing strategies accordingly to encourage reduced waste generation.

Fleet Management

Flexible fleet scheduling, sensors and smart waste bins can let fleet vehicles known when to pick up disposed trash rather than relying on a regular cycle for trash disposal. This can improve the collection speed as well as potentially reduce the amount of emissions from the waste collection fleet of vehicles.

Frameworks For Recycling

As products increasingly consist of a mix of materials, policy frameworks to encourage mono-material packaging to simplify recycling and reuse. For complex appliances, disassembly frameworks for recycling can similarly help to sort out components which are then easier to recycle or reuse accordingly and reduce landfill waste.

Circular Economy

Recycling

Recycling takes waste materials to convert them into new feed material for products and services of a similar nature. Common waste categories for recycling are plastics, paper, metals and glass.

Organics to Fuels

Various technologies exist in this field, such as hydrolysis, gasification, fermentation and anaerobic digestion, which serves to convert organic materials into a fuel, be it landfill gas, ethanol or gasoline. Some sources such as methane gas from a landfill can be captured and burned to provide heat while simultaneously preventing methane leakage into the atmosphere.

Waste to New Products

Waste is directly converted into new products such as food waste into fertiliser and biogas or fly ash into concrete. There are many developments in this area ranging from plant leather, structural bricks and synthetic oils and chemicals and similar organic products for use in industry.

Direct Waste to Energy

Incineration is a tried and tested technology of burning waste to reduce its volume while providing electrical energy. A offshoot technology, plasma incineration of waste materials which operates similarly but at extremely high temperatures is in development, to produce vitrified waste which is believed to be more environmentally friendly being chemically inert and less likely to leach into the environment when landfilled.

CASE STUDY E1:
INNOVATIVE FOOD WASTE MANAGEMENT MECHANISM IN SUZHOU

In 2011, Suzhou was approved as one of the first batch pilot cities for the resource recycling and harmless treatment of food waste in China. Through nearly ten years of exploration and practice, Suzhou has leveraged the promotion of comprehensive resource recycling and green circular development to gradually construct and improve the food waste collection, transportation, and treatment system. A supervision system based on on-site supervision, supplemented by information supervision, supported by third-party supervision, and guided by public scrutiny has been established. An innovative governance model – "two-level governments management and market integrated operation of collection, transportation and treatment" – that was created by Suzhou has not only brought changes to the residents living in the city but also provide a practical experience to the cities across the country on food waste management.

These changes are facilitated by the introduction of the organic waste disposal plant pictured in Figure 51 below, which handles the incoming kitchen waste from restaurants and canteens and is planned to be expanded to residential kitchen waste too

Figure 51 Suzhou Integrated Organic Waste Disposal Plant *(Source: Suzhou Industrial Park)*

WHY HAS THE CITY TAKEN ACTION

Catering services and canteens generate a large amount of food waste every day, which could cause serious environmental pollution if not rightly dealt with. With the social and economic development, Suzhou's catering industry has undergone a rapid expansion. According to a survey on catering companies in Suzhou, about 400 tonnes of food waste is generated each day as of 2011. Prior to the standardised management, around 60% of the food waste was used at farms in the suburbs as pig feed or was made into edible oil illegally and the other 40% was mixed into domestic waste (Suzhou Municipal Government, 2011). Immediate actions are needed to secure food safety and protect the environment from further pollution.

In addition, the exposure of illegal use of "waste oil" in the production of edible oil has raised public concern about food security issues. As of 2010, the State Council has released the *Opinions on Strengthening the Remediation of Waste Oil and Food Waste Management*, which aims to tackle the problem of "waste oil" and tighten up food waste management to ensure food safety. However, without a comprehensive and effective collection, transportation and treatment system for food waste and waste oil, the issue cannot be fundamentally solved (National Development and Reform Commission, 2010).

In order to explore a sustainable mechanism for food waste management, in the year of 2010, the national government released the *Notice on Organising and Carrying Out the Resource Utilisation and Harmless Treatment of Food Waste Pilot,* and initiated a pilot programme to promote the recycling of food waste to achieve economic, social and environmental good. Moreover, food waste recycling is not only an important part of the circular economy transition, but also a fundamental measure to tackle food security problems (National Development and Reform Commission, 2010). In 2011, Suzhou was selected as one of the 33 pilot cities.

GOALS AND OBJECTIVES

The key aim of the project is to strengthen the supervision of the whole process of generation, collection, transportation and treatment of food waste: The whole-process monitoring is realised through the set-up of on-site supervisors, inspections and IoT data collection for analysis. To accomplish these goals Suzhou aims to target the source of food waste and proactively reduce food waste generated. Furthermore with the data collected to crackdown on non-compliant conducts in the catering and food industry, improving public supervision over the process and preventing illegal collection, transportation and disposal of food waste through collaboration of the municipal police department, urban management department, department of transportation, department of health, environmental protection department. These collective goals are:

- Establish localised legal and regulatory framework and supervision system for food waste management
- Explore technologies on resource recycling and use of food waste that fit the local context
- Develop resource recycling supply chain for food waste
- Prevent the illegal use of "waste oil" in edible oil production

- Avoid food waste feed back into the food chain as animal feed
- Tackle the problem of direct discharge of food waste into the sewerage system
- Divert food waste from landfill or incineration
- Promote sustainable consumption to reduce food waste from it source

PROJECT IMPLEMENTATION

Suzhou has established an integrated operation mode of "collection-transport-treatment". The process is managed by a sole company contracted by the government. This is a city-wide pilot programme, covering six districts and four county-level cities with 10,720,000 residents. County-level cities or districts are responsible for supervision and management within their judiciary boundaries the city appearance and environmental sanitation departments, while the food waste collection and transportation management, assessment and supervision fall into the responsibility of street offices.

Suzhou government subsidises the food waste collection, transportation, and disposal to improve efficiency. Moreover, the subsidies are included into the fiscal annual budget to guarantee continuous funding. The unit price of subsidy has gone up from 118.8 CNY/ton (18.7 USD/Tonne) at the initial stage of the pilot to 173.8 CNY/tonne (27.3 USD/Tonne). By April 2020, the fiscal subsidies (city and district level combined) have been added up to 152 million CNY (around 239 million USD). In order to expand the pilot model of food waste treatment through multiple channels and aspects, other district and county-level cities in Suzhou have also adopted PPP and BOO (build, own, operate) models.

ICT Monitoring of Food Waste: Suzhou has developed a food waste information management system utilising IoT core technologies, such as sensors, radio frequency identification, and wireless communications, adding on the conventional GPS and geographic information system. The platform enables monitoring and supervision on food waste collection, transportation, treatment, as well as its end-products.

The whole process data are made available owing to the use of ICT:

- Catering companies information
- The volume and weight of food waste
- Food waste transportation process
- Food waste recycling and utilisation process
- End-products made from food waste

Through data analytics, the managing departments can standardise and improve the management of food waste.

Food Waste Treatment and Utilisation: The food treatment technologies are very diverse, including aerobic composting, anaerobic biogas generation, biogas purification, among others. In terms of using food waste as a resource, Suzhou explored making it into fly maggot proteins and biofuels to boost the value of the end-product. It should be noted that most food waste projects consider saving land spaces for future development, while taking the increase of food waste volume and the co-treatment of food waste into consideration. Food waste treatment plants in Suzhou are located in close proximity to other waste treatment plants to achieve integrated recycling and treatment of different kinds of waste and thus improve resource recycling rate and efficiency, reduce pollutants and reduce environmental impact (National Development and Reform Commission, 2020).

Taking Suzhou Industrial Park's Food Waste Treatment Project as an example, the treatment capacity of the project is 600 tonnes of food waste per day and it has achieved synergies with other waste treatment facilities in the park in terms of treatment objects, pollutants management and resource utilisation. For disposal objects, various types of organic wastes can be co-processed, including kitchen waste (including cooking oil) and organic waste at the farmer's market, and expired foods. For the pollutants management, the leachate of the project is compatible with the leachate of the municipal solid waste transfer station and thus can be co-treated. Finally, the project's biogas residue and the garden waste can be made into nutrient soil while the biogas is purified and transmitted directly into the city gas pipeline network (China Construction News, 2021).

In collaboration with Tsinghua University, Suzhou has achieved plenty of technological breakthroughs in the process of the pilot programme. To name a few, the food waste wet-heat hydrolysis technology, efficient separation and recovery of food waste oil technology, and advanced wastewater treatment technologies. These cutting-edge technologies have been applied in the process of food waste utilisation, making Suzhou a front-runner of the country in terms of utilisation rate: The conversion rate into feed ingredients is 10%, and the oil extraction rate is 90% (National Development and Reform Commission, 2016).

IMPACTS

Carbon Reductions: No carbon reduction data is available for the whole pilot programme. For specific projects like the Suzhou Industrial Park Project mentioned above, it is estimated that each tonne of food waste treated can reduce about 0.75 tonnes of CO_2. The project has the capacity to treat 90,000 tonnes of food waste. Therefore, the carbon reduction is estimated to reach 67,500 tonnes of CO_2. The natural gas produced from biogas purification can replace 7000 tonnes of standard coal each year which can reduce 8000 tonnes of CO_2. The waste diverted from landfill is equivalent to annual savings of an area about 10 mu (6666.7 m^2) (Suzhou Daily, 2019).

Job creation: In order to promote the treatment and recycling use of food waste, Suzhou has built 5 food waste treatment plants, and 3 regional food waste facilities. 276 professional collection and transportation teams have been established as well as on-site supervisors. Such a set-up creates plenty of jobs.

FACTORS FOR SUCCESS

- The establishment of regulatory and legislative framework for food waste management
- High political commitment marked by the set-up of leading group at city-level and the two-level management mechanism
- Innovative governance on the whole process including food waste generation, collection, transportation and treatment
- Integrated treatment of food waste and accelerate technology advancements
- Sustainable financial subsidy and exploration of various financing models such as PPP and BOO
- Integrated operation mechanism of "collection, transportation and treatment" carried out by a sole enterprise while strengthen the supervision of the whole process

LESSONS LEARNED

Building on the success of the pilot, Suzhou's ambition on waste management expanded to household food waste and initiated a corresponding pilot programme from 2018, which enabled the set-up of different small and medium-sized on-site treatment facilities. With the enforcement of *Suzhou Municipal Domestic Waste Segregation Management Regulations* in 2020 and based on the previous construction and operation experience of food waste facilities, Suzhou adopted the anaerobic treatment technology for newly built centralised treatment facilities, which have been built by each district. In the meantime, a food waste management information system has been developed to ensure fine management of food waste facilities and its safe and stable operation. To this point, a food waste (household's included) ecosystem has been built. By September 2021, the city's daily average collection and treatment of food waste (households' included) had reached 4341 tonnes, accounting for about 24% of the total municipal waste (China Construction News, 2021).

CASE STUDY E2:
RECYCLE AND REUSE OF RETIRED EV BATTERIES IN WUHAN

This project was initiated and managed by GEM Co., Ltd, which is a leading Chinese company on waste recycling and reuse. The goal of the project is to is apply innovative technologies to recycle and reuse power batteries to reduce batteries' environmental impact and preserve valuable raw materials, which is a vital part of the sustainable development of the EV industry. Through the development of intelligent battery disassembly system, battery testing and selection technology and the information management system for full life cycle traceability of power batteries, 1575 tons of retired EV batteries have been reused and recycled in 2020. This project demonstrated a low-carbon approach to the achievement of comprehensive and systematic tracking, recycling and re-utilisation of retired power batteries.

WHY HAS THE CITY TAKEN ACTION

Increasing numbers of retired EV batteries: Wuhan is a national demonstration city for new-energy vehicles. With the rapid development of the new-energy vehicle industry, the number of retired power batteries is increasing greatly. Recycling these batteries is becoming an urgent environmental challenge as they contain organic electrolytes and heavy metals such as cobalt, nickel, and manganese, which are toxic and harmful to people and the environment. Failure to properly recycle these batteries will cause great environmental pollution and potential safety hazards from electrical shocks, fires and explosions.

Necessity to conserve and reuse battery resources: Many decommissioned power batteries still retain 70%-80% of capacity. After testing and selection, they can be reused to meet low-power needs or as energy storage to save valuable metal resources. But to scale up this process of power battery recycling and reusing, it is necessary to come up with technologies and innovations that can make the process more effective, efficient, and safe.

GOALS AND OBJECTIVES

This project has received full support from Wuhan Municipal Government. Wuhan Power Battery Regeneration Technology Co., Ltd. was recommended by Wuhan Municipal Government to be selected in the List of companies that meet the "Industry Standards and Conditions for the Comprehensive Utilisation of Waste Power Batteries for New Energy Vehicles" by the Ministry of Industry and Information Technology. Its core goals are to:

- Develop a set of smart solutions for the disassembling of battery packs that enables intelligent, flexible, precise and efficient dismantling of retired power batteries of multiple specifications and types.
- Reduce the impact on the environment and safety risks caused by the discarding of retired EV batteries.
- Promote resource conservation, recycling and reusing through circular economy

PROJECT IMPLEMENTATION

The Hubei Provincial government issued "The Implementation Measures for the Management of Recycling of Scrapped Motor Vehicles (Trial Version)" to give guidance to enterprises that recycle and dismantle power batteries, also in terms of increasing the safety during the whole process. As part of the initiative, new technologies was developed to sort and dismantle retired EV power batteries of different dimensions and designs accurately and efficiently and a comprehensive information management system was established that covers the full life cycle traceability of retired power batteries and allows for the collecting, graded utilisation, resource recycling, material processing, and power battery pack re-making. This way, it is ensured that the most value possible is extracted from discarded power batteries and that life cycle of power batteries can be closed, which on the one hand prevents discarded batteries from causing harm and on the other hand is a big step forward to achieving a circular economy and is depicted in Figure 52 below.

Figure 52 Battercy reclycling value chain *(Source: GEMS Co. Ltd.)*

Intelligent and highly compatible disassembly technology for power batteries: Based on the multi-dimensional dynamic identification of retired power batteries, the intelligent dismantling workstation forms a dismantling operation plan, makes execution commands and defines operation parameters through intelligent decision-making and dynamic planning system, the automatic sorting system reduces manpower requirements and allows for greater automation during the disassembly process on known battery assembly types.

Battery testing and selection technology for further graded utilisation: This technology tests and analyses the cell model, composition and electrochemical parameters of retired battery cells of different shapes and sizes. This information is then used to form optimised cell combination for further graded utilisation to meet different power needs, where cells are reassembled back into a package for commercial or industrial use. Cells identified as not suitable for further utilisation are sent for recycling to extract metals for other product manufacturing, forming a circular reuse and recycling model.

The information management system for full life cycle traceability of power batteries: This system consists of four subsystems, which are: an information system on retired power battery recycling, a warehouse management system, a disassembly manufacturing execution system for retired power batteries, and a third-party interface platform and data analysis system. The system provides information on the entire process of recycling, transportation, storage, dismantling, reengineering, and graded utilisation of new energy vehicle power batteries.

The innovative technologies were researched and developed by GEM Co., Ltd including intelligent and flexible disassembly technology for power batteries, testing and selection technology for graded utilisation of power batteries and the information management system for full life cycle traceability of power batteries. All these technologies work together to achieve systematic tracking, recycling and utilisation of power batteries of new energy vehicles via a low-carbon pathway. The total investment of this project is 500 million CNY, of which 300 million CNY was provided by the enterprise and 200 million CNY by banks.

IMPACTS

Resource conservation and environment protection: For every ton of power batteries recovered, 0.79 tons of valuable metals can be recovered, and 340,000 cubic meters of water pollution, 78 tons of solid waste, 8,500 square meters of soil pollution, and 250.3 tons of CO_2 emissions can be reduced. It is estimated that for every ton of power batteries recovered, 19.2 ton of coal equivalent (TCE) can be saved.

Economic benefit from circular economy: This project boosts local economies by developing a circular economy around the retired battery industry. Retired power batteries can also be reused to meet low-power needs or as energy storage to save strategic non-ferrous metal resources and avoid water pollution and soil contamination. As estimated, the power battery inventory of Hubei province will reach 50GWh in 2025, and the graded utilisation can create an output value of 24.5 billion Chinese yuan.

FACTORS FOR SUCCESS

Strong political and financial support in the fledgling industry ensures the initial profitability concerns can be focused towards the development of innovative technologies towards achieving the goals of the developing a comprehensive and systematic tracking, reuse and recycling of decommissioned EV power batteries, the

technologies developed can then spread into the wider ecosystem and help to foster further self-guided development.

LESSONS LEARNED

At present, the top-level design of power battery recycling in China needs to be strengthened with a systematic recycling system. The recycling process and technical skills and knowledge needs to be improved and the profitability of enterprises ensured for long term viability. The research and application of the recycling and dismantling of decommissioned power batteries and their utilisation is still ongoing and to standardise the quality control on every link of the graded utilisation process to ensure the safety and quality of the secondary products in the entire process of graded utilisation from decommissioning of used battery pack to disassembly to sorting re-assembly for recommission or decommissioning and recycling.

CASE STUDY E3: LOW-CARBON UTILISATION OF BULK SOLID WASTE THROUGH TECHNOLOGICAL INNOVATION IN XUZHOU

Figure 53 Image depicting the indutrial sintering and cleanup complex.

The project of "Low-Carbon Utilisation of Bulk Solid Waste in Xuzhou" was jointly initiated and designed by the Jiangsu Zhenfeng Environmental Protection Group and Chinese Academy of Sciences as a demonstration project of the green, low-carbon, and sustainable utilisation of bulk solid waste. This project consists of two parts: firstly, it researched and established an innovative, synergistic disposal system for bulk solid waste (capable of handling coal gangue, sludge, and contaminated soil), to secondly, showcase several technologies to address the challenge of bulk solid waste treatment and utilisation in low-carbon approaches such as waste heat power generation and emission reduction facilities. The project has a processing volume of 1.16 million tons of coal gangue, 520,000 tons of contaminated soil, 420,000 tons of industrial sludge, and 3.9 million tons of river bottom sludge, and will generate 80 million kWh of power from waste heat annually.

WHY HAS THE CITY TAKEN ACTION

Heavy pollution caused by accumulated bulk solid waste: Xuzhou has been one of China's main coal production bases for over 130 years. In the process of coal mining, a large amount of coal gangue is generated. For instance, in 2019 this amounted to 2.3 million tons. If this solid waste is not properly collected, treated, and disposed of, it will lead to heavy pollutions in the atmosphere, water, and soil, further causing damage to public health.

Necessity for resource conservation and low-carbon treatment technology: Bulk solid waste is of great value as it can be reutilised as raw materials for industrial manufacturing or as fuel source for power generation. It has been recognised as an effective way to utilise the calorific value of coal gangue in the process of making sintered bricks to save energy. For raw materials, traditional sintered brick manufacturing mainly uses a large amount of non-renewable resources such as clay and shale, which has caused the destruction of land and mountains.

Alternatively, solid waste (sludge and contaminated soil) can be an idea candidate as raw materials for making sintered bricks. Besides, the traditional approach to treat sludge and contaminated soil is energy-intensive and highly polluting, such as sludge dehydration, drying or incineration, and thermal desorption of contaminated soil.

It is urgently needed to develop a synergistic treatment system to incorporate using sludge and contaminated soil as the raw material (being treated by the calcination process) and utilising the energy from cola gangue to power the brick making process through technology innovation.

GOALS AND OBJECTIVES

The national government is putting more emphasis on low-carbon technologies that can further advance a circular economic model. In that vein, it published policies that enabled this project, such as "National Law on the Prevention and Control of Environmental Pollution by Solid Waste", "Regulations on Comprehensive Utilisation of Coal Gangue". These policies were followed up with local policies by the Xuzhou Municipal Government that further stressed the task to improve the capacity of industrial solid waste processing and enhance the reutilisation of solid waste as resources. These policies include: "'Thirteenth Five-Year' Circular Economy Development Plan" and "Implementation Plan for Piloting 'Zero-Waste City' in Xuzhou", which guides the objectives for the project of:

- Demonstrating an innovative synergistic treatment and utilisation system for bulk solid waste (coal gangue, sludge, and contaminated soil) as a solution to the challenge of bulk solid waste treatment.
- Reduce energy consumption and greenhouse gas emissions caused by traditional solid waste utilisation technologies.
- Enhance resource conservation and recycling by creating a circular economic system

PROJECT IMPLEMENTATION

A new synergistic treatment and utilisation for bulk solid waste was developed jointly with the Chinese Academy of Sciences, in which the coal gangue, sludge, and contaminated soil are co-processed as raw materials to be treated and used in the manufacture sintered bricks whilst coal gangue simultaneously functions as an energy source. The whole calcination process only relies on the energy coming from the autoignition of coal gangue, instead of from supplied energy from coal firing, thus saving a lot of energy. Meanwhile, using advanced infrastructures for pollution reduction, such as dust removal, desulfurisation, denitrification, VOCs treatment, flue gas treatment, as well as online monitoring, ensures that final emissions meet air quality standards.

In order to build the pilot plants, 2 key technology areas needed to be developed into a facility and workflow process:

- **Solidification and stabilization technology for contaminated soil:** This technology pre-treats heavy metal pollutants in the contaminated soil to ensure that the soil meets pollution standards and can be used as a raw material to manufacture sintered bricks to prevent secondary pollution from leaching.

- **Low-temperature plasma coupling technology for industrial waste gas treatment:** The technology removes unconventional air pollutants (mercury and dioxins) from industrial waste gas effectively and economically. It solves the problem of the activated carbon adsorption material not only having a small adsorption capacity but is also difficult to regenerate and harmful to dispose of as hazardous waste.

In addition to the developed technologies for treatment of solid bulk waste, several key design considerations of the plants were also made to reduce pollution and improve working conditions and safety:

- Dust-free Pretreatment: all crushing, grinding and mixing are implemented in a fully enclosed semi-underground warehouse, with supporting waste gas collection and treatment facilities;
- Unmanned brick-making: fully automatic brick-making, brick-unloading, and packaging production lines are adopted to reduce personnel safety accident rates and improve occupational hygiene;
- Full collection of exhaust gas: all production workshops are fully enclosed, the drying process is modified with micro-negative pressure, and exhaust gas is collected;
- Intelligent temperature control and waste heat power generation: using the intelligent temperature control system to realise the controllable sintering temperature of the tunnel kiln, and supporting waste heat power generation;
- Large-scale co-processing: 2 million tons of approved solid waste (i.e. River Sludge), including 420,000 tons of industrial sludge and 520,000 tons of contaminated soil;
- High standards for waste gas treatment: dust removal, desulfurisation, denitrification, Volatile Organic Compounds (VOCs) treatment, dioxin control, flue gas de-whitening, 60-meter high-altitude emission.

Two new production lines to manufacture sintered bricks from bulk solid waste (coal gangue, sludge, and contaminated soil) are to be set up, equipped with a set of waste heat power generation system, as the waste heat power generation can be operated around the clock while one of the brick production lines is in maintenance. The project has a processing volume of 1.16 million tons of coal gangue, 520,000 tons of contaminated soil, 420,000 tons of industrial sludge, and 3.9 million tons of river bottom sludge, and will generate 80 million kWh of power from waste heat annually.

The total investment is 300 million Chinese yuan for two production lines to manufacture sintered bricks from bulk solid waste (coal gangue, sludge, and contaminated soil), equipped with a set of waste heat power generation systems. The majority of funds are self-raised by the enterprises. Part of the funds will be supported by loans from the China Development Bank, as recommended by the Ministry of Ecology and Environment and the National Development and Reform Commission.

IMPACTS

Carbon Emissions Reductions: The estimated carbon emission reduction for this demonstration project is 1.75

million tons per year, with the reductions estimated to come from the following three areas: The first is 1.23 million tons from replacing mined clay with coal gangue to make sintered bricks, porous bricks, and other new wall materials. Second is an estimated 308 thousand tons from utilising the calorific value of coal gangue and power generated from waste heat. Lastly, an estimated reduction of 246 thousand tons from energy efficiency improvements of the industrial process for solid waste utilisation compared to the traditional process from energy recovery. In addition, there are several co-benefits:

- Non-renewable resources saved: 2 million tons of clay and shale is saved every year by replacing them with coal gangue and sludge to make sintered bricks, porous bricks, and producing new wall materials.
- 80 million kWh of power generated per year from waste heat and 1 million tons of water saved per year.
- Jobs have been created and the local economy boosted by the development of new, sustainable businesses practices and a circular economy.

FACTORS FOR SUCCESS

This project has demonstrated that with the right political and financial support, this can be a successful model to be replicated in other places for processing. The combination of technologies proved successful to treat and utilise bulk solid waste as a resource for building materials in an energy-efficient and low-pollution way.

LESSONS LEARNED

The treatment of bulk solid waste has been traditionally known as highly energy-intensive, water-intensive, and polluting. Therefore, there is an urgent need to promote technology innovations efficient and effective treatment of bulk solid waste across the field, which can also provide economic benefits and products. It is important to test innovative technologies through demonstration projects to build up confidence for enterprises to retrofit industrial kilns by adopting power generation from waste heat and combined heat for power generation.

F. Building energy efficiency

Introduced in Chapter I, building energy efficiency consists of two core areas of improvements, namely energy efficiency and thermal efficiency, some of the key technology areas are outlined below. Two case studies on successful implementations of building energy and thermal efficiencies will also be presented.

Energy Efficiency

Smart Buildings

Smart buildings use a combination of sensors to automate processes within a building, such as smart charging and discharging of battery reserves into the grid or for the building use, as well as automating lights, thermal control as well as ventilation and water.

Energy Efficient Appliances

Efficient DC motors and inverter systems can help to reduce energy consumption, appliance energy efficiency rating schemes and energy cost estimates can help consumers make better purchase choices with regards to their financial planning and encourage selection of energy efficient appliances.

Energy Efficient Lighting

Fluorescent and LED lighting are energy efficient alternatives to incandescent lighting. They can be as mentioned in smart buildings be paired with sensors where appropriate to reduce energy consumption.

Water Reuse and Recycling

In building terms, a water source such as rainwater is captured and stored for use in areas like toilet flushing or landscape watering, reducing the strain on national water grids.

Thermal Efficiency

Thermal Storage

In conjunction with smart buildings, thermal storage of hot and cold water which can be used in conjunction with radiant floor or wall thermal control or similar air systems. Thermal mass of a building can also help to regulate internal temperatures when used appropriately.

Heating and Cooling Technologies

Heat pumps can provide simultaneous heating and cooling, district level heating and cooling technology can be more efficient than having multiple systems in a given area via economies of scale. It can also be paired with smart buildings and thermal management systems.

Insulation and Thermal Management

Insulation and thermal management has improved significantly with developments in materials technology. Technologies, such as rock wool, triple paned glass windows as well as automated ventilation and heat recovery have helped to reduce the thermal cost of maintaining a comfortable temperature in buildings.

Radiative Space Cooling

While solar heating has been used extensively by absorbing thermal radiation, highly reflective coatings in most of the solar spectrum, that emit thermal radiation at wavelengths which are not absorbed strongly in the atmosphere generating a net cooling effect are being developed and promising passive alternatives to pair with building cooling systems to reduce energy costs.

CASE STUDY F1:
REDUCING BUILDING EMISSIONS - SEOUL'S NOWON ZERO-ENERGY HOUSING COMPLEX

Initiated as an R&D demonstration project for zero-energy building by the Ministry of Land, Infrastructure and Transportation (MoLIT), the first energy zero housing complex was built in Nowon-district (gu), Seoul (Ministry of Land, Infrastructure and Transportation, 2019). The consortium consists of Seoul city, Nowon district, Myongji University, KCC E&C, and Seoul Housing and Communities Corporation Research implemented the project from 2013 and 2017. A budget of about 18 million USD was spent on developing the housing, with a complex model designed to use passive and active strategies to minimise energy consumption from buildings. Since early 2018, energy supply and consumption of the complex has been monitored for four years; the monitoring result has been shared between the Ministry, Korean District Heating Corporation, Seoul City, Nowon-district, and Nowon Environment Foundation on a regular basis. After the first round of monitoring ends by 2021, the complex will continue to be monitored in connection with other energy buildings in the district. The district is shown in Figure 54 below.

Figure 54 Nowon Energy Zero Housing Complex *(Source: (Nowon Energy Zero Centre, 2020))*

WHY THE CITY HAS TAKEN ACTION

With the Paris Agreement entering into force, the national and local governments of the Republic of Korea set a carbon neutrality target by 2050. The national government sets a greenhouse gas (GHG) emissions reduction target of 40% from the level of 2018 by 2030 which was presented at 2021 United Nations Climate Change Conference (COP26) (Government of Republic of Korea, 2021). Seoul Metropolitan Government (SMG) sets a GHG emissions reduction target of 40% and 70% from the level of 2005 by 2030 and 2040 (Climate and Environment Headquarters, 2021a).

In 2018, buildings were the largest emitter in the energy sector. GHG emissions from the building sector accounted for 68.8% of the total GHG emissions of the city. To be specific, as is shown in figure 55 below, there were residential buildings with a portion of 27.9%, commercial buildings with a portion of 37.1%, public buildings with a portion of 3.8%, and agriculture and fishery buildings with near negligble emissions contributions (Climate and Environment Headquarters, 2021c). The city needs effective measures to cap GHG emissions from buildings considering the increase of the Gross Floor Area (GFA) (Climate and Environment Headquarters, 2021b).

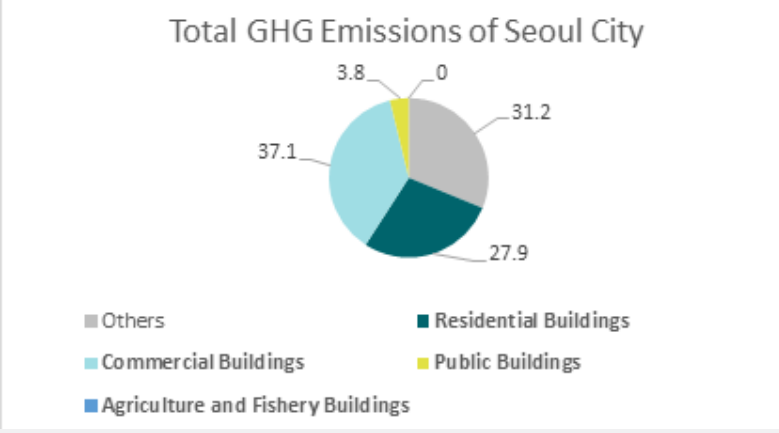


Figure 55 Total GHG Emissions of Seoul City *(Source: Climate and Environment Headquarters, 2021)*

Under the leadership of MoLIT, Zero Energy Building (ZEB) initiative is suggested as a technological solution in reducing GHG emissions from buildings, especially the newly-built buildings. The national mandatory roadmap for the ZEB initiative identified goals and strategies to be implemented in three stages: laying the foundation, promoting the popularisation, and initiating enforcement (Zero Energy Building Certificate System, n.d.).

Aligning with the national approach, Seoul city develops the ZEB initiative. Although the timeline for enforcement varies according to building types in terms of ownership and GFA, the city moves up the enforcement of the ZEB initiative earlier than the national government (Climate and Environment Headquarters, 2021b). Given this, it is arising that the need for assessing technology development and identifying the direction for making synergy effects from a collaboration between technology and policy-based initiatives.

GOALS AND OBJECTIVES

The national government and SMG adopt laws and regulations to control GHG emissions from buildings by presenting the ZEB initiative. For instance, the national government has enforced relevant laws such as the Green Building Construction Support Act and the Energy Use Rationalisation Act. SMG also develops legal and regulatory frameworks for promoting the ZEB initiative by adopting Ordinance on the Support for Construction of Green Building, Energy Saving Design Standard Building, and Green Building Construction Plan of Seoul city.

According to the national government, the ZEB regulation is to be imposed on public buildings with GFA at 1,000m^2 or larger from the year 2020 and those with GFA at 500m^2 or larger from the year 2023; and private buildings with GFA at 1,000m^2 or larger from 2025 and 30 private housing complexes or more from 2025 (Zero Energy Building Certificate System, n.d.). According to SMG, the ZEB regulation is to be imposed on public buildings with GFA at 1,000m^2 or larger from 2020 and those with GFA at 500m^2 or larger from 2021; and private buildings with GFA at 100,000m^2 or larger from 2023 and those with GFA at 10,000m^2 or larger from 2024 (Climate and Environment Headquarters, 2021b).

PROJECT IMPLEMENTATION

The project scale is about 11,344 m^2 land area, involving 121 household residential facilities, including rental housing, an apartment-type building (106 households), a villa-type building (9 households), and a detached house building (6 households).

To manage and reduce energy demand to near zero. This is achieved through passive and active energy technologies to maximise insulation performance and minimise grid energy demand, while adopting renewable energy sources to satisfy the remaining energy demand.

Passive Technologies: High energy-efficient materials equipped to four sides of housing, including walls, roofs, floors, ceilings, windows, and doors, to minimise energy loss. For instance, technology was applied in the following manner (Hong, S., 2020):

- Calcium carbonate composite to the internal and external walls, provide insulation and prevent mold.
- Enhancing window insulation by utilising triple-paned glass windows;
- Reducing heat loss especially during winter using anchors, rubber pads, and German Isokorb;
- Block wind by using tape made of seaweed and electrical outlet caps for minimising heat loss;
- Ventilation inside of the house even if the window is closed, by installing a heat-recovery ventilator connected with an internet of thing (IoT) equipment in every room;
- Ventilate the inside of the housing on rainy days by installing tilt and turn windows;
- Reducing heat loss and noise from outside by installing a thick door with a frame rubber packing;
- To control daylight illumination, automatically controlled external blinds which stop operating when the wind speed reaches twelve metres per second.

Active Technologies: 1284 solar panels were installed on external walls and 130 geothermal heat pumps were installed underground. All structures generated clean and renewable energy that can be used for heating and cooling. The heat from people and electronic devices also was used for heating and cooling (Cho, K., 2018). The active technologies employed in the project can be seen in Figure 56 below.

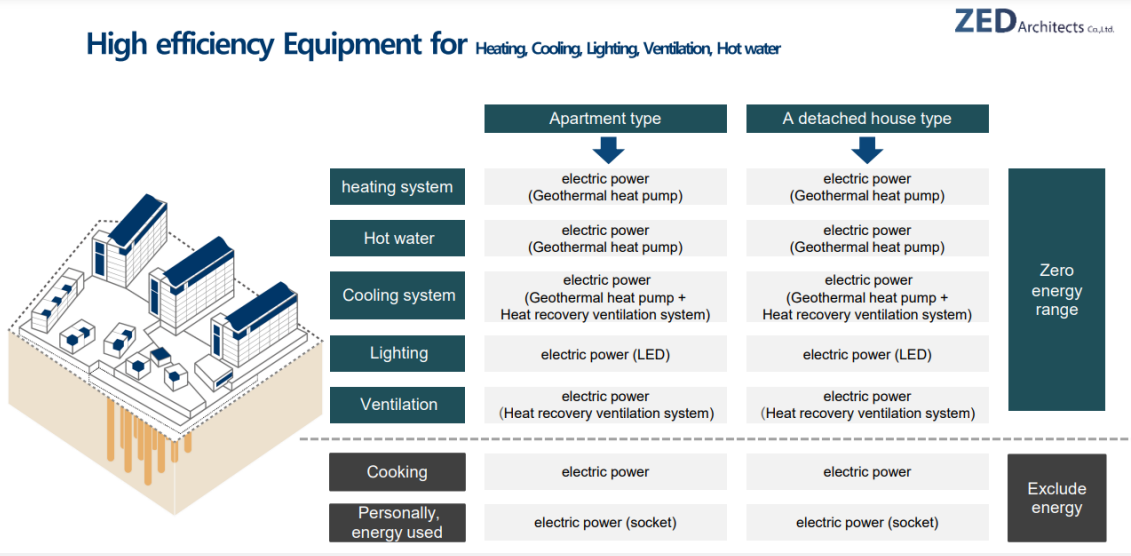


Figure 56 High efficiency equipment for heating, cooling, lighting, ventilation and hot water. *(Source ZED Architects Co. Ltd)*

IMPACTS

One characteristic of energy zero housing is the ability to maintain a relative constant indoor temperature regardless of outside temperature change with little energy use. In 2018, the average indoor temperature was 22℃, even the temperature rose to 26℃ in summer (Cho, K., 2018), as shown in Figure 57 below.

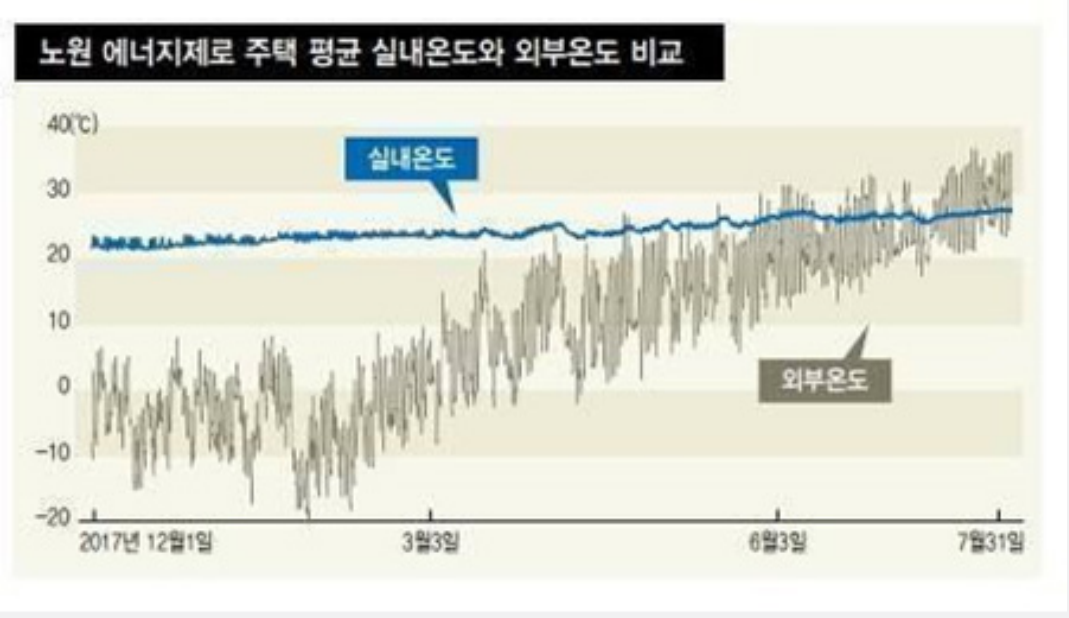


Figure 57 The indoor temperature of Nowon Energy Zero Housing Complex *(Source: Cho, K., 2018)*

The insulating properties of the retrofits reduced energy use for heating and cooling. Monitoring results of energy supply and consumption of the experimental house at the complex is illustrated as follows. During cold waves, energy consumption from November 2016 to February 2017 (221 kWh) was 96.9% lower than that of an ordinary house (7242.9 kWh). Given the experimental house used a pellet boiler, housings using geothermal heat at the complex would likely consume less energy for heating. During strong heat waves in 2016, energy consumption for using the air conditioner all day at the experimental house (574 kWh) was also 15% lower than energy consumption for using the air conditioner for four hours per day at an ordinary house (675 kWh) (Korea Energy Agency, 2017). This potentially suggests a daily energy savings extrapolated of 574 kWh versus 4,050 kWh comparing the experimental house to an ordinary house which is almost an 86% energy savings for cooling.

Cost-Saving: Another key characteristic of energy zero housing is to save electricity bills. Energy generated from solar panels and geothermal heat pumps is used to satisfy energy demand from the complex. The rest of the renewable energy is sold to Korea Electronic Power Corporation (KEPCO). The energy offset process helps residents pay fewer electric fees. Between December 2017 and March 2020, the complex generated renewable energy of 976,104 kWh while consuming 770,130 kWh of energy. Due to the ratio of energy generated to energy consumed was 122%, each household paid a monthly electricity fee of about 41 USD equivalent to about one USD per day (Yeo, I., 2020).

Improvement of Indoor Air Quality: Mechanical ventilation of energy zero housing contributes to improving Indoor Air Quality (IAQ). According to the comparison study on IAQ between Nowon Energy Zero Housing Complex and a conventional housing complex in close proximity, the level of indoor PM_{10}, $PM_{2.5}$, CO_2, and VOCs was lower in the energy zero housing complex than that in the conventional housing complex. As a result, residents in the energy zero housing complex are exposed to fewer health risks linked to air pollution such as eye fatigue, allergic rhinitis, and atopic dermatitis. For example, the risk level of children's atopic dermatitis and allergic rhinitis were significantly lower in the energy zero housing complex than in the conventional housing complex.

FACTORS FOR SUCCESS

This project was implemented based on cooperation between the national government (MoLIT), the local governments (Seoul Metropolitan Government, and Nowon-gu District Office), a private construction company (KCC E&C), a university (Myongji University), and a research centre (SH urban institute). The multi-layered perspective created a synergistic effect and encouraged the successful implementation of the project and promotion of its application to buildings. Governments provide regulatory, administrative, and financial support. A private company provides professional knowledge and skills to construct the buildings as it was planned. A university and a research centre also provided professional knowledge and skills to design the building and analyse the effectiveness of the project.

LESSONS LEARNED

Expensive cost for construction of the building model is a major challenge. No matter how effective the model is in terms of energy-saving and efficiency, the cost is a practical barrier to the promotion of the building model, especially the mass uptake from the private sector. According to MoLIT, in 2019, public buildings accounted for 2.8% of the total number of buildings in Korea. However, only 8 out of 357 ZEBs are owned by the private sector. Given this, active engagement of the private sector seems to be essential to decarbonise the building sector fast. However, the high level of construction cost hampers private engagement (Park, S., 2020). For instance, the construction cost for Nowon Energy Zero Housing Complex might be 24.5% higher than that for a general rental housing complex. In this regard, the incentives provided by the city government seem to be too small to cover the expensive construction cost (Park, S., 2020).

Considering the engagement of the national and local governments, this zero energy housing model expects to be easily applied to buildings at a nation- and city-wide scale. Governments' efforts to implement the ZEB roadmap in phases is expected to enable scaling of the model. For instance, small social rental housing buildings constructed by private companies for public interest in Seoul are especially recommended for the project, given that small residential buildings with GFA at 500m^2 or smaller account for 74.4% of the total number of buildings in the city (Park, S., 2020).

Both passive and active technology used for the housing complex was effective in controlling energy demand from buildings. The passive technology maximised insulation performance and accordingly minimised energy demand and loss. The active technology maximised energy generation from solar power and geothermal heat and accordingly reduced dependence on external energy sources for heating and cooling. Although the effectiveness of technology was witnessed from energy savings leading to carbon reduction, lowering the construction cost for ZEB remains the major challenge.

CASE STUDY F2: ACCELERATING BUILDING ENERGY EFFICIENCY IN CHANGING DISTRICT, SHANGHAI, CHINA

China declared its NDCs in 2009 until 2030. It committed to reducing 40 to 45% of the overall emission of carbon dioxide by 2020, incrementing the use of non-fossil fuels energy to 15% of the total energy consumption by 2020 (Xi et al., 2017). This agenda contributed to the action plan for Shanghai, especially for Changing to navigate solutions on energy transition at the district level, as shown the map for Shanghai in Figure 58 below.

Figure 58 The location of Changning District in Shanghai Core Districts (basemap: Shanghai Platform for Common Geospatial Information Service)

The building energy efficiency program aims to reduce energy use and cost at Changning District, a vibrant business hub located in the central part of Shanghai metropolitan. Changning district houses multiple types of business sectors, varying from Hongqiao transportation functional zone, trading and exhibition centres, and hosts headquarters of many established international companies. The dense building infrastructure provides connectivity and centralised service to business, but the operations are also a source of GHGs emissions. The program is led by the Shanghai Changning District Urban Renewal and Low Carbon Project Management Centre (URLCPMC), under the supervision of Development and Reform Commission of Changning District, together with multiple international and local institutions.

WHY THE CITY HAS TAKEN ACTION

High energy consumption in Changning was estimated to be 165,000 tonnes of coal equivalent (tce) in 2009. The

Hongqiao Functional area is the highest energy consumer in Changning District due to the transport and logistics companies. Building (90.5%), industry (9%) and transportation (0.5%) are the main energy consumers, and it is mainly powered by electricity, accounting for 84.4% of total energy source (World Bank, 2013).

For long-term sustainable development, energy efficiency and transition are urgently needed. There is a strong political commitment on low-carbon development. To cope with climate change, energy saving is one of the Shanghai government's priorities as exemplified in the 11th Five-Year Plan (2006-2010). However, there were limited political or governmental guidelines and practical knowledge at that time. Therefore, there is a strong need for Changning District to work with international experts to develop guidelines and build pilot projects as one of the main pioneer cities in China working on building energy efficiency.

GOALS AND OBJECTIVES

Instead of adopting top-down directives, the goal was the development of benchmarks on international, national, and local guidelines as references to enhance the practicality and localisation of a guidebook on energy efficient upgrading. *Carbon Abatement Cost Curves* is the main method used to conduct preliminary assessment, including four steps (World Bank, 2013):

- a bottom-up survey for collecting data and identifying abatement measures;
- applying the abatement measurements to develop Carbon Abatement Cost Curves;
- prioritising the measures by cost and ease of implementation; and
- formulating the low-carbon targets guided by abatement scenarios, which gets involved into the implementation of *Green Energy for Low-Carbon City in Shanghai Project*.

The comprehensive survey covers the whole district, specifically on energy supply and consumption. The 58 abatement measures are categorised into six main groups:

- Retrofitting existing commercial buildings;
- Development of green power;
- Remodelling of existing residential buildings;
- Low-emissions new buildings;
- Encouraging behaviour change;
- Green mobility.

For each group, there are various options for abatement, such as air conditioning efficiency improvement and overall insulation for commercial buildings. This method provides explicit details on how much an option costs (for both abatement and energy saving), the total amount of investment, and the amount of emissions reduction and energy saving.

PROJECT IMPLEMENTATION

Innovative governance is the most important experience as the building efficiency program is made possible through the governance structure and political design. The Shanghai Changning District URLCPMC plays an essential role in the building energy efficiency program, which is an agency composed of different entities and stakeholders as shown in figure 59 below. In contrast to the traditional siloed structure of governmental bodies, the building sector involves cross-departmental collaboration. Therefore, this specialised centre focuses on sustainability and low-carbon development. The centre mobilises resources easily based on realistic needs and at the same time, addresses the challenge in cross-departmental coordination.

Figure 59 How stakeholders are integrated by URLCPMC in Changning District *(Source: Szum et al., 2020)*

The URLCPMC setup enables stakeholder coordination. This system consists of three main stakeholders with differentiated yet coordinated roles (Szum et al., 2020):

- government departments, whose work includes setting goals, classification of policies, monitoring management;
- financial institutions, who mainly work on amplification effect, mechanism innovation, and capacity building;
- and other market subjects, including building owners, service companies, and end users.

The program is implemented through the reiterative process of 'knowledge-action-reflection-implementation'. Changning submitted its initial application to the Global Environment Fund (GEF) in 2011, to fund the projects that are related to the following components: green building development; transformation to low-carbon energy types; green transportation; and institutional set-up. The GEF supported several innovation piloting projects in Changning, including policies, financing, zero-emission building, as well as slow-traffic system (the World Bank Group, 2012).

An IT Tool package known as Energy Consumption Monitoring Platform (ECMP), enabled the real-time monitoring, analysis, processing, exchange, and public disclosure of energy consumption data for large commercial buildings in the district area. (Wu, 2019).

Building Characteristics:

- Location (e.g., address)
- Type and function (e.g., office building, shopping mall, hotel, cultural and education building, hospital, sports building; mixed-use building)
- Building size (i.e., including gross floor area and indoor garage floor area)
- Construction year (e.g., before 1990; 1991-1995; 1996-2000; 2001-2010; or 2011-present)
- Occupancy (e.g., number of users of electricity)

Building Energy Data:

- Total building energy consumption and energy consumption per unit of floor area
- Energy consumption by end-uses/system (e.g., air conditioning electricity, power electricity,
- lighting electricity, special electricity, elevator, plug, etc.)
- Energy consumption by fuel type (e.g. electricity, thermal/heat energy, natural gas, solar power, etc.)

Other:

- Building water consumption data
- Building retrofit information[23]

This led to the survey of 100 large commercial and state buildings (6 offices, 13 hotels, 7 shopping centres, 46 commercial buildings, 9 mix-use buildings, and 19 others) within the Hongqiao Economic and Technology Demonstration Zone (ETDZ), to rank and select structures for the energy retrofit projects. The initial survey had resulted in several methods by which to determine which buildings were to be retrofitted.

Ranking by kWh/m^2

Using the national building codes as targets, which stipulated that energy consumption of a type of building should be at least 50% lower than a baseline building from the 1980s. It was estimated that this would result in a 33,400 TCE of energy savings but at an estimated cost of 430 million CNY or 456 CNY/m^2). While considered a quick and cost-effective judge, it did not consider building use and was therefore not pursued further as a means of identifying buildings for the upgrading program. The estimate is shown in Figure 60.

23 Information added after retrofits (SABR 2019)

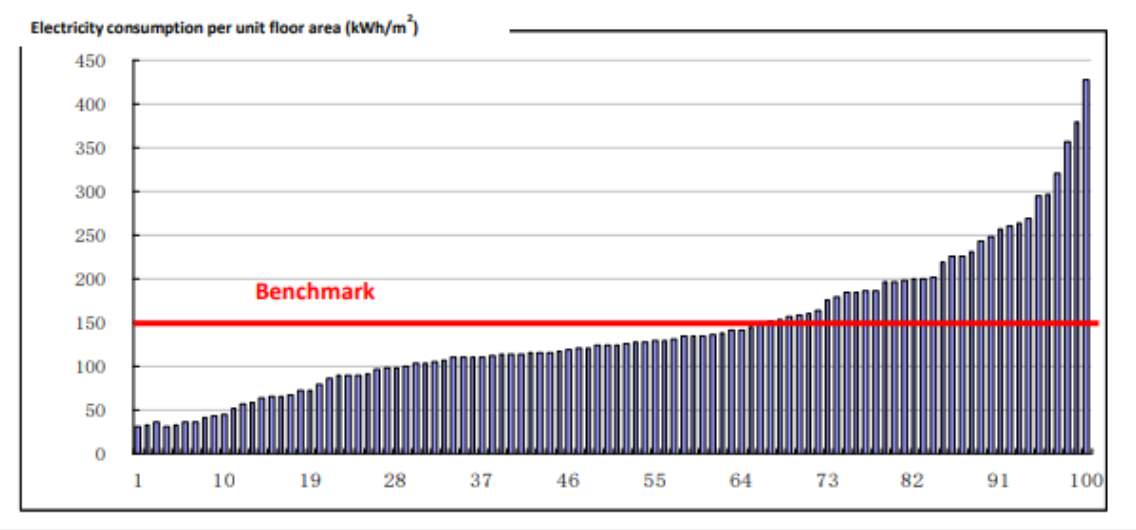


Figure 60 Ranking kWh/m^2 for all Buildings (Overall Ranking). *(Source: SECSC 2013.)*

Ranking by Categories and kWh/m^2

Accommodating the differences in functions, such as 24 hours operations. The 100 buildings, were categorised into the aforementioned categories: office buildings, hotels, shopping centres, commercial buildings, mixed use and others and similarly the energy use intensity targets were revised by categories at 105.1 kWh/m^2 , 168.0 kWh/m^2 , 236.7 kWh/m^2 , 103.4 kWh/m^2 , 178.6 kWh/m^2 , and 38.9 kWh/m^2 respectively. In this method of calculation, an estimated energy savings of 36,000TCE at an estimated cost of 598 million RMB or 244 RMB/m^2. The revised calculations and targets are shown in Figure 61 below.

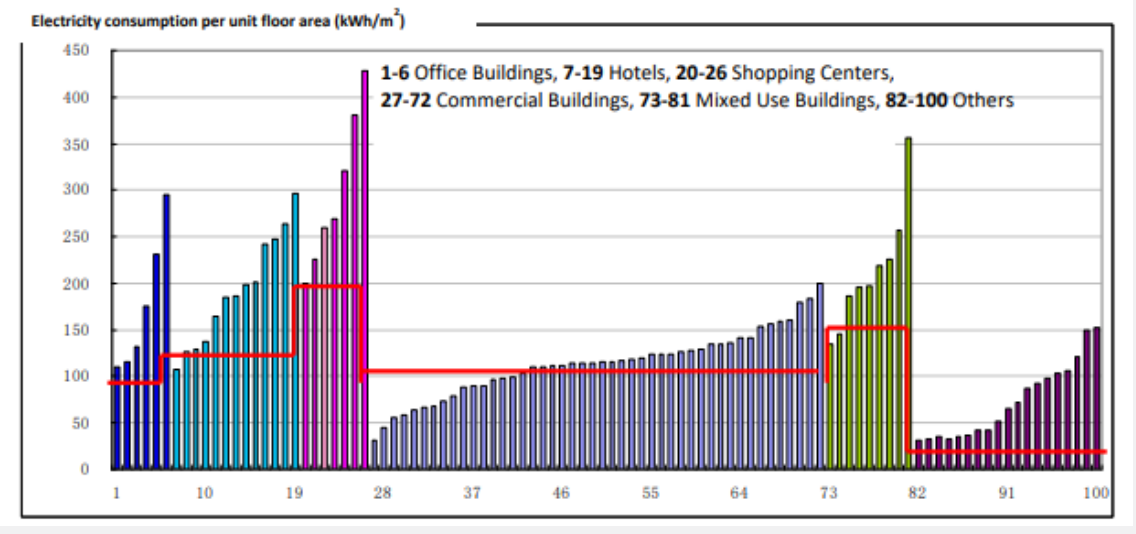


Figure 61 Ranking kWh/m^2 for all Buildings (Overall Ranking). *(Source: SECSC 2013.)*

The ranking method had improved identification but as it did not differentiate between actual building use (i.e office or data centre, 3 or 5 star hotels), out of a closer survey of identified buildings 58% of those did not have viable energy efficiency projects to meet the targeted energy savings. (SESC, 2013)

Top Runner Ranking by Categories and kWh/m^2

The final ranking method used was an adaptation of the second type but the top runners meeting the Energy Conservation Design Code for Public Buildings (50% energy savings compared to reference buildings in 1980) were used as the targets instead resulting in Figure 62 below.

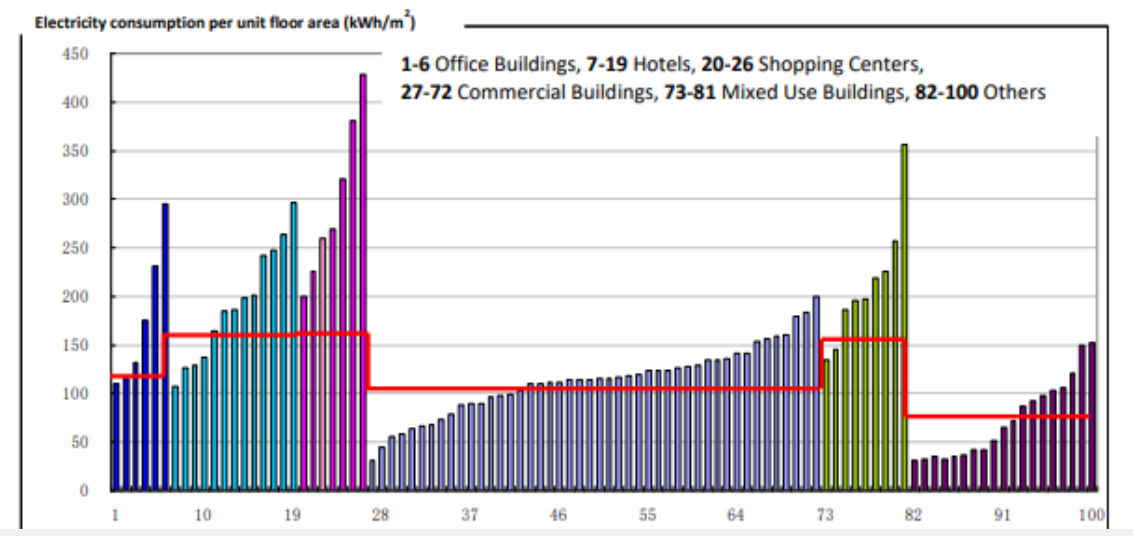


Figure 62 Ranking kWh/m^2 for Buildings in Each Category and Using Top Runner Buildings as the Benchmark. *(Source: SECSC 2013.)*

The corresponding kWh/m^2 benchmarks were 111.7 kWh/m^2 , 151.6 kWh/m^2 , 152.4 kWh/m^2 , 97.9 kWh/m^2, 144.7 kWh/m^2 , and 76.4 kWh/m^2. This method, a total of 64 buildings were identified for improving energy efficiency performance, with the estimated savings was 48,000 TCE, at a total investment of 800 million RMB or 288 RMB/m^2. However, it still did not differentiate between building use to a fine detail level category.

Adjusted Normalised Energy Targets based on Building Types

Due to those deficiencies, the Changning district performed a normalised study with a finer level category breakdown the final existing building energy efficiency targets for five-star, four-star, three-star hotels, commercial office buildings, and shopping centres was set at 71 KgCE/(m^2.a), 47KgCE/(m^2.a), 37 KgCE/(m^2.a), 34 KgCE/(m^2.a), and 76 KgCE/(m^2.a), respectively. The expected energy savings based on this method was 17,151 TCE with a total investment of 262 million RMB or 161 RMB/m^2. The normalised target setting surveys were only conducted on 68 buildings rather than the original 100 that had been earmarked for surveys. As part of this

normalisation study, the following estimates were produced shown in Table 6 below.

Table 6 Economic and Financial Summary Based on the Normalised Benchmark (SESC, 2013)

Building Type	Hotels	Commercial Office Buildings	Shopping Malls
Retrofit Investment (US$ million)	6.81	26.42	4.84
Energy Savings (TCE)	2,570.6	7,709.7	6,871.2
Investment per TCE (US$/TCE)	2,648.55	3,427.25	6,871.2
Investment per m^2 (US$/$m^2$)	19.12	29.30	12.80
No. of buildings to be retrofitted	10	28	5
% with payback 0-3 years	30%	4%	100%
% with payback 3-5 years	0%	18%	-
% with payback 5-10 years	20%	39%	-
% with payback 10-15 years	30%	21%	-
% with payback > 15 years	20%	18%	-

With buildings identified for upgrading, the district developed policy options with incentives ranging from tax incentives, low-interest loans, technical assistance, grants to rebates. Penalties meanwhile could have been administrative fines, higher utility rates and surcharges or a name and shame list. Marketing strategies to the various building types were conducted to get owner buy-ins on the project execution, as energy efficiency upgrading was not mandatory.

To achieve its goal to reduce energy consumption in 100 existing building in the Hongqiao ETDZ by 18%, equivalent to 33,000 TCE, Changning District adopted a three-phase implementation plan as follows:

- Phase I – focuses on improving energy efficiency in the buildings where actual energy utilisation index is higher than the target value. They represent large energy saving potential that can be achieved at lower cost (e.g., operational improvements, lighting retrofits).
- Phase II – focuses on improving energy efficiency in buildings where actual energy utilisation index is higher than the target value. They represent large energy saving potential that can be achieved at higher cost (e.g., envelop retrofit).
- Phase III – focuses on buildings where actual energy utilisation index is higher than the target value, but the actual energy saving potential is small

Results from each upgrading project further contributed to policy making, grant applications and the implementation of Changning's energy saving actions. Based on measurements and energy consumption types recorded by the Carbon Abatement Cost Curve, localised approaches were developed focusing on various

upgrading methods, technical support, and incentive mechanisms for different types of buildings. The ECMP platform has collected a huge amount of data, which can be used for future building upgrades, and has been made available and accessible to other districts that have similar interests in improving building energy efficiency.

In addition to GEF / World Bank funding, an incentive mechanism was financed by government budgeting, a total number of 18 buildings were subsidised by the Shanghai Changning District government with a total subsidy of 27.095 million CNY (3.93 million USD) (Shanghai Academy of Building Research, 2019). By the end of the project, a total of 45 existing buildings, with a total floor area of 2.87 million m^2, completed energy efficiency upgrades (Szum et al., 2020).

IMPACTS

Carbon Reductions: Reduced energy consumption led to a reduction of GHG emissions in Changning District. The 45 existing buildings in Changning which were upgraded reduced energy consumption by 25,423,662 kilowatt hours (kWh) and avoided 63,285 tons of CO_2 emissions emissions annually.

Valued Data: In addition to the cost curves data obtained through the program, Changning District and Shanghai also analysed financial internal rate of return (FIRR) of different technologies adopted by upgraded buildings by type. The eventual 100 upgraded buildings in Changning achieved a high average energy saving rate at 22.19%, and the average FIRR was up to 20.48% (SABR 2019). These metrics provide valuable benchmarks for cities globally as to the potential savings for expected basal energy expenditure targets and improvement programs. The program continued and a total of 187 or approximately 95% of all large commercial and state buildings in the district were added to the ECMP system for monitoring and potential future retrofit programs.

FACTORS FOR SUCCESS

A key part to the success of the project is the initial mapping of the energy efficiency landscape in the city through the use of smart technologies to monitor building energy consumption. The clear mapping of the status quo and benchmarking practices allowerd for proactive political engagement through incentives and promotion policies by the local government towards energy efficiency retrofits and prioritizing projects according to the speed and difficulties of implementation.

Furthermore, cross-departmental collaboration which sustained the entire transformation process allowed for comprehensive financing and technical assistance mechanisms to assist building owners and tenants through the retrofits and transitions, encouraging building owners to engage in the implementation of more complicated retrofits such as envelop retrofits, which were bolstered with strong supporting data on expected financial rate of

returns from the monitoring mechanisms and baseline information gathered.

LESSONS LEARNED

The project in Changning District inspired change in other districts. The combination of retrofitting technology and the use of photovoltaic technology to enhance building energy efficiency and sufficiency can be replicated in other districts and easily adapted for old and new buildings.

Formulating a task force with clear functions is instrumental in coordinating cross-departmental collaboration and engaging a wide variety of stakeholders. On one hand, innovative urban governance is essential for this transformation process. It consists of political commitment at the beginning, flexibility within the institutional set-up, strong financial and other policy support, as well as openness to involve international players with different backgrounds to discover possible solutions. On the other hand, this program uses a step-by-step and bottom-up approach. It showcases an extraordinary example about how to ensure the policymaking process is science-based, and most importantly, how to include the feedback process for adaptive governance. By using the tool *Carbon Abatement Cost Curves*, the focused, comprehensive and solution-oriented research and measurement resulted in valid data and mapping which navigate follow up policymaking and grant application.

Chapter III

Reflections

Leveraging Science, Technology and Innovation for Low Carbon and Resilient Cities

CASE STUDY REFERENCES

Chapter III : Reflections

In the fight against climate change, governments need to use the full arsenal of innovation to mitigate environmental damage and climate impacts, which can range from policies up to the large-scale coordination of high technology ICT projects that encompass an entire city. These range of implementation options are demonstrated in Chapter II, often combining a mix of policy, technology, and private sector involvement in order to ensure the success of a project and achieving longer term goals.

The application of science and technology can be constrained in feasibility depending on local conditions, which can range from political, economic, human capital, technology access or even natural resource constraints. It is thus important for local governments to consider projects to carefully weigh the costs and benefits of a project in local contexts carefully before initiating any long-term work. Parsing large project goals into smaller projects in a phased implementation approach, could also be a means to test and develop innovative approaches based on local constraints and serve as a litmus test for a project's feasibility in being adopted on a larger scale but can also be used as a capacity building mechanism to build up local expertise and improvements over time by analysing the outcomes of smaller implementations.

Furthermore, not all projects necessarily have direct measurable benefits in terms of energy savings. As an example intangible benefits such as residential access to public services promoting urban social resilience as well as acceptance of upgrading works and changes would also need to be considered and the impacts may not be immediately apparent. Long term biodiversity effects are also areas that are difficult to quantify accurately and often have interactions with their surroundings well beyond a limited neighbourhood but can have positive effects for the urban environment to make it more liveable, improving upon a city's long-term resilience.

Finally, as a takeaway message, governments do not have to attempt everything by themselves, civil organisations, international organisations and the private sector are potential partners to project successes and can bring innovations, resources or expertise to a project and in some ways help to ensure that the impacts of a project extend beyond the implementation scope of a one-time program such as spreading innovations and developed technologies through a industry or advocating for certain best practices. These impacts could potentially result in a longer-term structural shift, that grants urban emissions and resilience projects, an influence far larger than its original outcomes.

CASE STUDY REFERENCES

Case Study A1

- Guangdong Low-Carbon Development Promotion Association. (2017). 广东省碳普惠制的运用与发展. *http://www.gdditan.com/Information.aspx?id=675*
- Liu and S. Zheng. (2018). 广东省碳普惠机制实施进展研究. Available Online: *https://m.fx361.com/news/2018/0529/3574037.html*
- NRDC. (2021). CASE STUDIES ON PROJECTS DEVELOPED BY GOVERNMENTS AND ENTERPRISES TO PROMOTE INDIVIDUAL LOW-CARBON CONSUMPTION BEHAVIOURS IN CHINA.
- X. Tian, X. Wang, and S. Zaidi. (2019). What drives public willingness to participate in the voluntary personal carbon-trading scheme? A case study of Guangzhou Pilot, China. Ecological Economics, 165. Available Online: *https://doi.org/10.1016/j.ecolecon.2019.106389*

Case Study A2

- Bundesnetzwerk Verbraucherforschung. (2021). Newsletter 02/2021. Available Online: *https://www.netzwerk-verbraucherforschung.de/NVF/SharedDocs/Newsletter/DE/2021-02_newsletter.pdf?__blob=publicationFile&v=1*
- City of Essen. (2021a). TRANSCITY ESSEN-Sozialräumliche Inklusion durch Instrumente des Klimaschutzes. Available Online: *https://media.essen.de/media/wwwessende/aemter/gha/2021_dokumente/TRANSCITY_Projektbeschreibung_Werden.pdf*
- City of Essen. (2021b). Altenessen-Süd. Retrieved from *https://www.essen.de/dasistessen/stadtteile/altenessen_sued/altenessen_sued_startseite.de.jsp*
- City of Essen. (2021c). TRANSCITY. Retrieved from *https://www.essen.de/leben/umwelt/klima/klimaschutz/transcity.de.html*
- Clemens, K. (2021). Klimaschutz in Essen: Werden erteilt "Transcity" eine Absage. Retrieved from *https://www.waz.de/staedte/essen/klimaschutz-in-essen-werden-erteilt-transcity-eine-absage-id233679689.html*
- Kerr, L. (2017). A TALE OF TWO GREEN CITIES - Exploring the role of visions in the development of green infrastructure in two European Green Capital Cities. Retrived from *https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwiuvveLnML0AhXYZt4KHfu1Cq4QFnoECAYQAQ&url=https%3A%2F%2Ftheses.ubn.ru.nl%2Fbitstream%2Fhandle%2F123456789%2F5457%2FKerr%252C_Laurie_1.pdf%3Fsequence%3D1&usg=AOvVaw3ZdhAX_EGay8oZ2Q5WHxV5*
- Thiesen, A. (2016). Die transformative Stadt. Bielefeld: transcript Verlag.
- Thiesen, A., & Fischedick, M. (2020). Bildet die TRANSCITY! vhw.
- Thiesen, A., Steizer, F., & Weber, L. (2021). Retrieved from TRANSCITY IMPACT: *https://prezi.com/p/hyxfhuyyuixc/transcity-impact/*

- RheinMain University of Applied Sciences. (2021). TRANSCITY - SOCIAL SPACE INCLUSION THROUGH CROSS-DISTRICT EMISSIONS TRADING. Retrieved from *https://www.hs-rm.de/de/fachbereiche/sozialwesen/forschungsprofil/pb-vorlage-sozialwesen-2*
- Stiftung Mercator. (2021). What we work on. Retrieved from *https://www.stiftung-mercator.de/en/what-we-work-on/projects/*
- UNFCCC. (2017). Essen: A Beacon of City Climate Action. Retrived from *https://unfccc.int/news/essen-a-beacon-of-city-climate-action*

Case Study A3

- CLC. Centre for Livable Cities. (2018a). Retrieved from A Resilient Singapore: *https://resilientcitiesnetwork.org/downloadable_resources/Network/Singapore-Resilience-Strategy-English.pdf*
- CLC. Centre for Livable Cities. (2018b). Urban System Studies - Technology And The City Foundation For A Smart Nation. Singapore : CLC Publications.
- GPSC. Global Platform for Sustainable Cities. (2017). Data-informed Urban Planning. Retrieved from *https://www.thegpsc.org/sites/gpsc/files/26_feb_using_data_for_urban_planning_0.pdf*
- Huang, Z. (2018). Data Analytics in Urban Planning: New Tools for Old Problems. Retrieved from *https://www.brinknews.com/data-analytics-in-urban-planning-new-tools-for-old-problems/*
- Huang, Z. (2021). AI in Urban Planning: 3 Ways it will Strengthen how we Plan for the Future. Retrieved from *https://www.ura.gov.sg/Corporate/Resources/Ideas-and-Trends/AI-in-Urban-Planning*
- Lim, T., Ignatius, M., Miguel, M., Wong, N., & Juang, H.-M. (2017). Multi-scale urban system modeling for sustainable planning and design. Energy Build, 78-91.
- Lim, T. K., Rajabifard, A., Khoo, V., Sabri, S., & Chen, Y. (2020). The smart city in singapore: How environmental and geospatial innovation lead to urban liveability and environmental sustainability. In Kim, H. M., Sabri, S., & Kent, A.. (Eds.), Smart Cities for Technological and Social Innovation: Case Studies, Current Trends, and Future Steps (1st Edition ed., pp. 29-48). Academic Press.
- Morwenj. (2020). Plantech and the Singapore experience . Retrieved from *https://theknowledgeexchangeblog.com/2020/09/07/plantech-and-the-singapore-experience/*
- Tay, S. (2021, February 18). Inside Singapore's vision for data-driven urban planning. Retrieved from *https://govinsider.asia/insights/huang-zhongwen-ura-inside-singapores-vision-for-data-driven-urban-planning/*
- URA. Urban Renewal Authority Singapore. (2017, November 26). Harnessing the Power of Digital Technologies. Retrieved from *https://www.ura.gov.sg/Corporate/Resources/Ideas-and-Trends/Harnessing-the-Power-of-Digital-Technologies*
- URA. Urban Renewal Authority Singapore (2021a). Adapting to Climate Change. Retrieved from *https://www.ura.gov.sg/Corporate/Planning/Master-Plan/Themes/A-Sustainable-and-Resilient-City-of-the-Future/Adapting-To-Climate-Change*

- URA. Urban Renewal Authority Singapore (2021b). Our Digital World. Retrieved from *https://www.ura.gov.sg/Corporate/Get-Involved/Plan-Our-Future-SG/Innovative-Urban-Solutions/Our-Digital-World*
- URA. Urban Renewal Authority Singapore (2021c). Using Data for Urban Planning . Retrieved from *https://www.smartnation.gov.sg/initiatives/urban-living/urban-planning*

Case Study B1

- Cities Alliances. TOPIS: The "Control Tower" for Seoul's Intelligent Transportation System. Retrieved from citiesalliance.org: *https://www.citiesalliance.org/sites/default/files/Seoul-TOPIS_0.pdf*
- Korea IT News. 2020. Seoul-si looking to connect the entire area of Seoul through IoT sensors. Retrieved from Korea IT News: *https://english.etnews.com/20200218200001*
- Lee, S.-h., Oh, D.-s., Seo, J., Yoon, J.-y., Choi, C.-h., and Yoon, S.-c.. 2014. Establishment of Intelligent Transport Systems (ITS). Ministry of Strategy and Finance, Republic of Korea.
- Seoul Solution. 2017. Retrieved from Seoul's Intelligent Traffic System (ITS): *https://www.seoulsolution.kr/sites/default/files/policy/%EA%B5%90%ED%86%B5_6_Seoul%27s%20Intelligent%20Traffic%20System%20%28ITS%29_final.pdf*
- Seoul Metropolitan Government. 2020. Retrieved from english.seoul.go.kr: *http://english.seoul.go.kr/seoul-topis-portal-to-open-by-end-of-2021-for-public-private-big-data/*
- Lee, S. 2017. TOPIS: Seoul's Intelligent Traffic System (ITS). Seoul: Seoul Urban Solutions Agency.
- Seoul Solution. 2021. Seoul Transport Operation & Information Service: TOPIS. Seoul, Republic of Korea: Seoul Campus.
- SMG and Seoul Institute. 2020. Seoul transportation system: Energy consumption status. Seoul.

Case Study B2

- Seoul Facilities Corporation. 2021. 2021 Ttareungyipo Operation Plan.
- Seoul Metropolitan Government. 2021. "6000 additional Ttareungyi will be introduced by next year.". Available Online: *https://mediahub.seoul.go.kr/archives/2003017*
- Seoul Facilities Corporation. 2021. Comprehensive report on the status of the public bicycle management office.
- Huh, G. 2021, November 2. Oh Sehun's "Ttareungyi season 2." News1. Available Online: *https://news.v.daum.net/v/kosOVW9l6w*
- Seoul Facilities Corporation. 2021. "Improved efficiency of maintenance of Ttareungyi." Available Online: *https://www.sisul.or.kr/open_content/main/bbs/bbsMsgDetail.do?msg_seq=673&bcd=report*
- "Learning Ttareungyi on Metabus." (2021). Seoul Metropolitan Government. *https://opengov.seoul.go.kr/mediahub/23564522*

- Seoul Facilities Corporation. 2021. Operational plan of the public bicycle quarantine team.
- Seoul Metropolitan Government. 2021. Seoul Metropolitan Government Weather Statistics. *https://data.seoul.go.kr/dataList/414/S/2/datasetView.do#*
- Seoul Metropolitan Government. 2021. "The Seoul Metropolitan Government renews the Ttareungyi application." (2021). *https://news.seoul.go.kr/traffic/archives/505259*
- Seoul Metropolitan Government. 2021. "The Seoul Metropolitan Government will reduce the usage fee of Ttareungyi by up to 30% for those who pass the bicycle driving ability certificate test." . *https://opengov.seoul.go.kr/press/23756218*
- Seoul Facilities Corporation. 2019. "Seoul's public bicycle "Ttareungyi Repair" will be handled by a local bicycle agency." *https://www.sisul.or.kr/open_content/main/bbs/bbsMsgDetail.do;jsessionid=u5e26sIOY1V12HUCwXi811k2wd2dJGFSLwrSNvt1aAum8edcJEIT3Jbja7Qn1Nnu.etisw1_servlet_user?msg_seq=506&bcd=report*
- Seoul Metropolitan Government. 2021. "Ttareungyi deficit increases as the number of users grows." (2021). *https://www.seoul.go.kr/news/news_explanation.do#view/299039?tr_code=snews*
- Seoul Metropolitan Government. 2021a. 2021 The Seoul Metropolitan Government Transportation Office Report.
- Seoul Metropolitan Government. 2021b. 2020 Seoul citizens' public transportation report card. Available at: *https://blog.naver.com/haechiseoul/222286979978*
- S. Yim, 2019. "Controversy over Ttareungyi delivery." The JoongAng. *https://www.joongang.co.kr/article/23640116#home*
- Seoul Bike Main Website. 2018. "Terms and conditions of Ttareungyi.". *https://www.bikeseoul.com/app/use/moveUseMenuClauseInfo.do*

Case Study B3

- Jeju Self-Governing Province & Jeju Research Institute. 2018. *Jeju EV policy brief | What are the success factors for electric vehicle dissemination?. Available Online: https://www.jri.re.kr/contents/index.php?mid=0413&job=download&seq=2750&no=1&gubun=h*
- J.-T Ko. 2019, September 2. Drive, plug in your EV car and wait a long time. Available Online: *Korea JoongAng Daily*. *https://koreajoongangdaily.joins.com/2019/09/02/industry/Drive-plug-in-your-EV-car-and-wait-a-long-time/3067500.html*
- Korea Trade-Investment Promotion Agency. n.d.. *Green Energy | Jeju*. Retrieved 12 November 2021, from *https://www.investkorea.org/jj-en/cntnts/i-1506/web.do*
- Korea Trade-Investment Promotion Agency. 2021a, February 4. *CFI 2030 (Carbon Free Island 2030) Part 2View Details | Industry Trends | Jeju*. *https://www.investkorea.org/jj-en/bbs/i-1536/detail.do?ntt_sn=3*
- Korea Trade-Investment Promotion Agency. 2021b, November 8. *Use Renewable Energy as Much as You Want, and Get Local Currency as a Bonus!View Details | Industry News | Jeju*. *https://www.investkorea.org/jj-en/*

bbs/i-2584/detail.do?ntt_sn=8

- Kwon, Y., Son, S., & Jang, K. (2018). Evaluation of incentive policies for electric vehicles: An experimental study on Jeju Island. *Transportation Research Part A: Policy and Practice*, *116*, 404–412. *https://doi.org/10.1016/j.tra.2018.06.015*
- Son, S. (2020a). *Major EV Policy Issues in Jeju in 2019*. Jeju Research Institute. *https://www.jri.re.kr/contents/index.php?mid=0413&job=detail&seq=2765&gubun=h*
- Son, S. (2020b). *Electric bus operation status in Jeju Province*. Jeju Research Institute. *https://www.jri.re.kr/contents/index.php?mid=0413&job=detail&seq=2785&gubun=h*

Case Study C1

- BBC. (1998, January 14). Koreans give up their gold to help their country. *BBC NEWS*. *http://news.bbc.co.uk/2/hi/world/analysis/47496.stm*
- Korea Environmental Industry and Technology Institute. (2018, February 13). *Zero carbon Olympics: 2018 Pyeongchang Winter Olympics and Paralympics*. KOMETIC. *https://www.konetic.or.kr/infocenter/cardnews_view.asp?INTNUM=166*
- Lee, G., & Seo, J. (1999, June 8). Seoul city announced the New Seoul Our Han River Master Plan. *DongA Ilbo*. *https://www.donga.com/news/Society/article/all/19990608/7446194/1*
- Lee, Y. (2021, August 19). *2021 KIA Challenge Eco project 3: A waste landfill site changed into an ecological park*. *https://www.kyeonggi.com/news/articleView.html?idxno=2377242*
- Park, Y. (2020, February 10). Seoul city is making a plan to revitalize Sangam areas. *Seoul Economic Daily*. *https://www.sedaily.com/NewsVIew/1YYVAHIM6J*
- Seoul Institute. (2014). *2014 Modularization of Korea's development Experience: Nanjido Eco Park Restoration from Waste Dumping Site*.
- Seoul Metropolitan Government. (2010, March 16). *Seoul wins UN-HABITAT Scroll of Honor award* -. Seoul Metropolitan Government. *https://english.seoul.go.kr/seoul-wins-un-habitat-scroll-of-honor-award/*
- Seoul Metropolitan Government. (2014, May 16). *Nanjido Ecological Park Construction Project*. Seoul Solution. *https://www.seoulsolution.kr/ko/content/%EB%82%9C%EC%A7%80%EB%8F%84-%EC%83%9D%ED%83%9C%EA%B3%B5%EC%9B%90-%EC%A1%B0%EC%84%B1%EC%82%AC%EC%97%85*
- Seoul Metropolitan Government. (2015a, May 27). *Development of Sangam Digital Media City (DMC)*. Seoul Solution. *https://seoulsolution.kr/ko/content/%EC%84%9C%EC%9A%B8-%EC%83%81%EC%95%94%EB%94%94%EC%A7%80%ED%84%B8%EB%AF%B8%EB%94%94%EC%96%B4%EC%8B%9C%ED%8B%B0dmc%EC%9D%98-%EC%A1%B0%EC%84%B1*
- Seoul Metropolitan Government. (2015b, June 20). *Landfill Recovery Project: Transformation of Landfill to Ecological Park*. Seoul Solution. *https://seoulsolution.kr/en/content/landfill-recovery-project-transformation-landfill-ecological-park*

Case Study C2

- Seoul Urban Farming White Paper (2011-2020): *http://ebook.seoul.go.kr/Viewer/TEUXPKKDVX59*
- Seoul Urban Agriculture 3.0 Master Plan: *https://cityfarmer.seoul.go.kr/brd/view.do?nttSn=4785&key=1905228803942&pageIndex=1&sc=&sw=&sc_cate=&tr_code=sweb*
- Cho, H., Son, C., Yoo, G., Choi, Y., Lee, Y., & Kim, J. (2017). *A Study on Heat Wave Adaptation Strategies in Seoul*. *https://www.si.re.kr/node/64575*
- Climate and Environment Headquarters. (2021, April 13). *GHG inventory of Seoul city (2017-2019)*. Seoul Metropolitan Government. *https://news.seoul.go.kr/env/environment/green-house-inventory*
- Economic Policy Office. (2020). *The Seoul Urban Agriculture 3.0 Master Plan*. Seoul Metropolitan Government. *https://cityfarmer.seoul.go.kr/brd/view.do?nttSn=4785&key=1905228803942&pageIndex=1&sc=&sw=&sc_cate=&tr_code=sweb*
- Korea Meteorological Administration. (n.d.). *Statistic data on the annual mean temperature of Seoul city between 1960 and 2020*. Korea Meteorological Administration. *https://data.kma.go.kr/climate/RankState/selectRankStatisticsDivisionList.do*
- Ministry of Agriculture, Food and Rural Affairs. (n.d.). *Urban Agriculture Activation: The Second Five-year Plan for Urban Agriculture Development (2018-2022)*. Ministry of Agriculture, Food and Rural Affairs. *https://www.mafra.go.kr/mafra/2097/subview.do*
- Seoul Institute. (2018, October 10). *Public Release: Green areas in Seoul city accounts for 34% of the total urban areas*. Seoul Institute. *https://www.si.re.kr/node/60502*
- Seoul Metropolitan Government. (2019a, March 12). *Seoul city introduces Sangja gardens*. Mediahub Seoul. *https://opengov.seoul.go.kr/mediahub/view/?nid=17359636*
- Seoul Metropolitan Government. (2019b, September 26). *Sangdo station sets up a metro-farm first in South Korea*. Mediahub Seoul. *https://mediahub.seoul.go.kr/archives/1253512*
- Seoul Metropolitan Government. (2020a). *Seoul Urban Farming White Paper (2011-2020)*. *http://ebook.seoul.go.kr/Viewer/TEUXPKKDVX59*
- Seoul Metropolitan Government. (2020b, March 10). *Seoul city sets up 264 rooftop gardens*. Mediahub Seoul. *https://mediahub.seoul.go.kr/archives/1272771*
- Seoul Metropolitan Government. (n.d.). *Organization Chart*. Seoul Metropolitan Government. *http://org.seoul.go.kr/org/orgChartView.do*
- Shim, H. (2021, August 25). Residents in Seoul city plant vegetables in Jaturi gardens near the Jungrang stream. *Seoul Public News*. *https://go.seoul.co.kr/news/newsView.php?id=20210826014007*
- Yang, Y., Lee, H. S., Suh, H. L., Uchida, T., & Hori, Y. (2021). *Best Practices of Circular Food Production and Consumption in Japan and Korea: A Handbook for Local Governments*. *http://eastasia.iclei.org/upload/portal/20210423/6f1e2510a30c6aa6046c3cd68ab6f1c3.pdf*

Case Study C3

- AFRY. (NA). *From dirty sewer to green haven*. Retrieved from *https://afry.com/en/project/dirty-sewer-green-haven*
- Bryce, E. (2017, August 1). *GERMANY'S TRANSITION FROM COAL TO RENEWABLE ENERGY OFFERS LESSONS FOR THE REST OF THE WORLD.* Retrieved from *https://ensia.com/features/german-transition-coal-renewable-energy/*
- City of Essen . (2018). *Green up your life.* Retrieved from *https://media.essen.de/media/wwwessende/aemter/0115_1/gruene_hauptstadt_5/GHE_Dokumentation_Kurzfassung_EN_final_web.pdf*
- City of Essen. (2017). doi:10.2779/63675
- Deutschland. (2017, January 23). Retrieved from Essen is green: *https://www.deutschland.de/en/topic/culture/town-country/essen-is-green*
- Early, S. (2018, January 02). *From coal city to European Green Capital - Essen's extreme makeover*. Retrieved from *https://www.dw.com/en/from-coal-city-to-european-green-capital-essens-extreme-makeover/a-36975499*
- European Union. (2017). *ESSEN - European Green Capital.* Luxembourg: Publications Office of the European Union.
- Green Capital Essen Project Office. (2018, January). *The magazine of the EUROPEAN GREEN CAPITAL – Essen 2017.*
- Kufen, T. (2017, March 27). Retrieved from Essen: The European Green Capital 2017: *https://www.openaccessgovernment.org/essen-european-green-capital-2017/32562/*
- Ramon, M. (2019, December 12). *The glorious past returns: How Essen is harnessing its industrial legacy to accelerate sustainability.* Retrieved from *https://talkofthecities.iclei.org/the-glorious-past-returns-how-essen-is-harnessing-its-industrial-legacy-to-accelerate-sustainability/*
- Sustain Europe. (2017, June 29). *The European Green Capital – Essen 2017 creates harmony.* Retrieved from *https://www.sustaineurope.com/essen-european-green-capital-2017-29062017.html*
- Wuppertal Institute; University Alliance Ruhr. (2018). *Monitoring of Selected Action Field of the European Green Capital Essen 2017.*

Case Study C4

- Byun, B. (2021). Suggestion for restoration of urban water circulation. *Water Journal*, *200*, 85–88.
- Gyeonggi Urban Innovation Corporation. (2013, September 24). Suwon Eco-city Tour Part. 2: How does Suwon city rainwater harvest? *GH Corporation's Blog. https://blog.naver.com/gico12/20196211186*
- Han, M. (2009). Rain City Initiative: Rainwater harvesting is a solution to water stress in the city. *Weekly DongA*, *678. https://weekly.donga.com/3/search/11/87148/1*
- ICLEI Korea. (2016, November 18). *Suwon city: A Rain City with rainwater resource circulation*. ICLEI Korea. *https://www.icleikorea.org/_04/notice/view?seq=1513&search_name=&search_value=&page=82&pagelistno=9*
- Kang, C. (2013, November 7). Suwon city installed an automatic road-spraying and anti-icing system using rainwater. *Yonhapnews. https://www.yna.co.kr/view/AKR20131107156700061*
- Kang, S. (2017, February 7). Suwon city begins the Rain City Initiative. *MeaillIbo*. *http://www.m-i.kr/news/*

articleView.html?idxno=287972

- Kang, T. (2014, February 14). Suwon City starts accepting applications for the installation of the newly invented rainwater collector. *Maeilllbo*. *http://www.m-i.kr/news/articleView.html?idxno=109566*
- Kim, B. (2018, September 15). The Rain City Initiative helps Suwon city to handle heat waves and droughts. *Seoul Shinmun*. *https://www.seoul.co.kr/news/newsView.php?id=20180915500001*
- Kim, J. (2021, August 24). *The Rain City Initiative of Suwon city was introduced at SIWI World Water Week 2021*. WaterMeail. *http://www.watermaeil.com/news/articleView.html?idxno=5758*
- Korea Water Resources Corporation. (n.d.). Suwon city starts the Rain City Initiative to regain its reputation like the meaning of its name. *K-Water Official Blog*. *http://m.water.or.kr/knowledge/history/history01_detail.do?CONTS_ID=CONTS_00000000000010*
- Lee, M., Han, Y., & Hyun, K. (2014). Ordinance and regulation on Low Impact Development adopted by local governments and suggestions for LID demonstration. *Water for Future*, *47*(12).
- Ministry of Environment. (2020, September 9). *Public Release: An integrated management system for water security is promoted under the theme of the Green New Deal.* Ministry of Environment. *http://www.me.go.kr/home/web/board/read.do?pagerOffset=10&maxPageItems=10&maxIndexPages=10&searchKey=&searchValue=&menuId=286&orgCd=&boardMasterId=1&boardCategoryId=&boardId=1396720&decorator*
- National Assembly Water Forum. (2021, August 28). *1. SUWON THE RAIN CITY*. *https://www.youtube.com/watch?v=_qHkv5K4XmE*
- Park, S., & Ha, J. (2013). *Rainwater collector and facilities.* (Republic of Korea Patent No. 10–1340799). Korea Intellectual Property Office. *http://kpat.kipris.or.kr/kpat/biblioa.do?method=biblioFrame&applno=1020130093150&index=0&start=fulltext&openPageId=View03*

Case Study C5

- Byun, J. (2017, September 3). *10th anniversary of Jeju Olle: Will you walk on Jeju Olle tomorrow, the day after tomorrow, or 100 years later?* Yonhapnews. *https://www.yna.co.kr/view/AKR20170901087900056*
- Heo, H. (2011, May 25). *Jeju Olle piled up waste from the construction of Jeju Naval base*. Hankyoreh. *https://www.hani.co.kr/arti/area/area_general/479758.html*
- Hong, J. (2021, November 14). *Burberry Korea Ltd. Becomes a partner company of Jeju Olle*. Maeil Kyungjae. *https://www.mk.co.kr/news/culture/view/2021/11/1070662/*
- Hwang, K. (n.d.). *Urban development project careless of environment threats Jeju Olle*. Seoul Public News. Retrieved December 8, 2021, from *https://go.seoul.co.kr/news/newsView.php?id=20190514017001*
- Jeju Olle Foundation. (n.d.a). *People*. Jeu. Retrieved December 8, 2021, from *https://www.jejuolle.org/office/kor/sub/people.asp*
- Jeju Olle Foundation. (n.d.b). *Activities*. Jeju Olle Foundation. *https://www.jejuolle.org/office/eng/sub/project.asp*

- Jeju Olle Foundation. (n.d.c). *Jeju Olle*. Jeju Olle Foundation. *https://www.jejuolle.org/office/kor/sub/office_olle.asp*
- Jeju Olle Foundation. (n.d.d). *Networking*. Jeju Olle Foundation. *https://www.jejuolle.org/office/kor/sub/networking.asp*
- Jeju Olle Trail. (n.d.). *Jeju Olle Trail*. Jeju Olle Trail. *https://www.jejuolle.org/trail/eng/default.asp*
- Jeju Special Self-Governing Province. (n.d.). *Jeju: UNESCO triple crown holder*. Jeju Special Self-Governing Province. *http://www.jeju.go.kr*
- Jejunews. (2010, February 15). *Green ecological tourism with low carbon emissions*. Jejunews. *http://www.jejunews.com/news/articleView.html?idxno=530607*
- Jeon, J. (2012, December 13). *A huge argument over making the ordinance on management of Jeju Olle*. Yonhapnews. *https://www.yna.co.kr/view/AKR20121213116400056*
- Kim, D. (2012). Current status of trail tour projects and improvement plans. Korea Research Institute for Local Administration, 52.
- Kim, G. (2021, June 2). *Jeju Olle Green Leader project as a solution to tourists' safety and environmental management*. Jejunews. *http://www.jejunews.biz/news/articleView.html?idxno=54628*
- Kim, T. (2020, July 22). *The share of service industries is increasing in the economy of Jeju Special Self-Governing Province*. Jejuilbo.net. *http://www.jejuilbo.net/news/articleView.html?idxno=148327*
- Korea Law Information Centre. (n.d.). *Enforcement Rules of the Ordinance on the Establishment of Administrative Organisations in Jeju Special Self-governing Province*. Korea Law Information Center. *https://www.law.go.kr/%EC%9E%90%EC%B9%98%EB%B2%95%EA%B7%9C/%EC%A0%9C%EC%A3%BC%ED%8A%B9%EB%B3%84%EC%9E%90%EC%B9%98%EB%8F%84%ED%96%89%EC%A0%95%EA%B8%B0%EA%B5%AC%EC%84%A4%EC%B9%98%EC%A1%B0%EB%A1%80%EC%8B%9C%ED%96%89%EA%B7%9C%EC%B9%99/(523,20170315)*
- Lee, D. (2020, June 30). *Construction industry drives economic growth and recession of Jeju Province*. Jejusori. *http://www.jejusori.net/news/articleView.html?idxno=317411*
- Lee, S. (2010). Management plan for Jeju Olle which adds value to paths for walking. *Jeju Development Institute*, 107. *https://www.jri.re.kr/contents/index.php?mid=0406&job=detail&seq=483&gubun=6*
- *Lee, S. (2014).* Current status of Jeju Olle hikers and the management improvement plan. *Jeju Research Institute, 50, 64–75.*
- Lee, W., et al. (2019). Estimating the Carbon Dioxide Emission in Jeju Ecotourism. *Journal of Climate Change Research*, *10*(2), 79–87. *https://doi.org/10.15531/ksccr.2019.10.2.79.*
- Oh, J. (2020, July 18). *A reduction plan for rental cars operating in the island poses a challenge to tourists*. ChosunMedia. *https://www.chosun.com/site/data/html_dir/2019/01/23/2019012300495.html*
- Yoo, H. (2019, May 31). *What challenges does the cap on rental cars pose?* Kyotongshinmun. *http://www.gyotongn.com/news/articleView.html?idxno=230221*

Case Study C6

- Chinese Society for Urban Studies. (2015). Practice of low-carbon ecological model—The connotation, way and prospect of sponge city 低碳生态模式践行-海绵城市的内涵、途径与展望. In *China Low Carbon Eco-city Development Report (2015)* 中国低碳生态城市发展报告（*2015*）(pp. 64–75).
- Crystal News 晶报多媒体数字报刊平台. (2016, September 22). *More than 80% of the city's built-up areas will meet the requirements of sponge cities in 2030* 2030年我市建成区八成以上将达海绵城市要求. *http://jb.sznews.com/html/2016-09/22/content_3623298.htm*
- General Office of the State Council 国务院办公厅. (2015, October 16). *General Office of the State Council on the guidance of promoting the construction of sponge cities* 国务院办公厅关于推进海绵城市建设的指导意见. *http://www.gov.cn/zhengce/content/2015-10/16/content_10228.htm*
- Guangming Government Online 光明政府在线. (n.d.). *Guangming District Phoenix Area wins in sponge city pilot performance evaluation* 光明区凤凰片区在海绵城市试点绩效评价中夺冠. Retrieved 20 October 2021, from *http://www.szgm.gov.cn/xxgk/ztzl/SpongeCity/*
- International Water Association. (n.d.). *Shenzhen*. International Water Association. Retrieved 22 October 2021, from *https://iwa-network.org/city/shenzhen/*
- Environmental quality standards for surface water 地表水环境质量标准_中华人民共和国生态环境部, GB 3838-2002 (2002). *https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/shjbh/shjzlbz/200206/t20020601_66497.shtml*
- Office of the Leading Group for the Implementation of Sponge City Construction in Guangming New District 光明新区海绵城市建设实施工作领导小组办公室. (2017). *On the issuance of "Guangming New Area sponge city Construction Technology Guide* 关于印发《光明新区强基惠民项目海绵城市建设技术指南》的通知. *http://swj.sz.gov.cn/ztzl/bmzdgz/hmcsjs/zhyw/201912/P020191202641094816078.pdf*
- Promoting Green Buildings in Shenzhen 深圳市绿色建筑促进办法, (2013). *http://www.sz.gov.cn/zfgb/2020/gb1144/content/post_7130799.html*
- Shenzhen Finance Committee 深圳市财政委员会 & Shenzhen Sponge City Construction Office 深圳市海绵城市建设工作领导小组办公室. (2018). *On the issuance of "About the Municipal Finance Notice on the Implementation Plan for Supporting Sponge City Construction (for Trial Implementation)* 关于印发《关于市财政支持海绵城市建设实施方案（试行）》的通知. *http://swj.sz.gov.cn/ztzl/bmzdgz/hmcsjs/zhyw/201805/P020180529419417546269.pdf*
- Shenzhen Government Online, 深圳政府在线. (2017, May 12). *Guangming New Area is the only demonstration area of low impact development and comprehensive utilization of rainwater in China* 光明新区是全国唯一低影响开发雨水综合利用示范区—投资环境. *http://www.sz.gov.cn/cn/zjsz/fwts_1_3/tzfw/tzhj/content/post_1352534.html*
- Shenzhen Online 深圳政府在线. (2018, February 22). *The definition of flooding point* 内涝点的定义是什么？—河道. *http://www.sz.gov.cn/hdjl/ywzsk/shuiwj/hd/content/post_7864244.html*
- Shenzhen Planning and Land Resources Committee 深圳市规划和国土资源委员会 & Shenzhen Urban Planning and Design Co. 深圳市城市规划设计有限公司. (2019). *Shenzhen Sponge City Construction Special*

Planning and Implementation Plan (Optimization): Text 深圳市海绵城市建设专项规划及实施方案（优化）：文本. *http://pnr.sz.gov.cn/attachment/0/850/850388/5841591.pdf*

- Shenzhen Sponge City Construction Office 深圳市海绵城市建设工作领导小组办公室. (2017). *Working Brief on Shenzhen's Sponge City Construction* 深圳市海绵城市建设工作简报 (2017.1-6). *http://swj.sz.gov.cn/ztzl/bmzdgz/hmcsjs/gzjz/201703/P020170327526599091388.pdf*
- Shenzhen Water Affairs Bureau, 深圳市水务局. (2019). *Shenzhen Water Strategy 2035 (draft)* 深圳水战

Case Study C7

- Wang SG. (1998). Status quo of coastal wetlands and their protection in Guangdong Province. *Chongqing Environ Sci* 20:4–11.
- Han, Q., Huang, X., Shi, P., & Zhang, Q. (2006). Coastal wetland in South China: Degradation trends, causes and protection countermeasures. *Chinese Science Bulletin*, *51*, 121–128. *https://doi.org/10.1007/s11434-006-9121-z*
- MCF - Shenzhen Mangrove Wetland Conservation Foundation 深圳市红树林湿地保护红树林基金会. (2015). *MCF Annual Report 2015* 红树林基金会*2015*年报. *http://www.mcf.org.cn/u_file/MCF2015.pdf*
- MCF - Shenzhen Mangrove Wetland Conservation Foundation 深圳市红树林湿地保护红树林基金会. (2016). *MCF Annual Report 2016* 红树林基金会*2016*年报. *http://www.mcf.org.cn/u_file/download/17_08_25/5fa084c153.pdf*
- MCF - Shenzhen Mangrove Wetland Conservation Foundation 深圳市红树林湿地保护红树林基金会. (2017). *MCF Annual Report 2017* 红树林基金会*2017*年报. *http://www.mcf.org.cn/u_file/download/18_07_23/f04ca1d6d8.pdf*
- MCF - Shenzhen Mangrove Wetland Conservation Foundation 深圳市红树林湿地保护红树林基金会. (2018). *MCF Annual Report 2018* 红树林基金会*2018*年报. *http://www.mcf.org.cn/u_file/download/20_01_09/dd09c994a5.pdf*
- MCF - Shenzhen Mangrove Wetland Conservation Foundation 深圳市红树林湿地保护红树林基金会. (2019). *MCF Annual Report 2019* 红树林基金会*2019*年报. *http://www.mcf.org.cn/u_file/download/20_06_16/888849bc48.pdf*
- National Development and Reform Commission Ministry of Natural Resources on the issuance of National Major Project for the Protection and Restoration of Important Ecosystems Master Plan (2021-2035)【关于印发《全国重要生态系统保护和修复重大工程总体规划(2021-2035年)》的通知(发改农经〔2020〕837号)】-国家发展和改革委员会, [2020]837 (2020). *https://www.ndrc.gov.cn/xxgk/zcfb/tz/202006/t20200611_1231112.html?code=&state=123*
- Ramsar. (n.d.). *About the Convention on Wetlands | Ramsar*. Retrieved 10 December 2021, from *https://www.ramsar.org/about-the-convention-on-wetlands-0*
- Spalding, M. D., & Leal, M. (Eds.). (2021). *The State of the World's Mangroves* (p. 41). Global Mangroves Alliance. pdf

Case Study C8

- Asian Development Bank. (2005, September 30). *Suzhou Creek Rehabilitation Project* (China, People's Republic of) [Text]. Asian Development Bank. *https://www.adb.org/projects/documents/suzhou-creek-rehabilitation-project*
- Asian Development Bank. (2017, April 11). *Built to Last: Suzhou Creek Rehabilitation Project, PRC* (China, People's Republic of) [Text]. Asian Development Bank. *https://www.adb.org/feature/built-to-last-suzhou-creek-rehabilitation-prc*
- Chen, X. 陈玺撼. (2018, December 30). The 20 years of Suzhou River environmental restoration 苏州河整治走过20年！一图看懂苏州河治理的前世今生_上观新闻 [Review of *The 20 years of Suzhou River environmental restoration* 苏州河整治走过*20*年！一图看懂苏州河治理的前世今生_上观新闻, by Y. 张奕 Zhang]. *Shanghai Observer* 上观. *https://www.shobserver.com/news/detail?id=124616*
- China Economic Net, 中国经济网. (2021, July 28). The rebirth of Suzhou River 苏州河重生记. *China Economic* 中国经济网-《经济时报》. *http://www.ce.cn/xwzx/gnsz/gdxw/202107/28/t20210728_36755299.shtml*
- Dong, Y. 董怿翎. (2020, December 31). Walk along the Suzhou River—Through the River | The History and Future Development of Suzhou River 沿苏州河而行·贯通 | 苏州河的治水历史与未来发展_城市漫步_澎湃新闻-The Paper. *The Paper* 澎湃新闻. *https://www.thepaper.cn/newsDetail_forward_10594578_1*
- Shanghai Design and Promotion Center for Urban Public Space, 上海市公共空间设计促进中心. (2020, September 11). *Reading Suzhou Creek| Fuxin Flour Factory, the prosperity of national capital* 阅读苏河丨福新面粉厂，实业兴国的民族资本之证. *https://mp.weixin.qq.com/s?__biz=MzAwMDU1ODY4MA==&mid=2650378513&idx=1&sn=26efe2cb78db9105b2681a8c43f75547&chksm=82ea2226b59dab30fa80b12b494513d29fa82fa8c08c4bf824b20eced0892b004588da00116a#rd*
- Shanghai Planning and Land Resource Administration, 上海市规划和国土资源管理局. (2018). *Development Plan for Huangpu River and Suzhou River: Striving for World Class Waterfront Area* 黄浦江、苏州河沿岸地区建设规划：迈向世界级滨水区. *http://hd.ghzyj.sh.gov.cn/hdpt/gzcy/sj/201808/P020180823633440944805.pdf*
- Shanghai Planning and Natural Resources Administration, 上海市规划和自然资源局. (2020). *Suzhou River Waterfront Area Construction Plan* 苏州河沿岸地区建设规划. *https://ghzyj.sh.gov.cn/cmsres/07/076cb65a59ce4024a00d60500ed6195d/ef341341100d0924e2eb9f1eb56e2a39.pdf*

Case Study C9

- Chu, C. 楚倡, Li, X. 李星, & Qiao, J. 乔俊杰. (2020). Research on the technical methods to guide land use function optimization and traffic facility improvement based on road network carrying capacity assessment 基于路网承载力评估引导用地功能优化及交通设施改善技术方法研究. *Chengdu Urban and Rural Plan* 成都规划, *58*, 70–77.
- Fan, X. 范新浩. (2016). The preliminary research on the Smart City Design in Tianfu New Town 天府新区智慧城市建设初步研究. *Chengdu Urban and Rural Plan* 成都规划, *42*.

- He, M. 何敏, & Wang, X. 王璇. (2016). The exploration of upgrading design for historical communities in the aging era 老龄化背景下的历史街区传统民居改造设计探析. *Chengdu Urban and Rural Plan* 成都规划, *42*.
- Li, Y. 李永华, Zhou, Y. 周逸影, & Dong, C. 董晨. (2020). The discovering road planning of Chengdu's 'Park City design' with Humanitarian Perspective 人本理念下成都公园城市街道一体化规划探索. *Chengdu Urban and Rural Plan* 成都规划, *58*, 20–28.
- Wang, D. 王弟鑫. (2016). The planning of intersections with the perspective of pedestrian 基于行人视角的交叉口规划分析. *Chengdu Urban and Rural Plan* 成都规划, *42*.
- Yit 一条. (2021, September 22). *The Chengdu Community Second to None in China: Grandpas enjoying coffee outside, and granmas are bouncing with young people* 敢称全国第一的成都社区：大爷街头喝咖啡，大妈和年轻人一起蹦迪. Weixin Official Accounts Platform. *http://mp.weixin.qq.com/s?__biz=MjM5MDI5OTkyOA==&mid=2665669825&idx=1&sn=f649bab7e547ddfa7be895f324066dc2&chksm=bd50a6b68a272fa0467e89443e89d431a0b17f4d7b02cc1b0b5244d4aba6ed22059fe62a6229#rd*
- Zeng, T. 曾甜, Chen, Y. 陈颖果, & Xie, Y. 谢雨杉. (2020). New Trends and Experiences in Child-Friendly City Construction at Home and Abroad 国内外儿童友好型城市建设新趋势与经验借鉴. *Chengdu Urban and Rural Plan* 成都规划, *58*, 50–54.
- 一条Yit. (2021, September 22). *[EngSub]Visiting Chengdu Communities: Enviable Life Second to None* 探訪成都社區：生活令人羡艷，敢稱中國第一. *https://www.youtube.com/watch?v=QAFczmrQckw*

Case Study D1

- China Shuifa Singyes Energy Holdings Limited. Available Online: *http://www.sfsyenergy.com/index.php/business/?tid=15*
- Wu. Y. 2018. Zhuhai Xingye New Energy Industrial Park R&D Building. Construction 21. Available Online: *https://www.construction21.org/case-studies/cn/zhuhai-xingye-new-energy-industrial-park-r-d-building.html*

Case Study D2

- Climate and Environment Headquarters. (2019). *Seoul Energy Self-Sufficiency Village White Paper*. *http://www.edutopia.or.kr/node/2651*
- Climate and Environment Headquarters. (2020). *2019 Energy White Paper*.
- Climate and Environment Headquarters. (2021, April 13). *GHG inventory of Seoul city between 2017 and 2019*. Seoul Metropolitan Government. *https://news.seoul.go.kr/env/environment/green-house-inventory*
- Energy and Climate Policy Research Institute & Seoul National University. (2017). *Seongdaegol Energy Self-Sufficiency Village Activity White Paper*.
- Lee, J. (2017). *An Analysis of the Energy Saving Performance of Seoul Energy Self-Sufficiency Villages*. Korea University.

- Lee, Y. (2017, June 14). *A case of public engagement and its impacts in metropolitan cities*. *https://www.cni.re.kr/main/search/down.do?gcd=AC0000064167&seq=3*
- Ministry of Trade, Industry, and Energy. (2019). *The 3rd Energy Basic Plan*. *https://www.motie.go.kr/common/download.do?fid=bbs&bbs_cd_n=81&bbs_seq_n=161753&file_seq_n=1*
- Seongdaegol People. (n.d.) *Seongdaegol people featured in the news press*. Seongdaegol People. *http://sdgpeople.or.kr/*
- Seoul Institute. (2016). *Seoul Energy Self-Sufficiency Village: Sustainable Energy Policy Recommendation with a Case of Voluntary Public Engagement*.
- Seoul Institute. (2020). *The 5th Regional Energy Master Plan of Seoul: 2020-2040*. Seoul Metropolitan Government.
- Seoul Metropolitan Government. (2017, February 14). *Seoul city is accepting applications for energy self-sufficiency villages*. Seoul Mediahub. *https://mediahub.seoul.go.kr/archives/1062198*
- Seoul Metropolitan Government. (n.d.a). *One Less Nuclear Power Plant*. Seoul Metropolitan Government. *https://news.seoul.go.kr/env/environment/climate-energy/one-less-nuclear-power-plant*
- Seoul Metropolitan Government. (n.d.b). *Solar City, Seoul*. Seoul Metropolitan Government. *https://news.seoul.go.kr/env/environment/climate-energy/seoul-the-city-of-the-sun*

Case Study D3

- Choi, S. (2020, June 3). South Korea selects Ulsan city as a Free Economic Zones. *UlsanPress*. *https://www.ulsanpress.net/news/articleView.html?idxno=352950*
- Cryogenic Industrial Gases Magazine. (2013, August 1). *The world's largest hydrogen town is Ulsan city*. Cryogenic Industrial Gases Magazine. *http://www.igasnet.com/news/articleView.html?idxno=8514*
- In, J. (2021). The future of Ulsan hydrogen city. *Korea Development Institute*, *366*(5), 34.
- Kim, H. (2020). *Research on the development of Ulsan hydrogen city*.
- Ministry of Trade, Industry, and Energy. (2019, January 16). *The Korean government unveils the roadmap for promoting hydrogen.* Korea Policy Briefing. *https://www.korea.kr/news/pressReleaseView.do?newsId=156313559*
- Shin, E. (2014, July 1). Hydrogen Part 1: The world's largest hydrogen town in Ulsan city. *OhmyNews*. *http://www.ohmynews.com/NWS_Web/View/at_pg.aspx?CNTN_CD=A0002008705*
- SK Gas. (n.d.). *Business Introduction: Fuel cell development*. SK Gas. *https://skgas.co.kr/Business/Fuel_Energy.html*
- Ulsan Metropolitan Government. (2013, July 9). The world's largest hydrogen fuel cell town is in Ulsan city. *Ulsan Metropolitan City Blog - Ulsannuri*. *https://blog.ulsan.go.kr/3713*
- Woo, H. (2014). A demonstration project for Ulsan hydrogen town. *Korea Electric Association*, *452*(8), 35–41.

Case Study E1

- China Construction News. (2021, November 21). 苏州全链条破解厨余垃圾分类难题. Retrieved from *http://www.chinajsb.cn/html/202111/21/24182.html*
- Deutschland. (2017, January 23). Retrieved from Essen is green: *https://www.deutschland.de/en/topic/culture/town-country/essen-is-green*
- National Development and Reform Commission. (2010, May 4). 关于组织开展城市餐厨废弃物资源化利用和无害化处理试点工作的通知. Retrieved from *https://www.mee.gov.cn/gkml/hbb/gwy/201005/t20100518_189653.htm*
- National Development and Reform Commission. (2016, September 27). 第一、第二批国家餐厨废弃物资源化利用和无害化处理试点城市成功经验模式 . Retrieved from *https://www.ndrc.gov.cn/fggz/hjyzy/fzxhjj/201609/t20160927_1203371.html?code=&state=123*
- National Development and Reform Commission. (2020, April 29). "强化监管 优化模式"——苏州市推进餐厨废弃物回收体系建设典型经验. Retrieved from *https://www.ndrc.gov.cn/fggz/hjyzy/fzxhjj/202004/t20200429_1227135.html?code=&state=123*
- Suzhou Daily. (2019, September 21). 打造"绿色公用"循环产业链. Retrieved from
- *http://news.sipac.gov.cn/sipnews/yqzt/25th/mtjj/201906/t20190621_1033847.htm*
- Suzhou Municipal Government. (2011, March 01). 苏州市区*1/3*餐厨垃圾无害化处理. Retrieved from *http://www.suzhou.gov.cn/szsrmzf/szyw/201103/YL5LWGDOXJJXTJOIBI38NLJ69MTFQT6P.shtml*

Case Study E2

- GEM Recycling for the future!. Available Online: *http://en.gem.com.cn/en/UsedBatteryRecycling/index.html*

Case Study E3

- Jiangsu Zhenfeng Environmental Protection Group Co., Ltd. 2021.

Case Study F1

- Cho, K. (2018, August 16). *The sustainable energy transition is a solution to heat waves: Nowon Energy Zero Housing Complex*. The Hankyoreh. *https://www.hani.co.kr/arti/economy/economy_general/857810.html*
- Climate and Environment Headquarters. (2021a). *2050 GHG Emissions Reduction Strategic Plan*. Seoul Metropolitan Government.
- Climate and Environment Headquarters. (2021b). *2050 Seoul Climate Action Plan*. Seoul Metropolitan Government.
- Climate and Environment Headquarters. (2021c, April 13). *GHG inventory of Seoul city (2017-2019)*. Seoul

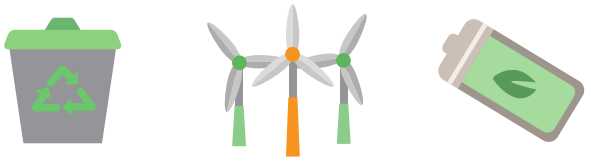
Metropolitan Government. *https://news.seoul.go.kr/env/environment/green-house-inventory*

- Government of the Republic of Korea. (2021). *Republic of Korea NDC (updated version)*.
- Hong, S. (2020, January 2). *Nowon EZ Centre suggests a solution for zero energy use*. Seoul Mediahub. *https://mediahub.seoul.go.kr/archives/1267663*
- Korea Energy Agency. (2017). *Analysis report on renewable energy and incentives for Zero-energy building*.
- Lim et al. (2021). Effects of mechanical ventilation on indoor air quality and occupant health status in energy-efficient homes: A longitudinal field study. *Science of The Total Environment*, *785*, 147324.
- Ministry of Land, Infrastructure, and Transportation. (2019, June 20). *Public Release: A strategy plan for promoting Zero Energy Buildings (ZEB)*. Ministry of Land, Infrastructure, and Transportation. *http://m.molit.go.kr/viewer/skin/doc.html?fn=1723310abf9af4c8eb4c608ce335777f&rs=/viewer/result/20190620*
- Nowon Energy Zero Centre. (2020, August 20). *News Press: 2020.08.06 Buildings for Net-zero, Nowon Energy Zero Housing Complex.* Nowon Energy Zero Centre. *http://www.ezcenter.or.kr/bbs/board.php?bo_table=sub4_1&wr_id=41*
- Park, S. (2020, October 6). *Buildings manage energy supply and demand by themselves*. ChosunMedia. *https://www.chosun.com/special/future100/fu_general/2020/10/06/AKUCROXNQ5A2RLWZA227XOWFQM/*
- Yeo, I. (2020, July 5). *Energy demand and renewable energy supply of Nowon EZ housing complex*. Korea Heating Air-conditioning Refrigeration & renewable energy News. *http://www.kharn.kr/news/article.html?no=13085*
- Zero Energy Building Certificate System. (n.d.). *Zero Energy Building (ZEB): Policy trends*. Zero Energy Building. *https://zeb.energy.or.kr/BC/BC02/BC02_02_001.do*
-

Case Study F2

- SECSC Shanghai Energy Conservation Supervision Center, Government of Changning, and World Bank. (2013). "Policy Frameworks and Business Models for Building Retrofit in Changning District, Shanghai." Unpublished manuscript, last modified February 29, 2013.
- SABR Shanghai Academy of Building Research. (2019). Shanghai Low Carbon City Green Energy ProjectProject Summary Refinement (Final Report). Shanghai, China: SABR.
- People's Government of Changning District, Shanghai, 上海市长宁区人民政府. (2010, December 30). *Changning District Government Press Conference: Energy Saving and Low Carbon Development in Changning District* 长宁区政府新闻发布会上介绍：长宁区节能降耗与低碳发展情况. *https://www.shcn.gov.cn/art/2010/12/30/art_6993_424511.html*
- Shanghai Platform for Common Geospatial Information Service, 上海市地理信息公共服务平台. (n.d.). *Standard maps* 上海市地理信息公共服务平台（天地图·上海）. Retrieved 22 December 2021, from *http://shanghai.tianditu.gov.cn/map/views/standardMap.html*
- Szum, C., Hou, J., & Zhou, N. (2020). *Building Efficiency Targets Playbook*. Lawrence Berkeley National Laboratory.

- the World Bank Group. (n.d.). *Development Projects: Green Energy Schemes for Low-carbon City in Shanghai - P127034* [Text/HTML]. World Bank. Retrieved 24 November 2021, from *https://projects.worldbank.org/en/projects-operations/project-detail/P127034*
- the World Bank Group. (2012). *Working Plan for the Green Energy for Low-Carbon City Project in Shanghai GEF*上海低碳城市绿色能源机制项目实施计划. World Bank.
- World Bank. (2013). *Applying Abatement Cost Curve Methodology for Low-Carbon Strategy in Changning District, Shanghai. https://openknowledge.worldbank.org/handle/10986/16710*



Leveraging Science, Technology and Innovation for Low Carbon and Resilient Cities