様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　元 年　 ６ 月 １２ 日現在

機関番号：１７１０２
研究種目：基盤研究(C)（一般）
研究期間：2016～2018
課題番号：１６Ｋ００６５０

研究課題名（和文）Assessing the multiple benefits of clean energy policies in Asian mega-cities

研究課題名（英文）Assessing the multiple benefits of clean energy policies in Asian mega-cities

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交付決定額（研究期間全体）：（直接経費）　　3,600,000円

研究成果の概要（和文）：この研究は、クリーンエネルギー政策と低排出ガス開発戦略（LEDS）が、東京、上海、デリー、クアラルンプールの選択された都市で費用対効果の高い方法で複数のエネルギー、環境、公衆衛生および経済的利益を達成する方法を実証することに焦点を当てます。 。 定量分析の結果、2030年までに多数の死亡例の防止と、これらの都市でのコスト削減とともに、CO2と他の地域の大気汚染物質の排出が大幅に削減されたことが示されました。 よりクリーンな燃料への抜本的な転換や主要な需要側管理のためのロードマップを想像するよりも伝統的な情報源。 上海やクアラルンプールなどの都市では、都市化は大気汚染の増加と相関していました。

研究成果の学術的意義や社会的意義
-Formulating the Urban Sustainable Development Index for the comparative analysis of LEDs in Asian cities.
- Local stakeholder engagement in quantifying the climate co-benefits in the selected cities.

研究成果の概要（英文）：This research focuses on demonstrating how clean energy policies and Low Emission Development Strategies (LEDS) can help to achieve multiple energy, environmental, public health and economic benefits in a cost-effective way in selected cities of Tokyo, Shanghai, Delhi, and Kuala Lumpur. The results of the quantitative analysis showed a significant reduction of CO2 and other local air pollutant emissions together with the prevention of numerous cases of mortality, and cost savings in these cities by 2030. The results revealed that Delhi's local government's focus seems to be more on gradual supply augmentation of traditional sources than envisioning a road map for a radical shift towards cleaner fuels or major demand-side management. In cities like Shanghai and Kuala Lumpur, the urbanization was correlated with the increase in air pollution. However, when the income rises, average emissions decline and the LEDS play a crucial role in these cities.

研究分野：低炭素社会

キーワード：Low Carbon Society　Asian Mega Cities　Energy modeling　Global Warming　Air pollution

科学研究費助成事業　研究成果報告書

１．研究開始当初の背景 (Background)

Many local governments in Asian mega-cities face a dual challenge in achieving top priority local development goals, such as improving standards of living through extending access to modern energy and increasing employment while also supporting national climate change action. To support broader development goals while also reducing GHG (Greenhouse Gas) emissions, a number of governments are developing and implementing LEDS (Low Emission Development Strategies) which aim to achieve development priorities with minimal GHG emissions as part of their national objectives. Historically, the literature on evaluating the impacts of a shift to a low emissions pathway has focused on the costs (i.e. GDP, etc.), but in fact, the benefits may outweigh the costs when considering broader impacts (public health, for example). By including the broader set of benefits in the cost-benefit analyses conducted during planning processes, local governments get more comprehensive assessments of their potential LEDS investments. In concert with sustainable development frameworks, a successful LEDS should be integrated with the "economic, social and environmental objectives of society, using a multiple benefit assessment approach. Studies seeking the knowledge-based approach to assess the multiple benefits of LEDS are therefore increasingly important in order to identify where the most prospective points for public policy intervention exist. Two common challenges exist with the previous studies: 1) Quantitative Analysis (QA) efforts have mostly focused on specific aspects of LEDS in individual sectors, but there have been few attempts to develop an integrated modeling approach that span across multiple benefits of LEDS in urban areas; 2) There is no holistic consideration of the Implementation Analysis to test the outcomes of QA. To address the two aforementioned challenges, this research will try to develop effective science-policy interaction to address the opportunities where LEDS can be used to support energy system, environmental, and economic development planning strategies across the Asia mega-cities.

２．研究の目的 (Purpose of research)

This research focuses on demonstrating how clean energy policies and LEDS can help achieving multiple energy, environmental, public health, and economic benefits cost-effectively in Asian mega-cities. To this aim, the specific target is set to design and develop an analytical approach which helps policymakers and relevant stakeholders to determine opportunities for LEDS and also to address the main relevant policy instruments available, based on the analysis of the practical experience with LEDS and related processes to date in their respective cities. Identifying objectives of a LEDS are the first step. These objectives are more concrete than the general scope determined initially and should connect the urban-LEDS to the country's development priorities, clearly articulating how a LEDS would contribute to reaching national development goals. Second step: sectors that represent the highest priority for low emission development in the urban area should be determined, wherein this proposal, the selected sectors are: 'Buildings', 'Waste' and 'Transport. The modeling framework is used in assessing BAU and LEDS scenarios to study the effects of different policies on emissions generated by these sectors. The evaluation of the BAU and LEDS scenarios developed during this project would serve as a good basis for the decision making, in particular in determining economy-wide and sectoral goals for limitation of GHG emissions growth or for setting absolute quantified goals for GHG emission reduction. The two main issues which will be addressed in this research are:

1. How the concept of LEDS has evolved in the climate policy discourse and explores how it could usefully add to a large number of existing strategies, action plans, and reporting documents that are already available.
2. Gaps that LEDS could fill, the elements it could contain, and how LEDS can be prepared to ensure that they are productive and efficient in delivering their intended goals.

The main objectives of the research project can be addressed as:

1) Quantifying the implications of the proposed LEDS and estimate the potential impacts on both sides of demand and supply

2) Finding the optimal (least cost) plausible portfolio of LEDS in the selected cities of Tokyo, Shanghai, Delhi, and Kuala Lumpur.

3) Estimating the multiple benefits (Energy, environment, public health, and economic development) of the optimal portfolio of LEDS in the selected cities.

4) Prioritizing the policy objectives of the optimal plausible portfolio across the drivers/barriers in each city

5) Developing a road map (strategic plan) of LEDS in the selected cities.

３．研究の方法 (Research method)

1- Development of the QA framework: In this investigation, to be able to quantify the multiple benefits (energy, environment, health, and economy), the concept of LCS (Low-Carbon Society) has been used. To this aim, a city-level CGE (computable general equilibrium) model has been developed based on the general equilibrium theory. It uses actual economic data from a SAM (social accounting matrix) which is an accounting framework that reflects the circular flow of city's economic activity to estimate how a city might react to changes in clean energy policies. The CGE model has two main parts: supply and demand. On the supply side, the microeconomic principles have been utilized to develop a concept that would represent the behavior of an urban energy system in a market with perfect competition. The local government, as a decision-maker in this market, strives for maximum satisfaction (or utility) of delivering certain energy service to the end users, such as providing required electricity at the end-user level. On demand side, a spreadsheet simulation model based on bottom-up end-use method and the Avoid-Shift-Improve (A-S-I) approach has been applied to the end-user level (buildings, transport, and waste) in order to assess the effect of different scenarios of socioeconomic, technological, and demographic developments on energy consumption and emissions of the citywide energy system in a multi-sectoral context. The model systematically relates the GHG and air pollution emissions based on the specific energy demand in the end-user sectors in cities to the corresponding social, economic, and technological factors that affect this demand. Assessing the public health benefits of clean energy development in the selected cities was based on the concentration-response (C-R) functions of the health effects include premature mortality and exacerbation of health conditions such as asthma, respiratory disease, and heart disease, which were collected from epidemiological research. The C-R functions have been used to link the estimated changes in concentrations to several health endpoints. The CGE model was implemented as a mixed integer linear programming problem using the GAMS (General Algebraic Modeling System) to find the minimum total cost of delivering a certain level of energy service through the optimal combination of available technologies and resources in the urban energy system (Figure 1).

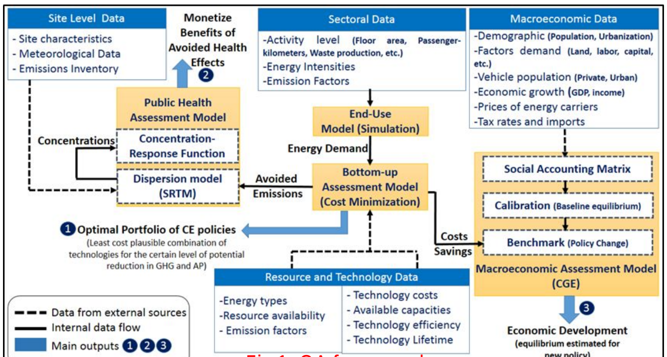

Fig 1- QA framework

2- Data gathering: Required detail data were collected from the local energy office and academic organizations in selected cities. We organized several collaboration trips to the selected cities to visit our research collaborators and related stakeholders to obtain insight into specific proposed LEDS including scale, challenges and plans in their cities and to ensure common understanding and consensus by all parties involved.

3- Benchmarking: Base on the results obtained from the QA, we developed a composite index that consists of a unique set of 4 dimensions (energy and climate, City planning, social welfare, and economic). The values of the indicators are aggregated based on the Min-Max method for a final ranking (Figure 2). We conducted comprehensive desk research on data collection

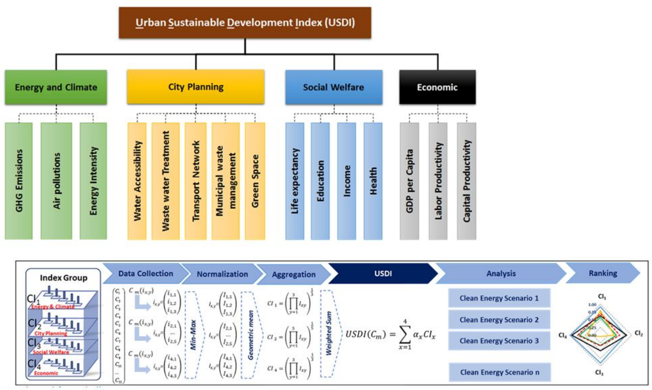

Fig 2. USDI Development Model

from 22 cities in Asia, including our selected mega-cities in this research and applied this index to compare the selected cities for potential changes in the final ranking based on the quantified LEDS.

4．研究成果 (Results)

Case of Delhi, India: Implementation of two main scenarios of Clean Transport (CT) and Zero Electricity Deficiency (ZED) in the case of Delhi, India revealed a significant reduction of CO_2 and other local air pollutant emissions by 4.8 and 0.4 million tons, respectively, prevention of about 22,000 cases of mortality, and cost savings of more than USD 35 million by 2030. The larger numbers for the projected reduction of cases of cardiovascular mortalities implied that the pollution impact on these cases is more serious than others. Among all pollutants, the reduction of PM_{10} plays a significant role in achieving the desired health outcome. Improving energy efficiency at the end-user levels results in a rapid, cost-effective decrease in emissions in this city. The proposed scenarios help to motivate both the power supply system and the energy consumers to participate in reducing the emissions in the city.

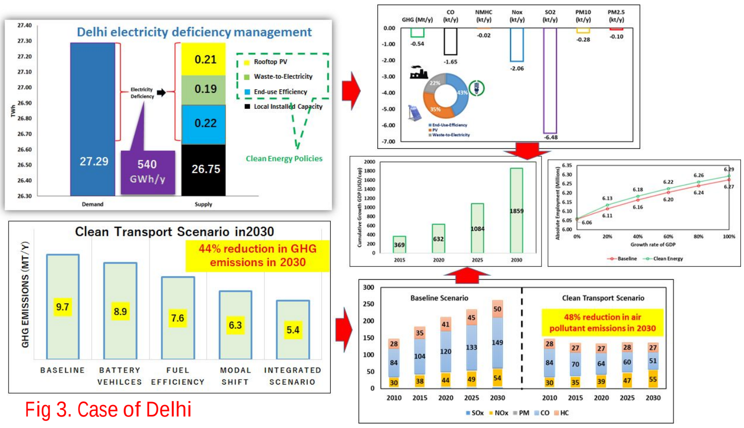

Fig 3. Case of Delhi

Case of Shanghai, China: Three scenarios of slower socio-economic development, rapid socio-economic development and the master plan which was defined as a slower socio-economic development with reinforced energy efficiency programs were considered. The major reduction in coal consumption is expected from boosting green mobility, shutting more outdated steel and coke capacity and gradually improving clean coal's share in the industry sector through replacing it with natural gas and alternative fuels. The decline in the total amount of carbon emissions from the major sectors such as iron and steel complexes, power plants, transport sector, service sector, chemical industries and other sectors compared to the baseline scenario are expected to be approximately 2.8, 5.6, 4.9, 1.1 ,0.9 and 2.3 $Mt_{CO2\text{-}eq}$, respectively, which contributes significant to the job creations and raise GDP by the tertiary sector to increase the share of green employment in Shanghai total workforce by 46% in 2030.

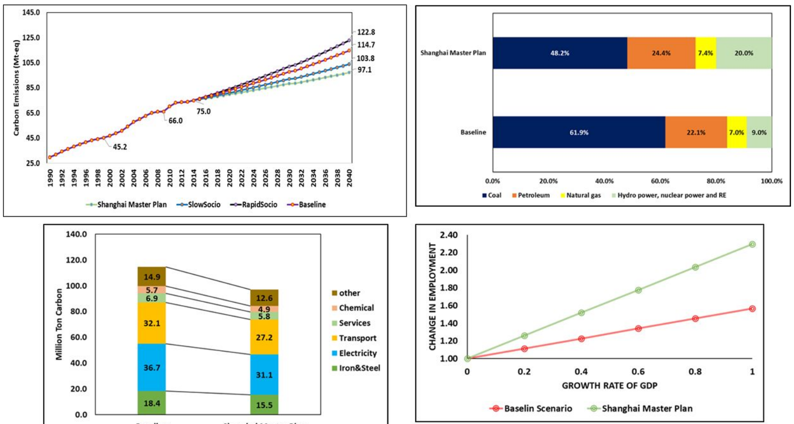

Fig 4. Case of Shanghai

Case of Kuala Lumpur, Malaysia: Implementation of a transport convenient, easier, accessible and more efficient in Kuala Lumpur was assessed through the "Green *mobility plan*". The modal share of the public transport will increase from 19% in the baseline scenario to 42% in the Green mobility plan. The fuel-saving potential from the implementation of the Green

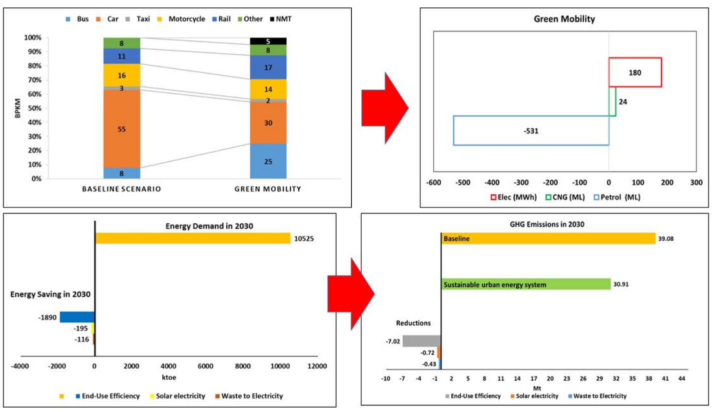

Fig 5. Case of Kuala Lumpur

mobility plan is estimated at 27.3% of the total energy consumption of Kuala Lumpur's transport system in 2030. The most significant saving, estimated at 531 million liters in 2030, is expected to result from reducing gasoline consumption by private vehicles. The decline in the total amount of harmful gas emissions, such as SO_2, NO_X, PM_{10}, and CO, compared to the baseline scenario are expected to be approximately 23%, 15.8%, 13% and 23.8%, respectively. The "Sustainable urban energy system *scenario"* was introduced for increasing the sufficiency of resources to meet energy demand at competitive and stable prices as well as improve the resilience of the energy supply system in this city. The major actions include solar energy utilization, waste-to-Electricity, and End-use Energy efficiency. The total potential reduction in GHG emissions from the implementation of this scenario is estimated at 26.4%. The largest reduction can be obtained from the EEE program, followed by solar energy utilization and waste-to-electricity.

Comparative Analysis: Tokyo performs reasonably well in USDI with almost equal share of different indicators which showed that, Tokyo Metropolitan Government developed and successfully implemented a number of policies and subprograms including the Tokyo Metropolitan Environmental Security Ordinance, the Tokyo Climate Change Strategy, and finally the Tokyo Metropolitan Environmental Master Plan that collectively aimed at reducing the energy-related GHG emissions of urban facilities. In addition to the reduction of GHG emissions

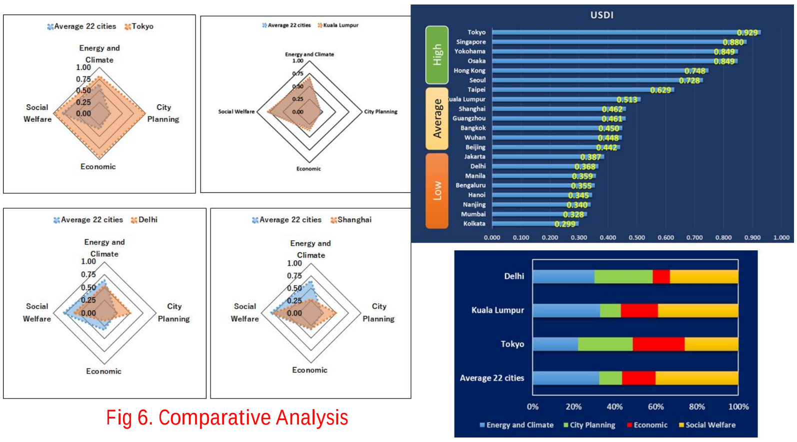

Fig 6. Comparative Analysis

and the consumption of energy, these policies set a target to increase the ratio of renewable energy consumption to about 20% by 2030. The strategies that are incorporated within these policies such as mandatory emission reductions, stakeholder interaction, and predefined emission targets should be considered as the most effective in terms of alleviating environmental pollution within the boundaries of an urban environment. The results of the comparative analysis also revealed that the cities like Delhi with using the least energy tend to have the lowest incomes. In qualitative terms, Delhi's policy is primarily top-down, influenced by the national discourse in climate change and energy. At present, there is no single or specific policy towards pushing clean energy applicable to Indian cities; the case of Delhi appropriately demonstrates this state of affairs. The Delhi government's focus seems to be more on gradual supply augmentation of traditional sources than envisioning a road map for a radical shift towards cleaner fuels or major demand-side management. On the contrary, it is seen that bold and strict decisions from the government or the judiciary like bans seem to work in Indian cities. Various urban amenities in Delhi are highly subsidized, and their price does not adequately reflect the input and operational cost, be it for electricity, water, LPG, waste disposal, etc. In the cities like Shanghai and Kuala Lumpur, the urbanization was correlated with the increase in air pollution. However, when the income rises, average emissions decline and policy execution like the LEDS which were proposed in this research play a key role in these cities. In Shanghai, reinforcing LEDS will have positive effects on per capita carbon emissions and per unit GDP carbon emissions. Evaluation of USDI in Shanghai showed that the growth of the tertiary sector based on modern, knowledge-intensive and service-based will result in increasing the USDI. Therefore, Shanghai's government should continue to pursue its policy to relocate its heavy industry to make room for the tertiary sector. Moreover, the Shanghai's local government needs to strengthen its economic restructuring policy, not only rely on technological improvements alone to reduce carbon emissions.

	Delhi		Shanghai		Kuala Lumpur	
Index	Before	After	Before	After	Before	After
Energy and Climate	0.33	0.53	0.27	0.48	0.67	0.75
City Planning	0.43	0.51	0.50	0.54	0.21	0.24
Economic	0.14	0.15	0.31	0.44	0.37	0.39
Public Health	0.64	0.82	0.81	0.88	0.82	0.89
USDI	0.37	0.46	0.46	0.56	0.51	0.55

Tab 1. USDI Before/After Analysis of implementation of LEDS

Stakeholder workshops: Concerning the LEDS implementation in the selected cities, the local governments need to profound challenges through a collaboration with the relevant stakeholders. In this context, several expert workshops with local and regional authorities in the selected cities were organized in order to engage stakeholders, enhance communication, and update of LEDS to understand how goals are set, how strategies are elaborated to achieve them, and to what extent the interface between development and climate change planning is addressed. To this aim, we organized a series of international workshops at Kyoto University and Kyushu University between 2016-2018, In addition to a one-day stakeholder workshop in Delhi (May, 21, 2018, ISARD), Shanghai (June, 8, 2018, Tongji University) and Kuala Lumpur (May, 3, 2018, University of Malaya). The stakeholders included business, industry, non-governmental organizations and local and regional authorities in the selected cities.

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６．研究組織

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