Takeshi Yao
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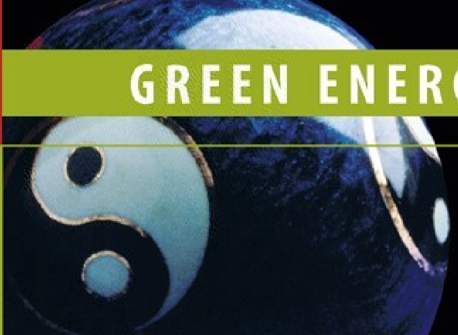

# Zero-Carbon Energy Kyoto 2010

Proceedings of the Second International Symposium of Global COE Program "Energy Science in the Age of Global Warming—Toward $CO_2$ Zero-emission Energy System"

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Proceedings of the Second International Symposium of Global COE Program "Energy Science in the Age of Global Warming—Toward $CO_2$ Zero-emission Energy System"

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# Preface

Since 2008, four departments of Kyoto University, Japan—the Graduate School of Energy Science, the Institute of Advanced Energy, the Department of Nuclear Engineering, and the Research Reactor Institute—along with the Institute of Economic Research have been engaged in a Global Center of Excellence (COE) Program entitled “Energy Science in the Age of Global Warming—Toward a CO2 Zero-emission Energy System”. (Here, we have abbreviated all greenhouse gases including carbon dioxide to “CO2.”) This Global COE Program is being carried out under the auspices of the Ministry of Education, Culture, Sports, Science and Technology of Japan with the support of Kyoto University. The aim is to establish an international education and research platform to foster educators, researchers, and policymakers who can develop technologies and propose policies for establishing a scenario toward a CO2 zero-emission society no longer dependent on fossil fuels by the year 2100.

Last year, the Global COE held its First International Symposium, Zero-Carbon Energy, Kyoto 2009, at the Kyoto University Clock Tower and published the proceedings in a book by the same title. This year, the Second International Symposium of the Global COE was held at Kyoto University’s Oubaku Plaza. The many excellent lectures and discussions by invited speakers and members of the Global COE and the interesting presentations by students of the GCOE Unit for Energy Science Education reflect the progress achieved by the program. This book is a compilation of those lectures and presentations.

As part of the further agenda of the Global COE, the Scenario Planning Group is setting out a CO2 zero-emission technology roadmap and drawing up a CO2 zero-emission scenario based on analyses of social values and human behavior. The Advanced Research Cluster is promoting a socioeconomic study of energy, a study of new technologies for renewable energies, and research on advanced nuclear energy by following the roadmap established by the Scenario Planning Group. At the GCOE Unit for Energy Science Education, students are planning and conducting interdisciplinary group research of their own, combining social and human sciences with natural science and working toward CO2 zero emission. By participating in the scenario planning and through interaction with researchers from other fields, students will acquire the ability to survey the whole energy system and to apply the experience to their own research. The Global COE is striving to foster young researchers who will be able to employ their skills and knowledge with a broad international perspective and expertise in their field of study in order to respond to the needs of society in terms of various energy and environmental problems.

The Global COE is publicly promoting the achievements of the platform by making information available on the website of the Global COE; by publishing annual reports, quarterly newsletters, books, and self-inspection and -evaluation reports; by hosting domestic and international symposia and activity report meetings; by hosting the industry–government–academia collaborative symposia and citizen lectures; and by co-hosting related meetings both domestically and internationally.

For securing energy and conservation of the environment, which are the most important issues for the sustainable development of human beings, the Global COE continues to take action for the establishment of “low-carbon energy science” as an interdisciplinary field integrating social science and human science with the natural sciences.

Takeshi Yao
Program Leader
Global COE “Energy Science in the Age of Global Warming —
Toward a $CO_2$ Zero-emission Energy System”

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# Part I
# Scenario Planning and Socio-economic Energy Research

# (i)
# Invited Paper

# Singapore's Perspective on Energy and Future Cities

**Seeram Ramakrishna**

**Abstract** With physical constraints of land size and with no natural energy resources, Singapore has to harness the human and intellectual capital of the nation to have sustainable economic growth in an urban setting. Many cities of the future have similar constraints like Singapore. With UN estimating that about 60% of the world's population is expected to be living in urban cities by 2030, we have to develop new energy models urgently. Singapore had taken a whole-of-government approach that engaged the global, regional and local talent, industries, academicians and the citizens to develop long term strategic plans to address the challenges of energy sustainability in a holistic manner. The strategic objective is to build a distinctive global city which is liveable and lively into the future. Singapore has no natural energy resources of coal, oil gas, hydro, geothermal and biomass power. The prevailing wind speed is not high enough to be tapped with the current technology. The tidal wave is not strong enough to be tapped. Singapore has limited options and is highly dependent on fossil-based energy source. Between fuel oil and natural gas, it has gradually move to natural gas as it emits 40% less $CO_2$ than fuel oil. The other energy options are to increase waste to energy, consider option of biofuels, promote solar energy and studying the feasibility and option of nuclear power. Enhancing energy efficiencies in all sectors of electricity generation, industries, transportation and housing are key strategies to reduce carbon footprint of future city. Increasing electrification of urban mobility and increasing connectivity in the various transportation of walking, cycling, cars, buses and trains will make city travel more energy efficient. For the built environment, zero-energy building and green building certification will encourage the use of more climate-neutral energy sources. With the strategic location that Singapore is just 1° north of the equator, solar energy is expected to provide 10–15% of the primary energy source for Singapore.

**Keywords** Climate change • $CO_2$ emissions • Energy • Future cities

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## 1 Introduction

Rapid economic development, urbanization and consumerism have led to soaring demand for energy. The global energy crisis is at the forefront of current events.

According to the United Nations, 60% of the earth's population (4.9 billion people) will live in cities by 2030. The number of megacities, which metropolises with a population of more than ten million, will increase from 22 today to 26 by 2015. There are more than 300 cities with over a million inhabitants.

Today, about half of the world's population lives in cities. Cities consume about 75% of the world's energy. They emit 80% of the world's green-house gases. The urban population is expected to increase. As such, if urbanization continues on the same scale, there will be an increasing demand by city dwellers to access to energy, water, mobility and efficient, affordable healthcare (Fig. 1).

City planners and developers will need to rapidly scale up their urban infrastructure to provide for the city dwellers, who will need good access to energy, water, mobility and affordable housing. Cities, by virtue of their high human density and economic growth, are the hotspots of climate-changing practices such as high energy consumption, pollution and deforestation.

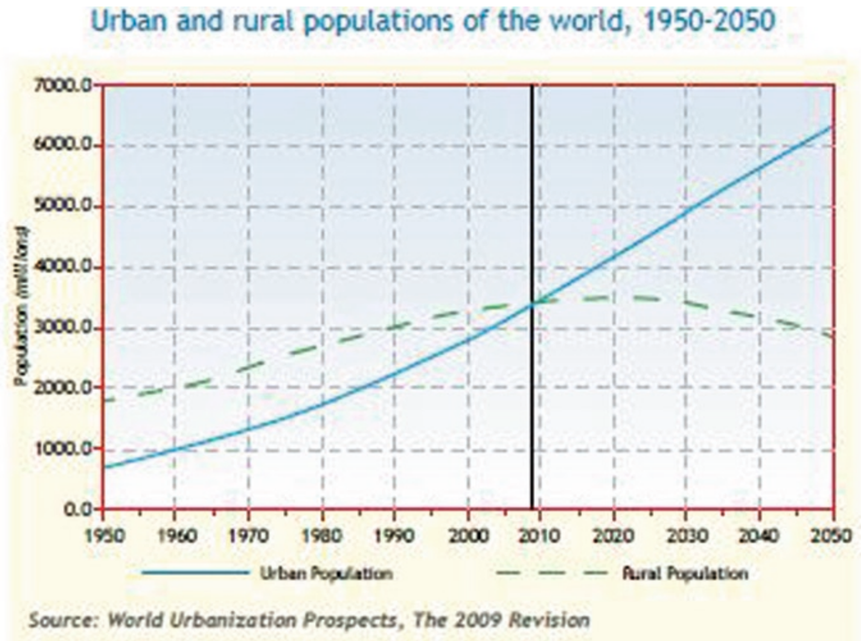


**Fig. 1** Urban and rural population of the world, 1950–2050. Source: World Urbanization Prospects, The 2009 Revision

## 2 Singapore

Singapore is a small city, densely populated, with few natural resources and an open economy. Global problems, from the financial crisis to the threat of climate change, cast a large shadow on our small island nation.

We are a city-state of 5.08 million people[1] on a small island with no natural hinterland. We import much of what we consume. All the elements of a functioning state – our homes and offices, factories and power plants, roads, reservoirs, airports – have to be located within the 700 km$^2$. At the same time, we need to ensure that our people have a clean, green and comfortable environment to live in.

Singapore's overall goal is to grow in an efficient, clean and green way. The strategic objective is to build a distinctive global city which is liveable and lively into the future.

Singapore's economy had grown from labour intensive to knowledge and innovation intensive economy in less than 50 years. Like most countries that do not have natural energy resources, the key challenges are sustainable economic growth and safeguarding our energy security and natural environment (Fig. 2).

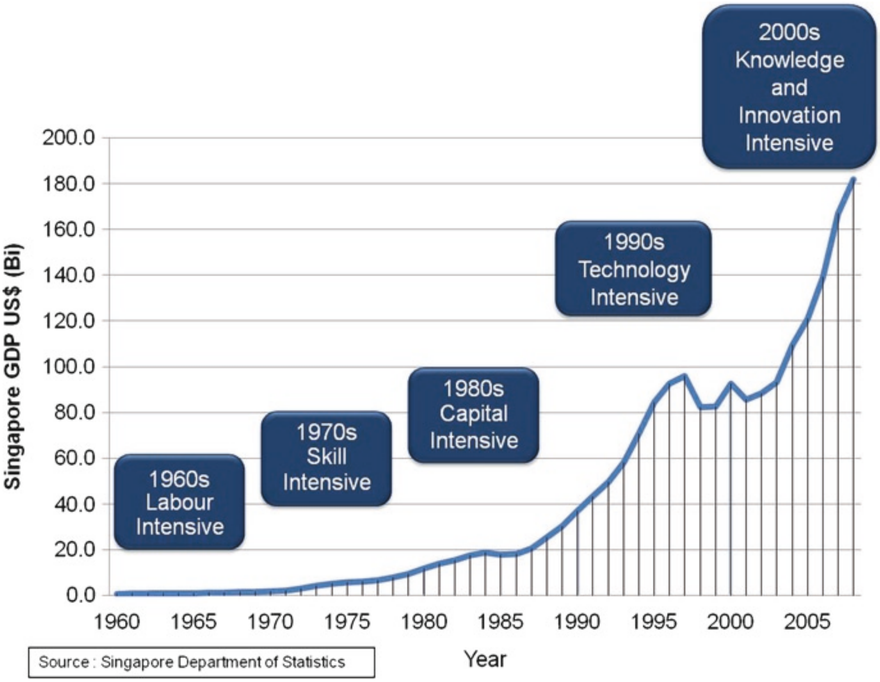


**Fig. 2** Singapore economic development journey. Source: Singapore Department of Statistics

[1]Statistics Singapore www.singstat.gov.sg Singapore's total population was 5.08 million as at end June 2010. There are 3.77 million residents, of which 3.23 million were Singapore citizens and 0.54 million were permanent residents.

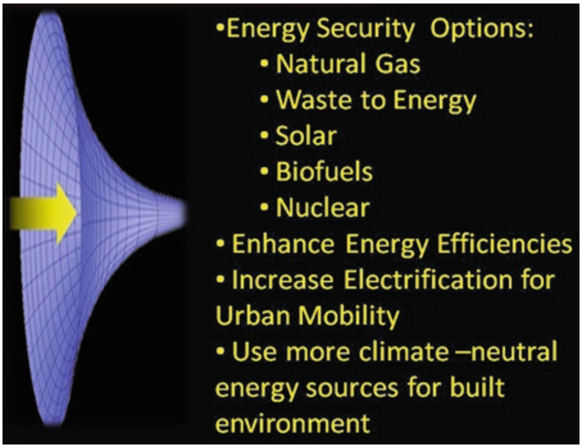


**Fig. 3** Drivers for change

With Singapore physical constraint of land size and with no natural energy resources of coal, oil, gas, hydro, wind, tidal, geothermal and biomass power and the need to mitigate climate change, Singapore is driven to find new ways for sustained economic growth while safeguarding our energy security and natural environment (Fig. 3).

Under the leadership of the Prime Minister, the country took a whole-of-government approach and appointed international advisory panels of top minds, form inter-ministerial committees, engaged the academics and industrials in local panels and using web-based platform to engage the public in consultation and feedback to tackle the challenges.

The four key areas of focus include: look at all available energy options, for short term will increase fuel mix to use more natural gas, built more waste incineration plants for electricity generation, deploy more solar panel applications, work on biofuels and undertake feasibility of nuclear option.

Energy Efficiencies are immediate actions can be taken for all sectors. Increase electrification of urban mobility. And use more climate-neutral energy sources for built environment.

Climate change and energy issues are complex and cut across different sectors and industries, and involve policies from different ministries and agencies. The Energy Policy Group (EPG) was set up in 2006 with four working groups on Economic Competitiveness, Energy Security, Climate Change and the Environment, and Energy Industry Development, headed by the different agencies as shown in Fig. 4.

The clean energy movement in Singapore gained momentum in 2007, when Prime Minister Lee Hsien Loong announced that Singapore will be developing the clean energy industry as a key growth area, generating a potential $1.7 billion in revenue and 7,000 jobs by 2015 [1].

The National Energy Policy Report developed by the Ministry of Trade and Industry (MTI) and released in November 2007 outlines six strategies for Singapore

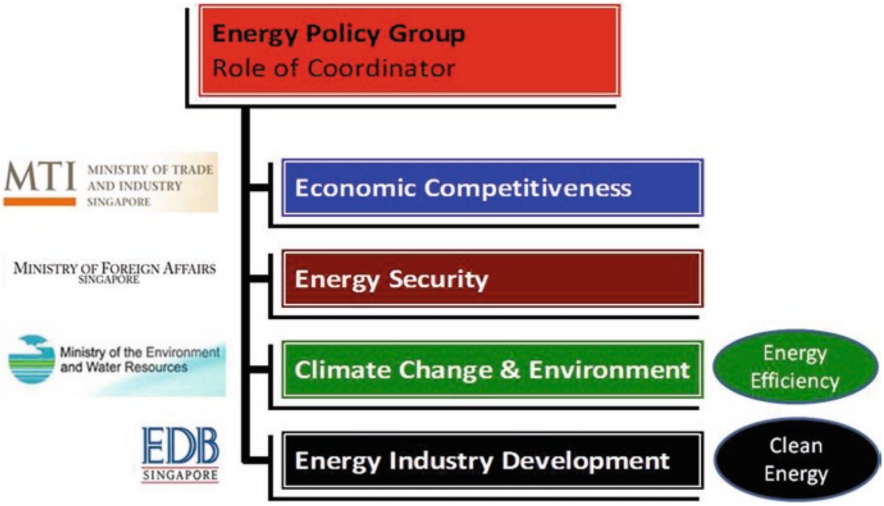


**Fig. 4** Energy Policy Group

to strengthen its economic competitiveness, enhance energy security and improve environmental sustainability [2].

The six key strategies are:

1. Promote Competitive Markets
2. Diversify Energy Supplies
3. Improve Energy Efficiency
4. Build Energy Industry and Invest in Energy R&D
5. Step Up International Development
6. Develop Whole-of-Government Approach

In April 2009, the Singapore Government unveiled an S$1 billion (US$730 billion) Sustainable Development Blueprint which contains strategies and initiatives developed towards achieving both economic growth and a good living environment for Singapore over the next two decades [3]. The blueprint is based on a four-pronged strategy: boosting our resource efficiency, enhancing our urban environment, building our capabilities, and fostering community action.

Some of the aggressive targets set include:

1. To achieve a 35% reduction in energy intensity (consumption per dollar GDP from 2005 levels by 2030.
2. To raise overall recycling rate to 70% by 2030.
3. To improve air quality by reducing ambient PM 2.5 (fine particles) levels to an annual mean of 12 μg/m$^3$ by 2020, and maintain the same levels up to 2030.
4. To build Singapore into an international knowledge hub in sustainable development solutions.
5. To achieve a community in Singapore where environmental responsibility is a part of our people and business culture.

The government has taken actions to catalyze collaborative innovation. For instance, to encourage energy-efficient building technologies, the Building and Construction Authority (BCA) has set aside a $5 million fund to encourage local developers to partner experts worldwide to develop prototype building designs that can achieve at least 50% improvement in energy efficiency [4].

Besides new buildings, the Government has also established a $100 million fund to help building owners upgrade and improve the energy performance of their existing buildings. At the same time, the Housing and Development Board (HDB) has embarked on the largest solar test-bed in Singapore to understand and adapt solar technology to our local conditions.

Through the Housing Development Board public housing programme implemented over the last 50 years, over 80% of Singaporeans live in 900,000 HDB flats across the island, with 95% of them owning their homes. As the largest housing developer in Singapore, HDB plays a key role in spearheading sustainable development practices.

In Singapore, we have a Green Mark Scheme under the BCA. This is a green building rating system, promoting and adoption of green building design and technologies. Under this scheme, buildings are assessed on factors including energy and water efficiency, indoor environmental quality and environmental protection. We have set a target of at least 80% of buildings in Singapore should attain Green Mark certification by 2030.[2]

NUS has achieved the Green Mark awards for its University Town, University Town's Education Resource Centre, the Mochtar Riady Building at the NUS Business School and the T-Lab.

The Singapore Government is taking the lead in embracing the green mark standards for all public sector buildings. For its part, the HDB is aiming for the Green Mark Platinum standard, the highest green mark rating, for some important public housing projects.

HDB is also developing its first Eco-Precinct, named the Treelodge@Punggol. Punggol is a coastal town located at Singapore's northeast.[3] With its eco-friendly features that capitalize on nature and the use of green technologies, the precinct will create a green living environment and raise popular awareness of environment sustainability. Punggol will serve as a 'living laboratory' to test new ideas and technologies in sustainable development, integrating urban solutions to create a green living environment. R&D studies will be conducted to address the diverse expectations and changing aspirations of residents. Urban solutions in the areas of energy, waste and water management will be explored. Eventually, HDB hopes to lower the implementation cost of these solutions and to replicate them across other towns.

[2]Economic Development Board (EDB).

[3]Housing and Development Board (HDB).

Going forward, Singapore seeks to serve as a "Living Laboratory" where new ideas and technologies in sustainable development can be tested (Fig. 5). It invites companies to partner our government agencies, local companies and research institutes for a diversity of R&D activities. Singapore will be a "Living Laboratory" to test new concepts, develop and commercialize cutting-edge urban solutions, capitalizing on Singapore's experience in systems-level integration across six focus areas (See footnote 2) (Fig. 6). One key area is in promoting of energy efficiency. Energy efficiency reduces the carbon footprint in our city and also saves costs for businesses and consumers.


**Fig. 5** Singapore as a Living Laboratory

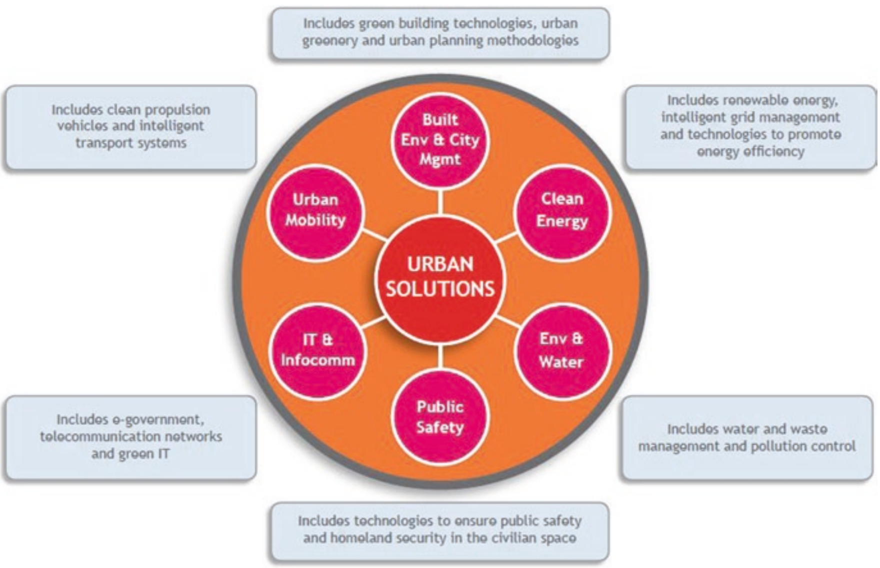


**Fig. 6** Urban solutions focus areas

In addition, Singapore forms global partnerships with other countries to develop innovative prototypes for the sustainable cities of tomorrow. One good example is the Tianjin Eco-city in China [5]. The Governments of Singapore and China are jointly developing the 30 $km^2$ city into an environmentally friendly, socially harmonious and resource efficient city. This project involves putting in place key infrastructure to support sustainable development, such as a light-rail transit line to link the Eco-city to Tianjin City and surrounding districts, a pneumatic waste collection system, a new wastewater treatment plant, and major rehabilitation works for existing water bodies.

In July 2010, a ground-breaking ceremony was held at Jurong Island where Singapore will build the world largest Experimental Power Grid of 1 MW [6]. This S$38 million (US$27.5 million) facility will be ready by second half of 2011. This Experimental Power Grid Centre (EPGC) will perform research on “intelligent grids” and distributed energy resources. This power grid will allow power from solar, fuel cells, and electric/hybrid vehicles to feed energy back into the system.

NUS performs high-quality research over a broad range of disciplinary and cross-disciplinary areas. It has a wide energy and environment cluster as shown below (Fig. 7).

The Solar Energy Research Institute of Singapore (SERIS) is Singapore’s national institute for applied solar energy research, jointly set up by NUS and the Economic Development Board (EDB). It performs quality research and work closely with the industry in solar photovoltaic devices as well as innovative materials for solar and energy-efficient buildings. It has a research funding of S$130 million over 5 years.

The Energy Studies Institute (ESI) is established by the Singapore Government and hosted by NUS. As Southeast Asia’s first think-tank on energy issues, ESI play an important role in the development of energy policies in the region on three key areas – Energy Economics, Energy Security, and Energy and the Environment.

The NUS Global Asia Institute (GAI) is an initiative of NUS President Tan Chorh Chuan on research and scholarship directed at topics pivotal to Asia’s future. The institute will bring together existing expertise from NUS and other universities, particularly those with expertise in India and China, in its quest for solutions that will solve the critical issues within Asia [6].

In the area of nuclear energy, subject to the Singapore Government’s support, NUS is prepared to undertake the following high impact research in areas such as:

1. Nuclear Forensics and Detection
2. Radio Chemistry and Nuclear Defense
3. Reactor Engineering
4. Nuclear Medicine
5. Material Sciences
6. Environmental Sciences
7. Life Sciences

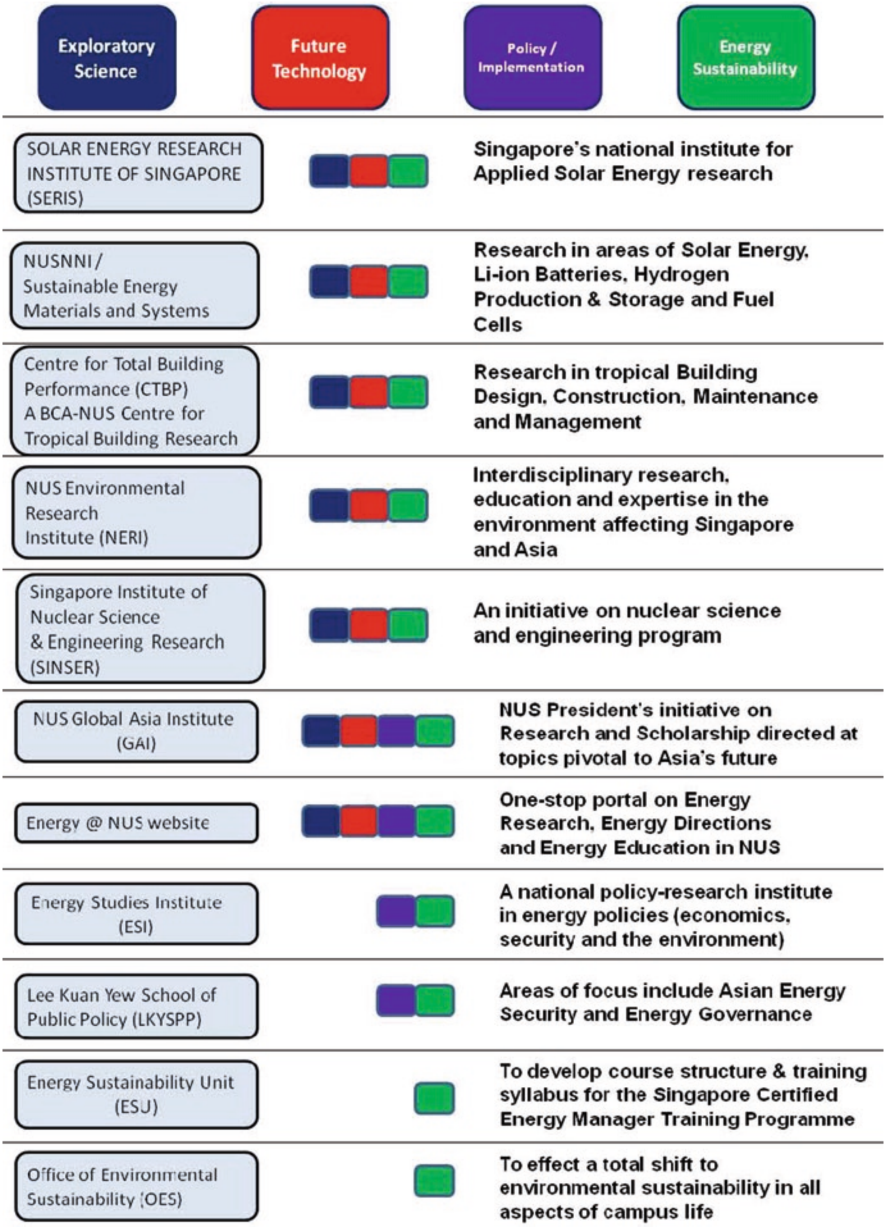


**Fig. 7** NUS energy and environment cluster (color figure online)

## 3 Conclusion

Cities today face many similar challenges arising from pressures such as urbanization, climate change, and energy constraints. No one city is able to solve all the problems it faces. Only by collaborating with one another through sharing of ideas and expertise, cities of the world can learn from one another as they grow and develop sustainably.

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# (ii)
# Contributed Papers

# Long-Term Scenario Analysis of a Future Zero-Carbon Electricity Generation System in Japan Based on an Integrated Model

**Qi Zhang, Benjamin Mclellan, Nuki Agya Utama, Tetsuo Tezuka, and Keiichi N. Ishihara**

**Abstract** The realization of a zero-carbon electricity system is of vital importance to a future zero-carbon energy system and society. Nuclear power and renewable energy are expected to contribute significantly to this in the future in Japan. Therefore, in the present study, their roles in future zero-carbon electricity system was examined using long-term scenario analysis from 2005 to 2100 based on an integrated analysis model. The analysis is conducted in three steps to (1) estimate electricity demand and load pattern based on lifestyle and industrial structure in the future using a bottom-up simulation sub-model; (2) plan the optimized power generation mix to satisfied obtained electrical demand and load subject to various constraints including natural resources, economic, environmental, geographic, natural conditions, etc. using an optimization sub-model (3) confirm the reliability of the obtained best mix power generation system by using an hour by hour simulation sub-model. The results give the schedule of nuclear and renewable energy development from 2005 to 2100 and show that they will contribute 60% and 40% respectively in terms of electricity production by 2100. Finally, the whole system is proven as technically feasible with the help of EV (Electric Vehicle) batteries and hydrogen for daily and seasonal electric storage respectively, operated based on smart control technologies.

**Keywords** Electricity generation system • EV • Nuclear power • PV • Zero-carbon

## 1 Introduction

In an examination of potential zero-carbon energy futures for Japan, it was considered that the $CO_2$ emission reductions required could be achieved mainly in three different ways: by a reduction in energy demand, an expansion in nuclear power or

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the increase in renewable energy production. Several studies also show that this reduction could be achieved by increasing the share of electricity utilization on the end-user side [1, 2], which is considered to be the most effective way to reduce demand through technology substitution and energy saving, and increase the penetration of nuclear power and renewable energy simultaneously. The philosophy adopted in this study agrees with these studies and considers that society is becoming more reliant on electricity, which further highlights the need to move to a zero-carbon electricity system based on zero-carbon power sources including nuclear power and renewable energy (Photovoltaic (PV), wind, biomass, etc.).

Although some future zero-carbon energy system scenarios based on renewable energy (solar, wind, wave, etc.) have been proposed both for individual countries or globally [3, 4], the most common criticism is that renewable energy produces electricity too intermittently and is too costly. Thus, nuclear power is expected to contribute as a low-carbon energy source much more in the future in Japan [1, 5]. On the other hand, in the future, renewable energy is likely to become cheaper and cheaper, but nuclear power may become more and more expensive due to the price rise of nuclear fuel. Furthermore, too much nuclear power without effective nuclear waste treatment will convert the $CO_2$ problem to a nuclear waste problem. Therefore, in the present study, long-term planning of a scenario for a zero-carbon electricity generation system with maximum renewable energy from 2005 to 2100 is conducted using a developed integrated model.

## 2 Scenario Analysis for Electricity Generation System and Proposal for an Integrated Model

The basic idea of the present study is to conduct the scenario in three steps to (1) estimate electricity demand and load pattern based on lifestyle and industrial structure in future; (2) plan the optimized power generation mix to satisfy electrical demand and load subject to various constraints including natural resources, economic, environmental, geographic, natural conditions, etc. (3) study the reliability of the obtained best mix power generation system using an hour by hour simulation. Therefore an integrated model has been proposed including (1) a bottom-up simulation model, (2) an optimization model (3) an hour by hour simulation model. As shown in Fig. 1, three sub-models are connected with each other through data flow.

## 3 Estimating Future Electricity Demand

The final total electrical demand and load is obtained using the bottom-up simulation model as shown in Fig. 1 based on framework comprised of residential, commercial, industrial and transportation sectors and their several sub-sectors. The simulation is

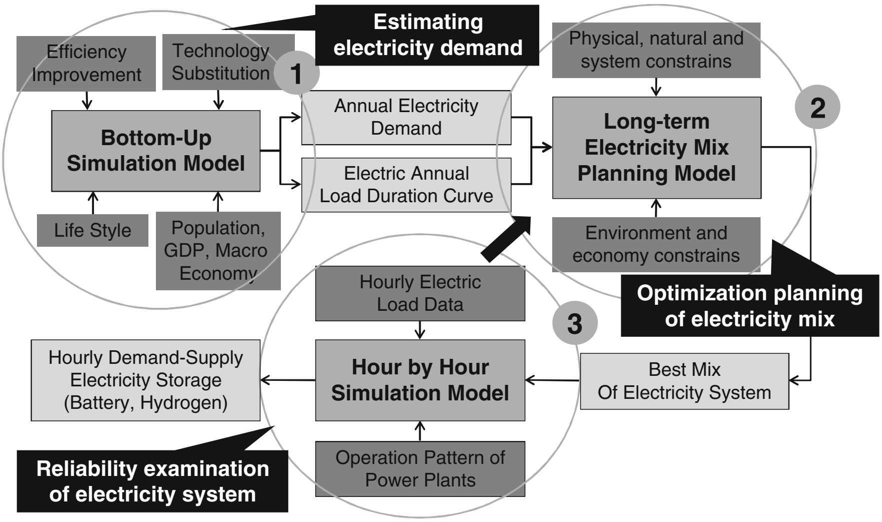


**Fig. 1** Proposed Integrated Scenario Analysis model for Zero-Carbon Electricity system (ZCE-ISAM)

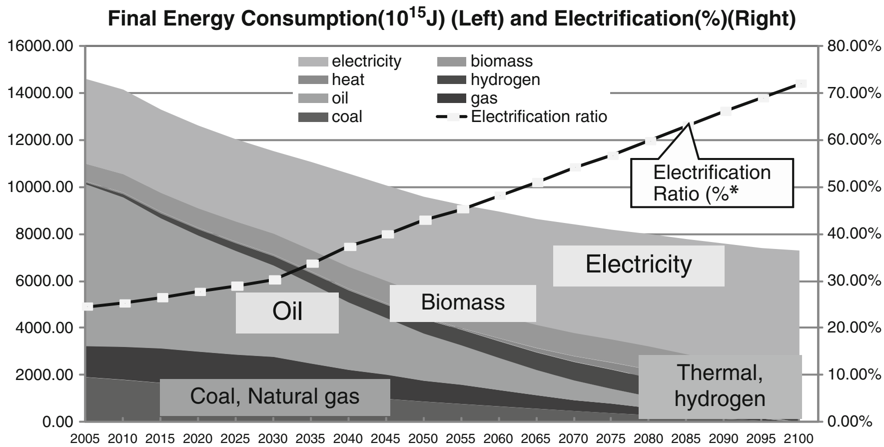


**Fig. 2** Obtained final energy demand by using the bottom-up simulation model

conducted in several steps based on the base year data, assuming parameters such as efficiency, share design according to socio-economic and technology parameters such as lifestyle, macro economy, technology improvement and technology shift. The simulation results are shown in Fig. 2, in which the electricity demand is shown to increase from 1,000 TWh to 1,500 TWh from 2005 to 2100 [6].

## 4 Long-Term Optimization Planning of Electricity Generation

The detailed long-term optimization planning model in the proposed integrated model is shown in Fig. 3. The model aims to find the least total $CO_2$ emission solution to meet the electrical demand obtained in the previous step, subject to various constraints including physical space, replace schedule, generation grid technology, environmental, economic, resource availability, and so on. The proposed optimization method is quite different to many models proposed in past studies such as MARKAL and AIM (Asia-Pacific Integrated Model), which aim to find the least cost solution. The philosophy is that the external costs that will arise from the negative environmental impacts of fossil fuel burning and climate change are not considered in the existing least cost analysis models, meaning that these results cannot be accepted as realistic. Therefore, if humanity is really serious about the climate change issue, the least total amount of $CO_2$ accumulation in the atmosphere should be the goal pursued, which means a least total $CO_2$ emissions path for a final zero-carbon energy system should be pursued.

The obtained optimization results (subject to the main constraints listed in (Table 1) are shown in Fig. 4. The results indicate that to realize a zero-carbon electricity generation system by 2100, Japan will still be dependent 60% on nuclear power, with 35% on all renewable energy and 5% on energy storage.

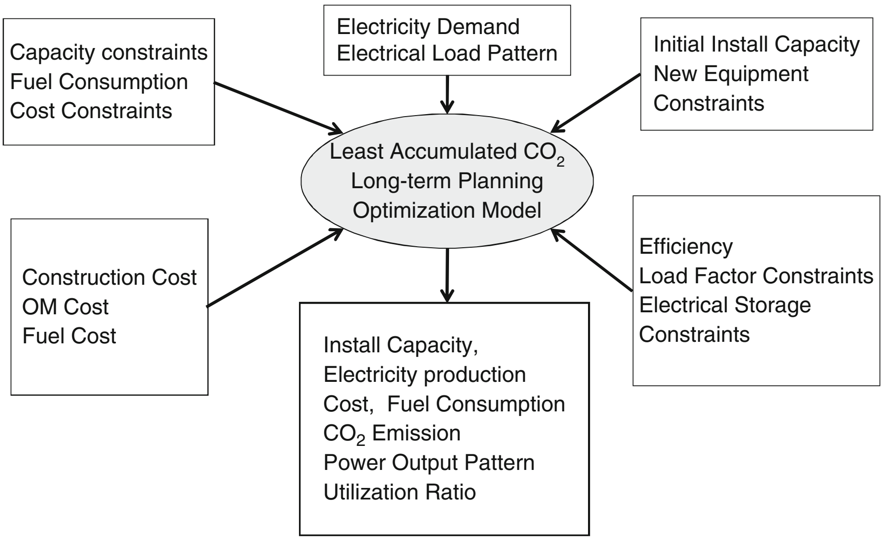


**Fig. 3** Long-term optimization planning model for electricity generation mix