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Development of the Eco Town Model in the ASEAN Region through Adoption of Energy-Efficient Building Technologies, Sustainable Transport, and Smart Grids

Edited by

Shigeru Kimura

Romeo Pacudan

Han Phoumin

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Foreword

The concept of a low-carbon city or eco town to curb the increasing energy demand and to mitigate emissions of greenhouse gases is gaining popularity among the countries of the Association of Southeast Asian Nations (ASEAN). This is because both increasing energy demand and carbon dioxide emissions could threaten the sustainability of future energy supply and could impact the environment, health, and tourism – thus, the quality of life – of these countries. Towards energy saving and green environment, the eco town concept is considered as an ideal solution. This study then focuses on introducing current and future energy efficiency technologies on buildings and road transport as well as smart grid technologies to be applied to a future town in Temburong District in Brunei Darussalam, or to any other city in ASEAN.

The Ministry of Development of Brunei Darussalam plans to design the Temburong District as a world-class and green city. The framework for the development of Temburong District, developed by the Town and Country Planning Department, highlights a new bridge, a new university, commercial and industrial centres, housing, schools, flood prevention projects, and public facilities. Thus, the need for sustainable urban development is highly crucial to secure Temburong District's reputation as the 'Green Jewel of Brunei'. Protecting the area's abundant natural resources is key, and providing facilities to attract tourists will contribute to economic growth.

The ongoing construction of Temburong Bridge, which will link Temburong District to the rest of the country, is scheduled to be completed by the end of 2019. With this, the government expects a boost in tourist arrivals in the district, necessitating the eco town concept to be applied to facilitate the influx of tourists as well as to preserve the ecosystem of the national park. Temburong District in Brunei Darussalam could become the world's best example of an eco town, boasting the best facilities to host world-class summits, meetings, and conferences, while enjoying the rich nature of the district.

The Economic Research Institute for ASEAN and East Asia (ERIA) is committed to support the future development and study of Temburong District in Brunei. In 2017, ERIA and the Brunei National Energy Research Institute (BNERI) will look closely at the climate data of Temburong District and conduct a simulation model to optimise the size of renewable electricity sources, such as solar/photovoltaic (PV), wind, biomass, and backup power generation facilities. Based on the renewable electricity plan, ERIA and BNERI will also come up with a smart city development design in Temburong in the next stage.

I hope that this study will benefit Brunei. I further hope that the eco town concept could be replicated in other countries in the region, tailor-made to meet their respective economic, social, and environmental capabilities.

Hidetoshi Nishimura
President
Economic Research Institute for ASEAN and East Asia

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Working Group Members

List of Project Members

Mr Shigeru Kimura: Special Advisor on Energy Affairs, Economic Research Institute for ASEAN and East Asia (ERIA)

Dr Han Phoumin: Energy Economist, Economic Research Institute for ASEAN and East Asia (ERIA)

Dr Romeo Pacudan: Interim Chief Executive Officer (CEO) and Chief Researcher, Brunei National Energy Research Institute (BNERI), Brunei Darussalam

Mr Muhammad Nabih Fakhri Matussin: Researcher, Renewable and Alternative Energy Department, Brunei National Energy Research Institute (BNERI), Brunei Darussalam

Mr Majid Haji Sapar: Consultant (Former Senior Researcher, Energy Efficiency and Conservation Department, Brunei National Energy Research Institute (BNERI), Brunei Darussalam)

Ir Lam Kim Seong: Director, Prudenergy Consulting Private Ltd, Malaysia

Ir Leong Siew Meng: Managing Consultant, Green Tech Solutions Inc., Malaysia

Mr Takayuki Kusajima: External Affairs Division, Toyota Motor Corporation, Japan

Professor Yuichi Ikeda: Kyoto University, Japan

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List of Abbreviations

ASI	Avoid, Shift, Improve
BAGUS	Brunei Accredited Green Unified Seal
BAU	business as usual
BCA	Building and Construction Authority, Singapore
BEI	Building Energy Intensity
CH_4	methane
CO_2	carbon dioxide
DCS	district cooling system
EEC	energy efficiency and conservation
EEI	Energy Efficiency Index
EUI	Energy Use Intensity
FEI	fuel economy improvement
GBI	Green Building Index
GHG	greenhouse gas
ICT	information and communications technology
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ktoe	kilotonnes of oil equivalent
kWh	kilowatt-hour
LTD	Land Transport Department
N_2O	nitrous oxide
OTTV	overall thermal transfer value
PEV	passenger electric vehicle
PV	photovoltaic

Executive Summary

The Association of Southeast Asian Nations (ASEAN) has been a remarkable driving force of economic growth for the past decades. Due to its robust growth, energy has been a backbone to support this growth. It is estimated that energy demand in ASEAN has grown 2.5 times since 1990 and is expected to triple by 2035. Therefore, ASEAN will need to apply the concept of a low-carbon city or eco town to reduce the energy demand and to mitigate the emissions of greenhouse gases (GHGs) as both increasing energy demand and CO_2 emissions could threaten the future sustainability of the energy supply and impact the environment, health, and tourism, and thus the quality of life. Therefore, this study on 'the eco town project' focuses on the introduction of current and future energy efficiency technologies for buildings, road transport, and smart grids. The key findings from this study are the following:

For energy efficiency in buildings, the green building system rating tool and concept have been provided from global experience. The concept aims to achieve benefits as a result of reduction in water and energy bills, improved indoor environmental quality, improved connectivity and community living, and others. In the ASEAN and East Asia region, Singapore, Malaysia, Thailand, Indonesia, Viet Nam, Japan, and Brunei Darussalam are some of the countries that have adopted building policies and regulations. Currently, building technologies comprise passive and active design strategies. The passive design of energy-efficient buildings takes into consideration the building's orientation, facades, use of insulating materials, use of daylighting, and natural ventilation. The active design strategy includes the use of energy-efficient air-conditioning and lighting systems coupled with sophisticated energy management systems and lighting control systems by using information and communications technology (ICT) to allow for optimum efficient management of energy usage of public and corporate facilities and infrastructures. The use of solar thermal cooling as well as district cooling system could also contribute to significant energy savings and reductions in GHG emissions.

For transport energy efficiency, the study focuses on highly efficient economy vehicles, transport modes, and a public paradigm shift using the 'Avoid, Shift, Improve' approach in policy making. 'Avoid' means policy measure pursuing less traffic through compact city design or change of lifestyle, 'Shift' means using public transport with higher efficiency instead of private vehicles, and 'Improve' means improving the penetration of greener and more efficient technologies and implementation of necessary policies. It is generally observed that as disposal income increases, so does private car ownership. In most ASEAN countries, car ownership is on the rise and has yet to reach saturation at the highest per capita gross domestic product (GDP) level. In Brunei Darussalam, road transport is one of the sectors with a significant increase in energy demand. The increase in the population, and hence private vehicles, has been accompanied by an approximately 5 percent increase in GHG emissions since 1990. As a result of the overwhelming use of private vehicles, Brunei Darussalam's public transport is still in its infancy. Therefore, the Land Transport White Paper and Land Transport Master Plan that outline the policies and strategies to improve the country's transport

infrastructure were introduced. In analysing the transport demand in Brunei, the business-as-usual (BAU) case showed that the fuel economy improvement (FEI) scenario could save 397 kilotonnes of oil equivalent (ktoe) from the BAU level in 2035, corresponding to a GHG emissions reduction of 1.14 million tonnes of CO_2 equivalent. The penetration of electric vehicles (EPV) scenario would further increase the savings to 432 ktoe, corresponding to a GHG emissions reduction of 1.31 million tonnes of CO_2 equivalent.

A smart grid is an important component of a potential eco town as it helps in the reduction of GHG emissions through its smart system to reduce energy demand. A smart grid aims to put into practice key power grid functions of sustainability, dependability, flexibility, affordability, and scalability of energy efficiency. 'Sustainability' means avoiding climate change and limiting the use of fossil fuels and other natural resources. 'Dependability' means to supply stable and quality power for use in technology-intensive industries such as semiconductor device manufacturing and automotives. 'Flexibility' is also related to the sustainability and stability of the power system. The smart grid system can handle a high penetration of variable renewable energy, such as wind and solar power, and the system can establish a demand and supply balance using dispatchable power sources, such as thermal and hydropower plants. 'Affordability' is obtained by avoiding extremely expensive technologies. 'Scalability' is especially important for the development of an eco town. A smart grid can deliver energy more efficiently, to integrate more new renewable energy into existing networks, to manage increasing numbers of electric vehicles, to enable customers to have greater control of their energy, and to reduce global carbon emissions through demand respond management.

CHAPTER 1

Background

The Association of Southeast Asian Nations (ASEAN) and East Asia region has been experiencing a rapid growth in urbanisation in the last few years which is likely to continue for some time. In particular, the increase in urbanisation has been remarkable, among others, in China, Indonesia, the Philippines, Thailand, and Viet Nam. Such growth has seen overall energy demand rise, driven by the increase in energy for the power sector and the transport sector (Kutani, 2013). The total primary energy demand in the ASEAN region is projected to increase by 80 percent by 2040 (IEA, 2015).

Energy efficiency and conservation (EEC) has been given top priority in the Energy White Paper (2014) of Brunei Darussalam, and this has further been stressed no less by the decree of the Sultan of Brunei Darussalam at the United Nations 2014 Climate Summit held in New York. In his speech, he stated that the country is targeting to reduce total primary energy consumption by 63 percent from its 2009 baseline. One path towards energy sustainability is a low-carbon path to energy security. The introduction of low-carbon or energy technologies in the town planning of Brunei to boost energy efficiency and reduce fossil energy use is vital to manage rapidly growing energy consumption levels in urban areas to achieve a more secure and sustainable energy future for the country. The concept here is called the eco town.

1.1. Concept of an Eco Town

An eco town (or eco city) is generally a settlement modelled on the principles of environmental sustainability, with the goal to reduce and eliminate carbon emissions through application of energy efficiency and of renewable energy resources. In the ASEAN context, the settlement can be scaled to any size in reference based on the geographical, social, and economic features of each ASEAN economy which seeks to develop a concrete low-energy development plan irrespective of its size, characteristics, and type of development (greenfield or brownfield development).

The origin of the eco town concept emerged when Urban Ecology was established in 1975 by Richard Register and others to rebuild cities or towns in balance with nature. Specifically, the non-profit organisation aims to plant and harvest fruit trees on streets, to develop solar-powered greenhouses, to establish energy-related regulations, and to promote bicycles, pedestrian walking, as well as using buses as an alternative to private automobiles (Register, 1994). Urban Ecology (1996) states that any city or town that is eco-friendly follows 10 principles (Devuyst et al., 2001):

1. Create compact, diverse, green, safe, pleasant, and vital mixed-use communities around main transport facilities.

2. Establish transport infrastructure that promotes foot walking, cycling, and use of efficient automobiles.
3. Restore damaged urban environments, especially creeks, shorelines, ridgelines, and wetlands.
4. Establish housing that is affordable, safe, and community-friendly.
5. Create improved opportunities for all, especially women, people with disabilities, and minorities.
6. Support local agriculture, urban greening projects, and community gardening.
7. Promote recycling and use of innovative technologies and conserve resources while reducing pollution and hazardous wastes.
8. Collaborate with businesses to support eco-related activities while discouraging pollution, waste, and the use and production of hazardous materials.
9. Promote voluntary simplicity and discourage excessive consumption of material goods.
10. Increase public awareness on the local environment and bioregion through community projects and programmes.

For the last 20 years or so, however, the dimensions of an eco town have been generalised to include:

- sustainable development
- sustainable urban development
- community economic development
- appropriate technology
- bioregionalism
- social ecology
- green movement and green cities/communities.

1.2. Objectives

The objectives of this study are as follows:

- To encourage the creation of low-energy and energy-efficient smart communities in urban development plans, and to share best practices in making such communities a reality and possible even to less developed countries in the region.
- To learn from a particular eco town in the region as the base case for Brunei to build on and to be able to replicate it in other countries in the region, for example, Cambodia, the Lao People's Democratic Republic, and Myanmar according to their respective economic

capability.

- To provide capacity building, lessons learnt, and references specifically for policymakers and regulators in South East Asian countries who would like to consider a similar model to achieve their respective national overall energy reduction targets.
- To establish a methodology that can be easily replicated in other countries in the region.

The study will look into three main areas that will potentially achieve those aims, mainly through a combination of individual modelling and analysis and in an integrated approach:

- building technologies
- transport
- smart grids.

1.3. Overview of Temburong District

The district of Temburong is located at the eastern edge of Brunei but is separated from the remainder of the country by the Malaysian state of Sarawak and the South China Sea to the north. Known as the Green Jewel of Brunei, the district is home to the country's most extensive forest area, of which 500 square kilometres in the south is still pristine (Hadi, Sarini, and Noorhijrah, 2011).

The district comprises five provinces: Bangar, Bokok, Amo, Batu Apoi, and Labu. Bangar is the main urban centre within the district as it contains Bangar town, which is the capital town with the most significant development.

Although Temburong is the second largest district within Brunei Darussalam, its population was just 8,900 in 2015, which equates to about 2.2 percent of the whole population of Brunei Darussalam (DEPD, 2015). This can be attributed to underdevelopment, especially in certain areas in the central and southern parts which are characterised by mountainous terrain and river catchments. The northern region is mostly low-lying which makes it prone to tidal flooding. The district's development has therefore concentrated around central Temburong which has access to river valleys and the main road system.

Currently, access to Temburong from the other districts is either by speedboat or by road vehicle, although the latter involved going through multiple border crossings which takes several hours. In order to smoothen the access, the Government of Brunei Darussalam has begun the construction of a bridge linking Temburong and other districts. The bridge, which is anticipated to reduce the travel time to about 20 minutes between the districts, will foster further development in commercial and industrial areas to attract residents from other districts as well as tourists. The bridge is slated for completion in 2019.

Electricity is supplied through a transmission network from a 12-megawatt (MW) diesel power station situated at Belingus village, about 5 kilometres away from Bangar town. The power station currently supplies an average of 34,300 megawatt-hours (MWh) of electricity per year, corresponding to an average diesel consumption of 10.46 million litres per year. As the population is envisaged to grow, the demand for electricity will increase, which would have economic and environmental impacts, and improvement in efficiency and a switch to cleaner energy would be an important policy for the government.

1.4. Bangar Town: A Potential Eco Town Model

The Government of Brunei Darussalam has devised the Temburong District Master Plan (2006–2025), which includes strategies for the expansion of Bangar town (Town and Country Planning Department, 2010). The key strategies include an enhanced commercial area building in the centre of Bangar town, expansion of Temburong Industrial Estate, expansion of the residential area within Bangar, and identification of land for development of a tertiary education campus.

The Ministry of Development has raised the possibility of establishing a smart town or eco town in the district with the aim to reduce the carbon footprint via the application of green technology. The Energy and Industry Department of the Prime Minister's Office recently announced plans to replace the Belingus diesel power station with a solar power plant in 2019. This was announced during the High-Level Signing Ceremony of the Paris Agreement in New York in April 2016. The fact that Bangar town is the only town in the district makes it the ideal candidate for an eco town model. Furthermore, the town is still relatively small and compact and hence the potential for expansion is very significant.

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CHAPTER 2

Building Technologies

2.1. Green Building Rating System

There have been numerous international initiatives with the purpose of enhancing or improving energy security and lowering greenhouse gas (GHG) emissions to mitigate the negative environmental impacts of energy consumption. The United Nations Environment Programme Sustainable Buildings & Climate Initiative (UNEP-SBCI 2009) in its report states that the building sector's environmental footprint includes 40 percent of energy use, 30 percent raw materials use, 25 percent of solid waste, 25 percent water use, and 12 percent of land use. The report goes on to state that almost 90 percent of the energy used by buildings is consumed during its operational phase for heating, cooling, ventilation, lighting, and so on, while the remaining amount is consumed during the extraction and processing of raw materials, manufacturing of products, construction, and demolition. Furthermore, significant energy is used in transporting occupants, goods, and services to and from buildings.

Many countries have turned to developing and adopting a green building rating system to address the needs for sustainable utilisation of natural resources and mitigation of negative environmental impacts. A green building rating system provides a holistic approach through a systematic and comprehensive framework for assessing the overall environmental performance of new and existing buildings and townships to promote sustainable design, construction, and operating practices. In the ASEAN region, Singapore and Malaysia have embarked successfully on their green building rating systems since 2005 and 2009, respectively. The two countries have successfully promoted and implemented sustainability in the built environment and raised environmental awareness among developers, building owners, designers and builders, as well as communities. The benefits of green buildings are reduction in water and energy bills, improved indoor environmental quality, improved connectivity and community living, reduced environmental impact, meaningful differentiation of buildings in the real estate market, and improved corporate image. It has been recognised to be a game changer in the construction industry. If implemented properly, it can lead to continual improvement in the built environment and economic growth in the construction sector as well as the goods and services sector.

The green building rating systems in Singapore and Malaysia have a similar approach in terms of assessment criteria with emphasis on energy efficiency but with differing priorities to suit the needs of the respective countries. The similarities are due to the fact that both countries are located in a hot and humid climatic zone. The difference between Singapore's Building and Construction Authority (BCA) Green Mark rating system and Malaysia's Green Building Index (GBI) rating system, however, is in the implementation. Malaysia's GBI was developed and implemented by professional bodies and adoption is on a voluntary basis, which is supported by the Government of Malaysia through green building incentives upon award of green building certification. The implementation of Singapore's Green Mark is mandatory under the BCA through the Building Control (Environmental Sustainability) Regulations (under the Building Control Act), which apply to:

- all new building works with gross floor area of 2,000 square metres (m^2) or more
- additions or extensions to existing buildings which involve increasing gross floor area of the existing buildings by 2,000 m^2 or more
- building works which involve major retrofitting to existing buildings with gross floor area of 2,000 m^2 or more.

Brunei Darussalam is in the same climatic zone, so the green building rating systems from these two countries can be adopted in Brunei, especially for the development of an eco town. Brunei recently launched and unveiled its rating system version called the Brunei Accredited Green Unified Seal (BAGUS). During the launch, three government buildings were awarded with the BAGUS. Buildings awarded with the seal must have reduced their electricity consumption by more than 15 percent per year and meet the government-mandated energy efficiency index (EEI) of 175 kWh/m^2 per year. At this stage, information about the rating system is not readily available for public use and will not be compared in this report. However, in the development of the rating tool, both Green Mark and GBI were used as main references.

Table 1 below provides a brief comparison of the two green building rating systems for non-residential buildings. Table 2 provides the qualifying marks for the various rating classifications. Both rating systems cover a wide range of building types, for example non-residential buildings, residential buildings, healthcare facilities, retail buildings, hotels and resorts (for GBI), interiors, data centres, townships (for GBI), district projects (for Green Mark), restaurants (for Green Mark), supermarkets (for Green Mark), parks (for Green Mark), and industrial buildings (for GBI).

Table 1: Comparison of Green Building Rating Tools

Name of Green Building Rating System	Building and Construction Authority (BCA) Green Mark* Singapore		Green Building Index (GBI) Malaysia	
	Non-residential Building	**Maximum Points**	**Non-residential New Construction**	**Maximum Points**
Assessment Criteria	1. Energy Efficiency	116	1. Energy Efficiency	35
	2. Water Efficiency	17	2. Indoor Environmental Quality	21
	3. Environmental Protection	42	3. Sustainable Site Planning & Management	16
	4. Indoor Environmental Quality	8	4. Materials & Resources	11
	5. Other Green Features & Innovation	7	5. Water Efficiency	10
			6. Innovation	7
Total Score		190**		100

Notes:

* Based on BCA Green Mark for non-residential buildings, version NRB/4.1.

** To achieve the Green Mark Award, buildings must comply with a prerequisite of a minimum of 30 points from the energy-related requirements and 20 points from other green requirements.

Source: Building and Construction Authority, Singapore (2013), and Green Building Index Sdn Bhd, Malaysia (2009).

Table 2: Green Mark and GBI Rating Classification

	Green Mark		Green Building Index (GBI)	
Points & Rating	90 and above	Platinum	86+ points	Platinum
	85 to <90	Gold^{Plus}	76 to 85	Gold
	75 to <85	Gold	66 to 75	Silver
	50 to <75	Certified	50 to 65	Certified

Source: Building and Construction Authority, Singapore (2013), and Green Building Index Sdn Bhd, Malaysia (2009).

2.2. Building Policy and Regulations

Green, sustainable, and energy-efficient buildings hold particular importance in most cities as buildings are the largest energy-consuming sector worldwide, accounting for more than 40 percent of the global energy use and responsible for an estimated 30 percent of CO_2 emissions. Buildings, therefore, have an immense potential for global energy savings. A recent report from the International Energy Agency (2012) has mentioned that the world's built stock accounts for up to 41 percent of the global energy saving potential by 2035. This is primarily due to green buildings using approximately 40 percent less energy and 30 percent less water than standard buildings of the same size.

The rapid growth of energy use worldwide has also raised concerns over problems of energy supply and exhaustion of energy resources. Most of the developed countries, and to some extent developing countries, are implementing building energy regulations such as energy standards, codes, and so on to reduce building energy consumption.

Typically, building policy and regulations include standards and codes that cover structural, construction, fire, earthworks and roads, water drainage and sewerage, and electrical installations. Building energy efficiency standards only arise when the concern for rising oil prices and climate change comes to the fore. Today, mandatory minimum energy efficiency requirements in the form of building codes or standards exist in nearly all developed and some developing countries.

However, substantial differences persist between legislation of states, regions, and cities. Regulations for energy efficiency in buildings in developing countries, especially in rapidly developing countries such as India and China with the economic capacity to install cooling or heating systems, seek to improve comfort and to reduce the dramatic increase in energy consumption in this sector.

Irrespective of the political and socioeconomic situation of the countries, having a robust and well-regulated building policy and regulations especially related to energy use in buildings has an impact on the reduction of CO_2 emissions and dependency on fossil fuels. Local and regional governments are uniquely positioned to implement policies that influence the commitments towards sustainability measures in the building sector and to encourage their corporate citizens to build green and their citizens to live green.

The present status of building energy regulations in selected countries internationally and regionally was reviewed and summarised in Table 3 to provide an understanding of how energy consumption and carbon emissions are reduced and tackled nationally.

Table 3: Building Policies and Regulations in Selected Countries in ASEAN and East Asia

Country	Policy and Regulation	Codes and Standards	Remarks
Brunei Darussalam	Building Control Order 2014 (Enforced-Nov 2015) Building Control Regulations	PBD 12: 2014 – Building Guidelines and Requirements (Mandatory) Energy Efficiency & Conservation Guidelines for Non-Residential Buildings (2015) Mandatory (Public Buildings only)	PBD 12 covers space, light and ventilation; structural, construction, and fire requirements; electrical installations; earthworks, road, and water; and drainage and sewerage
Indonesia	Building Energy Codes (Mandatory): ● Law No. 28/2002 (regarding buildings) ● National Energy Efficiency Standards (SNI) for Building	<u>Applicable Standards (Mandatory)</u> ● SNI 03-6389-2000: Energy Conservation for Building Envelope of Buildings ● SNI 03-6390-2000: Energy Conservation for Air Conditioning Systems in Buildings ● SNI 03-6197-2000: Energy Conservation for Lighting Systems	Applicable sectors: residential and commercial buildings

		in Building Structures ● SNI 03-6196-2000: Energy Auditing Procedure for Buildings <u>Building Rating Tool (Voluntary)</u> GREENSHIP – Green Building Council of Indonesia (GBCI)	
Japan	Two mandatory laws pertaining to building: ● Building Standard Law (BSL) ● Fire Standard Law (FSL)	BSL consists of three sections: ● General provisions ● Building codes ● Planning codes Applicable Codes: ● JIS Q 50001: Energy Management System Requirements with Guidance for Use ● JIS Z 9204: General Rules for Energy Evaluation Method by Available Energy ● JIS A 1431: Method of Measurement of Air Quantity for Ventilation and Air Conditioning System ● JIS B 9908: Test Method of Air Filter Units for Ventilation and Electric Air Cleaners for Ventilation	● BSL is applicable to all types of buildings. ● The building codes section contains all codes pertaining to structural design, fire protection, and building equipment (HVAC, plumbing, and sanitation) ● Codes can be better described as laws in Japan. The codes are documented in the laws, and thus there are multiple codes. Some of the standards have been converted into codes as codes are mandatory and standards may not be. Thus, codes are mandatory standards, while standards are not mandatory.

- JIS C 0364: Electrical Installations of Buildings
- JIS C 8105: Luminaires in Buildings
- JIS Z 9120 to 29: Lighting for Indoor Workplace, Outdoor Workplace, Sports Lighting, Tennis Court, Sport Stadiums, Swimming Pools, Etc.
- ISO 8995: Lighting for Work Place: Indoor, Security, and Outdoor
- Ministry of Energy’s Design Code for Outdoor Light Pollution

There are no green building codes in Japan. Energy efficiency codes and indoor air quality codes have been included in the BSL.

<u>Building Rating Tool (Voluntary)</u>

Comprehensive Assessment System for Built Environment Efficiency (CASBEE) – Japan Green Building Council (JGBI)

Republic of Korea	The Building Act (2009)	Building Energy Conservation Code (BECC) The code specifies a set of mandatory design criteria for the four main building sections (building envelope, mechanical systems, electrical systems, and renewable energy systems) as well as an evaluation of the Energy Performance Index (EPI). Korean Standards (KS) are referenced in the ordinance of the Ministry of Land, Infrastructure and Transport (MOLIT). The ministry also allows equivalent codes and international standards to replace referenced KS, i.e. ASHRAE, IBC, IEC, IMC, and others. The green features that are mandatory in Korea include (selected): 1. Energy efficiency and construction waste recycling (under the Building Act's Energy Efficiency and Utilization of	Green features are introduced into the regulatory system through the Building Act. The act mandates energy efficiency, construction waste recycling and reuse, and water efficiency standards for buildings. The Building Act has included the certification of environmentally friendly buildings. It also has requirements for energy efficiency and construction waste management (including a certification for energy efficiency in buildings).

		Construction Waste section) 2. Energy saving building design criteria and a building certification system, under the Building Act 3. Protection of indoor air quality, under the Ministry of Environment's Indoor Air Quality Control <u>Building Rating Tool:</u> Mandatory: - 1. Building Energy Efficiency Certification System (BEECD) – Ministry of Trade, Industry, and Energy (MOTIE) and MOLIT 2. Green Standard for Energy and Environmental Design (G-SEED) – MOLIT and Ministry of Environment	1. BEECS administered by MOLIT and MOTIE. 2. Includes all building types (for public buildings only with total floor area of above 3,000 m^2)
Malaysia	● Uniform Building By-Laws (1984) ● Building (Federal Territory of Kuala	Voluntary: ● MS 5125: Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings	No mandatory regulation related to energy efficiency or green features (except Uniform Building By-Laws gazetted in Selangor)

	Lumpur) By-Laws Street, Drainage and Building Act (1974)	● Building Energy Efficiency Technical Guideline for Passive Design, Building Sector Energy Efficiency Project (BSEEP), Public Works Department, Malaysia ● ASHRAE 90.1: Energy Standards for Buildings Except Low-Rise Residential Buildings <u>Building Rating Tool (Voluntary)</u> ● Green Building Index (GBI) – Greenbuildingindex Sdn Bhd GreenRE – Real Estate & Housing Developers' Association, Malaysia (RHEDA)	
Singapore	Building Control (Environmentally Sustainability) Regulations, 2008	Mandatory: ● Code for Environmental Sustainability of Buildings ● SS 530: Code of Practice for Energy Efficiency Standard for Building Services and Equipment ● SS 531: Code of Practice for Lighting of Work Places ● SS 553: Code of Practice for Air-conditioning and	Requirements: ● New building works with gross floor area of 2,000 m^2 or more ● Increasing the gross floor area of an existing building by 2,000 m^2 or more ● Building works to an existing building which involve a gross floor area of 2,000 m^2 or more ● Achieved a minimum Green Mark certified

		Mechanical Ventilation in Buildings ● SS 554: Code of Practice for Indoor Air Quality in Air-conditioned Buildings ● BCA Code on Envelope Thermal Performance for Buildings ● ASHRAE 90.1: Energy Standards for Buildings Except Low-Rise Residential Buildings ● AHRI 550/590: Performance Rating of Water Chilling Packages Using Vapour Compression Cycle ● ASHRAE Guidelines 22: Instrumentation for Monitoring Central Chilled Water Plant Efficiency <u>Building Rating Tool (Mandatory)</u> Green Mark – Building and Construction Authority (BCA)	rating or higher rating as mandated by the Government Land Sales Programmes
Thailand	Energy Conservation Promotion (ENCON) Act	Mandatory: ● The Building Energy Code of Thailand (1995, 2009)	● Applicable to new and retrofitted building only ● Buildings larger than 2,000 m^2 ● Building type: hospital, academic institute,

	(1992, 2003 – 1st Revision, 2007 – 2nd Revision)	● Energy Efficiency Standard of Equipment and Machinery Required to meet standards for six green criteria: building envelope-OTTV, RTTV, lighting, hot water generating system, air conditioning, renewable energy, and overall performance <u>Building Rating Tool (Voluntary)</u> ● Thailand Rating Energy and Environment System (TREES) – Thai Green Building Institute (TGBI) ● Thailand Energy & Environment Assessment Method (TEEAM) –Ministry of Energy ● Adaptation of German Sustainable Business Council (DGNB) by Thai Association of Sustainable Construction (TASC)	office, condominium, hotel, department store, entertainment service, theatre, and exhibition building
Viet Nam	The Building Control Decree Building Code of Vietnam (BCV)	Mandatory: Energy efficiency under Building Code through Decree No. 102/2003/ND-CP on	Building type: Hotel, high-grade office, foreign affairs office, retail, high-grade condominium, dwelling house, public

	Thrifty and Efficient Use of Energy	building (education building, cultural building, medical building, sports building, commercial building, and office building)
	<u>Building Rating Tool (Voluntary)</u> LOTUS – Vietnam Green Building Council	

ASEAN = Association of Southeast Asian Nations, AHRI = Air-Conditioning, Heating, and Refrigeration Institute, ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers, BCA = Building and Construction Authority, HVAC = heating, ventilation and air conditioning, IBC = International Building Code, IEC = International Electrotechnical Commission, IMC = International Mechanical Code, OTTV = overall thermal transfer value, RTTF = roof thermal transfer value.

Source: Author's compilation.

2.3. Current and Potential Energy-Efficient Building Technologies

The consideration of energy-efficient building technologies for Brunei should be based on the understanding of local climatic conditions. In view of the fact that Brunei lies in a region of hot and humid climate, the demand for thermal comfort will take up the largest share of energy consumption in buildings. Therefore, a substantial energy saving potential can be expected to come from the cooling requirements in buildings. In view of this, the focus area for current energy-efficient building technologies should be the minimisation of energy use and efficient utilisation of energy for the cooling requirements in buildings.

In a hot and humid climate, all buildings have a primary function of providing an internal environment which is conducive and provides thermal comfort desirable for the purpose of occupancy in buildings. For a holistic approach to energy efficiency in buildings, it is important to firstly adopt a *passive design strategy* before considering an *active design strategy*. Energy efficiency in buildings can be optimised with a combined effort in architecture, engineering, site planning, and landscaping; in other words, a multidisciplinary approach to designing an energy-efficient building when passive and active devices are employed. The passive and active design strategies are being practised in green building design.

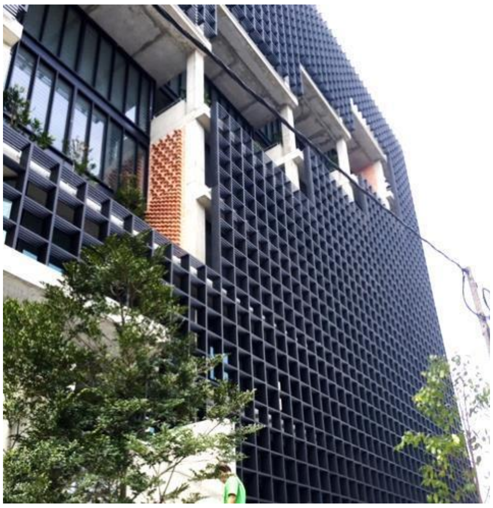
2.3.1. Passive Design Strategy

The primary objective in a passive design strategy is to minimise solar thermal heat gains so that the cooling requirements in a building can be reduced. Hence, its energy consumption will be reduced accordingly alongside the reduction in the cooling capacity of the air-conditioning equipment. Some examples of the key elements to be considered in this strategy are given as follows:

a) ***Building orientation*** that has the longer building axis facing North–South so that the narrow ends of the building would face East–West.

b) ***Building facades*** that provide shading to windows. Egg-crate louvres design (Figure 1) can provide effective shading to windows compared with horizontal projections (Figure 2).

Figure 1: Egg-Crate Louvres Design



Source: Ir. Leong Siew Meng. Photograph of the façade of Pertubuhan Arkitek Malaysia (PAM) Centre in Bangsar, Kuala Lumpur.

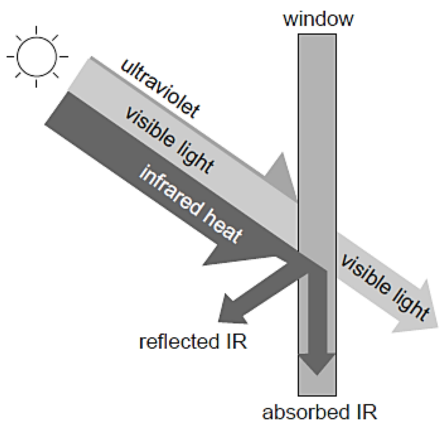
Figure 2: Horizontal Projections

Source: Leong (2013).

c) ***Fenestrations (windows)*** that provide low thermal transmittance and an effective shading coefficient of the glazing used in the fenestration system. Glazing selection is critical as solar radiation heat transfer through glazing can be as much as 80 percent. Glazing should be selected to minimise solar heat gain in order to minimise energy use while maximising daylight effectiveness and meeting architectural objectives. The solar heat gain coefficient (SHGC) or shading coefficient (SC) is the ratio of total transmitted solar heat to incident solar energy, typically ranging from 0.1 to 0.9, where lower values indicate lower heat gain. Another consideration is the selection of the U-value (thermal transmittance in watts per square metre, per degree kelvin, W/m^2K), which is a measure of heat transfer through the glazing. This glazing property is important for the estimation of the overall thermal transfer value (OTTV) when designing an appropriate building envelope.

Another property in glazing is spectral selectivity, which refers to the ability of a glazing material to respond differently to different wavelengths of solar energy. In other words, visible light is admitted while the unwanted invisible infrared heat is rejected. Glazing with relatively high visible transmittance and a low solar heat gain coefficient indicates that it is selective, as illustrated in Figure 3. For greater effectiveness in fenestration design, double glazing is recommended for consideration, but economic justification for the selection of double glazing should be worked out.

Figure 3: Spectrally Selective Glazing

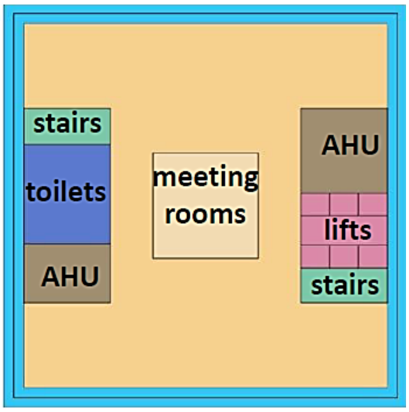


IR = Infrared.
Note: Spectrally selective glazing admits only the part of sun's energy that is useful for daylighting
Source: University of California (1997).

d) ***Building and insulating materials*** that provide low thermal transmittance of the opaque walls and roofs. Suitable building materials including insulating materials that have lower U-values are recommended to be used in roofs and walls. Such selection will improve the OTTV, which will result in lower heat transfer into a building through the building envelope.

e) ***Location of service cores***, such as lifts, staircases, air handling units (AHUs), and toilets, at the sides of a building especially facing East and West will help minimise solar heat gain through the building envelope as illustrated below in Figure 4. The overall thermal transfer for such a design will be reduced.

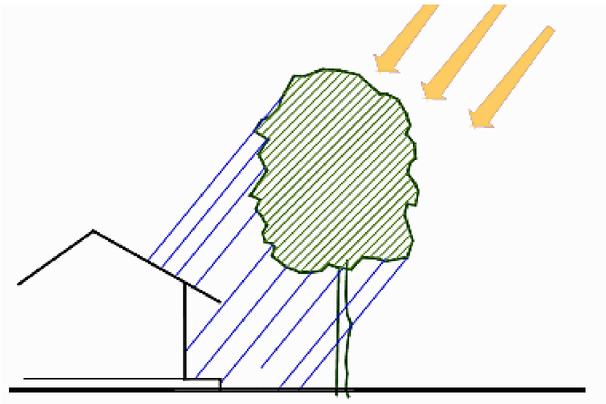
Figure 4: Service Cores at the Sides of a Building



Source: Leong (2013).

f) ***Strategic landscaping*** that provides shading from the sun, shielding from heat reflection, and use of paving materials with a high solar reflective index in the surrounding spaces will help create a cooler microclimate environment around the building (Figure 5).

Figure 5: Benefits of Strategic Landscaping to Improve Microclimate at Building Surrounding



Source: Nayak and Prajapati (2006).

g) ***Daylighting*** design that captures the natural daylighting to reduce the need for artificial lighting.

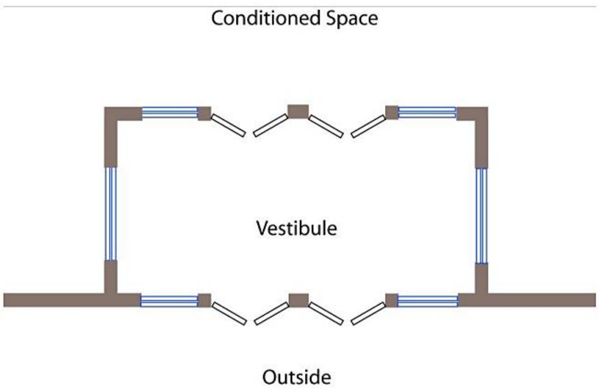
h) ***Natural ventilation*** that makes use of the natural forces of wind and buoyancy to deliver sufficient fresh air and air change to ventilate enclosed spaces without the needs of relying on air conditioning. There are two basic methods for providing natural ventilation:

   – cross ventilation (wind-driven)

   – stack ventilation (buoyancy-driven)

i) ***Measures to prevent air leakage*** as uncontrolled mixing of outside air with air-conditioned spaces requires more energy to remove moisture and heat gain contributed by air leakage. Air infiltration is commonly done through an entrance door that separates air-conditioned spaces from the exterior. Vestibules should be installed on primary entrance doors to reduce the infiltration of outside air for commercial buildings or buildings with large floor areas. The diagram in Figure 6 illustrates the design of a vestibule which will have interior and exterior doors not necessarily opened at the same time so that infiltration losses will be minimised.

Figure 6: Example of Vestibule Design



Source: US Department of Energy (2009).

2.3.2. Active Design Strategy

Having minimised the solar heat gain and maximised the capture of daylighting and natural ventilation, an active design strategy will play a key role to complete the achievement of energy efficiency in buildings. The extent of energy efficiency in active systems often depends on budget allocations. If budget permits, a sophisticated energy management system and lighting control system may be considered. The minimum approach in an active design strategy is to cover systems that consume higher shares of energy use, i.e. air-conditioning systems and lighting.

2.3.2.1 Air-Conditioning System

The design of an energy-efficient air-conditioning system requires a clear understanding of the building's functional requirements and consideration of many aspects, which may begin with accurate estimates of cooling load requirements, correct sizing, and configuration and selection of chillers or air-conditioning equipment, pumps, fans, motors, variable speed drives, and so on. Other considerations are appropriate zoning, effective air distribution and type of control, energy loss minimisation in ducting and piping systems, air leakage minimisation, and energy recovery system. The setting of air-conditioned space temperature during building occupancy will have a significant influence on the energy consumption of a building. The lower the temperature setting, the higher the energy consumption will be.

The adoption of a low-energy cooling system especially for space cooling, i.e. air distribution, should also be encouraged where possible. Technologies such as radiant ceiling panels, chilled beams, a displacement ventilation system (or underfloor air distribution), demand control ventilation, or a dedicated outdoor air-conditioning system (for latent heat removal) are among those that have the potential to save between 20 and 30 percent energy use as compared with a conventional system using a forced convection air handling unit (AHU) or fan coil unit (FCU). However, the minimum air movement requirement needs to be considered for thermal comfort in a hot and humid environment if design methods using radiant cooling and chilled beams are adopted.

2.3.2.2 Lighting

Lighting must provide a suitable level of illuminance for the performance of a range of tasks and provision of a desired appearance. In general, lighting for infrequently used areas should be designed with lower illuminance (e.g. 100 lux for corridors, car parks, etc.); lighting for working interiors should be designed with higher illuminance (e.g. 300–400 lux for general offices, reading and writing areas, 500 lux for proofreading, etc.). In addition, there should be guidelines for the design of lighting load, which should not exceed a maximum allowable power, for example 5 W/m^2 for hotel bedrooms, 8 W/m^2 for restaurants, 11 W/m^2 for museums and galleries, 14 W/m^2 for offices, 18 W/m^2 for classrooms and libraries, 24 W/m^2 for supermarkets and department stores, and so on. It should be noted that these are typical maximum values. For a higher energy efficiency standard, these values should be set lower. It is possible to achieve such design objectives by using high efficiency lamps with high efficacy (e.g. light fittings of more than 80 lumens per watt).

Further savings in lighting can be achieved by employing passive design methods as discussed earlier to capture daylighting in order to reduce artificial lighting, provision of lighting zone controls for energy saving, use of task lights, and use of lighting controls with timer, motion, and photoelectric sensors.

2.3.2.3 Lifts and Escalators

Traditionally, the focus in the design and installation of lifts and escalators has been on issues such as reliability, safety, riding comfort, and space restrictions. However, in line with the eco town concept, energy-efficient technologies should be considered and incorporated in lifts and escalators to help save energy and costs in the daily operation of lifts and escalators.

The following measures and criteria are recommended to be included in the design and specification of energy-efficient lifts and escalators:

- The design team should conduct an analysis of the transportation demand and usage patterns by the estimated building occupants and determine the optimum number and size of lifts, escalators, and/or moving walks. In addition, appropriate computerised control should be incorporated in the operation of lifts in order to optimise the operation of lifts for greater energy efficiency.
- The lift, escalator, and/or moving walk system with lowest energy consumption should be specified.
- For lifts, the following energy-efficient features should be considered:
  - The lifts operate in a standby condition during off-peak periods. The power side of the lift controller and other operating equipment such as lift car lighting, user displays, and ventilation fans switch off when the lift has been idle for a prescribed length of time. However, such lift car lighting being switched off shall not affect any lift emergency lighting requirement, which will switch on automatically in the event of any loss of power.
  - The lift car uses energy-efficient lighting and display lighting, i.e. an average lamp efficacy of >55 lamp lumens/circuit watt and lighting switches off after the lift has been idle for a prescribed length of time.
  - The lift uses a drive controller capable of variable-speed, variable-voltage, and variable-frequency (VVVF) control of the drive motor.
  - The lift has a regenerative drive unit so that any energy generated by a traction lift or by a hydraulic lift (due to running down) is used in the lift system or elsewhere in the building.
- For escalators and/or moving walks, each escalator and/or moving walk is required to comply with either of the following:
  - A load sensing device that synchronises motor output to passenger demand through a variable speed drive is fitted; or
  - A passenger sensing device for automated operation (auto walk) is fitted so that the escalator operates in standby mode when there is no passenger.

For a holistic approach, energy efficiency guidelines need to be established to ensure their proper and uniform adoption in professional design practices and construction practices. Such guidelines need to be supported by building codes for consistency and enforcement purposes.

2.3.3. Potential Energy-Efficient Technologies

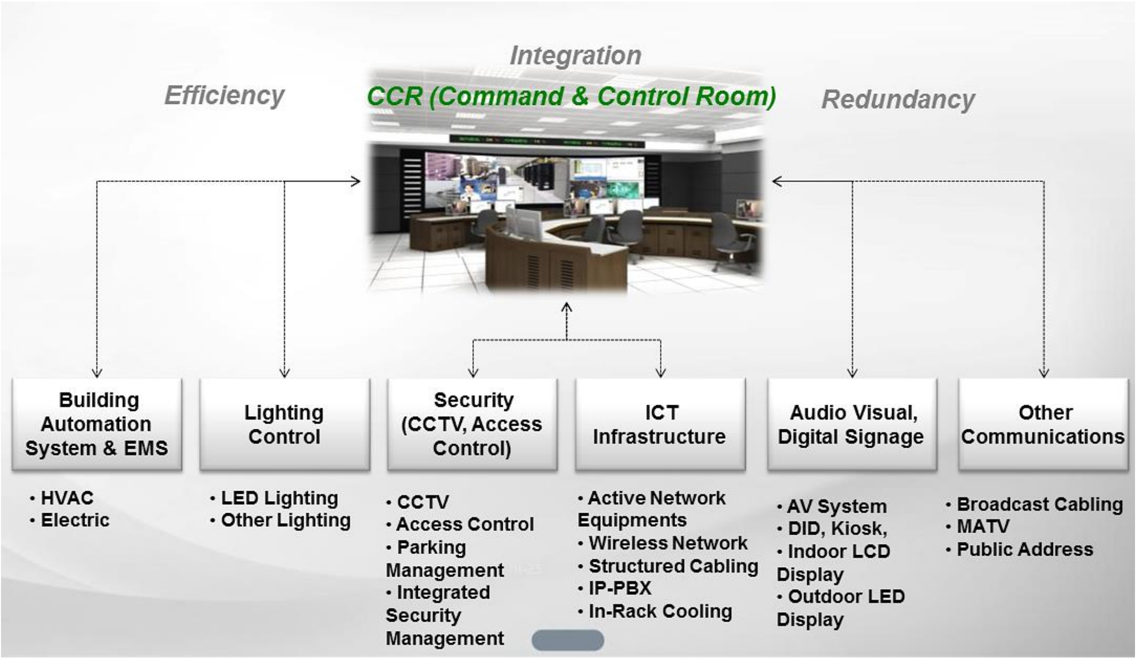
The demand for energy-efficient technologies is on the rise and so is the development and advancement of such technologies. For advanced technologies, the applications depend on the needs, economic viability, and competent operation and service support. One such area that can be explored is to make use of advancements in information and communications technology (ICT), which are wide-ranging and cover any communication application and integration of telecommunications, satellites, and computers, as well as software and storage.

2.3.3.1 ICT for Energy Efficiency

This report does not intend to explore the full capabilities of ICT. For eco towns, one suggestion is to narrow down the focus to two areas such as the following:

- Provide ICT infrastructures that will support more energy-efficient business models, work practices and lifestyles (e.g. e-commerce, e-banking, teleconferencing, online learning, e-government, etc.) to facilitate efficient work, business development and transactions, and lifestyles without having to travel long distances, which translates to energy savings as well as time savings.
- Provide integrated facility management of both public and corporate facilities and infrastructures so that all public facilities and amenities such as street lighting, parks, transportation hubs, and so on, as well as the security systems and building management systems of institutional and corporate buildings can be monitored and maintained using real-time tracking and control of energy usage in accordance with the needs and benchmarking standards such as building energy intensities (BEI). Energy efficiency in buildings can be enhanced using ICT for on-site or off-site control and monitoring capabilities for air-conditioning and ventilation systems, lighting, pumping systems, and other building services against predetermined industry practices and standards, which can be set lower or higher when desired. The diagram in Figure 7 illustrates the concept of integration of extra low voltage (ELV) systems, which includes building an automation system and energy management system (EMS) and provides streamlining in efficient operational control and monitoring. It should be noted that the diagram below does not depict the full capabilities of ICT.

Figure 7: Integration of ELV Systems



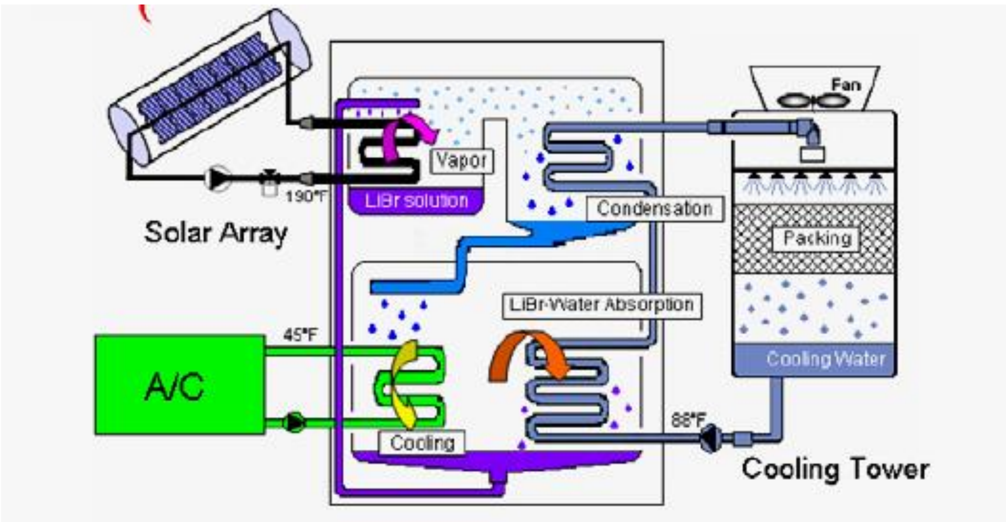
AV = audiovisual, HVAC = heating, ventilation, and air conditioning, CCTV = closed circuit television, EMS = energy management system, ICT = information and communications technology, IP-PBX = internet protocol–private branch exchange, LCD = liquid crystal display, LED = light-emitting diode, MATV = master antenna television.
Source: Quek (2016).

2.3.3.2 Solar Thermal Cooling

There is an abundance of solar energy in varying degrees in a hot and humid climate. Harnessing solar thermal energy to meet the cooling requirements in buildings in the ASEAN region will be an ideal situation. Solar thermal energy is harnessed through solar collectors for the production of hot water, which provides the driving heat source for the generation of chilled water through absorption chillers for air-conditioning purposes. Solar thermal cooling is based on the application of an absorption cycle instead of the conventional compression cycle in refrigeration. The conventional refrigeration system has four basic functions (evaporation, compression, condensing, and throttling-expansion cycles), whereas the basic solar thermal cooling system or solar thermal absorption refrigeration technology is based on a single-effect absorption cycle, which has the following four basic functions: evaporation, absorption, generation, and condensing.

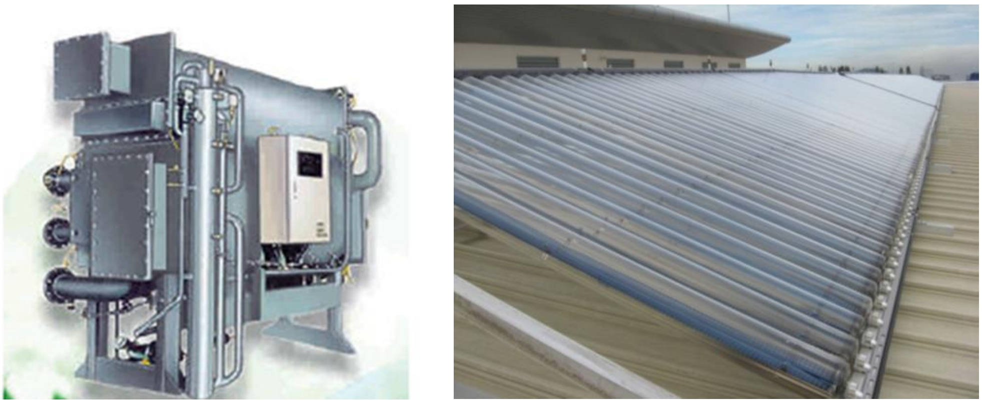
The diagrams in Figures 8 and 9 illustrate the basic solar thermal cooling system and equipment.

Figure 8: Flow Diagram of a Solar Assisted Single-Effect LiBr-H_2O Absorption Cycle



Source: Kong (2013).

Figure 9: Absorption Chiller and High-Efficiency Evacuated Tube Solar Collectors



Source: Kong (2013).

The main components of a solar thermal cooling system are the absorption chiller and high-efficiency evacuated tube solar collectors as illustrated above. Solar thermal cooling systems will provide the energy saving potential to be harnessed in commercial and office buildings, where the demand for air conditioning coincides with the greatest availability of solar radiation in a hot and humid climate and cooling is required the most during the day. In a hot and humid climate, air conditioning takes up the largest share of energy use in buildings. In addition, solar air-conditioning facilities can reduce the peak load demand for electricity and this certainly reduces considerably the infrastructure costs; otherwise, the transmission and distribution assets need to be sized to cater for the greater peak electricity demand. This will also result in a significant reduction in GHG emissions.

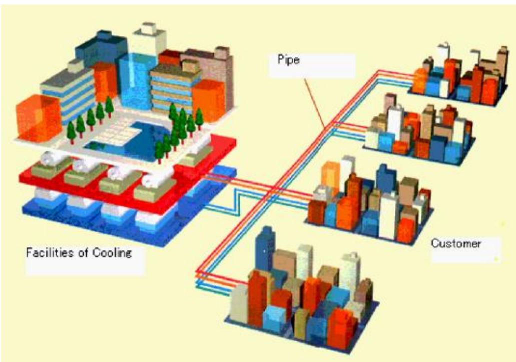
However, under the current technology development for this technology, there are limitations in this system such as the generation capacity fluctuation due to weather conditions, capacity constraints (not suitable for small cooling load), inflexible operation, installation space requirements, demanding operational and maintenance skills, and high capital costs. These limitations may be overcome with greater research and development as well as advancement in this technology.

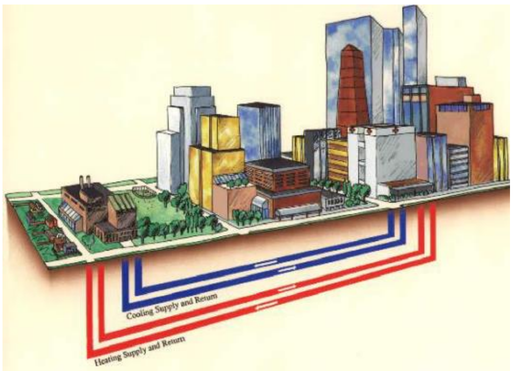
2.3.3.3 District Cooling System for an Eco Town

A district cooling system (DCS) refers to a system that generates cooling energy at a central plant and distributes chilled water through a network of supply and return piping interconnected with multiple buildings within the eco town via an energy transfer station (Figure 10). It is ideal for a township where there is mixed development of residential homes, offices, shopping centres, commercial centres, hotels, convention centres, hospitals, schools, and other institutional buildings.

It should be noted that DCS is not new, having started in 1930 in Denver, Colorado, United States, and in the 1960s the first two European systems in La Défense, France and Hamburg, Germany. It is, however, suggested that the eco town plant configuration of DCS incorporate a solar hybrid cooling system, which will comprise a solar thermal cooling system, electric centrifugal chillers, and thermal energy storage. This type of DCS configuration will capitalise on the free solar energy, while the electric chillers address the shortcomings of the solar thermal cooling system. The solar hybrid cooling system combined with thermal energy storage will be able to manage the cooling load demand profile including day and night load requirements of the eco town. With the proper planning, sizing, design, selection, and incorporation of the suitable control technology, the DCS will be able to provide energy savings and GHG emissions reductions.

Figure 10: Illustration of District Cooling System





Source: Ong (2016).

2.4. Energy Saving Potential

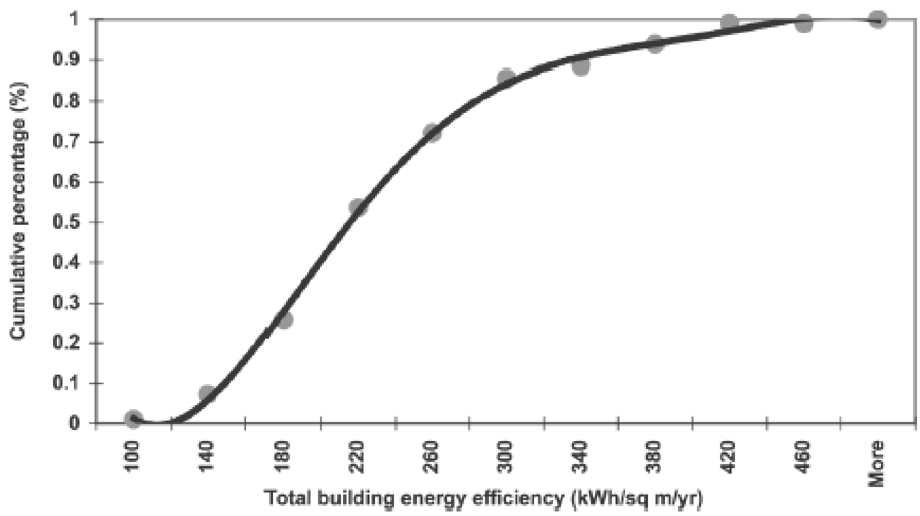
In order to assess the potential energy efficiency improvements through the adoption of energy-efficient building technologies, an energy use index is normally used to determine and compare building energy efficiencies. This is expressed typically in kilowatt-hours per square meter, per year (kWh/m^2/year). There is no standard term to express this value and different countries have different names to describe this indicator.

Malaysia under its GBI rating system, for example, uses the term Building Energy Intensity (BEI), while Singapore uses the term Energy Utilisation Intensity (EUI). In both cases, the definition is similar which is the total energy consumed in a building in a year expressed as kilowatt-hours (kWh) per gross floor area (m^2). For new buildings, the approach to determine this value is mainly through energy modelling or simulation exercises in consultation with project team members, i.e. mechanical and electrical engineers, building technologies manufacturers, and system vendors.

2.4.1. Building Energy Use Benchmarking

Before the energy saving potential can be determined, an energy use benchmark at the building level in the unit of kWh/m^2/year needs to be established first. Most countries within the region, especially Malaysia, Singapore, and Thailand, have developed their own benchmarks for different building types through rigorous study and research work jointly undertaken by the local building authority and institutions of higher learning. These are done mainly through continuous data collection and survey work to develop the building energy efficiency curve as in the example shown in Figure 11.

Figure 11: Total Building Energy Efficiency Curve for Singapore



Source: Sapar and Lee (2005).

From the curve, a performance target may be set for a short-, medium-, or long-term performance of the building. If the services' system energy data are available, a building can also determine the savings achievable from each of the systems from the benchmarking curves.

For new buildings, the minimum requirement in terms of the EUI or BEI value is specified typically in the green building rating tool. Examples of minimum EUI or BEI values are shown in Table 4 for three common building types for both GBI and Green Mark rating system, respectively.

Table 4: Minimum Energy Efficiency Index for Different Building Types

	Rating System	
Building Type	**Green Building Index (BEI)**	**Green Mark (EUI)***
Office	150	172
Hotel	290**	242
Retail	350	269

* Based on top 25 percentile: applicable for those buildings targeting the highest rating, i.e. 'Platinum'.
** 4-star and above
Source: Building and Construction Authority, Singapore, and Green Building Index Sdn Bhd, Malaysia.

2.4.2. Energy Saving Forecasting Methodology

To analyse the energy saving potential through the adoption of energy-efficient building technologies, a target needs to be set making reference at least to the minimum energy efficiency index like those tabulated in Table 4, both for new and existing building. For the purpose of developing an eco town, the target index for the different building types should be set higher, i.e. lower than the BEI or EUI. A minimum target index with an energy efficiency improvement of not less than 30 percent should be considered. In the case of an office building in Malaysia for example, a BEI of around 100 kWh/m^2/year or less should be the target (energy efficiency improvement of more than 30%) as compared to the minimum threshold of 150 kWh/m^2/year.

The steps that are applicable for both new and existing buildings to determine the potential savings are as follows:

- Set good design/post-retrofit targets and approximate the total savings using the total building energy efficiency curve. Take two examples:

For a new building:

$$Potential\ Energy\ Savings\ (\%) = \left(\frac{Minimum\ Benchmark - Design\ Efficiency\ Target}{Minimum\ Benchmark}\right) x\ 100\%$$

For an existing building:

$$Potential\ Energy\ Savings\ (\%) = \left(\frac{Current\ Benchmark - Design\ Efficiency\ Target}{Current\ Benchmark}\right) x\ 100\%$$

- Match total savings target against system performance benchmark to determine realizable savings versus cost outlay.
- Rank energy saving measures in terms of savings–cost ratio, investment quantum, and ease of installation/retrofitting work for management decision.

2.4.3. Further Work

For the next phase of the work, a more detailed assessment of the energy saving potential is proposed. To simulate future buildings and to determine reasonable efficiency target values and energy saving potential, research and consultation (with academicians, researchers, industry experts, manufacturers, and practitioners) need to be conducted to determine the energy subsystem equipment and technology improvements that are expected to be standard practice in future buildings. For example, the best technology available on the market today can be expected to be standard practice in 2017 or beyond.

However, predicting standard practices say in the medium term, i.e. 2022, is more challenging because a plethora of technologies that are currently in the R&D phase may only achieve market adoption in 5–7 seven years' time. The level of complication is even more pronounced when trying to predict and simulate standard practices by 2030.

The assessment will be carried out using globally established and well-validated energy simulation software such as EnergyPlus, IES, DesignBuilder, Bentley, and so on. For the purpose of this assessment, building types that would typically be built under the eco town concept are selected, i.e. offices, schools, shopping centres, institutes of higher education, hospitals, and so on.

The energy saving potential determination is carried out for the short-term (by 2018), medium-term (2022), and long-term (2030) time frames. For each of these time frames, three scenarios are assessed. The definition of the three scenarios is briefly explained in Table 5.

Table 5: Definition of Modelling Scenarios

Scenario	Remarks
Conservative	Technology improves with conservative energy efficiency targets
Moderate	Technology improves with moderate energy efficiency targets
Aggressive	Technology improves with aggressive energy efficiency targets

Source: Building and Construction Authority, Singapore (2014).

2.5. Issues, Challenges, and Recommendations

Energy-efficient technologies for buildings are being adopted throughout the world to varying extents. The adoption of energy saving technologies is on the rise and so is the advancement in technologies. There are issues and challenges to be considered in the decision- making process in identifying and selecting technologies, whether current or potential technologies. However, the mere adoption of energy-efficient technologies is not an effective way of achieving energy efficiency in buildings for the eco town project because sole reliance on energy efficiency may not be sustainable. Further, the impact to achieving the objective of energy savings may not have been optimised, and consistency in implementation may be lacking.

2.5.1. Non-technology Issues

Fundamental issues in most mega projects are normally non-technology related, such as unclear and conflicting objectives, lack of direction and framework, weak project management organisation, changing requirements during the project period resulting in loss of focus areas and priorities, change of project management personnel resulting in lack of continuity, financial constraints, and unforeseen developments.

The challenge is to convince the project owner to allocate a budget to conduct advance planning, which is to analyse, plan, and find a comprehensive solution so that a project management framework and master plan can be formulated for the implementation of the eco town project. To address these non-technology issues, it is recommended to conduct an eco town foresight study, which is a critical thinking process that can be used to facilitate forward thinking and planning. In addition, it is recommended to establish a project management framework and master plan as well as owner’s project requirements (OPR).

2.5.2. Eco Town Planning and Design Issues

People may interpret differently the concept of a sustainable township. It is important to develop a master eco town plan for the whole project and to ensure that it is consistent with the concept of sustainability. It is a challenge to have consistently competent town planning, design, project management, and construction teams who can adhere to the same standards and requirements. The best way to go about it is to use the methodologies laid out in the green building rating system, which promotes a holistic and systematic approach to be implemented by a multidisciplinary professional team. Therefore, it is recommended to identify and establish a green building rating system for the eco town project. It is also equally important to have competent professionals, who are responsible for the town planning, design, project management, and construction in the eco town project and who are familiar with and dedicated to the practice of a sustainable township and the multidisciplinary approach. The use of advanced design software that has simulation capabilities is recommended to address unforeseen design issues.

2.5.3. Technology Issues

As discussed, achieving energy efficiency is not merely adopting advanced technologies. The consideration of technologies should begin with fundamental design strategies, which are based on the understanding of local climatic conditions. Such strategies include the passive and active design strategies outlined in Section 2.3. Incorporating innovative and advanced technologies addressing the following issues is encouraged:

- effectiveness and potential benefits
- economic justification
- suitability and reliability in terms of applications, climatic conditions, durability, etc.
- sustainability in terms of design lifespan and availability of technology updates
- capabilities of continuous monitoring and verification of energy performance
- ability to operate and maintain in terms of availability of competent operational and maintenance personnel, availability of training, long-term service support, etc.
- adherence to the criteria set out in green building tools

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CHAPTER 3

Transport

3.1. Introduction

The transport sector in ASEAN countries accounts for 40–60 percent of the total energy demand. The sector is dominated by oil (gasoline and diesel), of which imports have been increasing rapidly in parallel to the slowing down of domestic production, which affects the security of supply (Kutani, 2013). Increased combustion of oil products has worsened the air quality, which potentially has great socio-economic impacts.

In many cases, there has been a rapid drop in infrastructure for public transport, walking, and cycling due to overbuilt roadways which accelerate more usage of private vehicles. Where the public transport system is inadequate and unreliable, there is often the urge to own a private vehicle or a motorised two-wheel vehicle. This also in turn makes walking and cycling redundant, mainly due to unfavourable and not-public-friendly walking and cycling pathways.

In light of this, efficient and sustainable transport infrastructure is vital for a particular town that aspires to be environment friendly. Sustainable transport offers a more balanced and holistic system for better mobility and more choices among the users.

This chapter first gives an overview of sustainable transport in an eco town as well as an approach to energy saving measures in the transport sector. It also touches upon a case study for Brunei Darussalam in terms of estimation of current and future energy demand and emissions, as well as the corresponding energy savings and emissions reductions achieved through different scenarios applied.

3.2. Sustainable Transport in an Eco Town

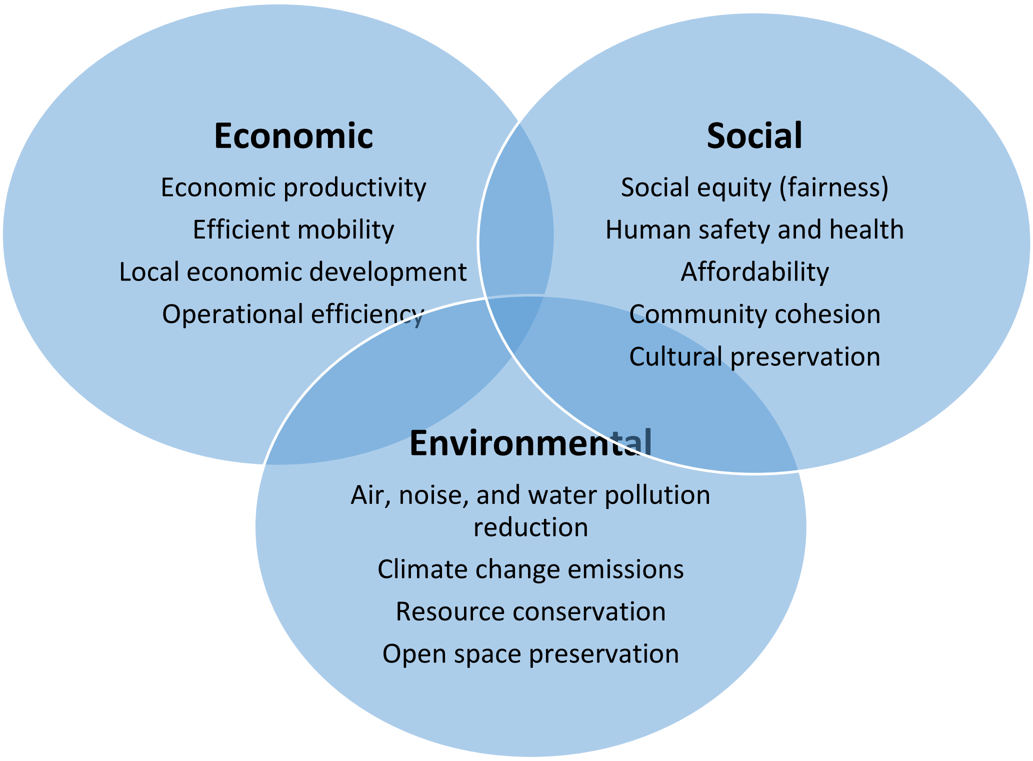
Sustainable transport aims to reduce greenhouse gas (GHG) emissions by switching from conventional vehicles to low-carbon ones, and at the same time encouraging walking and cycling within the town. An efficient and sustainable transport system is the one that (Gilbert and Cormier, 2005):

- allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;
- operates efficiently, is affordable, can offer various transport mode choices, and supports a vibrant economy; and
- minimises the consumption of non-renewable resources (fossil fuels) while using

renewable resources efficiently and sustainably, reuses and recycles its components, and minimises noise and the use of land.

An efficient transport infrastructure should support the sustainability goals that emphasise balancing economic, social, and environmental goals which often overlap with each other. For instance, GHG emissions from transport (environmental issue) can affect human safety and health (social issue) as well as productivity (economic issue). This is reflected in Figure 12 below.

Figure 12: Sustainable Transport Goals



Source: Author.

3.3. Policy Measures for Energy Savings in Road Transport

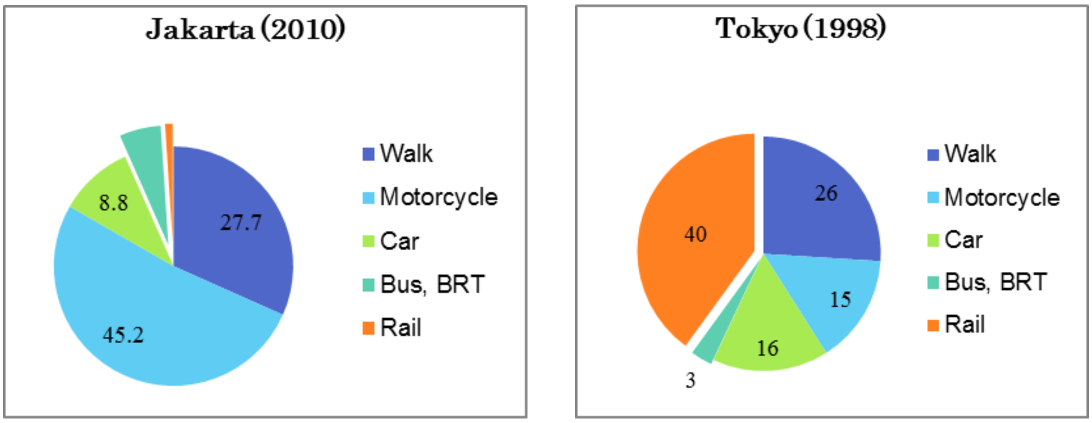
3.3.1. Introduction

Cities, in developed or in developing, face various problems in mobility, including air pollution, accidents, traffic jams, or lack of parking space. The following describes policies for energy savings in developing cities.

A common characteristic of today's developing cities is rapid motorisation with relatively poor public transport infrastructure. In cities like Jakarta and New Delhi, the number of vehicles is increasing at a rate of over 1,000 per week and many people have come to own their vehicles. The pace of motorisation in these cities is about six times as fast as in developed cities in the past (Table 6 – comparing Jakarta and Tokyo), so the public transport systems in the current developing cities are much more inadequate compared with the number of vehicles. Developed cities, on the other hand, tend to possess higher shares in public transport systems than private vehicles. For instance, Tokyo, being a developed city, had rail system as the highest percentage share in 1998 compared to that in Jakarta in 2010 which had the lowest percentage (Figure 13).

Huge traffic jams, caused by rapid private motorisation, may result in deaths due to fatigue or prolonged inhalation of exhaust pollutants. In 2016, a severe traffic congestion from Jakarta to Tegal, a city in Java Island, lasted for about 35 hours in East Brebes toll road (Figure 14). Eighteen people lost their lives mainly due to fatigue and accidents in road crossing.

Figure 13: Trip Mode Share in Jakarta and Tokyo (%)



BRT = Bus Rapid Transit.
Source: SITRAMP - The Study on Integrated Transportation Master Plan for JABODETABEK, JICA, Indonesia.

Figure 14: Traffic Jam in East Brebes

Source: Webb (2016).

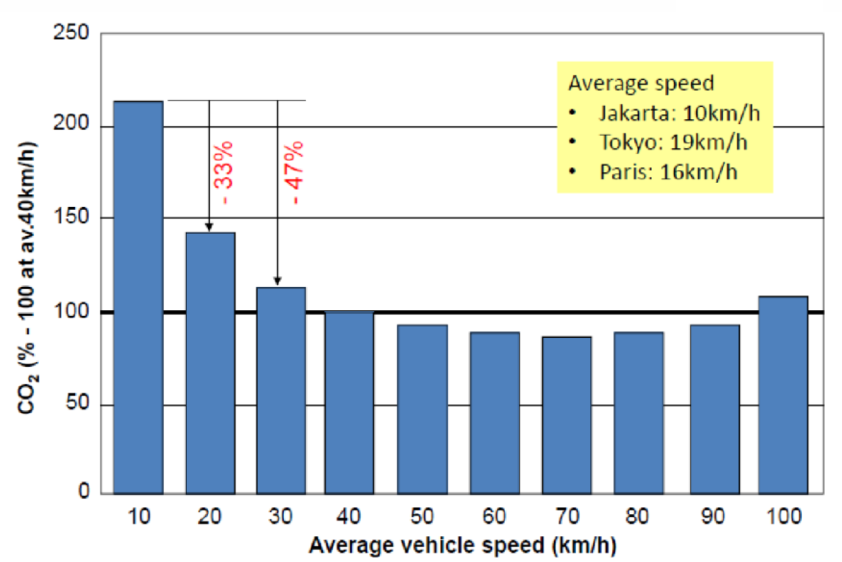
Table 6: Comparison of Motorisation in Tokyo and Jakarta

City	Tokyo		Jakarta	
Year	**1970**	**2009**	**2002**	**2009**
Number of Vehicles per Person	7.9	25.3	7.9	22.9
Percentage Growth Rate	3.1%		19.4%	
	39 years		7 years	

Source: Toyota InfoTechnology Center (using official government data).

Problems caused by traffic jams include not only economic losses but also, to the same extent, energy losses and air pollution from wasted energy combustion during traffic jams, which are 'invisible' but serious for cities as these problems cannot be seen through physical observation.

Figure 15: CO_2 Emissions (Fuel Consumption) by Average Speed



Source: Japan Automobile Research Institute (as cited in Maruyama, 2012).

The average vehicle speed on the road is around 10–20 kilometres per hour (km/h) in major cities. The National Institute for Land and Infrastructure Management, a Japanese research institute, has shown that an average speed improvement from 10 km/h to 20 km/h creates energy savings of a third and an improvement to 30 km/h as large as half (Dohi et al., 2012) (Figure 15).

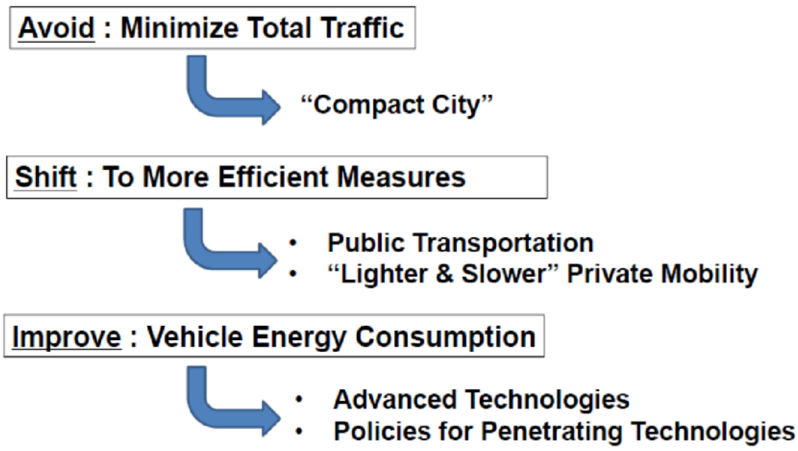
3.3.2. Approaches to Reduce Energy Consumption

3.3.2.1. 'Avoid, Shift, and Improve' Approach

The 'Avoid, Shift, Improve' (ASI) approach is becoming a common approach for policymakers and analysts. The following are some examples and difficulties pertaining to policy making for energy saving measures.

As shown in Figure 16, 'Avoid' means basically reducing traffic through city design or change of lifestyle. 'Shift' means transferring from personal mobility modes like using one's own car to public transport options like using trains with higher efficiency. The concept of autonomous driving with smaller and slower mobility tools like the Google car has recently been gaining attention; and sharing mobility through the use of mobile apps is growing in cities. The emergence of these types of new mobility, not perfectly private nor public, is categorised as 'Shift'. Finally, 'Improve' means applying greener technologies, an approach related not only to the technology itself but also to the necessary policies.

Figure 16: 'Avoid, Shift, Improve' Approach and Measures



Source: Author.

'Avoid': Compact City Approach

Figure 17: Example of a Japanese City

Source: Author's compilations from Aomori City webpage.

Figure 17 is an example of a compact city in Japan. The main objective of Aomori City is to cope with the country's aging society, since many of the elderly who have poorer mobility still live in the suburbs, and to cut city expenses for public services with less tax revenue.

The main policy contents of the compact city approach are to:

- build new offices and shops in the city centre funded by the local government
- move the elderly living in the suburbs into public apartments in the city centre
- provide houses to younger families at reduced prices, using the city budget.

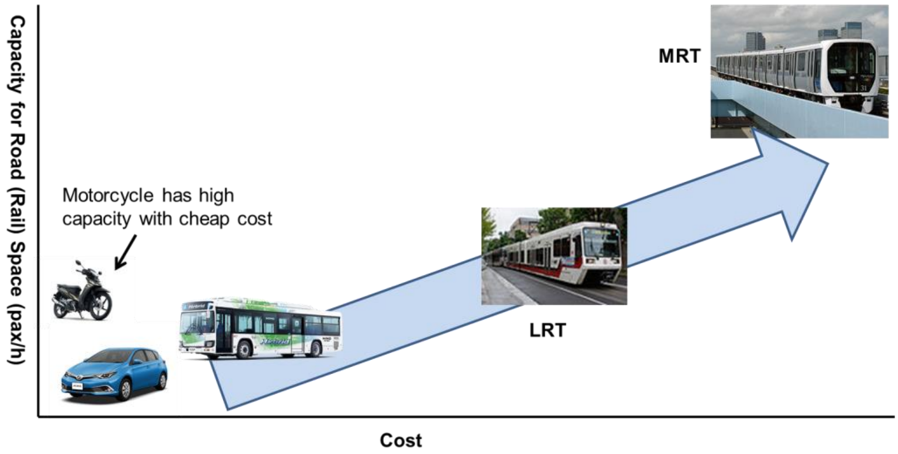
Tenants in city centre buildings have moved out and the number of people moving between the city centre and the suburbs is fewer than originally planned under the compact city. This is, first, because shops in new buildings lack attractiveness compared to mega-malls in the suburbs which have lots of shops, theatres, and various amusement options. As a result, the new buildings cannot absorb the traffic flow of shoppers or of office workers. Second, the city budget does not meet all the needs to move the elderly or acquire new houses.

This example shows that shopping at mega-malls in the suburbs cannot be replaced by shopping in shops in the city centre, because mega-malls occupy huge spaces to house not only shops and supermarkets but also facilities such as cinema complexes. Such huge spaces are easier to acquire in the suburbs than in the city centre. Considering this fact, even if the city government had sufficient budget to meet the needs of moving all the elderly to the city centre, the daily traffic would not change drastically because the attractive mega-malls would still be located in the suburbs. The same would be true for large hospitals where the elderly often go as such facilities also require huge amounts of land. Furthermore, for a community to be attractive, it requires a mix of economically active and elderly population, so the concept of an area like a residential zone for the elderly lacks vitality and is not attractive enough to become and maintain as a community.

City planning would fail without consideration for people's lives or companies like mega-malls, because people's or companies' motivation is not based on 'efficiency for the whole community' but individual efficiency or interest.

<u>'Shift': Shift to Public Transport</u>

Figure 18: Relation between Capacity and Cost by Modes



Source: Author.

Basically, a higher passenger capacity mode requires higher cost, as illustrated in Figure 18. It is often the case that local governments cannot introduce larger infrastructure like railways, even if they know the future growth of traffic demand, considering the deficit during the growth period when the demand does not meet the cost. Alternatively, even after they introduce the rail system, they reduce capacity (reduce frequency, etc.) or raise the fare (reduce demand).

Choosing the 'most fitting' transport system plan is quite difficult, because oftentimes local governments themselves change the capacity or demand from the original plan by changing supply and demand.

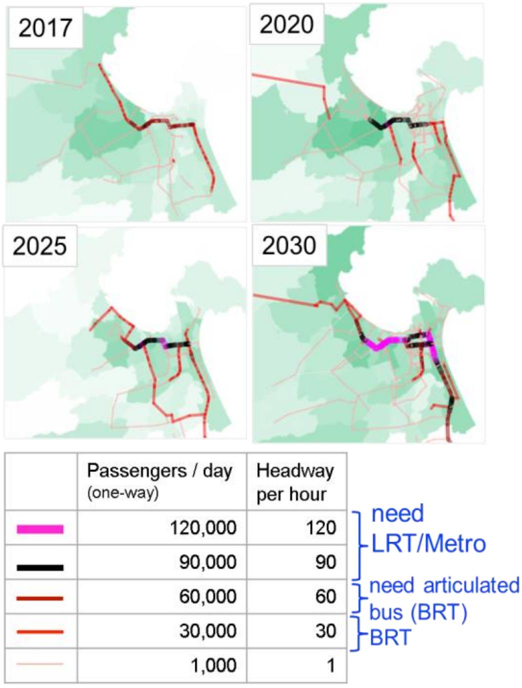
Figure 19 shows the example of future traffic demand in Da Nang City, Viet Nam. The research was conducted by ERIA and another working group in 2016. Da Nang has chosen a bus rapid transit (BRT) system, because its population is not so large and, considering the budget, BRT was considered the "best solution".

The simulation with information from the latest intention survey of the population of Da Nang and with current population projection by area shows that traffic demand in some areas will exceed the BRT's capacity in 2020, only 3 years after it starts operations.

Da Nang's current public transport system is not sufficient and most trips (around 80%) are conducted by motorcycle. As a result, people in Da Nang are not accustomed with the use of the public transport system, especially within the city. It is therefore important for the local government to instil the 'habit' of using public transport before starting operations on a larger scale.

During this early stage, patience is required of the local government. In policy implementation, the most cost-effective measure is often adopted first. However, the time required for people to change their daily behaviour should be considered. This will usually take longer than planned, because of which the introduction of the new transport system may appear to have failed. All new policies and new infrastructure have reached planned capacity only after gaining people's understanding and acceptance.

Figure 19: Example of Demand Simulation in Da Nang, Viet Nam

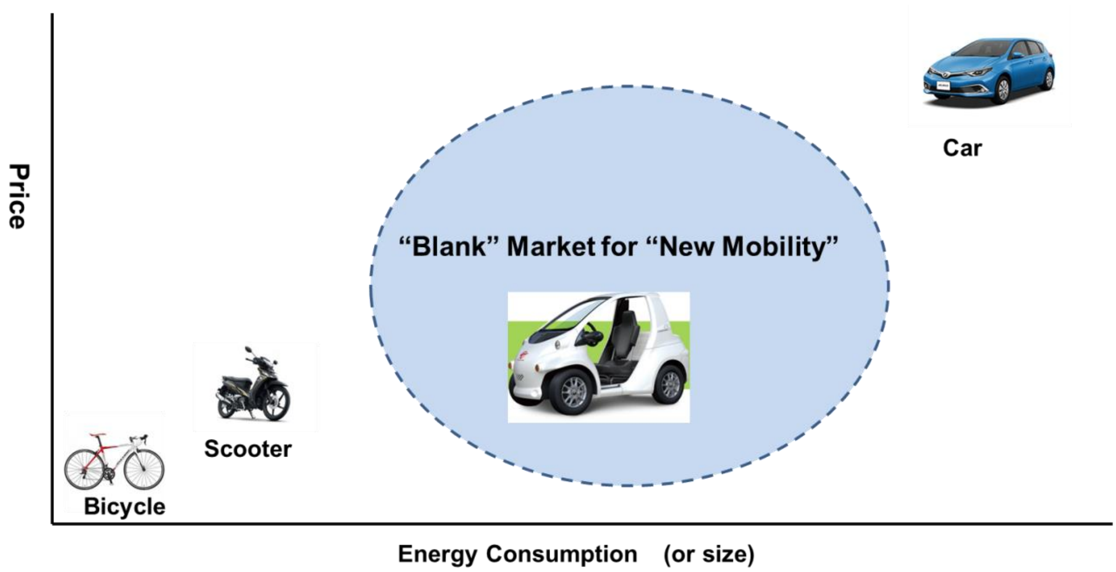


Source: ERIA (2016).

'<u>Improve': Shift to Smaller and Slower Traffic</u>

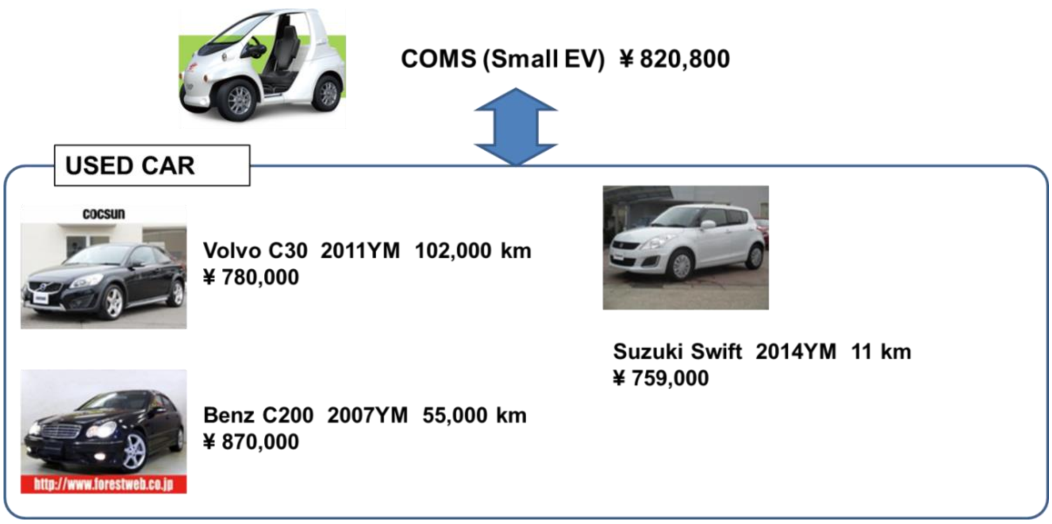
The force necessary to move objects is based on weight and acceleration (speed). To reduce energy use, a possible solution is to shift to smaller (lighter) and slower modes of transport such as bicycles. A lot of cars carry only one passenger (in other words, a 2,000-kilogram (kg) car carries a person of 60 kg) and some may criticise its 'wasted' energy. There are obvious reasons for a car's weight to be as heavy as 2,000 kg for safety and/or comfort. While there are already golf cart style 'small mobility' vehicles, they are unfortunately not so common. There may be a potential 'blank' market between motorcycles and small cars by size and price, and introducing 'new small mobility' solutions into this area could create a new market. Attempts to date have failed, however, as no big market exists in this area. This could be due to the cars being characterised as 'durable, expensive, and consumer goods' which gives rise to a used car market in parallel with new markets.

Figure 20: Typical Marketing Discussions for 'New Mobility'



Source: Author.

Figure 21: Example of the Used Car Market in Japan



EV = electric vehicle.
Source: Author.

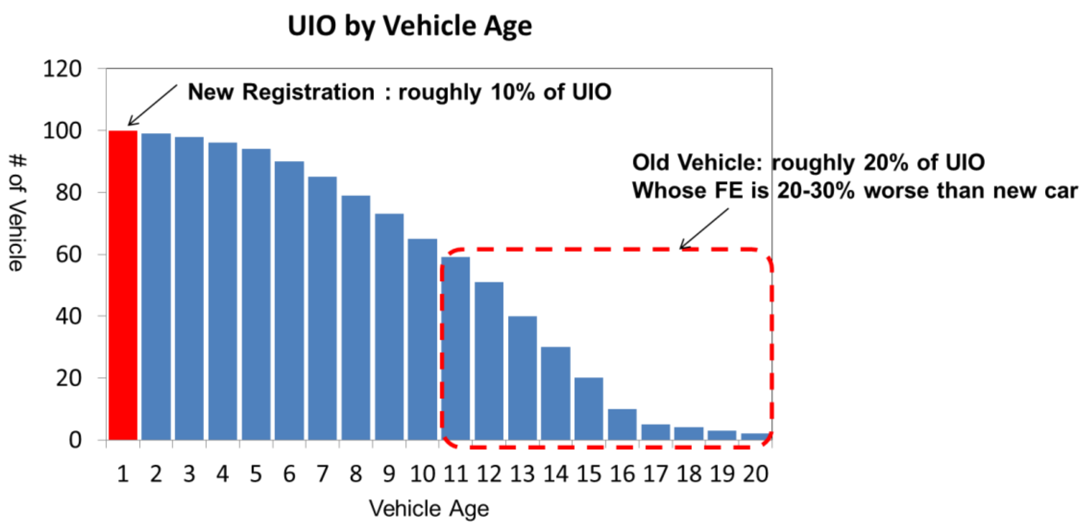
Figure 21 is an example of recent offers in the used car market in Japan. A small electric vehicle (EV) called COMS is priced at ¥821,000 (approximately US$7,000). This is much cheaper than a low-end new car, but considering the used car market, there are a lot of options, like an almost new Suzuki Swift or luxury brands like Volvo or Mercedes Benz. This is a reflection of the image of cars as 'durable' and 'expensive'. As for 'durable', cars can be used even after 10–15 years, and when consumers buy a new car, they often sell their old car for an initial payment of the new one. Additionally, the 'expensive' image of cars creates the used car market, because if the price gap between a new and a used car is not so large, consumers would not feel attracted to buy a used one.

Needless to say, buying a vehicle is a big purchase decision for customers. Even if they are offered a new small EV at a cheaper price, it may be natural for customers to choose a used car because it is much more convenient and far more comfortable.

<u>'Improve': Policy Options</u>

Energy efficiency standards are often adopted as an 'Improve' policy option in the road transport sector not only in developed countries but also in developing ones. It is important to point out, however, that this is not an only option.

Figure 22: Effectiveness of Fuel Efficiency Standards



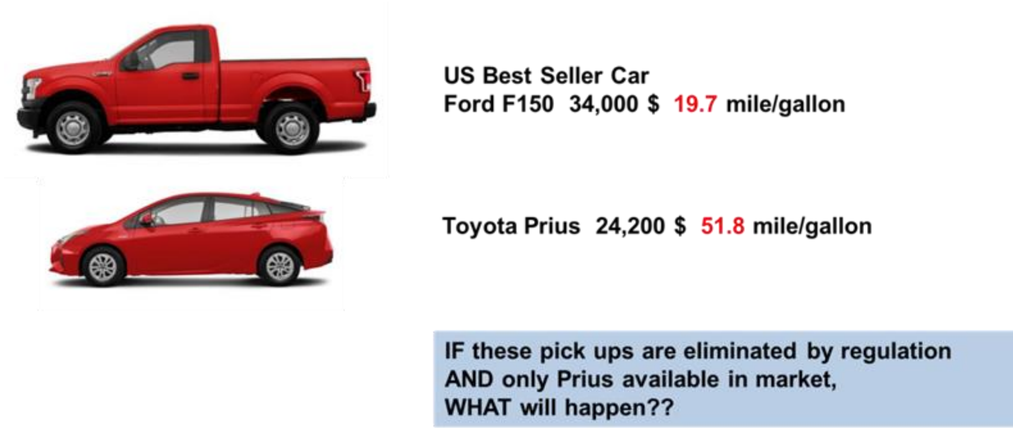
FE = fuel efficiency, UIO = units in operation.

Source: Author.

Figure 22 shows an example of the number of vehicles by vehicle age. The number of vehicles decreases the older they get. This is mainly because of scrappage of vehicles due to accidents or having no market value in the used car market. Roughly speaking, the portion of new vehicle registration is around 10 percent of the total vehicle population; thus, fuel efficiency standards affect only 10 percent. While raising fuel efficiency through regulation is a very important and effective policy, since it covers only 10 percent of the total vehicle population, it may be a policy for a longer time scope. On the contrary, older vehicles, whose fuel efficiency is much worse than newer ones, occupy 20 percent of the total vehicle population. A vehicle naturally lasts 10–15 years; in other words, once a technology is introduced, it lasts for 10–15 years, even if it is not the latest type. To promote better average fuel efficiency, it is also important to shorten the average vehicle age by promoting scrappage of old vehicle (scrap incentive).

It is also important to set the right target. The model mix or deployed technology differs by market, depending on differences in climatic conditions (hot or cold), income level (rich or poor), or fuel price including tax/subsidy. A regulator can easily copy regulation from other markets like the European Union. But without considering the current situation and customer preferences, the regulation cannot meet its target by itself.

Figure 23: Fuel Efficiency Regulation Assumptions in the US Market



Source: Yahoo! Autos.

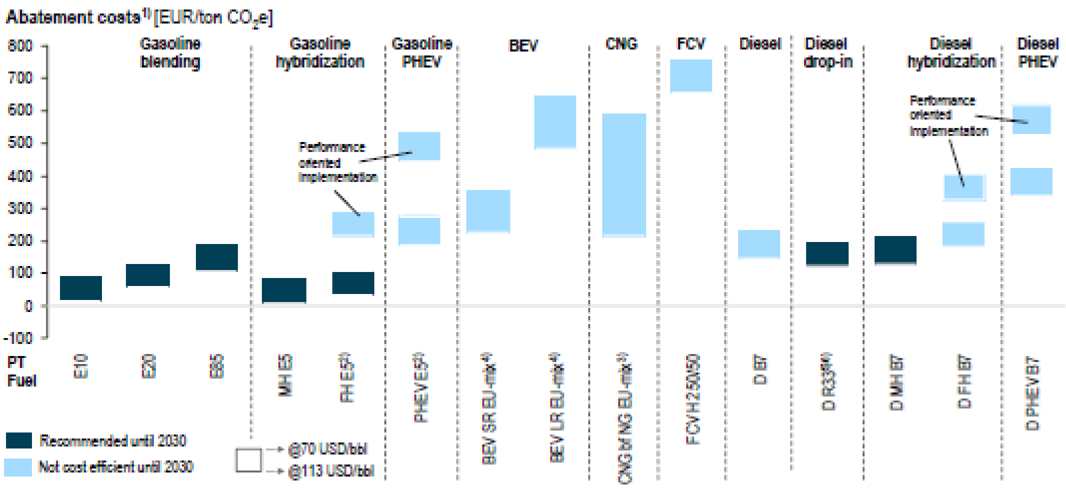
Figure 23 illustrates an example of the regulation in the US market. The best-selling model in the US market for years has been the Ford F150. Besides the F150, other manufacturers like GM or Chrysler sell pickup models to meet customer preferences. The fuel efficiency of the F150 compared with cars like a sedan is not very good. Suppose a US regulator were to introduce a ban on selling pickup trucks and force people to only buy the Toyota Prius. Whatever the regulation says, people's preferences do not change suddenly and they will buy a used F150 rather than a new Prius. Again, this should consider the characterisation of vehicles as goods. The result of unrealistic targets ignoring the market's condition or false measures will slow down the improvement of fuel efficiency, contrary to the policy intention.

<u>'Improve': Vehicle Technology Alternatives</u>

Finally, the following discussion provides a menu of vehicle technologies for better fuel efficiency. First, it should be stated that this refers to vehicle technologies currently developed for conventional vehicles. In other words, mobility tools like the Google self-driving car are not discussed, though it is much smaller in size, its speed is slower, and, as a result, its energy consumption is much lower than 'conventional' vehicles, regardless of the energy source. Several governments and original equipment manufacturers (OEMs) are discussing the way to reduce GHG emissions. Their main arguments are based on the current transport scheme, which is consistent with the current mobility system provided by current market players like OEMs. The autonomous car like the Google car is a kind of revolution for ordinary customers, because for most drivers, driving is a 'waste of time' and they might accept the autonomous car as a way to spend 'more fruitful driving time'. As a result, vehicle electrification may be achieved outside the current GHG mitigation discussion by the electric-powered Google car.

There are various alternatives for vehicles based on 'cost and effect' looking toward 2030. Presenting policymakers in each city with alternatives or candidates is quite important, because every city has different problems and different circumstances. Therefore, no single answer exists for this issue.

Figure 24: Abatement Costs by Technology in 2030



Note: Original data for the calculation were provided by vehicle manufacturers including Toyota and the oil industry.
Source: Roland Berger (2016).

Figure 24 analyses various powertrain technologies with cost per tonne of CO_2. The working group members who worked on the analysis have stated that current conventional engine-based technologies (including hybrids) will be cost-effective, including related costs like building energy infrastructure. For example, plug-in hybrid electric vehicles (PHEV) or battery electric vehicles (BEV) will not be cost-effective considering the cost to build battery or charging infrastructure even at an oil price of US$113 per barrel.

The story with ultra-low carbon mobility tools, which will meet future European Commission regulations equivalent to GHG emissions below 40 grams per kilometre, is different. Comparing total (well to wheel) GHG emissions by technology and fuel, all the current cost-effective candidates will not be able to meet future regulation targets other than the internal combustion engine (ICE) with biofuel. This means that using only the 'Improve' approach cannot solve the future problem of severe global warming. Some may say that once the regulation is made by regulators, all OEMs should comply with it, and, as a result, all new vehicles will become greener. However, all vehicle technologies will be deployed only when customers buy them. It is also important to say that most customers do not or will not have a strong interest for their vehicles to be 'green' and instead will only consider the cost merit and convenience. If all new vehicles are 'green' but expensive, customers will choose a used car rather than a new one. This will cause slower achievement of the policy goals (greener road mobility) contrary to their original intention.

Others may insist on the importance for a subsidy. It is true that subsidies or incentives are very important policy measures for deploying promising but expensive technologies at an early stage. Still, every budget has a ceiling, so choosing 'promising fast deployment' technologies for GHG mitigation not only for the transport sector but also for all other sectors is quite important considering the preference of people in choosing each product or service.

3.3.3. Conclusion

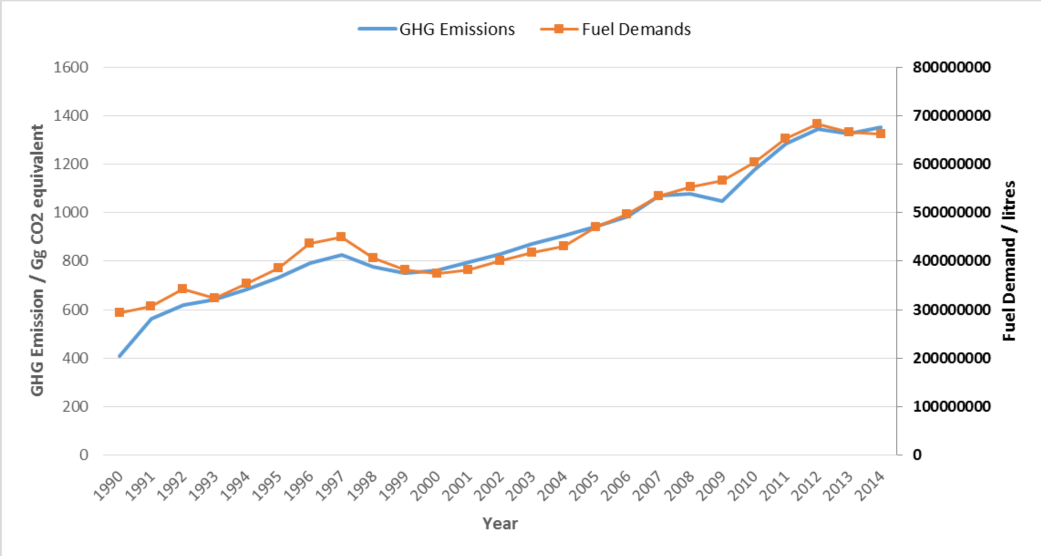
There are policy options to establish greener road mobility by using the 'Avoid, Shift, Improve' approach, but they also have drawbacks. To avoid these 'traps', each country or city has to determine the 'best' approach to improve the current situation or solve problems. Approaches vary and there are also many experiences in other cities. Thus, information sharing of each city's policy goal and concrete actions for the future as well as past successes or failures is important for making progress on the right and shortest way for each different city.

3.4. Brunei Darussalam's Transport Energy Demand and Emissions

3.4.1. Introduction

Road transport in Brunei Darussalam is one of the most energy-consuming sectors in the country, accounting for half of the total national energy consumption with 80 percent nearly consumed by cars alone. In 2010, the sector was the third-largest spender in fuel expenditure, accounting for B$521 million or 25 percent of the total energy expenditure, and it still stands at present. Transport is dominated by conventional gasoline and diesel vehicles, with a negligible share of hybrid vehicles. Statistics from the Land Transport Department (LTD) in 2014 show that 77 percent of the total number of vehicles in Brunei comes from gasoline vehicles, 22.9 percent from diesel vehicles, and the remaining 0.1 percent from hybrid vehicles. According to LTD, as of present only 601 hybrid vehicles have been registered and licensed since 2005. Statistics show that there were 262,649 registered and licensed passenger vehicles in 2014 for a population of 411,900, equivalent to a vehicle ownership of 638 vehicles per 1,000 persons.

Figure 25: Fuel Demand and GHG Emissions from Road Transport in Brunei Darussalam (1990–2014)



Gg = gigagram, GHG = greenhouse gas.
Sources: Fuel demand data from the Department of Economic Planning and Development; GHG emissions data from the Intergovernmental Panel on Climate Change (IPCC) Inventory for Brunei Darussalam.

Figure 25 illustrates the historical trend in fuel demand and its corresponding GHG emissions. Since 1990, the emissions from road transport have increased by about 5 percent, which is due to the increasing population and hence increase in gasoline and diesel demand.

Because of overwhelming use of private vehicles, Brunei's public transport infrastructure is still in its infancy. To provide a more integrated, robust, and efficient transport network, the government introduced the Land Transport White Paper and the Land Transport Master Plan which outline the policies and strategies to improve the country's transport infrastructure. The government is also currently exploring ways to reduce the number of new vehicles every year as part of its efforts to establish efficient and robust public transport.

3.4.2. Objectives

The study aims to forecast passenger vehicle energy demand and emissions and to analyse the potential scenarios of energy saving and implementation of alternative energy sources as well as emissions reductions in Brunei Darussalam. In order to forecast the conventional energy demand and emissions reductions, the vehicle ownership until 2035 is first projected for the whole of Brunei, based on the official statistics from 1979 to 2014. Then, the results are used to forecast the corresponding energy demand and emissions for three different scenarios:

- business-as-usual (BAU) scenario
- fuel economy improvement (FEI) scenario

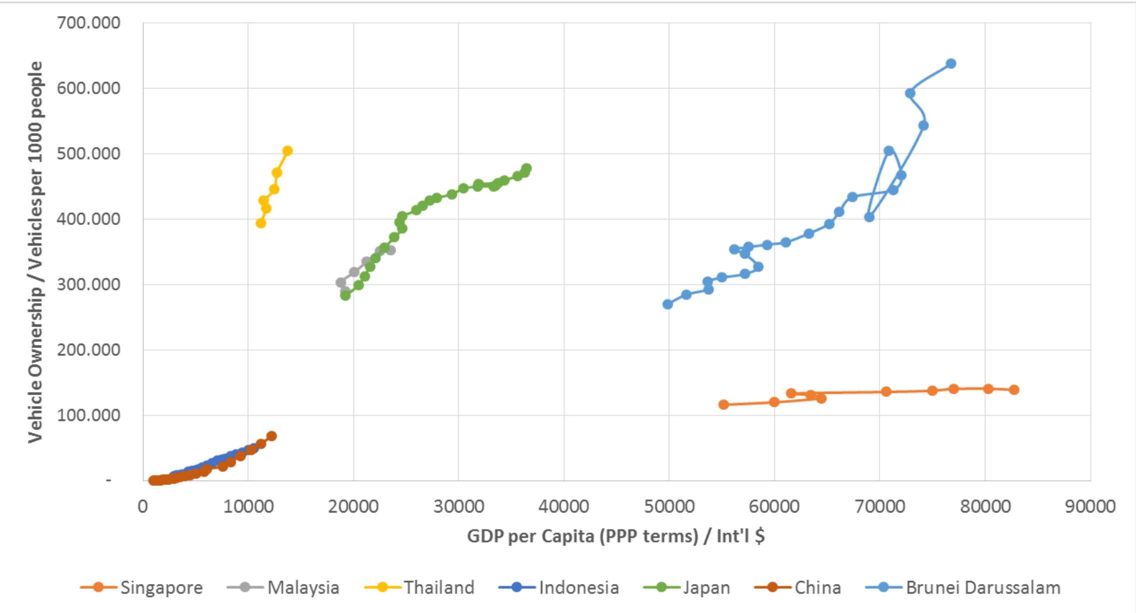
- electric passenger vehicle (EPV) scenario.

3.4.3. Overview of Road Transport in ASEAN and East Asia

3.4.3.1. Trends in Vehicle Ownership

Figure 26 illustrates the trends in passenger vehicle ownership of selected countries in ASEAN and East Asia against their per capita gross domestic product (GDP). There is a general relationship between vehicle ownership and GDP, albeit highly non-linear. Passenger vehicle ownership grows at a relatively slower rate at the lowest level of per capita GDP, then increases until reaching a saturation level at the highest per capita GDP level.

Figure 26: Passenger Vehicle Ownership against GDP per Capita of Selected Countries in ASEAN and East Asia



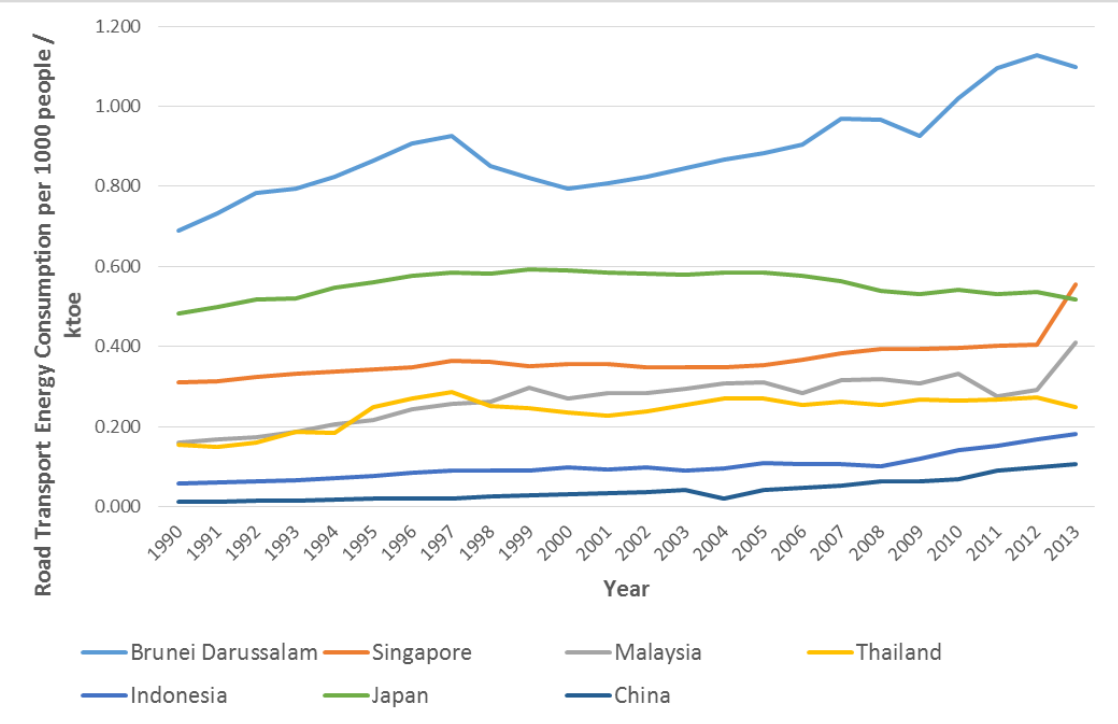
GDP = gross domestic product, PPP = purchasing power parity.

Sources: Data for Singapore from the Land Transport Authority; for Malaysia from the Road Transport Department; for Thailand from the Ministry of Transport; for Indonesia from BPS Statistics Indonesia; for Japan from the Statistics Bureau Japan; for China from the National Bureau of Statistics China; for Brunei Darussalam from the Department of Economic Planning and Development.

3.4.3.2. Trends in Energy Demand

Figure 27 illustrates the trends in energy demand (expressed in fuel consumption per 1,000 people) of seven countries. In general, the energy demand has been following a rising trend, ranging from that of China at 0.01 kilotonnes of oil equivalent (ktoe) to that of Brunei Darussalam at 1.09 ktoe. Despite having the smallest population among the countries, Brunei's energy demand has been the highest from 1990 until 2013, driven by fuel price subsidies.

Figure 27: Road Transport Energy Demand per 1,000 People in Selected Countries in ASEAN and East Asia



ktoe = kilotonne of oil equivalent.
Source: Asia Pacific Energy Research Centre (APERC).

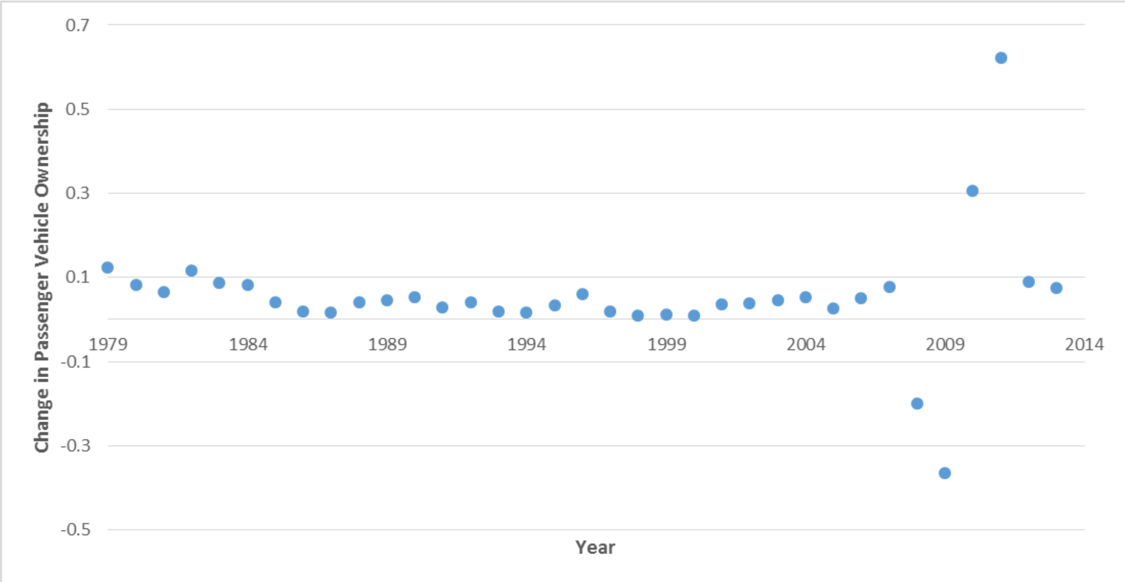
3.4.4. Forecasting Passenger Vehicle Ownership

3.4.4.1. Methodology

The growth in vehicle ownership is typically represented by a sigmoid or S-shaped curve.). This shape implies that ownership slowly increases at the lowest income levels and then grows rapidly as income rises until the curve reaches a saturation level. However, the saturation level must first be estimated either from the S-curve function (Singh, 2000), or by applying a rule of thumb, for instance one car per household (Palelink, 1960) or vehicle ownership per capita (Button, Ngoe, and Hine, 1993; Kobos, Erickson, and Drennen, 2003). The Transport and Road

Research Laboratory (TRRL) devised a statistical methodology, in which they analysed the relationship between the rate of change of vehicle ownership and the actual vehicle ownership in each country. The ownership level at which the rate becomes zero would be the ultimate saturation level in their logistic analysis. Despite the oversimplification of the estimation, the above method has been utilised in the United Kingdom and other countries to estimate the ultimate saturation level. As there are no studies pertaining to the passenger vehicle ownership in Brunei Darussalam, it is assumed that the saturation level is based on the rate of change of ownership.

Figure 28: Growth Change in Passenger Vehicle Ownership in Brunei Darussalam (1979–2014)



Source: Author.

Not taking into account the outliers between 2008 and 2011,[1] it can be shown in Figure 28 that the growth change generally decreases exponentially over time, with the lowest level between 1997 and 2000. Between 2005 and 2013, the growth slightly increased. This suggests that ownership has theoretically almost reached its saturation point. Assuming that the number of private cars is still increasing, 700 vehicles per 1,000 people is estimated as the ultimate vehicle ownership saturation point.

If *VO* denotes the passenger vehicle ownership growth per 1,000 persons at each year and *GDPPC* denoted GDP per capita, the Gompertz model can be expressed as:

$$VO = S \exp[-a \exp(-b\ GDPPC)], \quad (1)$$

[1] The outliers could be due to statistical discrepancies reported in the National Statistical Yearbook, especially between 2008 and 2011.

where *S* is the saturation level and *a* and *b* are the model coefficients that define the curvature of the function. In order to calculate these model coefficients via regression analysis, equation (1) is further converted into its linear form:

$$ln[ln(\frac{S}{VO})] = \ln a + (b\ GDPPC). \quad (2)$$

Similarly, the logistic function can be expressed as follows:

$$VO = \frac{S}{1+a\exp[-bt+c\ln⟦(GDPPC)]⟧}, \quad (3)$$

where *S* is the saturation level, *t* is the time series, and *a*, *b*, and *c* are the model coefficients that define the curvature of the function. Equation (3) can be converted into its linear form:

$$\ln(\frac{S-VO}{VO}) = \ln a + (-bt) + c\ln(GDPPC). \quad (4)$$

3.4.4.2. Results and Discussions

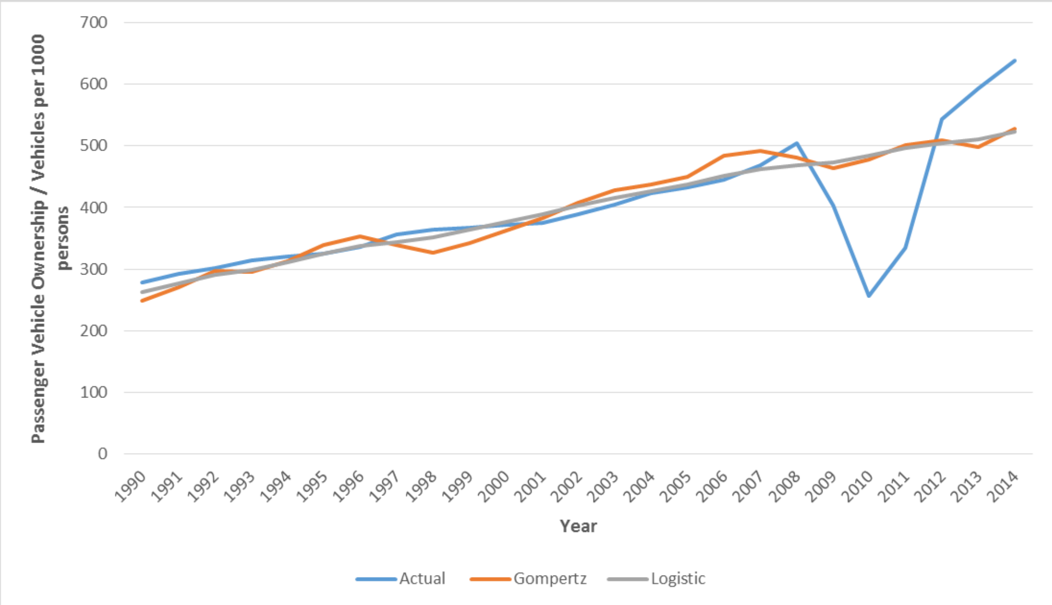
The estimated result of the growth of passenger vehicle ownership is illustrated in Table 7.

Table 7: Estimated Results of Gompertz and Logistic Models

Model	**Model Coefficient**			**R^2**	**MSE**
	ln a	**b**	**c**		
Gompertz	3.00	-0.0000557	-	0.554	0.145
Logistic	13.82	-0.0564	-1.205	0.558	0.211

Source: Author.

Figure 29: Graphical Comparisons between the Actual, Gompertz, and Logistic Vehicle Ownership



Source: Author.

As shown in Table 7 and Figure 29, both regression models fit the data relatively well, and the identical R-squared values of 0.55 imply that 55 percent of the variance in the passenger vehicle ownership can be found in the actual data. However, the Gompertz model illustrates a lower mean square error value than the logistic model. Furthermore, the lower range of the confidence intervals in the Gompertz model strengthens the evidence that the Gompertz model is a better fit than the logistic model.

3.4.5. Energy Demand and Emissions

3.4.5.1. Methodology

The energy demand of passenger vehicles per year is determined by the following formula:

$$ED_i = NV.ADT.PF_i.\frac{1}{FE_i}, \quad (5)$$

where ED_i is the energy demand of fuel type *i* (ktoe), *NV* is the number of passenger vehicles, *ADT* is the average distance travelled per year (km), PF_i is the proportion of passenger vehicles by fuel type *i* and FE_i is the fuel economy of passenger vehicles by fuel type *i* (km/l).

The corresponding emissions are defined by the following formula:

$$EM_{ij} = ED_i.EF_{ij}.GWP_j, \quad (6)$$

where EM_{ij} is the emission of greenhouse gas *j* from fuel type *i* (kg CO_2 equivalent), EF_{ij} is the emission factor of greenhouse gas *j* from fuel type *i* (kg/TJ), and GWP_j is the global warming potential of greenhouse gas *j*.

In this case, the fuel types *i* considered would be gasoline and diesel, from which carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the main greenhouse gases *j* emitted. Each of the default emission factors of the gases was obtained from the Intergovernmental Panel on Climate Change (IPCC) (see Table 8).[2]

Table 8: Emission Factors of Gasoline and Diesel Fuels

Fuel Type	Emission Factor (kg/TJ)		
	CO_2	CH_4	N_2O
Gasoline	69,300	33	3.2
Diesel	74,100	3.9	3.9

kg = kilogram, TJ = terajoule.

Source: Intergovernmental Panel on Climate Change.

Each greenhouse gas has its own global warming potential (GWP) value. The global warming potential of a gas is defined as the total contribution to global warming resulting from the emission of one unit of that gas with respect to one unit of the reference gas (CO_2), which is assigned a value of 1. Based on Table 9, 1 gram of N_2O has the highest impact on global warming, about 300 times higher than 1 gram of CO_2.

Table 9: Global Warming Potentials of Greenhouse Gases

Greenhouse Gas	Global Warming Potential
CO_2	1
CH_4	28
N_2O	265

Source: Intergovernmental Panel on Climate Change.

[2] The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science behind climate change.

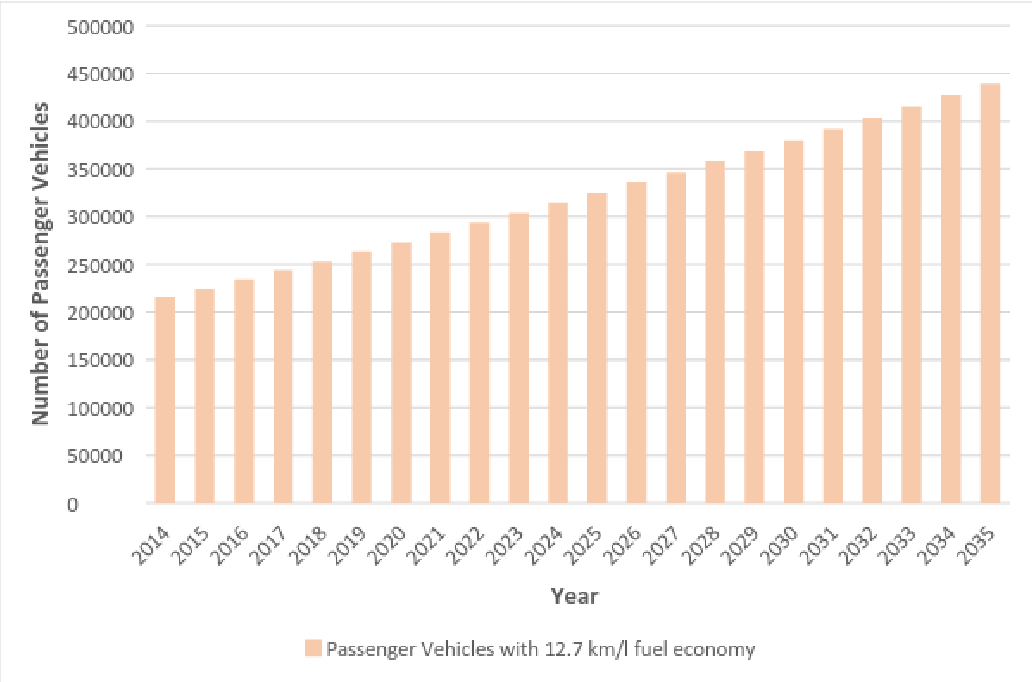
3.4.5.2. Scenarios

In order to analyse the impact of energy demand and emissions in road transport for various alternative scenarios, the business-as-usual (BAU) scenario was used as a base case. For the alternative scenarios, it is assumed that more efficient vehicles with higher fuel economies and electric vehicles will be implemented in the future.

<u>Business-as-Usual (BAU) Scenario</u>

In this scenario, the number of passenger vehicles is forecasted based on the passenger vehicle ownership growth, with the base year 1990. The average present fuel economy value in Brunei is about 12.7 km/l. Between 1990 and 2014, the average ratio of gasoline and diesel vehicles was about 69 percent to 31 percent. Therefore, it is assumed that the present efficiency of vehicles would be unchanged and the policies pertaining to more efficient vehicles would not be implemented in the future. This is illustrated in Figure 30, where all the vehicles are expected to have the average fuel economy value of 12.7 km/l.

Figure 30: Passenger Vehicles in the BAU Scenario in Brunei Darussalam



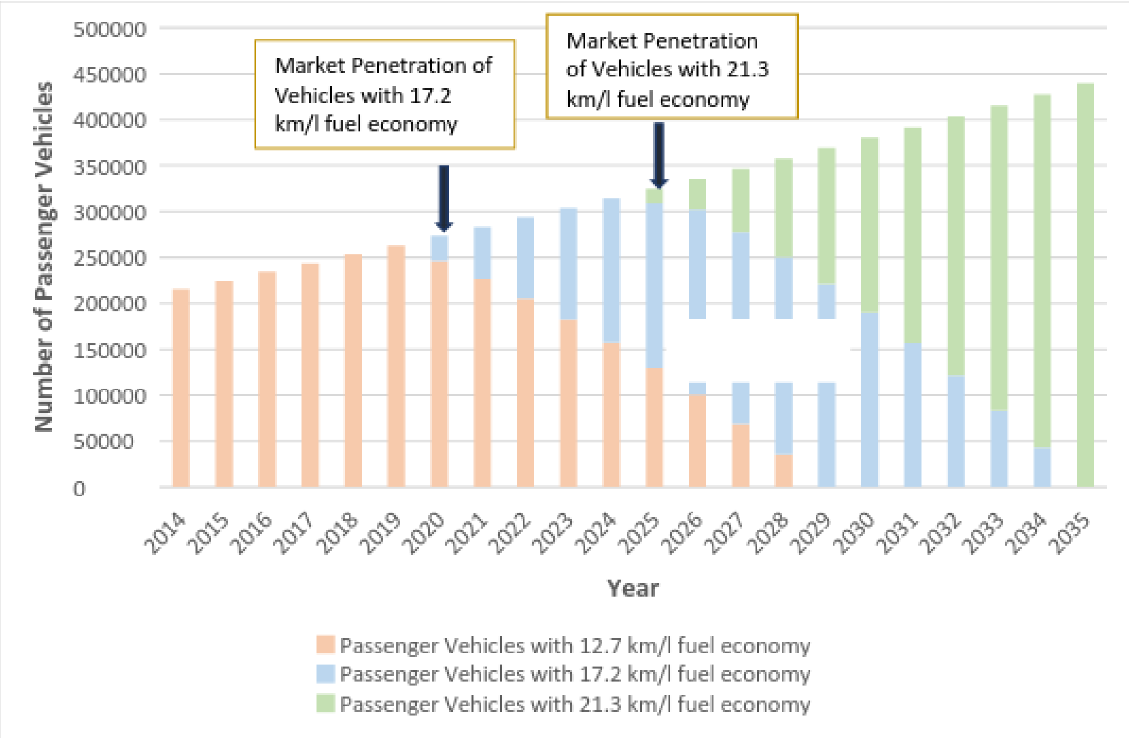
BAU = business-as-usual.
Source: Author.

Fuel Economy Improvement (FEI) Scenario

Fuel economy is one of the important factors in the reduction of energy demand and emissions in road transport. Many countries, including Singapore and Japan, have adopted the fuel economy regulation as a basis for energy efficiency in road transport. Fuel economy is basically an indicator to measure the relationship between the distance travelled by a particular vehicle and the amount of fuel being consumed by the same vehicle. It is generally expressed as kilometres per litre (km/l) and is used in Asia, continental Europe, parts of Africa, and Oceania. Miles per gallon (mpg) is commonly used in the Unites States, Canada, and the United Kingdom. The higher the value, the better the fuel economy of the vehicle.

Brunei is currently in the process of adopting the fuel economy regulation for all new vehicles, which are similar to those in the European Union (EU), for example 17.2 km/l by 2020 (EU 2016 equivalent) and 21.3 km/l by 2025 (EU 2020 equivalent).

Figure 31: Penetration of More Efficient Vehicles in Brunei Darussalam



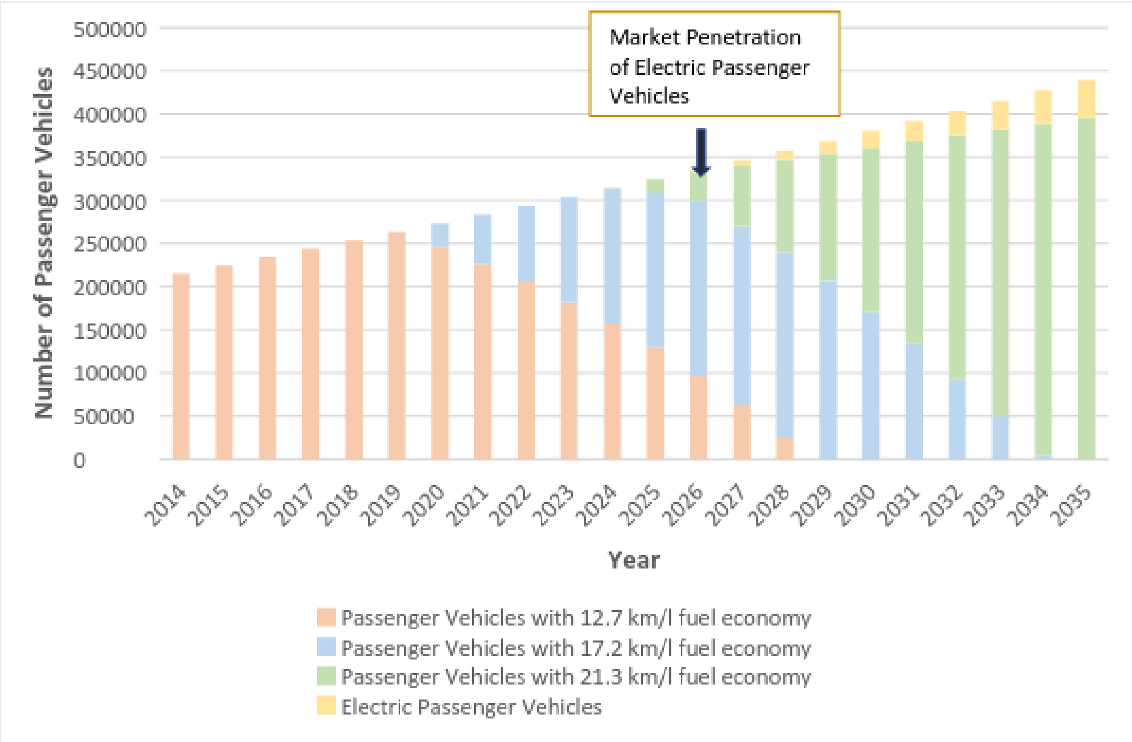
Source: Author.

Based on the above, the methodology in this scenario is devised in such a way that the penetration of more efficient vehicles will begin according to the respective regulations set up by the Government of Brunei Darussalam. As shown in Figure 31, 10 percent of vehicles with 17.2 km/l fuel economy are expected to enter into the market in 2020, while gradually decreasing the penetration of less-efficient vehicles. Similarly, by 2025, vehicles with 21.3 km/l fuel economy will be introduced, eventually phasing out all less-efficient vehicles by 2035.

Electric Passenger Vehicle (EPV) Scenario

An electric vehicle is a relatively new technology which relies entirely on electricity. It releases no tailpipe air pollutants and generates less noise at rest or in motion. Therefore, the adoption of electric vehicles would have significant net environmental benefits as they largely contribute to greenhouse gas emissions reduction.

Figure 32: Penetration of Electric Passenger Vehicles in Brunei Darussalam



Source: Author.

It is assumed that by 2035, 10 percent of the total passenger vehicles in Brunei will be electric-powered. Similar to the FEI scenario, electric passenger vehicles would gradually be introduced in 2026 until the 10 percent target is reached in 2035 (Figure 32).

Despite emitting no tailpipe air pollutants, a great deal of electricity is required to charge the electric vehicles at night or whenever required. If the electricity is sourced from a generic fossil power plant, the problem would be that the power plant itself would cause more emissions than a comparable gasoline or diesel-fuelled car coughed up from its exhaust pipe, as a higher amount of fossil fuel would need to be combusted to meet the demand. This eventually defeats the purpose of having electric vehicles while still relying solely on a thermal power plant for electricity.

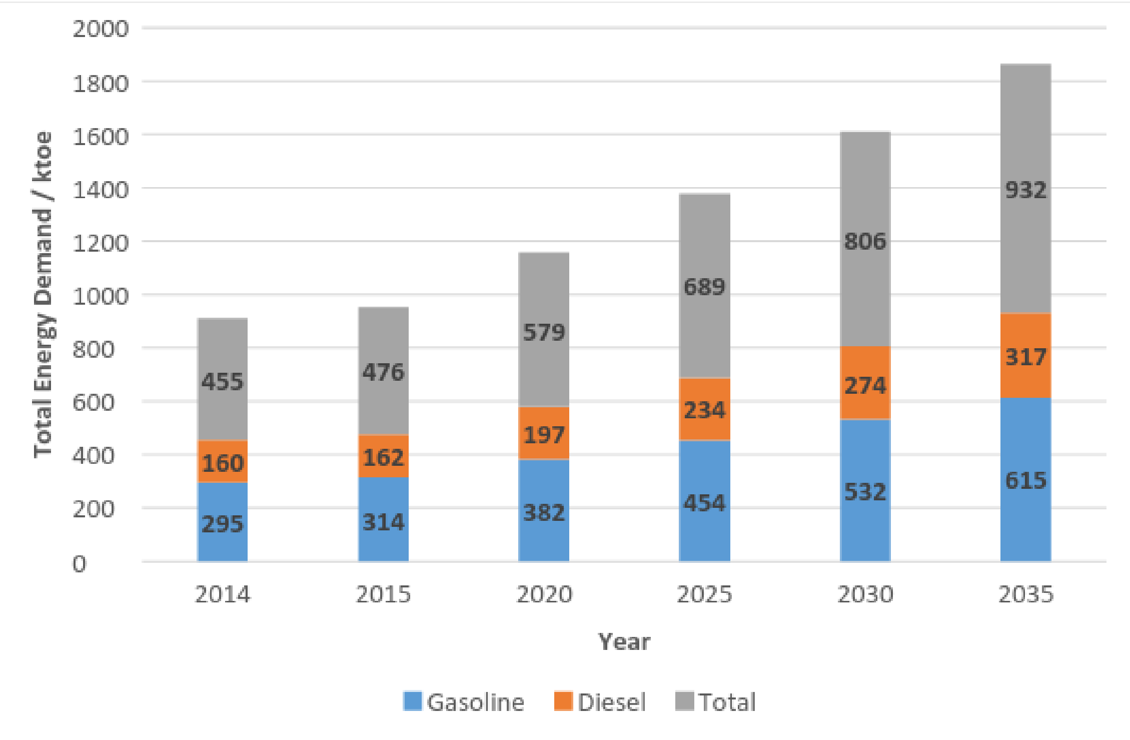
An efficient electric vehicles system requires a robust and reliable smart grid infrastructure with renewable energy integration and storage. By 2026, since Temburong would be the hub for smart grid infrastructure, all the electric vehicles would be supported by electricity coming from renewable energy.

3.4.5.3. Results and Discussions

Business-as-Usual (BAU) Scenario

The following graph in Figure 33 illustrates the energy demand from 2014 until 2035 based on the share of vehicles by fuel type.

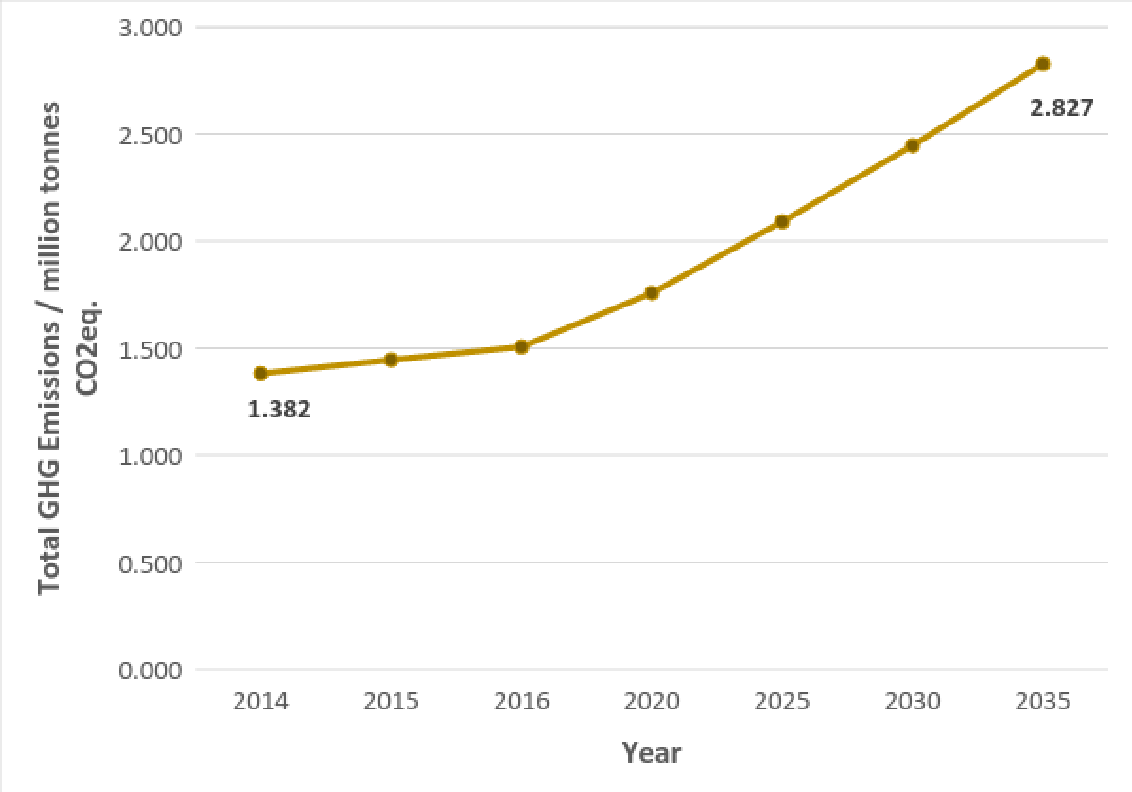
Figure 33: Total Energy Demand with Respect to Share of Vehicles by Fuel Type



Source: Author.

It is envisaged that the total energy demand will increase with an average annual growth of 3.31 percent from 455 ktoe in 2014 to 932 ktoe in 2035. Gasoline vehicles would continue to dominate ahead of diesel vehicles with an annual growth of 3.39 percent and 3.15 percent, respectively.

Figure 34: Corresponding Total GHG Emissions



GHG = greenhouse gas.

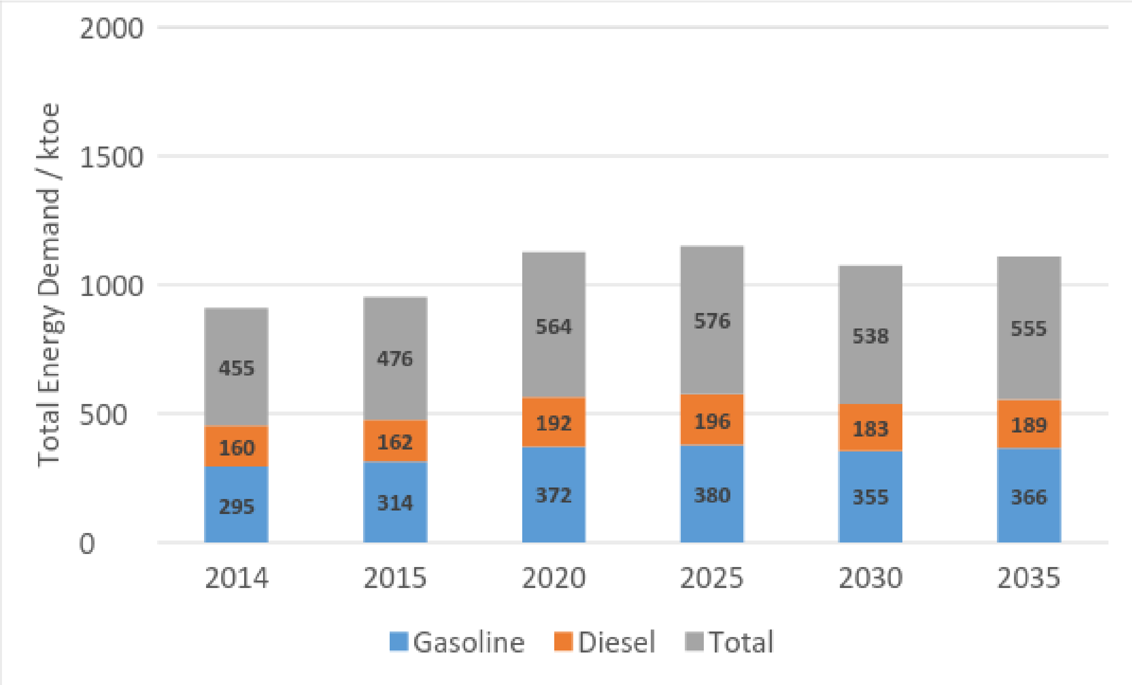
Source: Author.

In terms of the environment, total GHG emissions are expected to increase from 1.38 million tonnes of CO_2 equivalent (tCO_2e) to 2.83 million tCO_2e (Figure 34), corresponding to an average annual increase of 3.31 percent from 2014 to 2035. Since about 99 percent of the total GHG emissions comprise CO_2, the other gases can be neglected.

<u>Fuel Economy Improvement (FEI) Scenario</u>

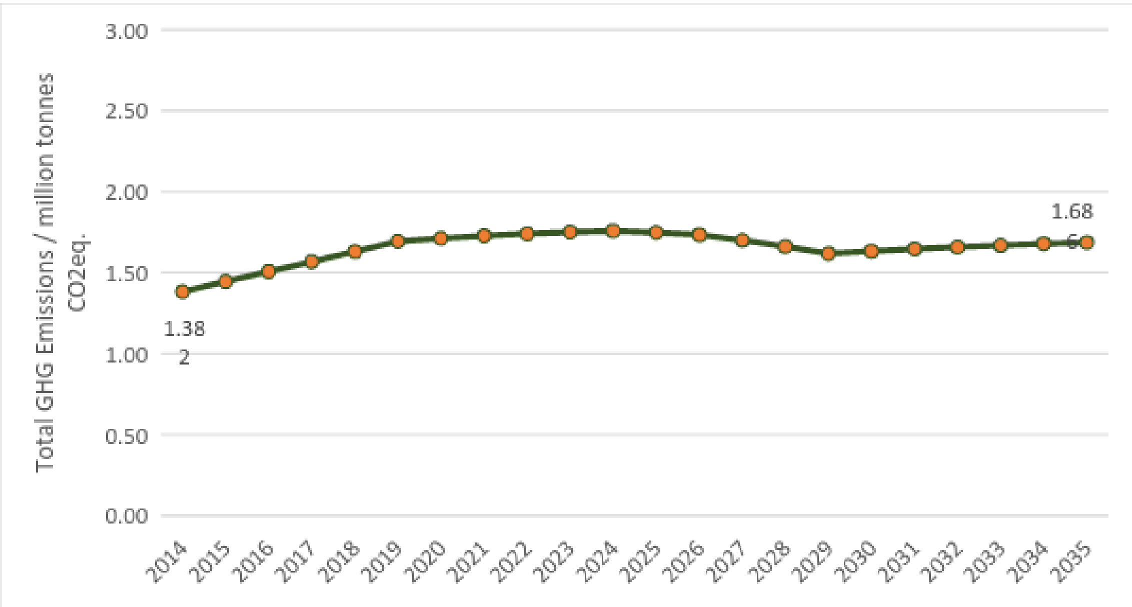
Due to the improvement in the fuel economy of passenger vehicles, the energy demand is expected to increase from 455 kilotonnes of oil equivalent (ktoe) in 2014 to 555 ktoe in 2035 (Figure 35), corresponding to about a 0.9 percent increase. The model predicts that there would be a reduction of about 40.3 percent in the energy demand in 2035 compared to the BAU scenario in the same year. As a result, the corresponding emissions would increase from 1.38 million tCO_2e to 1.69 million tCO_2e (0.9% increase) (Figure 36), with a reduction of 40.3 percent between the BAU and FEI scenarios in 2035.

Figure 35: Total Energy Demand for FEI Scenario



FEI = fuel economy improvement, ktoe = kilotonne of oil equivalent.
Source: Author.

Figure 36: Corresponding Total GHG Emissions of FEI Scenario



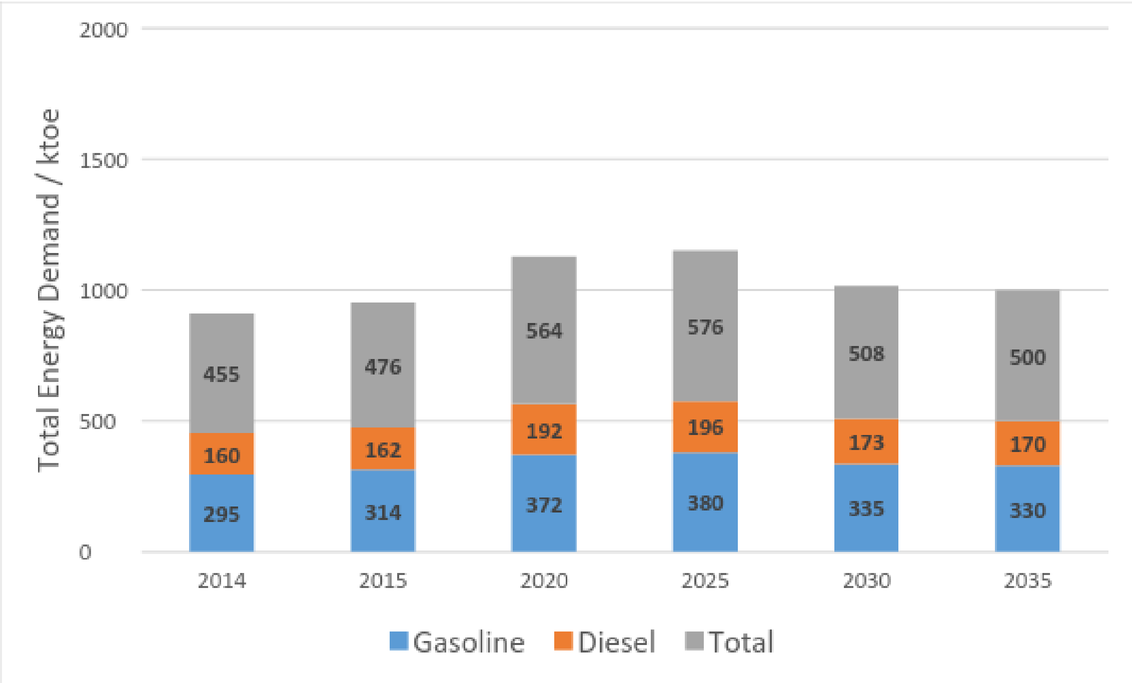
FEI = fuel economy improvement, GHG = greenhouse gas.

Source: Author.

__**Fuel Economy Improvement (FEI) + Electric Passenger Vehicle (EPV) Scenario**__

As shown in Figure 37, the inclusion of electric passenger vehicles in the FEI scenario is expected to further reduce the energy demand to 500 ktoe from the BAU and FEI levels of 932 ktoe and 555 ktoe, respectively, by 2035. It is expected that a reduction of about 46.3 percent from the BAU level can be achieved in this scenario by 2035.

Figure 37: Total Energy Demand in the FEI + EPV Scenario

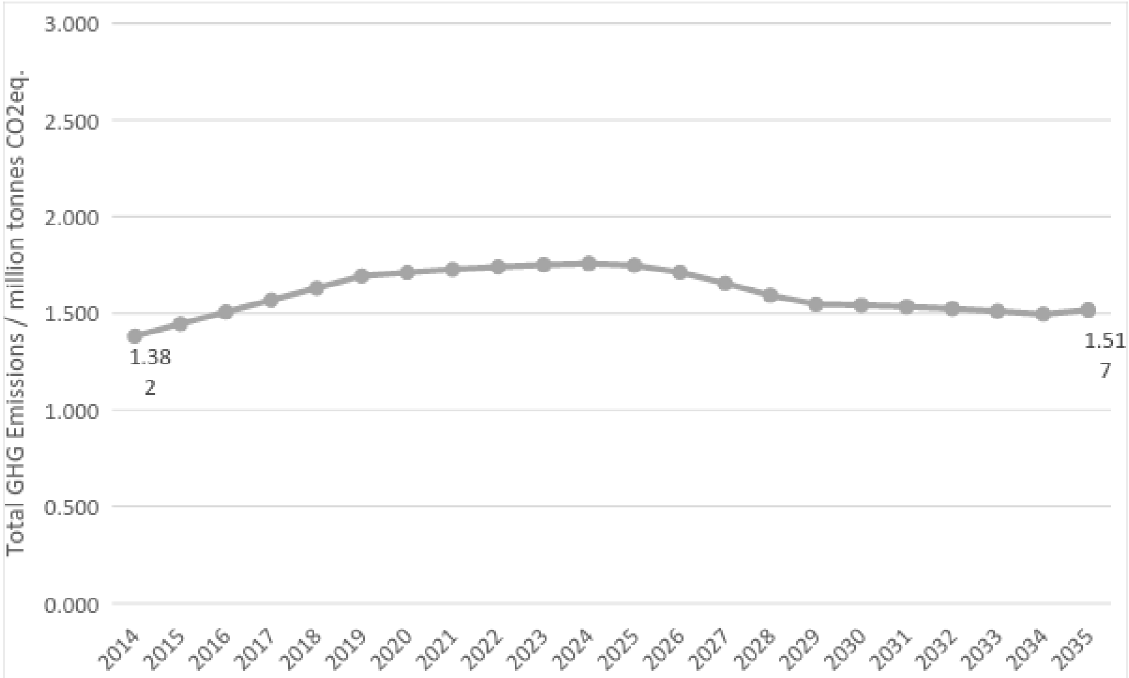


EPV = electric passenger vehicle, FEI = fuel economy improvement, ktoe = kilotonne of oil equivalent.
Source: Author.

The corresponding emissions would increase from 1.38 million tCO_2e to 1.52 million tCO_2e (0.4% increase) (Figure 38), with a reduction of 46.3 percent between the BAU and FEI scenarios in 2035.

The additional fuel savings from the introduction of electric vehicles are quite insignificant since the vehicles only constitute about 10 percent of the total number of passenger vehicles. However, mass production of electric vehicles could bring the overall cost down, potentially making them cheaper than conventional vehicles. In this case, beyond 2035 the fuel demand of 500 ktoe could be further reduced.

Figure 38: Corresponding Total GHG Emissions in FEI + PEV Scenarios



EPV = electric passenger vehicle, FEI = fuel economy improvement, GHG = greenhouse gas.

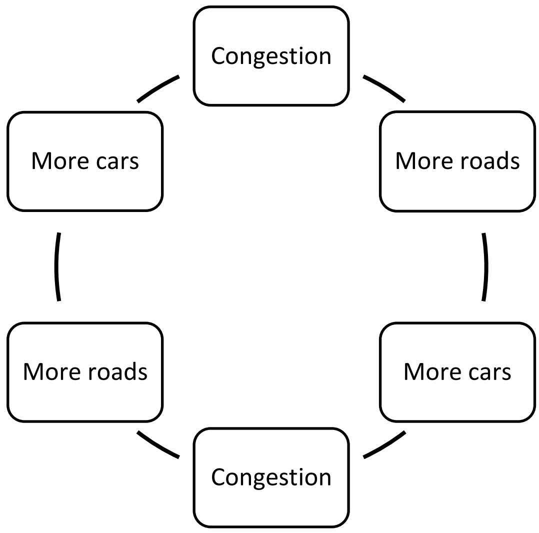
Source: Author.

3.5. Issues, Challenges, and Recommendations

The issues and challenges in achieving an energy-efficient and sustainable transport system are apparent in most countries, particularly in developing Asia, where the public transport system is considered unreliable and unsafe. Rapid increase in private motorisation, coupled with the use of low-quality fuels in relatively old and poorly maintained vehicles, has often resulted in inefficient use of fuels and hence high levels of air pollution.

Given that most developing countries are heavily reliant on roads for transport, they often tend to develop their transport system around road vehicles, by expanding infrastructure to cater to increasing private motor vehicles. Construction of more roads would only alleviate traffic congestions in the short term, however, and these new roads that cater to more vehicles would then give rise to heavier congestion, resulting in a vicious circle, as shown in Figure 39.

Figure 39: Vicious Circle of Vehicle-Oriented Development



Source: Buis (2009).

The real solution to the above cycle is not the expansion of roads and highways, but rather a balanced transport system that houses a variety of travel modes which will provide people with more options. Some possible answers are as follows:

- Provide funding for clean and efficient public transport, which includes fuel-efficient buses and light railways.
- Improve land-use and urban planning.
- Provide funding for cycling and pedestrian pathways. The funding would include incentive-based programmes that encourage walking and cycling, as well as carpooling.
- Limit or reduce funding for possible future road expansions.
- Establish and implement fuel economy regulations that allow for more efficient vehicles to enter the market and reduce the share of low-efficient ones in the market

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CHAPTER 4

Smart Grid

4.1. Smart Grid Systems for an Eco Town

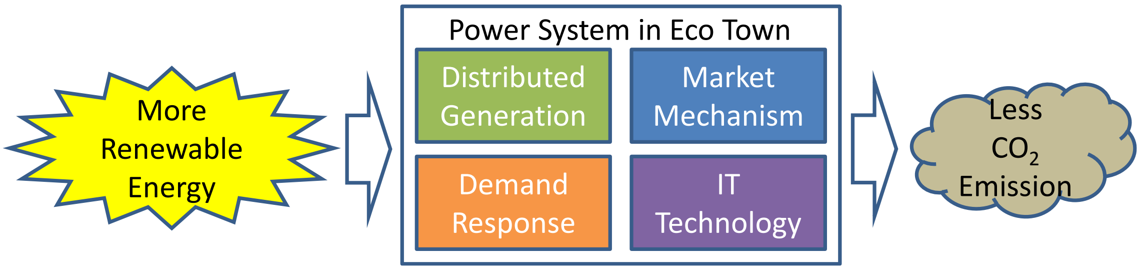
4.1.1 Power System in Sustainable Society

Carbon dioxide (CO_2) emissions and economic growth, expressed in terms of gross domestic product (GDP) are strongly correlated for countries worldwide. Similarly, GDP and energy consumption are also correlated. This implies that energy consumption needs to increase in order to achieve higher economic growth. As such, CO_2 emissions caused by the consumption of energy from fossil fuels are unavoidable. A notably large contribution to CO_2 emissions comes from coal power plants and, in fact, about 75 percent of global coal consumption is in the power sector. Yet many countries, including Japan, has set an energy policy goal of halving CO_2 emissions to contain the increase in temperature to within 2 degrees Celsius by 2050. This emissions reduction is required to establish a sustainable society in the future. To achieve this goal, the largest reduction in CO_2 emissions is expected in the power sector, by introducing renewable energy as much as possible.

Figure 40 depicts a power system with its components in a sustainable society. This system integrates more renewable energy to emit less CO_2 through the interaction of these components, each still new but nonetheless in place: distributed generation (wind power plants, mega-solar photovoltaic (PV) plants, rooftop solar PV systems on buildings), market system, demand response technologies and information technology (IT, i.e. data acquisition and communication).

The power system which enables to coordinate the interplay of the above-mentioned components is also known as a smart grid system. A smart grid is defined differently by several institutions, such as the European Union, World Economic Forum (WEF), US Department of Energy, and the International Energy Agency (IEA). The IEA defines a smart grid as an electricity network system that uses digital technology to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users (OECD/IEA, 2015). Such grids can coordinate the needs and capabilities of end-users and electricity market stakeholders in such a way that they can optimise asset utilisation and operation and, in the process, minimise both costs and environmental impacts while maintaining system reliability, resilience and stability.

Figure 40: Power System in a Sustainable Society



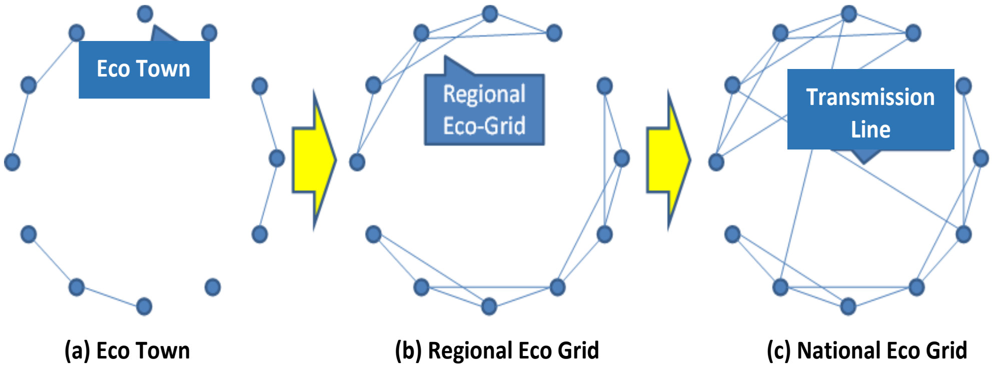
Source: Author.

4.1.2 Goal of the Smart Grid in an Eco Town

The goal of the smart grid in an eco town is to put into practice five key power system functions: (i) sustainability, (ii) dependability, (iii) flexibility, (iv) affordability, and (v) scalability.

'Sustainability' means avoiding climate change and limiting the use of fossil fuel and other natural resources. 'Dependability' means to supply stable and quality power for use in technology-intensive industries such as semiconductor device manufacturing and automotives. 'Flexibility' is also related to the sustainability and stability of the power system. Integrating variable renewable energy such as wind and solar power requires flexibility to establish a demand and supply balance using a dispatchable power source such as thermal and hydropower plants. 'Affordability' is obtained by avoiding extremely expensive technologies, such as nuclear fusion reactors, global super-grids, space solar PV, and artificial photosynthesis. 'Scalability' is especially important for the development of an eco town. Figure 41(a) shows an eco town in its early stage. Most eco towns are independent and a few are connected by transmission lines. Then, regional eco-grids are formed by connecting adjacent eco towns, as depicted in Figure 41(b). Finally, many transmission lines are added between regional eco grids to form a national eco grid, as in Figure 41(c). Scalability thus means that this evolution can be accomplished at a reasonable cost proportional to the system size. This scalability is obtained if each eco town has the four key elements from the early stage of the evolution. In particular, the market mechanism is essential even if the size of the power system is very small.

Figure 41: Scalable Evolution of Eco Towns



Source: Author.

4.2. Smart Grid Systems and Technologies, Including Storage Systems and Cost

4.2.1 Smart Grid Infrastructure

A smart grid system involves a complex arrangement of infrastructure whose functions depend on many interconnected elements. A smart grid system can be visualised as having four main layers whose elements are combined to create grid features that improve the grid's ability to achieve certain goals such as integrating more renewables, improving reliability, and reducing energy consumption (Madrigal and Uluski, 2015):

- The first layer is the 'hard' infrastructure, which is the physical component of the grid. This covers generation, transmission, and the distribution network as well as energy storage facilities.
- The second layer is telecommunications, which represent the telecommunication services that monitor, protect, and control the grid. This includes wide area networks, field area networks, home area networks, and local area networks.
- The third layer is data management, which ensures proper data mining and utilisation of data to facilitate smart grid applications;
- The fourth layer consist of tools and software technologies that use and process collected information from the grid to monitor, protect, and control the hard infrastructure layer and reinforce the grid to allow integration of renewable energy.

4.2.2 Reduction in Fossil Fuels with the Integration of Renewable Energy

The operation of conventional electric power systems is briefly described. The imbalance of supply and demand in electric power may cause a failure in production due to a power frequency problem or a blackout due to the ensuing shutting down of thermal power plants.

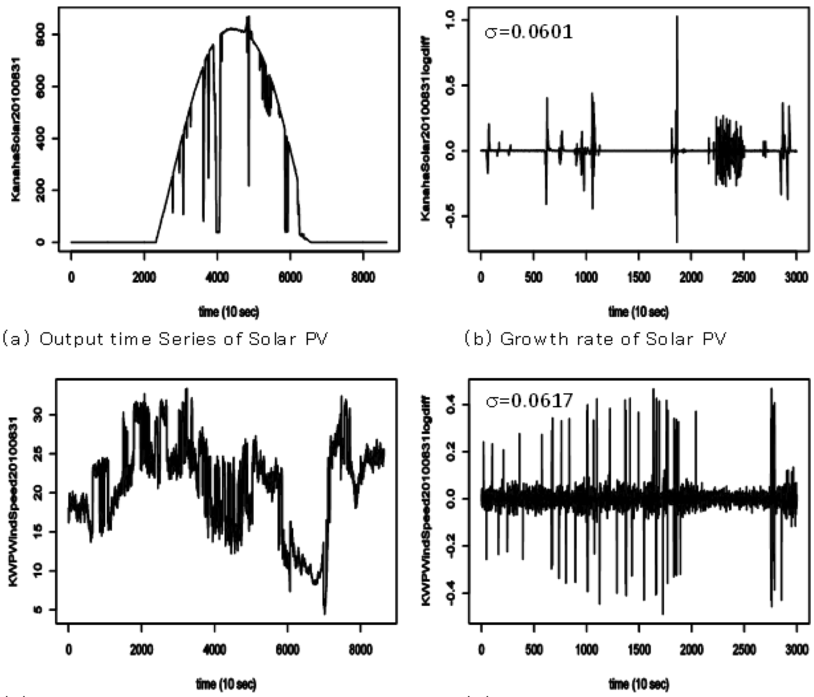
The usual operation of an electric power system requires centralised energy management to avoid the above failures and to maintain a stable supply of power.

Facilities such as power plants, power substations, and distribution and transmission lines have to play their own roles effectively for balancing supply and demand. For this purpose, rigorous operating procedures are determined and the central load dispatching office monitors the overall system and orders various load-dispatch instructions, such as parallel, parallel-off, power control, and operating switch.

The integration of renewable energy, including wind power, solar power, hydropower, biomass, and geothermal, into the power system to reduce the consumption of fossil fuels has been increasing in recent years. Wind and solar power notably have a characteristic not possessed by other renewables, which is output fluctuation, as depicted in Figure 42. Panels (a) and (c) show an output time series for solar PV and wind power, respectively, and panels (b) and (d) are the corresponding growth rate time series. The variability of output makes wind and solar power difficult to integrate into the conventional power system.

In the conventional system, load fluctuations are caused by fluctuations in demand. Load balance is restored by thermal and hydropower plants (Figure 43a). When wind power and rooftop solar PV power are integrated, load fluctuations increase as this characteristic of wind and solar PV power combines with demand fluctuations. If thermal and hydropower plants do not have a sufficient balancing capability, large electric storage devise such as batteries would be required (Figure 43b). However, if demand side management is introduced, electric storage on a moderate scale suffices to restore load balance. This implies that managing demand introduces additional balancing capability to the supply side of the system (Figure 43c).

Figure 42: Output Fluctuations of Renewable Energy



(a) Output time Series of Solar PV (b) Growth rate of Solar PV

(c) Output time Series of Wind Power (d) Growth rate of Wind Power

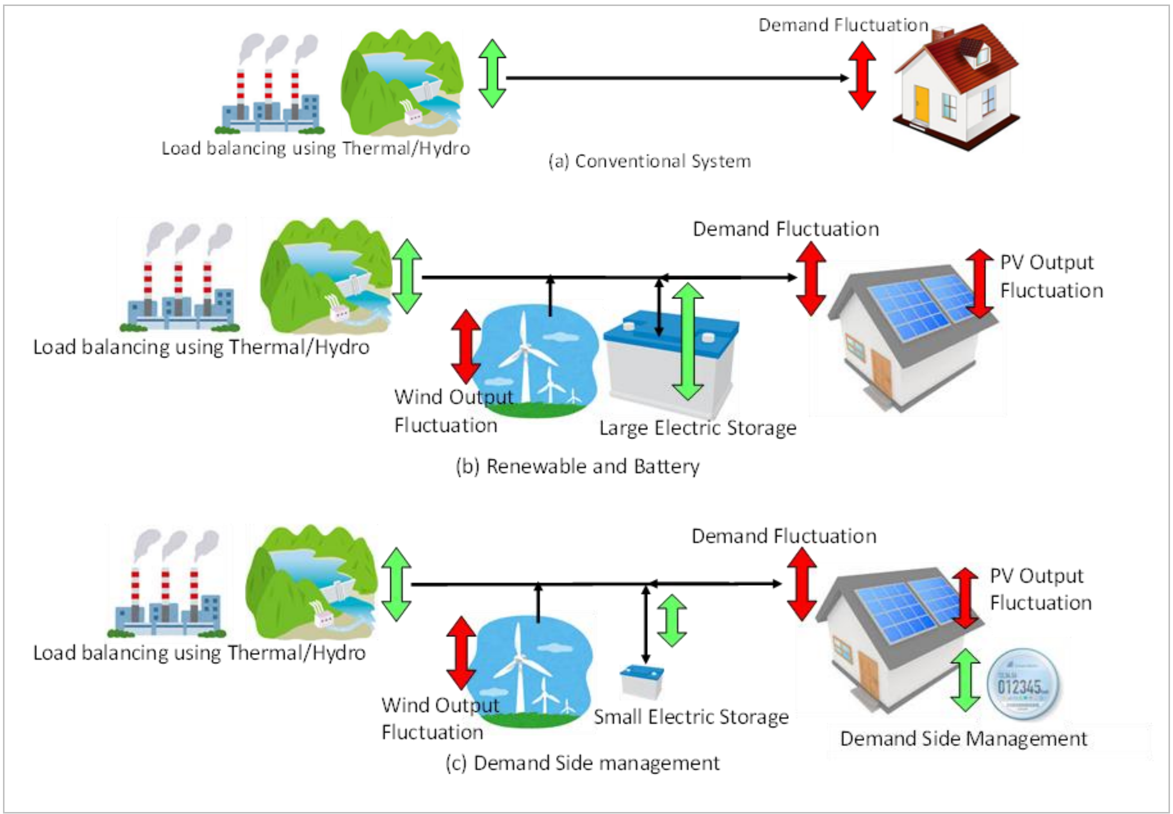
PV = photovoltaic.

Source: Author.

In an eco town, renewable energy will be integrated as much as possible to reduce fossil fuel consumption in order to establish a sustainable society. This is shown in Figure 44.

The first stage of an energy market is marked by long-term bilateral contracts. Generating companies and retailers conclude long-term bilateral contracts based on their own long-term forecasting of demand. Long-term bilateral contracts between generating companies and retailers will take up the largest share in the energy market.

Figure 43: Grid Integration of Wind and Solar PV



PV = photovoltaic.

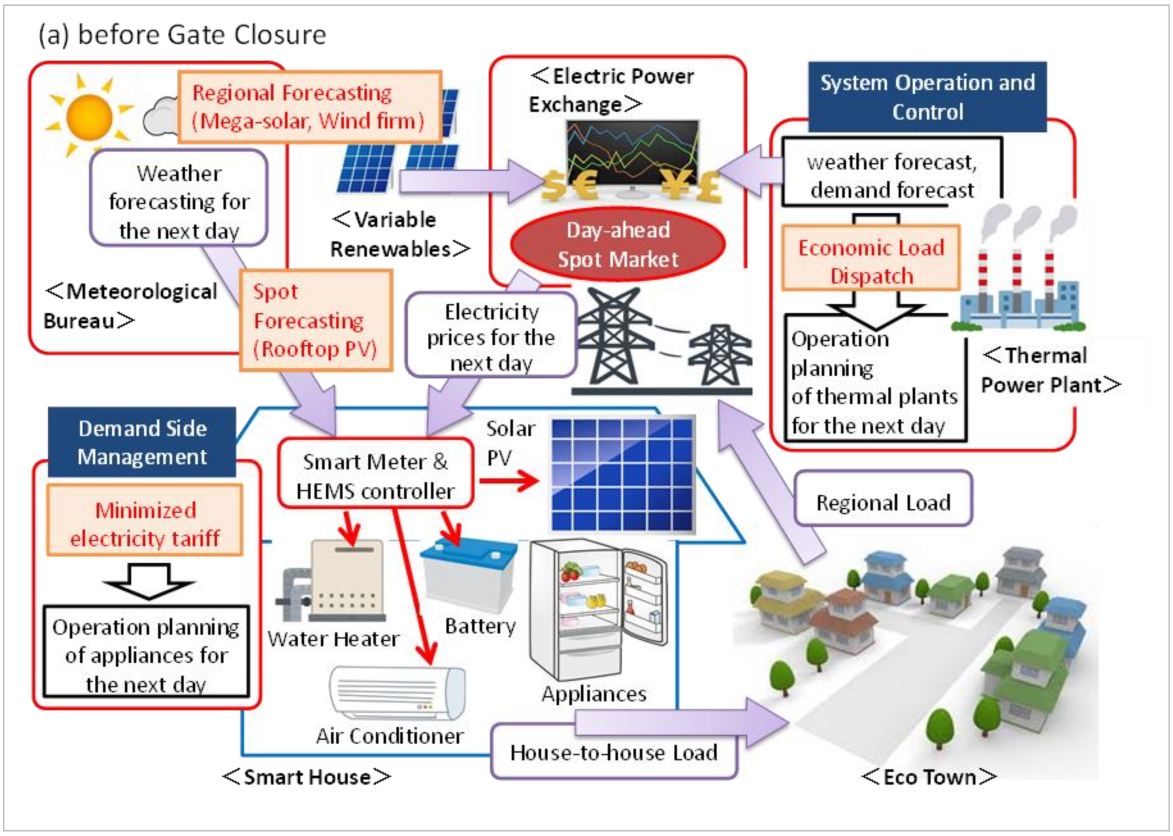
Source: Original drawings based on personal communication from Kazuhiko Ogimoto, University of Tokyo.

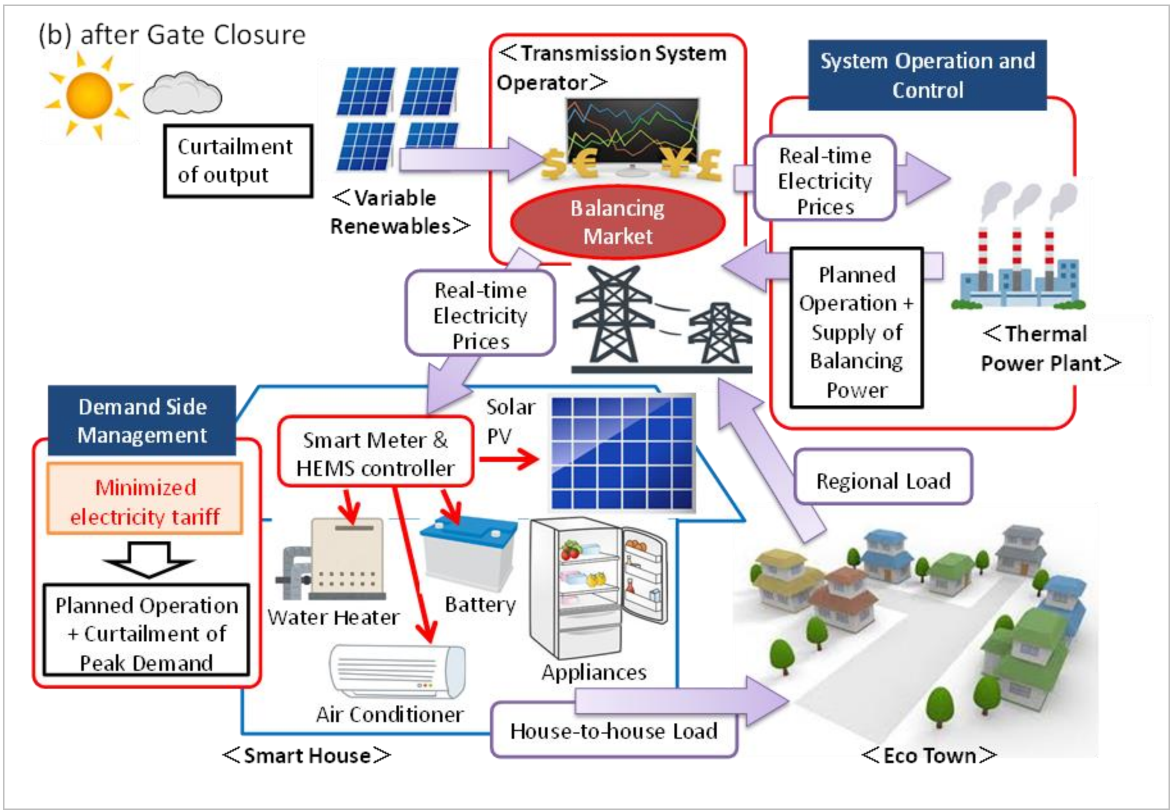
The second stage of the energy market is the day-ahead spot market (see Figure 44(a)). First, the meteorological bureau announces the weather forecast for the next day. Mega solar plants place their output electricity, estimated using the weather forecast, on the market. Home energy management systems (HEMS) located in smart houses estimate the house-to-house load by taking into account the output from rooftop solar PVs. Retailers estimate their regional load in eco towns by aggregating the load for all eco towns and bid on the market. Companies operating thermal power plants forecast demand and make operation plans based on economic load dispatch and place their supply on the market. The electric power exchange is responsible for operating the day-ahead spot market. The gate of the day-ahead spot market is closed before a certain time.

After the gate closure, the balancing market is opened by the transmission system operator (TSO). IT is key to making the balancing market possible, measuring demand in real time using smart meters and capturing the system-wide demand–supply imbalance through the supervisory control and data acquisition (SCADA) system. HEMS located in smart houses curtail peak demand to minimise the electricity tariff in each house, if the real-time electricity price rises. Companies operating thermal power plants place their balancing power on the market if they have extra capacity for generation. The TSO is responsible for operating the overall power system in the eco town, keeping demand and supply in balance. If PV output is too much to maintain a balance, the TSO can order mega solar plants to curtail their output.

As explained earlier, distributed generation, the market mechanism, demand response, and IT technology are the keys to integrating more renewable energy to emit less CO_2. Note that the power system in an eco town is clearly at the opposite end of the system operated by the central load dispatching office of an oligopolistic utility company.

Figure 44: Image of Eco Town before and after Gate Closure





Source: Original drawings based on discussions with Kazuhiko Ogimoto, University of Tokyo.

Table 10: Investment Cost and Levelised Cost of Electricity (LCOE) for Solar PV

		Investment Cost in 2015 (USD/kW)	LCOE in 2013 in California (USD/MWh)
Mega-Solar PV	Min	1522	-
	Max	2913	-
	Ave	2043	-
Rooftop PV	Min	1609	200
	Max	4739	316
	Ave	2130	-

PV = photovoltaic.
Source: International Energy Agency (IEA) (2014), *Energy Technology Perspective 2014*. Paris: IEA.

Table 11: Investment Cost and Levelised Cost of Electricity (LCOE) for CSP

		Investment Cost in 2015 (USD/kW)	LCOE in 2015 (USD/MWh)
CSP w/o storage	Min	3739	158
	Max	6348	263
	Ave	4609	191
CSP with 6-hour storage	Min	6348	146
	Max	9130	213
	Ave	7304	168

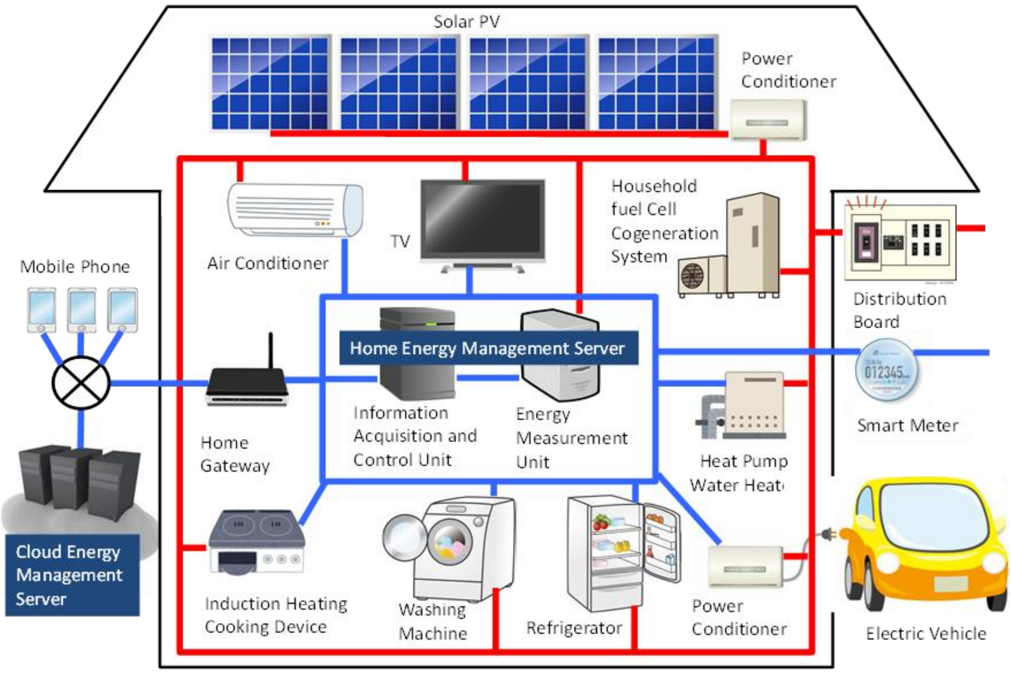
CSP = concentrated solar power.
Source: International Energy Agency (IEA) (2014), *Energy Technology Perspective 2014*. Paris: IEA.

Cost is another important factor to deploy renewable energy on a large scale. The investment cost and levelised cost of electricity (LCOE) are shown in Tables 10 and 11 for solar PV and concentrated solar power (CSP), respectively. The investment cost for solar PV is lower than that for CSP, but the LCOE for solar PV is higher than that for CSP. This means that solar PV is economically easy to implement, but recouping the investment takes longer. Note that the LCOE for CSP with storage is lower than that for CSP without storage, although the investment cost is higher. This is because storage allows for separating the acquisition of heat in the day and power generation after the sun sets. In a country where peak demand is in the early evening, this capability has a considerable economic advantage.

4.2.2. Key Technologies of Demand Side and Supply Side Management

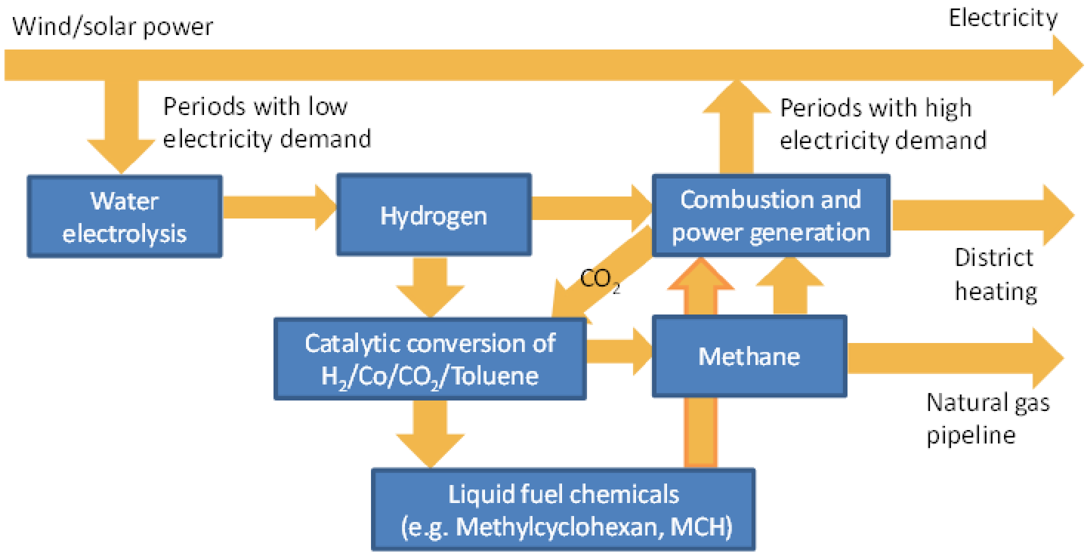
At the heart of demand side management is the HEMS, consisting of an energy measurement unit and an information acquisition unit (see Figure 45). The HEMS currently assumes time-based pricing, but it is ideal for dynamic pricing in the balancing market. The system makes it possible to manage power saving operations during the day (high price) and automatic operation at night (low price). In this system, smart appliances such as refrigerators, washing machines, air conditioners, television sets, heat pumps, water heaters, household fuel cell cogeneration systems, and induction heating cooking devices are controlled through a home gateway and a cloud energy management server via a mobile phone while outside the home. In addition to these appliances, DC air conditioners are efficient for residences or offices with a rooftop solar PV panel. This is because solar PV generates DC power and air conditioners use a DC brushless motor.

Figure 45: Key Technologies of Demand Side Management



Source: International Energy Agency (IEA) (2014), *Energy Technology Perspective 2014*. Paris: IEA.

Figure 46: Hydrogen Production in Wind and Solar Power

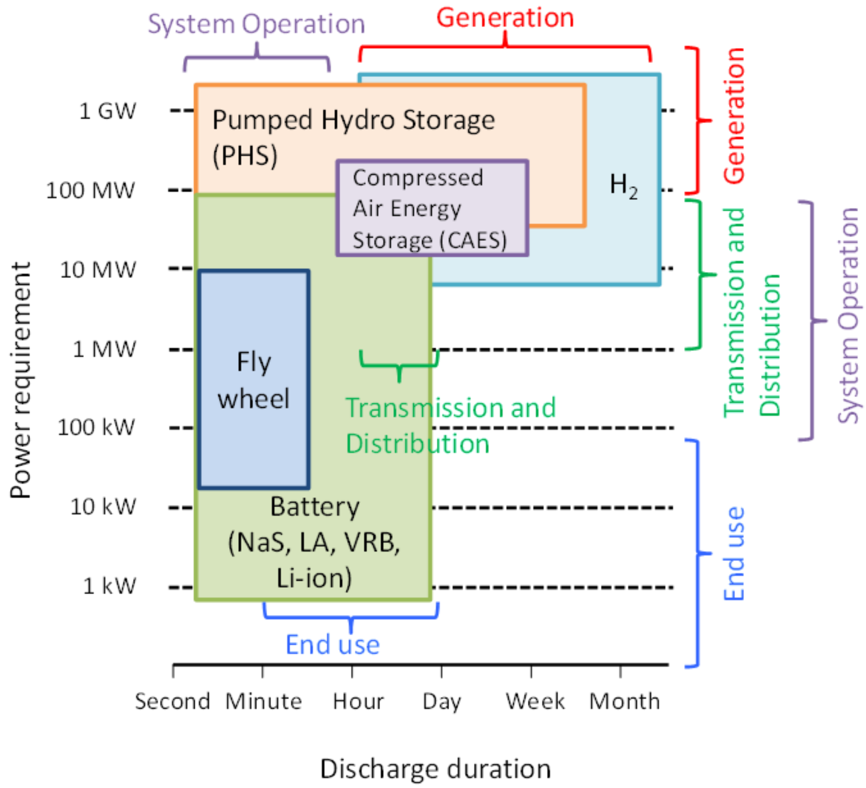


Source: Chiyoda Corporation (2014), 'SPERA Hydrogen System', IEA H2 Roadmap Asia Workshop, 26–27 June.

When the power system is modernised using market mechanism technology, demand response technology, and IT, but the system does not have adequate flexibility, technological innovations using various electricity storage technologies are needed. One of the most promising storage technologies is hydrogen production using extra wind or solar power (see Figure 46). During periods with low electricity demand, extra wind or solar power is used for water electrolysis to produce hydrogen instead of curtailing output power (IEA, 2014). The produced hydrogen can be stored in a high-pressure tank or as liquefied hydrogen. The stored hydrogen is combusted during periods with high electricity demand. Alternatively, methane is produced from a catalytic reaction of hydrogen and CO_2 in the exhaust gas of thermal power plants. Methane is liquefied at low temperatures and is stored in a tank in the same manner as storing natural gas. Another promising technology is a chemical reaction between toluene and hydrogen to synthesise methylcyclohexane (MCH), which is in a liquid state in an ambient environment (normal temperature and atmospheric pressure) (Chiyoda, 2014). Therefore, MCH is easy to store and easy to transport. This means that MCH could be exported, just like oil and natural gas.

Storage applications and technologies are characterised by the two-dimensional space of discharge power (MW) and discharge duration (hour) (IEA, 2014). For instance, application in generation is (100 MW–1 GW, hour–month), system operation is (100 kW–100 MW, second–hour), transmission and distribution is (1 MW–100 MW, hour–day), and end use is (100 W–100 kW, minute–day) (see Figure 47). Applications with large economic values are arbitrage in generation (US$80/MWh), load following in system operation (US$150/MWh), investment deferral in transmission and distribution (US$100/MWh), and off-grid in end use (US$330/MWh), where figures in parentheses are the economic value. Arbitrage in generation is storing low-priced power for later sale at a higher peak price, load following in system operation is charging power when generation exceeds demand or discharging power during times when demand exceeds generation, and investment deferral in transmission is the rescheduling of transmission investments.

Figure 47: Applications and Technologies of Electricity Storage



Source: International Energy Agency (IEA) (2014), *Energy Technology Perspective 2014*. Paris: IEA.

Meanwhile, distribution is relieving congestion on grid by placing storage units at the connection bottleneck and off-grid in end use is supplying power using solar PV with storage for small-scale users.

The appropriate technologies for the applications are shown in Figure 47 by coloured boxes, based on their characteristics of discharge power (MW) and discharge duration (hour). The investment costs for pumped hydro storage (PHS), H_2, and compressed air energy storage (CAES) are low in comparison to other storage technologies (Table 12). These three technologies are suitable for arbitrage applications in generation due to those most competitive levelised costs, PHS, CAES, and batteries (NaS) are suitable for a load following application in system operation. PHS, H2, and CAES are suitable for investment deferral application in transmission and distribution, and batteries are best for off-grid in end use. LA, VRB, and Li-ion batteries are relatively expensive but are easy to implement for small-scale users.

Table 12: Investment Cost and Levelised Cost of Electricity Storage

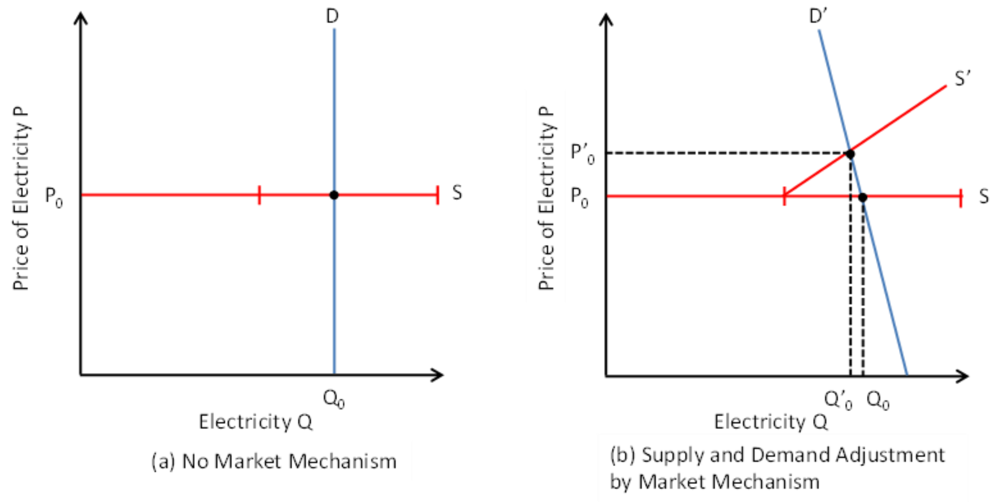
	Investment Cost		Levelised Cost of Electricity			
	Power (USD/kW)	Energy (USD/kWh)	Arbitrage	Load Following	T&D investment deferral	Off-grid
Pumped Hydro	500-4600	30-200	89-156	133-267	89-156	-
CAES	500-1500	10-150	67-178	111-289	89-178	-
Hydrogen	600-1500 (Electrolyser) 800-1200 (CCGT)	10-150	156-267	356-622	233-356	-
NaS Battery	300-2500	-	-	333-467	-	
Li-ion Battery	900-3500	-	-	-	-	767-1011
LA Battery	250-840	-	-	-	-	489-756
VRB	1000-4000	-	-	-	-	678-1011
Flywheel	130-500	-	-	-	-	

Source: International Energy Agency (IEA) (2014), *Energy Technology Perspective 2014*. Paris: IEA.

4.2.4. Competitive Market and Renewable Energy

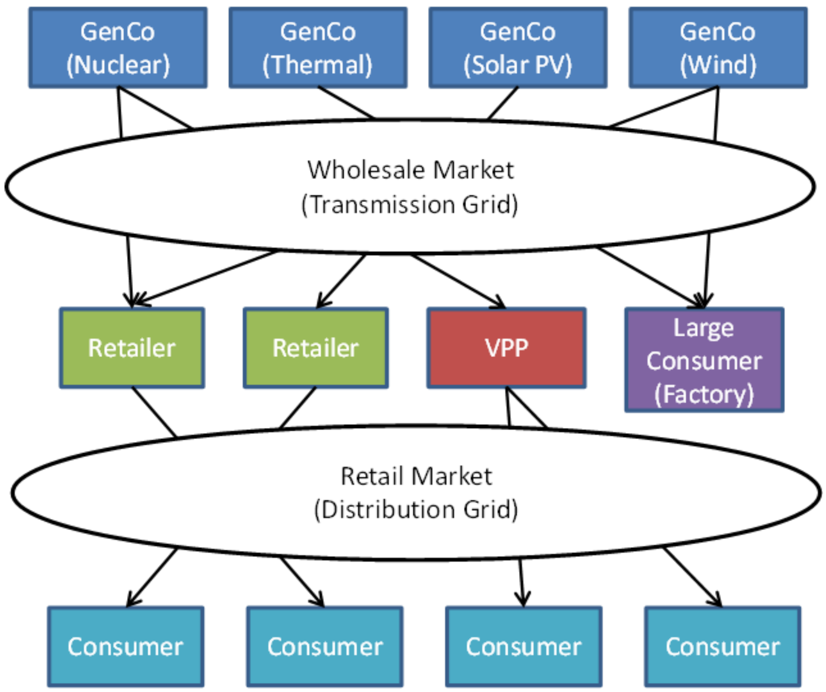
Energy is one of the factors of production of an economy. When there is no market mechanism, demand for electricity is presented graphically in Figure 48(a) by a vertical line D, which has no price elasticity of energy demand. Utility companies have the obligation to supply electricity Q_0 regardless of price P_0. On the other hand, when we have a market mechanism, demand for electricity is presented by the slant line D', which has price elasticity of energy demand (see Figure 48b). If the supply decreases due to output fluctuations in solar PV, a standby thermal power plant with higher costs supplies electricity S'. As a result, the price increases from P_0 to P'_0 and demand decreases from Q_0 to Q'_0.

Figure 48: Electricity Demand and Price



Source: Author.

Figure 49: Competitive Power Market



VPP = virtual power plant.
Source: D. Kirschen and G. Strbac (2004), *Fundamentals of Power System Economics*. Chichester, UK: John Wiley & Sons.

Prior to the liberalisation of the electricity industry that has been advanced by industrialised countries since the 1990s, regional monopolies were the most common electricity market structure globally. These monopolies lacked the flexibility to integrate renewable energy.

After liberalisation, competitive power markets were introduced (Kirschen and Strbac, 2004). One of the key market features of a competitive market is the existence of virtual power plants (see Figure 49) which mainly functions in balancing the market. They produce power by aggregating small-scale generating companies to supply balancing power. In a similar way, they produce negative power (decrease demand power) by aggregate consumer demand response to supply balancing power. This flexibility accelerates the integration of PV and wind power by promoting investment in balancing power. However, there are important new issues that arise with power markets. Liberalisation does not always lead directly to a lower electricity price. In Europe, electricity prices became higher because of the increase in fuel prices after the deregulation in the late 1990s. It has also been noted that investment in transmission and balancing capabilities is not sufficient for Europe's near-term needs.

4.3. Policy and Regulations

With one of the core objectives of ensuring sustainability through the integration of supply side and demand side measures, an eco town requires a robust and flexible grid structure that could be realised through the implementation of a smart grid. A smart grid controls and optimises electricity flow from both the demand side and supply side. It also provides better planning and management of existing and future electricity distribution and transmission grids, actively manages supply and demand, and enables new energy services and energy efficiency improvements (Connor et al., 2014).

In general, the benefits of a smart grid include the following: (*a*) deliver energy more efficiently, (*b*) provide the capacity to integrate more new renewable energy into existing networks, (*c*) provide the ability to manage increasing numbers of electric vehicles; (*d*) enable customers to have greater control of their energy; (*e*) provide a considerable capacity to reduce global carbon emissions, and (*f*) stimulate an array of new business models in the energy sector (WEF, 2010).

The establishment of an eco town provides a strategic direction and mandate to initiate smart grid development or pilot smart grid technologies. An eco town blueprint that specifies target reductions in consumption, carbon emissions, and generation from variable renewable energy technologies could form a basis for investments and set key parameters for policy and regulation related to smart grid deployment. The following identifies at least three main concerns in smart grid deployment that require policy and regulatory interventions: (i) funding smart grid investments, (ii) smart grid standards, and (iii) smart consumer policies.

4.3.1 Funding Smart Grid Investments

One of the key policy and regulatory concerns of smart grid development under an eco town framework is funding for smart grid investments. The costs of deploying smart grid technologies is often viewed as too high (high capital investment, high maintenance costs, and complex management requirements) given the uncertainty of return of investments associated with new technologies which is considered as the main economic barrier to smart grid deployment (OECD/IEA, 2015). Public utilities who will be responsible for smart grid investments must be assured of financial and regulatory support allowing them to recover their investments. Smart grid technologies can be broadly classified those that have been proven and largely tested whose risks of deployment are low and those that are more advanced but less tested whose risks of not achieving expected benefits may be high (Madrigal and Uluski, 2015; WEF, 2010).

Utility investments on proven and largely tested technologies should be considered as part of utilities expenditure programmes, and investments on deployment should be recovered through electricity tariffs. This may not require an additional regulatory process beyond what is being practiced under existing cost recovery models. On the other hand, for less tested technologies, this should require special funding schemes such as government grants (Madrigal and Uluski, 2015) or through public–private partnerships (WEF, 2010).

Large deployment of smart-grid technologies may also reduce electricity sales of utilities and will affect the service provider's financial viability. This may warrant a special regulatory treatment to ensure viability, and various cost recovery and performance incentive programmes may be employed (Madrigal and Uluski, 2015).

One of the cost recovery measures is the lost margin recovery scheme in which utilities are compensated for investments that cause reductions in electricity sales. Performance incentive programmes that make energy efficiency a profitable investment include performance targets and shared savings schemes.

4.3.2 Standards and Interoperability

With integration of variable renewable energy sources in eco towns, smart grid systems need to maintain optimal electrical conditions at all times. This can be achieved through coordinated operation of intelligent and flexible protection and control devices that can adapt to meet continuously varying system-level conditions and varying operating objectives (Madrigal and Uluski, 2015).

Communicating sensors and devices exchange information and interoperate. In order to interoperate effectively, a framework of interfaces, protocols, and consensus standards would be needed. Standards already exist for devices and sensors for distribution systems that require integration and interoperability. For smart grids, some of the interoperability standards are evolving and some are still being developed (Madrigal and Uluski, 2015; WEF, 2010; IEC, 2010). Interoperability standards that are still being developed include those of demand response technologies, smart inverters, electric vehicle charging standards, communication standards, and internet protocol (Madrigal and Uluski, 2015).

Smart grid deployment in eco towns, particularly those in developing countries, as much as possible should refer to and conform with smart grid standards that are developed by international standards institutes or agencies. Regulatory agencies should provide clear guidance on the use of existing standards and directions with respect to new and evolving standards.

4.3.3 Smart Consumer Policies

Smart grid benefits can be fully realised when customers are fully aware of incentives or service options that warrant behavioural changes. This would be the case for industrial customers and, to some extent, commercial customers where knowledge on energy management is high. For eco towns, most customers are residential customers and they are most often not aware of service options or pricing options needed to manage their demand. Smart grid customer policies could be categorised into feedback policies, pricing, and customer protection (OECD/IEA, 2011).

Under feedback policies, customers are expected to modify their behaviour when information related to energy services are visible. Consumer feedback could be provided through monthly electricity bills or through devices that provide information related to consumption and prices. Smart grid systems aim to optimise benefits by providing an automated response to consumption and demand according to price or other signals. This could be achieved through devices that are pre-programmed based on parameters set by customers. Smart grid and smart metering schemes are measures that provide automated end-user demand and energy efficiency response.

One of the objectives of smart grid deployment is to promote efficient consumption through pricing signals. Various smart customer studies have shown that time-differentiated pricing schemes stimulate behavioural changes and trigger demand response resulting in reduction of peak electricity demand. Smart grid deployment should be accompanied by pricing schemes that generate demand response benefits.

Under electricity pricing, at one end of the spectrum is flat-rate pricing while at the other end is real-time pricing. In between is time-of-use (TOU) pricing. Flat-rate pricing, which charges customers the same price throughout the day, does not encourage customers to shift demand to different times, while under real-time pricing, in which price is based on actual costs of generation, transmission, distribution, and supply, customers may not be able to reduce electricity demand during peak times. TOU pricing, on the other hand, takes advantage of the predictability of electricity costs on a daily and seasonal basis and thus reduces risks for customers by providing certainty (OECD/IEA, 2011).

There are other concerns related to consumer protection that need to be addressed when implementing a smart grid program. These include (*a*) privacy, ownership, and security issues associated with the availability of detailed customer data; (*b*) customer acceptance and social safety net issues associated with new types of electricity tariff rates; and (*c*) customer protection issues associated with remote disconnections made possible by smart grids (OECD/IEA, 2011). Regulatory agencies could take into consideration various lessons learnt in several pilot projects implemented internationally and take into account the emerging best industry practice in addressing these issues for eco towns.

4.4. Road Map and Guidelines

A road map is defined as 'a specialised type of strategic plan that outlines activities an organisation can undertake over specified time frames to achieve stated goals and outcomes' while the process by which a road map is created, implemented, monitored, and updated as necessary is termed road mapping (Madrigal and Uluski, 2015). Entities develop a road map when embarking on smart grid programmes. An officially sanctioned road map with an implementation plan becomes the basis for future smart grid activities.

4.4.1 Methodologies

Various methodologies and approaches exist for the preparation of a smart grid road map and can be found in the literature, including those from Sandia National Laboratories, the Electric Power Research Institute (EPRI), and the International Energy Agency summarised in Tables 13, 14, and 15, respectively.

Table 13: Sandia National Laboratory Phases of Technology Road Mapping

Phase 1: Preliminary activities	● Satisfying essential conditions ● Providing leadership/sponsorship ● Defining the scope and boundaries for the technology road map
Phase 2: Development of the technology road map	● Identifying the focus of the road map ● Identifying critical system requirements and targets ● Specifying major technological areas ● Specifying drivers and targets ● Identifying alternatives ● Recommending technology alternatives ● Creating a road map report
Phase 3: Follow-up activities	● Providing critique and validation of the road map ● Developing an implementation plan ● Reviewing and updating

Source: Author's compilation.

Table 14: EPRI Methodology for the Development of Smart Grid Road Maps

Step 1: Defining the vision	● Summarising what the utility intends to accomplish. Includes a mission statement that provides how the vision statement will be accomplished. Defining a vision statement begins with evaluating the essential business objectives and drivers that can be addressed by technology investments.
Step 2: Identifying the requirements	● Identifying and defining the requirements which include the needs and interactions of various actors and logical interfaces with the relevant attributes such as timing, accuracy, volume, and so on.
Step 3: Assessing and selecting the technology	● Ranking the technology by impact and effort. Selecting technology candidates for road map implementation. Conducting a gap analysis to identify the gaps between the current and desirable technology state.
Step 4: Planning	● Establishing fishbone diagrams that show the current situation as fish tail and the future objective as the head of the fish. The steps to be taken are the scales of the fish.
Step 5: Implementing the road map	● Delivering a report document, distributing to stakeholders, and performing project implementation and governance.

EPRI = Electric Power Research Institute.

Source: Author's compilation.

Table 15: IEA Methodology for the Development of Smart Grid Technology Road Maps

Step 1: Goals	● Clear concise set of targets that if achieved will result in the desired outcome
Step 2: Milestones	● Interim performance targets for achieving the goals, pegged to specific dates.
Step 3: Gaps and barriers	● List of potential gaps in knowledge, technology limitations, market structural barriers, regulatory limitations, public acceptance, or other barriers to achieving the goals and milestones
Step 4: Action items	● Actions that could be taken to overcome any gaps or barriers that stand in the way of achieving the goals
Step 5: Priorities and timelines	● List of most important actions that need to be taken to achieve the goals and the time frames taking into account interconnections among those actions and stakeholder roles and relationships

Source: Author's compilation.

The above-mentioned methodologies vary in detail but have common features in terms of the flow and sequencing of activities:

- The first steps in the preparation of the road map are the definition of visions, goals, and objectives.
- The last steps are often the preparation of the implementation and monitoring plans.
- In between could be a single step or a series of steps that identify drivers; gaps and barriers; identify, prioritise, and select technologies; and identify actions to be undertaken.

The use therefore of any of these methodologies would generate an appropriate smart grid road map for an eco town project.

4.3.2 Road Map Elements

Smart grid road maps vary from utility to utility, but they also have common elements: vision, drivers, theme areas, and pillars of action. Visions and objectives could be narrow, focusing mainly on the technology or the quality of services of the utility such as those of Pacific Gas and Electric in San Francisco and the State Grid Corporation of China. Alternatively, they could be broad, combining global, environmental, and social concerns at the national and utility levels such as those of Toronto Hydro-Electric System, the Provincial Electricity Authority of Thailand, and in France. This is shown in Table 16.

Table 16: Smart Grid Visions/Objectives of Selected Utilities

Pacific Gas and Electric, California (United States)	● Provide customers safe, reliable, secure, cost-effective, sustainable, and flexible energy services through integration of advance communications and control technologies
Toronto Hydro-Electric System (Canada)	● Climate protection and sustainable energy ● Energy security ● Customer satisfaction
Provincial Electricity Authority (Thailand)	● Increase energy efficiency and maintain the environment ● Improve quality of life ● Provide intelligent and green community in the future
State Grid Corporation of China	● Ultra-high voltage (UHV) grid as a backbone network and coordinated development of subordinate grids at all levels
France	● Attain emissions reduction objectives for greenhouse gases set for 2020 ● Compliance with European objectives for the integration of renewable energy

	• Maintaining the quality and security of supply in the electricity system • Consideration of social issues related to electricity supply

Source: Author's compilation.

A similar pattern can also be observed for smart grid drivers. Smart grid deployment can be driven by micro utility level concerns, by the structure of electricity markets or physical infrastructures, or by global environmental or national concerns. Drivers can be expressed as principles or can be initiatives or programmes of government agencies. This is shown in Table 17.

Table 17: Smart Grid Drivers of Selected Utilities

Pacific Gas and Electric, California (United States)	• Safety, reliability, and security • Customer empowerment • Efficient and flourishing electricity markets • Environmental sustainability • Consumer and technological advancement
Toronto Hydro-Electric System (Canada)	• Ontario Smart Grid Forum that promotes the industry's visions for the city's grid of the future • City of Toronto's 'Change is in the Air: Clean Air, Climate Change and Sustainable Energy Action Plan' that has a goal to make Toronto the renewable energy capital of Canada
Provincial Electricity Authority (Thailand)	• Energy security and environmental awareness • Customer demand for informative decisions • Society's demand for a safe and eco-friendly grid • Provincial Electricity Authority officers' demand for a safe and pleasant working environment
France	• Degree of intelligence in the electricity system and grids and the range of products and services associated with this capacity • Degree and type of decentralisation in the system and grids • Regulatory choices, business models, and the role of players affecting smart grids and electrical systems

Source: Author's compilation.

Pillars of actions of a smart grid road map could be presented under programme areas or functional priorities. As shown in Table 18, programme areas and functional priorities differ by utility and this is influenced mainly by the vision and the objectives in the deployment of smart grid systems. Table 19 presents the case of Pacific Gas and Electric where smart grid pillars of action are classified according to programme areas. On the other hand, a number of utilities present their activities in a time frame representing the deployment plan. Table 20 presents the smart grid deployment plan for Toronto Hydro-Electric System and the Provincial Electricity Authority of Thailand.

Table 18: Smart Grid Programme Areas/Functional Priorities of Selected Utilities

Pacific Gas and Electric, California (United States)	● Engaged customers ● Smart grid energy markets ● Smart utility ● Cross-cutting smart grid infrastructure
Toronto Hydro-Electric System (Canada)	● Climate protection and sustainable energy ● Energy security ● Customer satisfaction
San Diego Gas and Electric (United States)	● Customer behaviour/education ● Demand response ● Rate design
United States National Institute of Standards and Technology	● Wide area situational analysis ● Demand response ● Electricity storage ● Electric vehicles ● Applications (distribution grids management, advance metering infrastructure) ● Cross-functional areas (cybersecurity, network communications)

Source: Author’s compilation.

Table 19: Pacific Gas and Electric Smart Grid Programme Areas and Pillars of Action

Engaged Customers	Smart Energy Markets	Smart Utility	Cross-Cutting Smart Grid Infrastructure
• Leverage smart metres technology • Improve demand response resources • Support electric vehicles	• Improve forecasting techniques • Integrate large-scale renewable energy resources	• Enhance grid outage detection, isolation, and restoration • Enhance grid system monitoring and control • Manage grid system voltage and losses • Manage transmission and distribution asset condition	• Provide foundational and cross-cutting utility systems facilities and programmes necessary to continuously improve the application of smart grid technologies

Source: Author's compilation.

Table 20: Deployment Plan Phases and Pillars of Action

Toronto Hydro-Electric System		
Phase 1 (0–3 years)	**Phase 2 (3–10 years)**	**Phase 3 (10–25 years)**
• AMI integration • Early DR programmes • Cyber security systems • Early DA systems integration • Early DG programmes	• Substantial growth of DG installations • Integration of distributed energy storage systems • Early implementation of V2G • DA enhancement • Use of smart appliances at homes will grow	• Creation of micro-grids • Fully electrified transport • Decentralisation of energy generation will be completed • Fault anticipation
Provincial Electricity Authority of Thailand		
Planning and pilot project phase (2012–2016)	**Phase 2 (2017–2021)**	**Phase 3 (10–25 years)**
• Micro-grids • Integration of energy storage technologies • AMI implementation	• Large expansion of planning and pilot projects started during phase 1	• Decentralisation of power generation • Customers can buy or sell electricity

● Integration of customer-owned distributed generation technologies ● Enable options for information usage of electricity ● Use of smart appliances ● Incorporation of EVs and charging stations ● Electricity generation from waste ● Increase use of electric transport		● Virtual power plants creation ● Self-healing network ● Two-way power supply of electricity for EVs (V2G) ● Peak demand reduction through EV usage

AMI = advanced metering infrastructure, DA = distributed automation, DG = distributed generation, DR = demand response, EV = electric vehicle, V2G = vehicle to grid.
Source: Author's compilation.

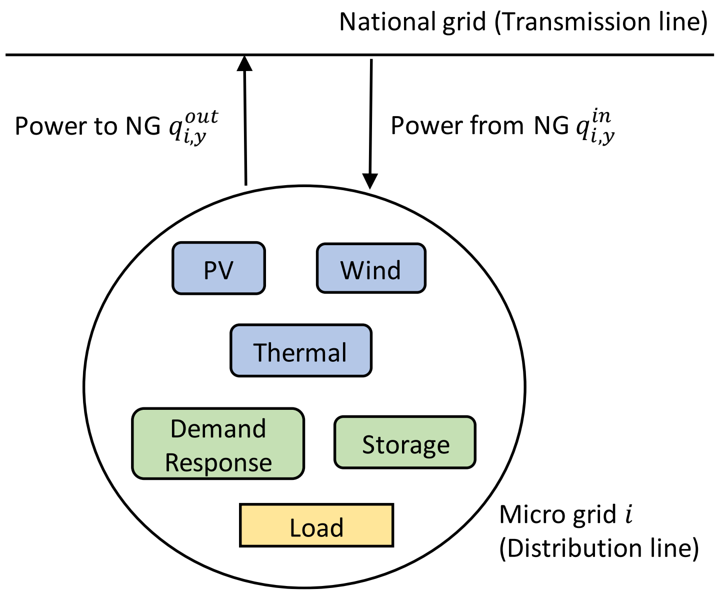
The review shows that though most road maps share common features, there is no standard format in presenting elements of a smart grid road map. Based on the existing smart grid road maps, Madrigal and Uluski (2015) in a study for the World Bank reviewed smart grid road maps of various utilities globally, and proposed five steps in defining the priorities of a road map:

- Step 1: Establish a vision and identify pillars. Under this stage, the long-term vision for smart grids is established which is based on energy sector goals. Also, key roles and responsibilities are defined.
- Step 2: Establish a timeline and goals for each phase. The timeline, either incremental or phases, for achieving smart grid vision is established.
- Step 3: Establish pillars of action. Pillars of action are established based on the road map vision. Also under this stage, risks, costs, and potential barriers are analysed.
- Step 4: Propose technology and functional applications. Under this stage, policies, regulations, and technology for each period and each pillar are suggested. The challenges associated with smart grid implementation are addressed.
- Step 5: Develop metrics and monitoring. This stage develops smart grid performance metrics to measure the success of implementation.

4.4. Cost Analysis of Smart Grid System in Eco Town

The following provides an outline of a methodology for analysing the cost and benefits of the smart micro grid system shown in Figure 50 (Rangarajan and Guggenberger, 2011; Morris et al., 2012). The methodology assumes the following basic parameters are obtained: (*a*) initial investment cost and maintenance schedule and cost per kilowatt for thermal power plants, transmission line (national grid), distribution line, solar PV power generation system, wind power generation system, electric storage system, and demand response equipment; (*b*) parameters of thermal power plants, such as generation capacity, fuel consumption rate, minimum up-time constraint, and minimum down-time constraint; (*c*) parameters of electric storage system, such as minimum discharge power, maximum discharge power, minimum stored energy, maximum stored energy, and efficiency; (*d*) scenario of fuel price used in thermal power plant (high, medium, low); (*e*) load profile (hourly and monthly) and growth rate; and (*f*) wind and solar profiles and fluctuation (hourly and monthly).

Figure 50: Smart Micro Grid System Connected to National Grid



NG = national grid, PV = photovoltaic.

Source: Author.

The outline of the methodology consists of the following six steps:

- Step 1: Selecting the case

We consider five cases in our cost–benefit analysis of smart micro grid systems. In the base case, all electric power is generated using only thermal power plants. The micro grid system is isolated from the national grid (transmission line) and therefore only a distribution line is used to supply power to consumers. In case 1, we consider the base case to connect the national grid, as depicted in Figure 50, in which electric power is transacted between two grids. In case 2, we consider case 1 with the integration of variable renewable energy, such as solar PV power and wind power. This means that we need fewer thermal power plants compared with case 1. In case 3, we consider case 2 with the addition of electric storage. This means that more variable renewable energy is integrated compared with case 2. We need fewer thermal power plants for the integration of variable renewable energy. In case 4, we consider case 3 with the addition of demand response capability. We need less electric storage for the integration compared with case 3.

- Step 2: Estimating the initial investment cost

We estimate the initial investment cost for the selected case at step 1 using basic parameters: initial investment cost per kilowatt for thermal power plants, transmission line (national grid), distribution line, solar PV power generation system, wind power generation system, electric storage system, and demand response equipment.

- Step 3: Setting the price parameter α

The parameter α is introduced to calculate the area price of electrical power $p_{i,t}$ in micro grid i at time t from generation cost $c_{i,t}^{j}$ of thermal power plants ($1 \leq j \leq K$) operating to supply power to consumers in micro grid i at time t,

$$p_{i,t} = \alpha \max_{1 \leq j \leq K} \{c_{i,t}^{j}\}. \qquad (1)$$

The initial value of α is set slightly larger than 1.

- Step 4: Calculating the yearly profit of generation $P_{i,y}$ in micro grid i

Effective load: The actual load subtracted by base load (hydro and nuclear power) $l_{i,t}$ in micro grid i at time t is defined by

$$l_{i,t} = q_{i,t}^{g} + q_{i,t}^{in} - q_{i,t}^{out}, \qquad (2)$$

where $q_{i,t}^{g}$, $q_{i,t}^{in}$, and $q_{i,t}^{out}$ are power generated by thermal power plants, power from the national grid to micro grid i, and power from micro grid i to national grid, respectively. $q_{i,t}^{j}$, $q_{i,t}^{in}$, and $q_{i,t}^{out}$ are calculated using the unit commitment model by minimizing the objective function,

$$\sum_{i=1}^{N} (C_{i,t} - E_{i,t}). \qquad (3)$$

The unit commitment model for the smart grid with variable renewable energy, electric storage, and demand response was formulated as a mixed integer problem (Ikeda et al., 2012; Ikeda and Ogimoto, 2013, 2014). Power generated by thermal power plants at time t is $q_{i,t}^{g}$ is summed power from each thermal power plant ($1 \leq j \leq K$),

$$q_{i,t}^{g} = \sum_{j=1}^{K} q_{i,t}^{j}. \quad (4)$$

The price of $q_{i,t}^{in}$ is calculated as the maximum of area price among area with $q_{i,t}^{out} > 0$,

$$p_t^{NG} = \max_{1 \le i \le N, q_{i,t}^{out} > 0} \{p_{i,t}\}. \quad (5)$$

The profit of generation in micro grid i at time t is calculated using

$$P_{i,t} = S_{i,t} - C_{i,t} - E_{i,t} - M_{i,t}, \quad (6)$$

where $S_{i,t}$, $C_{i,t}$, $E_{i,t}$, and $M_{i,t}$ are sales revenue $S_{i,t} = p_{i,t} q_{i,t}^{g} - p_t^{NG}\left(q_{i,t}^{in} - q_{i,t}^{out}\right)$, operation cost $C_{i,t} = \sum_{j=1}^{K} q_{i,t}^{j} c_{i,t}^{j}$, CO_2 emission cost $E_{i,t} = p_{CO2} \sum_{j=1}^{K} e_j q_{i,t}^{j}$, and maintenance cost $M_{i,t} = \sum_{j=1}^{K} m_{i,t}^{j}$, respectively. Here, $p_{CO2}$is CO_2 price per unit volume and e_j is the emission coefficient for thermal power plant j. $m_{i,t}^{j}$ is scheduled maintenance cost at t for thermal power plant j. Finally, the yearly profit of generation P_y in micro grid i is calculated using

$$P_{i,y} = \sum_{t=1}^{T} P_{i,t}. \quad (7)$$

- Step 5: Checking economic constraints

The economic constraints for investment for smart micro grid i are given by the positive net present value,

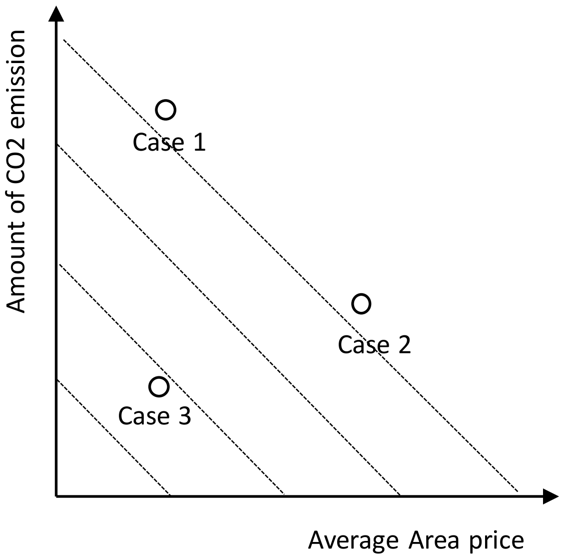
$$\mathrm{NPV} = \sum_{y=1}^{Y} \frac{P_{i,y}}{(1+r)^y} - I_i \ge 0. \quad (8)$$

Here, the investment cost for the national grid is not included. If the constraint (8) is not satisfied, we return to step 3 to increase parameter α, and then repeat steps 4 and 5. If the constraint (8) is satisfied, the calculation is complete.

- Step 6: Obtaining the price of electric power p_y and amount of yearly CO_2 emissions e_y

The location of cases is obtained in the plane of average area price and amount of CO_2 emissions. This is depicted in Figure 51. Equi-cost curves are shown by the dotted lines. This plot provides policymakers with information to decide which case is suitable for their purpose.

Figure 51: Image of Location of Cases in the Plane of Average Area Price and Amount of CO_2 Emissions



Source: Author.

4.5. Challenges and Recommendations

A smart electricity grid is an essential component of a fully functioning eco town or system of eco towns. A smart grid system allows optimal interaction of key elements such as distributed generation, demand response, IT, and market mechanism, and ensures that the overarching goal of establishing a sustainable society would be achieved in each eco town.

The deployment of smart grid technologies, however, faces major challenges for eco towns. As discussed, they include funding smart grid investments, interoperability of technologies, and consumer participation. The deployment as well as optimal operation and utilisation of smart technologies therefore requires policy and regulatory interventions.

Electric utilities are mainly responsible for investments of key smart grid technologies. Demonstration projects could be funded by grants from either public or private entities, but the replication of these projects in a system of eco towns requires a sustainable source of funding. Policy and regulatory mechanisms thus need to be established to ensure that utilities would recover their investments, whether on direct smart grid investments or to recover lost revenues due to energy efficiency improvements from smart grid deployment.

Smart grid technologies include communicating sensors and devices that exchange information and interoperate. Standards exist for some of these technologies but are still evolving for others. Regulatory agencies should ensure that smart grid technologies used in eco towns conform to existing international standards and should provide clear guidance and directions with respect to technologies that have new or evolving standards.

Smart grid technologies also elicit automated end-user demand and energy efficiency responses. To promote efficient consumption, this must be accompanied by the introduction of consumer incentives through pricing schemes. Time-differentiated pricing schemes are found to stimulate behavioural changes and trigger demand response.

To further promote consumer participation in demand response, regulatory agencies must also assure consumer protection, especially regarding privacy, ownership, and security issues related to access to detailed consumer data and other issues related to the social safety net associated with the introduction of new tariff rates, as well as protection associated with remote disconnections made by smart grid technologies.

Decentralised renewable electricity in eco towns, on the other hand, could be supplied not only by utilities or independent power producers but also by electricity consumers who are allowed to generate their own supply or to supply to the grid. Policy and regulatory interventions such as feed-in tariff and net metering schemes would also be required to provide incentives to consumers to invest in renewable energy technologies and be allowed to interconnect to the grid.

Considering the required level of investments and the evolution of technologies, the deployment of smart grid technologies should progress on an incremental basis. The development of a smart grid road map for eco towns is therefore critical. The road map could vary from one eco town to another and this will be influenced mainly by the priority objectives. If the main objective is for higher deployment of renewable energy technologies, smart grid technologies that could be rolled out initially would be those that facilitate higher integration of renewables. On the other hand, if the objective is to improve energy efficiency, then smart metering and other technologies that facilitate demand response would be prioritised for implementation.

Overall, in order to achieve a fully functioning smart grid system in an eco town that facilitates an interaction between variable energy supply and flexible demand through a smart distribution network, a strong policy and regulatory intervention is required to incentivise (*a*) the supply side, i.e. consumers to become producers of variable renewable electricity supply; (*b*) utilities to invest in standardised smart grid technologies; and (*c*) the consumption side, i.e. consumers to modify consumption patterns in response to time-differentiated pricing schemes.

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CHAPTER 5

Conclusions

Rapid urbanisation has led to a remarkable rise in energy demand across countries in the Association of Southeast Asian Nations (ASEAN) and East Asia in the last few years, particularly the use of fossil fuels in the power and transport sectors. The International Energy Agency (IEA) expects the total primary energy demand in the ASEAN region to increase by 80 percent in 2040.

Therefore, energy efficiency and conservation (EEC) is the main policy agenda towards achieving energy sustainability across ASEAN and East Asia. One of the strategies to achieve energy sustainability is to introduce low-carbon or energy technologies in the town planning to boost energy efficiency and decrease the use of fossil fuels, through the concept of eco towns. This will help manage the rapidly growing energy consumption levels in urban areas and achieve a more secure and sustainable energy future of the country.

For Brunei Darussalam, the town of Bangar in the district of Temburong would be the ideal candidate for an eco town model as Temburong is highly regarded as the 'Green Jewel of Brunei'. Furthermore, the Ministry of Development has raised the possibility of establishing an eco town or smart town within the district to reduce its carbon footprint through application of green and environmentally friendly technology.

This study looked into three main areas that will potentially achieve the energy efficiency aims, mainly through a combination of individual modelling and analysis and in an integrated approach: building technologies, transport, and smart grids.

Building Technologies

Green building rating systems have been developed and implemented by many countries as a way to address the needs to sustainably utilise natural resources while mitigating negative environmental impacts. Singapore and Malaysia are two ASEAN countries that have successfully embarked on such a rating system with achieved benefits such as reduction in water and energy bills, improved indoor environmental quality, improved connectivity and community living, and others.

A reduction in energy consumption in buildings could be achieved through the implementation of building energy regulations such as energy standards and codes that cover all aspects of a building (structural, construction, drainage, etc.). Such regulations currently exist in nearly all developed and some developing countries (Organisation for Economic Co-operation and Development members), regardless of the political, social, and economic situation in these countries. Singapore, Malaysia, Thailand, Indonesia, Viet Nam, Japan, the Republic of Korea, and Brunei Darussalam are a few countries that have adopted building policies and regulations.

Current building technologies comprise passive and active design strategies, for which the former should be adopted first before considering the latter for any energy-efficient building. The passive design strategy of a typical energy-efficient building considers the building's orientation, facades, use of insulating materials, use of daylighting, and natural ventilation. The active design strategy includes the use of energy-efficient air-conditioning and lighting systems coupled with a sophisticated energy management system and lighting control system. As the development and advancement of energy-efficient technologies are on the rise, the use of information and communications technology (ICT) could be integrated which allows for efficient management of energy usage of public and corporate facilities and infrastructures. The use of solar thermal cooling as well as district cooling systems could also contribute to significant energy savings and reductions in greenhouse gas (GHG) emissions.

To assess the potential energy efficiency improvements through the adoption of energy-efficient building technologies, an energy use index (expressed in kWh/m^2/year) is used to determine and compare building energy efficiencies. For an eco town, a more detailed assessment of the energy saving potential can be carried out using established energy simulation software on various building types, such as offices, schools, shopping centres, higher education institutes, hospitals, and others.

Issues, challenges, and recommendations are listed in the table below:

Issues	Challenges	Recommendations
1. Lack of direction and framework 2. Weak project management 3. Changing requirements 4. Changing project personnel	1. Allocation of project budget for advance planning	1. Conduct a foresight planning 2. Establish a project management framework and master plan 3. Establish owner's project requirements
1. Different interpretation in developing an eco town	1. Consistency of competency in the town planning, design, project management, and construction teams	1. Identify and establish a green building rating system for the eco town project. 2. Use advanced design software with simulation capabilities

Transport

A common characteristic of today's developing cities is the rise in motorisation and relatively poor public transport infrastructure. Hence, public transport is insignificant compared to private transport. The consequences of this are not only economic loss, but also, to the same extent, energy loss and air pollution from wasted energy combustion during traffic jams. To mitigate these problems, policy measures applying the ‘Avoid, Shift, Improve’ (ASI) approach are being used for policy making or analysis:

- Avoid: pursuing less traffic through compact city design or change of lifestyle
- Shift: using public transport with higher efficiency instead of private vehicles
- Improve: increasing use of greener and more efficient technologies and implementation of necessary policies.

There is generally a non-linear correlation between passenger vehicle ownership and gross domestic product (GDP) per capita in the countries in ASEAN and East Asia, with ownership growing at a relatively slower rate at the lowest level of per capita GDP and then increasing until reaching a saturation level at the highest per capita GDP level. Similarly, energy demand in these countries has been rising generally.

In Brunei Darussalam, road transport is one of the sectors with a significant energy demand. The increase in population, and hence private vehicles, has been accompanied by an increase in GHG emissions of approximately 5 percent since 1990. As a result of overwhelming use of private vehicles, Brunei’s public transport is still in its infancy. Therefore, the Land Transport White Paper and the Land Transport Master Plan that outline the policies and strategies to improve the country’s transport infrastructure were introduced.

A study on forecasting the passenger vehicle ownership and the corresponding energy demand and GHG emissions up to 2035 using a regression model was conducted based on three different scenarios: the business-as-usual (BAU), fuel economy improvement (FEI), and electric passenger vehicle (EPV) scenarios. The BAU scenario was used as a base case where no policy measures on energy efficiency would be implemented, whereas the FEI and EPV scenarios consider penetration of vehicles with higher fuel economy values and penetration of electric vehicles, respectively. For the FEI scenario, energy savings of 397 kilotonnes of oil equivalent (ktoe) would be achieved from the BAU level in 2035, corresponding to a GHG emissions reduction of 1.14 million tonnes of CO_2 equivalent. Penetration of electric vehicles in the EPV scenario would further increase the savings to 432 ktoe, corresponding to a GHG emissions reduction of 1.31 million tonnes of CO_2 equivalent.

Issues, challenges, and recommendations are listed in the table below:

Issues	Challenges	Recommendations
1. Fast pace of growth in private motorisation 2. Faster growth of road infrastructure 3. Minimal use of public transport 4. Lack of policies in promoting fuel diversification and use of energy-efficient vehicles	1. How to saturate the growth of low-efficient vehicles and increase the use of more efficient ones 2. Allocation of budget for urban planning	1. Establish and implement fuel economy regulations which will allow more efficient vehicles to enter the market and reduce the share of low-efficient ones in the market 2. Improve land use and urban planning for a compact city, provide more walkways, and reduce car trips 3. Improve ridership and expand the public transport system

Smart Grid

Smart grids play an important role in eco towns in that they help in the reduction of GHG emissions. A smart grid aims to put into practice sustainability, dependability, flexibility, affordability, and scalability:

- Sustainability: avoiding climate change and limiting the use of fossil fuel and other natural resources
- Dependability: supplying stable and quality power for use in technology-intensive industries, such as the semiconductor device manufacturing and automotive industries
- Flexibility: also related to the sustainability and stability of the power system. If variable renewable energy, such as wind and solar power, is integrated, flexibility is necessary to establish a balance between demand and supply using dispatchable power sources, such as thermal and hydropower plants.
- Affordability: obtained by avoiding extremely expensive technologies, such as nuclear fusion reactors, global super-grids, space solar photovoltaic (PV), and artificial photosynthesis
- Scalability: especially important for the development of an eco town.

Generally, a smart grid (*a*) delivers energy more efficiently, (*b*) provides the capacity to integrate more new renewable energy into existing networks, (*c*) provides the ability to manage increasing numbers of electric vehicles, (*d*) enables customers to have greater control of their energy, (*e*) provides a considerable capacity to reduce global carbon emissions, and (*f*) stimulates an array of new business models in the energy sector. However, smart grid deployment requires policy and regulatory interventions in terms of funding, standards, and policies that affect consumers. Public utilities must be assured of financial and regulatory support allowing them to recover their investments. Any smart grid deployment should refer and conform to smart grid standards that are developed by international standards institutes or agencies. Furthermore, public awareness of smart grids is important so that customers can fully capture the incentives or service options that warrant behavioural changes.

One of the first steps for the realisation of a smart grid is the establishment of a smart grid road map. Generally, there are five steps in defining the priorities of a road map, based on global smart grid road maps of various utilities:

- Step 1: Establish a vision and identify pillars. Under this stage, the long-term vision for smart grids is established based on energy sector goals. Also, key roles and responsibilities are defined.
- Step 2: Establish a timeline and goals for each phase. The timeline, either incremental or phases, for achieving the smart grid vision is established.
- Step 3: Establish pillars of action. Pillars of action are established based on the road map vision. Also under this stage, risks, costs, and potential barriers are analysed.
- Step 4: Propose technology and functional applications. Under this stage, policies, regulations, and technologies for each period and each pillar are suggested. The challenges associated with smart grid implementation are addressed.
- Step 5: Develop metrics and monitoring. This stage develops smart grid performance metrics to measure the success of implementation.

Issues, challenges, and recommendations are listed in the table below:

Issues	Challenges	Recommendations
1. Lack of funding on smart grid investments 2. Lack of clear smart grid standards 3. Lack of customer interest	1. How to encourage utilities to invest in smart grids 2. How to promote full deployment and replication of smart grid technologies 3. How to communicate to customers the benefit of smart grid investments	1. Establish policies on cost recovery mechanisms 2. Introduce standardisation and interoperability of technologies 3. Provide customer feedback 4. Introduce measures that provide automated end-user demand and energy efficiency response 5. Introduce time-of-use (TOU) pricing schemes 6. Ensure customer protection

CHAPTER 6

POLICY IMPLICATIONS

The study provides the following policy implications:

- **Energy efficiency in buildings:** Although some Association of Southeast Asian Nations (ASEAN) member states, including Brunei Darussalam, have adopted building policies and regulations, there is need to put policies into concrete energy efficiency and conservation (EEC) action plans to be implemented, which include building design and replacement of existing facilities and equipment with more efficient ones. For the building sector, both passive and active design policies such as the following will need to be considered:

    - Identify and establish a green building rating system for the eco town project.
    - Then, regulate "green building rating system" and apply it to the new buildings under the regulation.
    - Use advanced design software that has simulation capabilities.
    - Set up building codes and rewards for green buildings and enforce by law.
    - Provide government financial support to implement building energy efficiency measures for both new buildings and existing buildings (retrofit).
    - Establish government funds such as an energy service company (ESCO). Consider ways to raise funds such as levies on petroleum.
    - Explore and establish a good and practical green building business model that meets the context and situation.
    - Enforce energy building codes and designate large consumers and green buildings for energy audits.
    - Consider other energy saving measures along with energy-efficient buildings, including demand management systems such as household energy management systems (HEMS), building energy management systems (BEMS), and factory energy management systems (FEMS).
    - Improve thermal efficiency in the power generation sector by constructing or replacing existing facilities with new and more efficient generation technologies.

Energy efficiency in transport: In order to promote the 'Avoid, Shift, Improve' (ASI) approach, all stakeholders, including the ministries of energy, transport, and national development, should collaborate with each other to implement it. The road transport sector will need to consider measures to reduce energy consumption per unit of transport activity through model shift approaches such as the following:

- Improve the use of high-efficient fuel economy. Introduce policies to encourage the use of new and high-efficient fuel economy technologies.
- Promote and implement 'Shift' policy measures with higher efficiency as an alternative to using private vehicles, i.e. the shift in behaviour from personal to mass transport modes.
- Promote and implement 'Improve' policy measures through higher penetration rate of greener and more efficient technologies. Also, encourage the shift to more efficient technologies such as hybrid vehicles and clean alternative fuels.
- Promote and implement 'Avoid' policy measures through compact city design or change of lifestyle.
- For other related fuel use for transport, hydrogen fuel development is very important in the future. Thus, continue research and development of fuel cells for future clean fuel utilisation for transport and other purposes.

Smart grid: Smart grid deployment requires policy and regulatory interventions in terms of funding, standards, and policies that affect consumers. In order to achieve energy consumption and carbon emissions reduction and use of more renewable energy, governments should pay attention to the following three points: (i) funding smart grid investment, (ii) smart grid standards, and (iii) smart consumer policies. Public utilities must be assured of financial and regulatory support allowing them to recover their investments. Any smart grid deployment should refer and conform to smart grid standards that are developed by international standards institutes or agencies. Furthermore, public awareness of smart grids is important so that customers can fully capture the incentives and service options that warrant behavioural changes. To fully deploy a smart grid for an eco town, the following policy actions need to be considered:

- Establish an electricity market to support the effectiveness of the smart grid in terms of a mechanism for demand response.
- Develop a smart grid road map to identify necessary actions to be taken for the smart grid including the investment, risks, costs, and potential barriers.
- Develop functional applications of the smart grid and identify challenges associated with smart grid implementation which need to be addressed in each local context. These include policies on cost recovery mechanisms, standardisation and interoperability of technologies, customer feedback mechanism including automated end-user demand, and energy efficiency response.

- Develop metrics and monitoring, and support policy and implementation in place.
- Consider renewable energy electricity for the smart grid. An eco town could be attained by increasing the share of new and renewable energy in the energy mix. Several policies and actions will need to be considered including the backup capacity for the stability of grid.
- Ensure customer protection.
- Consider other policies in promoting renewable technologies in the eco town. These include energy policies and financial policies, such as a feed-in-tariff (FIT), a renewable portfolio standard (RPS), net metering, carbon tax, or carbon cap and trade. Financial policies include public financing, carbon financing, and banking regulations with sustainability requirements.
- Offer government investment in electricity storage technologies, especially for solar and wind power as the intermittent nature of renewable energy sources poses significant challenges in integrating renewable energy generation with existing electricity grids.

The Economic Research Institute for ASEAN and East Asia (ERIA) is committed to supporting the future development and study of Temburong district in Brunei Darussalam. In 2017, ERIA and the Brunei National Energy Research Institute (BNERI) will look more closely into climate data in Temburong district and conduct a simulation model to optimise the size of renewable electricity sources such as solar/PV, wind, biomass, and backup power generation facilities. Based on the renewable electricity plan, ERIA and BNERI will also come up with a design for smart city development in the Temburong area in the next stage.

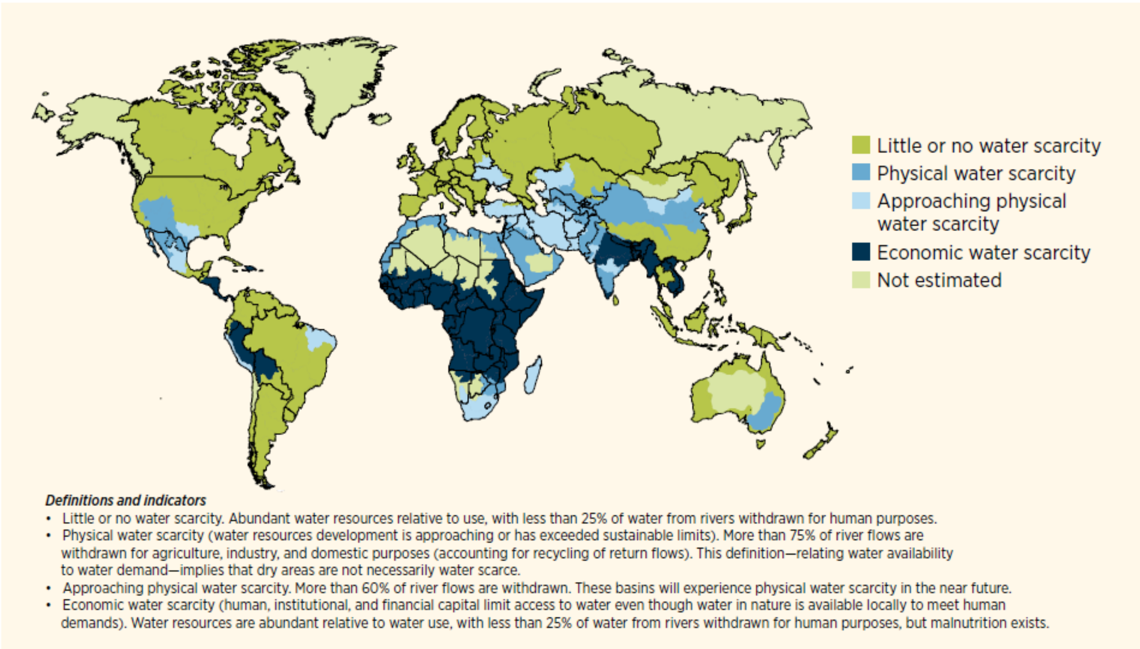
APPENDIX

Water Management in Buildings

Introduction

Figure A1 illustrates the physical and economic water scarcity worldwide. Water scarcity is a global issue arising from the supply–demand imbalance. The availability of good quality water is on the decline. Renewable freshwater availability per capita is on the decline and will be halved by 2050 relative to 2007 (The World Bank, 2007).

Figure A1: Global Physical and Economic Water Scarcity



Source: Connor et al. (2012), UNESCO.

By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two thirds of the world's population could be living under water-stressed conditions. With the existing climate change scenario, almost half the world's population will be living in areas of high water stress by 2030.

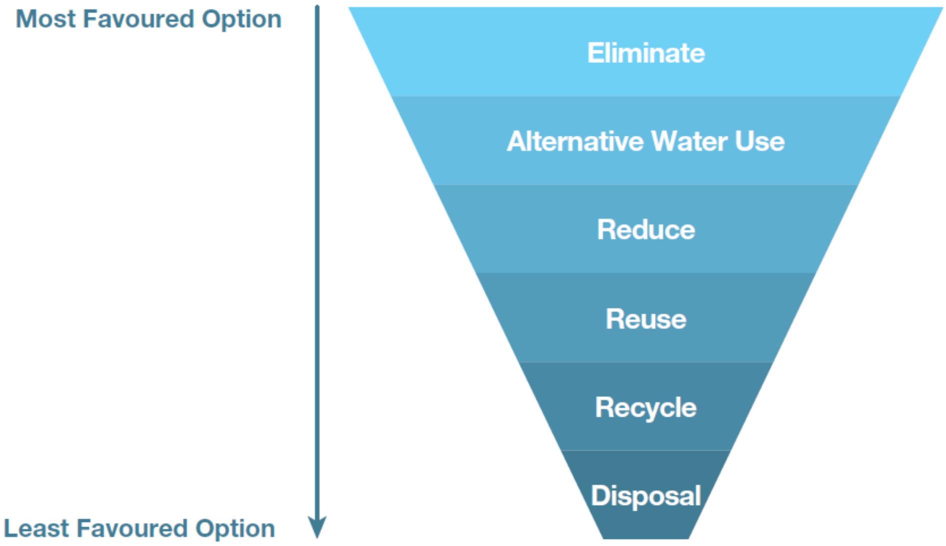
Increase in population, urbanisation, industrialisation, and lifestyle changes cause a rise in water demand, which is further worsened by climate change. Thus, access to a clean water supply will be of great concern in all parts of the world.

Water Efficiency in Buildings

As buildings consume 20 percent of the world's available water, water efficiency will be an important aspect in building design, construction, and operation with the increasing development of green buildings worldwide.

To improve water (use) efficiency in buildings, a systematic approach is required to ensure the success of all water efficiency initiatives undertaken and to achieve the highest possible return on investment (ROI). Cost-effective water-efficient opportunities have to be identified and prioritised.

Figure A2: Water Efficiency Hierarchy



Source: Invest Northern Ireland.

The water efficiency hierarchy shown in Figure A2 can be applied to all types of buildings such as offices, shopping centres, hotels, hospitals, as well as residential and institutional buildings. Water consumption depends on the type and function of a building including the type of facilities provided in the building. The following table illustrates the key areas of water consumption for different building categories:

Table A1: Water Consumption in Key Areas for Different Buildings

	Toilets	Showers	Kitchen/Sink	Laundry	Food & Beverage	Air Condition	Landscape	Pools
Residential	✓	✓	✓	✓			✓	✓
Office	✓		✓			✓	✓	
Retail	✓				✓	✓	✓	✓
Schools	✓				✓	✓	✓	
Hotels	✓	✓		✓	✓	✓	✓	✓
Hospitals	✓	✓		✓	✓	✓	✓	

Source: Author.

With key areas of water usage determined, it is possible to identify areas of water use where adoption of water efficiency strategies could be effectively implemented.

Water Efficiency Strategies

The water efficiency category for buildings addresses indoor use, outdoor use, and metering. Implementation of water saving strategies depends on project-specific water usage characteristics.

- **Toilets:** Toilets account for a major water use in most buildings. It is not only a good area to target but shall be the primary target for water efficiency improvement. This could be realised through behavioural changes and installation of water-efficient fittings.
- **Water closets:** Water closets that use more than 6 litres of water per flush, which are often provided in conventional flushing systems, are very inefficient. Low-flow systems with reduced flow of 4.5 litres per flush as well as dual-flush systems are readily available.
- **Urinals:** Urinal trays that employ a cyclic flushing system were a common fixture used in the 1970s and 1980s with a considerable amount of water being wasted. Urinal bowls introduced as replacements consume up to 3.8 litres per flush and are also very inefficient. Low-flow urinals using less than 1.0 litre per flush as well as waterless urinals are available.
- **Wash hand basins:** Conventional faucets have inefficient flow rates of greater than 6 litres per minute. Modern water-efficient faucets come with flow limiters to reduce water flow rates. Other water saving features available include automatic shut-off or self-closing taps and sensor operated taps that provide on-demand use.
- **Showers:** In the domestic sector, baths and showers account for up to 30 percent of total water consumption. In terms of water efficiency, showers are preferred over baths

but conventional shower heads with up to 13 litres per minute flow consume up to 65 litres of water for a 5-minute shower. Water-efficient shower heads, including those fitted with an aerator, have a much lower water flow and could save up to 50 percent of water use.

- **Shower mixers:** Shower mixers are provided for installations with hot and cold water supply. Automatic or easily adjustable shower mixers with temperature indicators would reduce water use as water wastage could be as high as 10 percent of the amount of water used in a shower while trying to adjust for a comfortable shower temperature.

Water Consumption in Air Conditioning Systems

Cooling towers can account for a high proportion of a building's total water consumption. Options to reduce water consumption in cooling towers include:

- specifying and selecting cooling towers with low drift loss
- exploring the application of non-chemical water treatment
- periodic checking of overflow levels and float valves settings to avoid overflow
- using alternative water sources.

Landscaping

Landscaping is an area where the non-use of potable water should be targeted. Good landscape design and proper management of landscape irrigation should be prioritised to reduce reliance on potable water use for watering. To avoid the use of potable water for irrigation, use of alternative sources such as recycled grey water or harvested rainwater should be considered.

Alternative Water Sources

To complement the water efficiency initiatives, use of alternative water sources is a viable option and offers multiple benefits and advantages. The following table lists three main alternative water sources and application for buildings:

Table A2: Alternative Water Sources for Buildings

Rainwater Harvesting	Wastewater Recycling	Air Conditioning Condensate Water Recovery
Landscape irrigation	Landscape irrigation	Cooling tower makeup water
Toilet flushing	Toilet flushing	Toilet flushing
Laundry	General washing	General washing
Water feature	Cooling tower makeup water	Landscape irrigation
Cooling tower makeup water		
Floor washing		
Car wash		

Source: Author.

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