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Roof of Lau Pa Sat, Singapore, 2009. Photo by William Cho (Permission under CC BY-SA 2.0).

INTRODUCTION

The theme of this issue is sustainable development through energy system modelling and policy analysis (Part 2 of 2).

To achieve the overarching goal of sustainable development, many countries have launched a basket of policies relating to energy and the environment. These policy packages exert significant influences on the local economy as well as on other countries through trade. The varied experiences of countries which have been implementing such policies for some years provide valuable lessons for countries that are just beginning to grapple with how best to achieve sustainable development.

The Economy-Energy-Environment (E3) modelling framework includes the top-down economy-wide model, bottom-up technology rich model, sectoral energy system model, integrated assessment model, life cycle assessment model, climate impact model, decision-making model, forecasting model, etc. Policy analysis based on these models can provide insights into the inter-relationships among economic development, energy consumption and the resulting impacts on the environment. In recent years, there has been growing interest in integrating the different models into a comprehensive modelling platform.

This issue of the ESI Bulletin provides summaries of five of the presentations delivered at ESI's 4th *Asian Energy Modelling Workshop on Sustainable Development through Energy System Modelling and Policy Analyses*, held on 19 January 2017. (Summaries of the first five presentations were published

In this issue ...

in the previous issue of the ESI Bulletin (vol. 10, issue 2, April 2017). In all, there were 10 speakers who came from China, France, Italy, Japan, Norway, Singapore and Taiwan. These summaries discuss the new developments in energy system models and their applications to issues relating to sustainable development at the city, national, regional and global levels.

Dr. Taoyuan WEI, Senior Researcher at the CICERO Center for International Climate Research in Norway, presented “Estimation of Global Rebound Effect Caused by Energy Efficiency Improvements”. This presentation offered an illustrative estimate of the global rebound effect based on a CGE model, and discussed how to obtain a better estimate. The estimate showed that energy efficiency improvements in economic activities other than energy production leads to limited reduction in emissions in the long term as the cost of fossil fuels drops even further vis-á-vis the cost of renewables, implying that improving the efficiency of renewables alone can be more effective in promoting renewable energy consumption and reduction in emissions. The preliminary results also showed considerable regional and sectoral differences in the rebound effect.

Dr. Minjun SHI, Professor at Renmin University of China, presented “From Efficiency Priority Strategy to Total Control Strategy in Beijing: Urban Transformation as an Adaptation to Resource and Environmental Constraints”. Beijing has been experiencing a water shortage that is likely to impede its future development as a sustainable city. An optimisation analysis based on an input-output framework was conducted to investigate Beijing’s urban transformation as an adaptive measure. The results showed that water resources have become a “hard constraint”, affecting industrial development in different phases. The analysis verified the great potential for industrial restructuring and water savings as well as economic growth and the need for a change from simply prioritising efficiency to cutting down the scale of industry.

Mr. Rocco De MIGLIO, Management Engineer and Co-founder of the E4SMA in Italy, presented “Developing an Integrated Energy Strategy for a Sustainable Transition Using a TIMES-Based Model”. This research was based on the application of a TIMES-based integrated and participatory modelling approach. A reference projection of a “city-wide” energy system was simulated and then modified through a number of actions and measures aimed at representing alternative sustainable planning hypotheses. For each scenario, the City-model returned the optimal energy and technology mix as well as economic and environmental responses. The benefits and trade-offs of such actions and measures were evaluated by comparing the outputs of the integrated model among the different scenarios with respect to the reference development of the city energy system.

Dr. Jyh-Jun CHEN, Researcher at the Energy Economics and Strategy Research Center of the Institute of Nuclear Energy Research (INER) in Taiwan, presented “Power Mix Scenario Analysis for Carbon Reduction Targets in Taiwan Using an INER-TIMES Model ”. Taiwan plans to phase out the use of nuclear power by 2025 and the government has set a high emissions reduction target. Incorporating these conditions, the simulation results showed that the shares of solar PV, offshore wind, carbon capture and storage, and gas increase rapidly in the power generation mix. The time slice function of the TIMES was utilised to analyse the requirements in 2030 and 2050 for energy storage technologies needed for the large-scale intermittent renewable energy integration. The results showed that gas-fired plants will be used for base power, and the system will depend more on pumped-storage hydroelectricity and chemical energy storage technologies to balance demand and generation.

Dr. Victor NIAN, Research Fellow at the ESI, presented “Assessment of Energy Technologies from a Whole System Perspective”. Planning for a portfolio of technologies is of strategic importance in the economic development of any modern economy. While a given technology may satisfy national objectives, it may have a wide-ranging influence on the sustainability of a greater system beyond the national borders. Despite the sheer number of analytical tools available, there is still a need for a simple, transparent, easy-to-interpret and yet robust tool which combines the advantages embedded in the various existing tools. This presentation reviewed the development of modelling tools in terms of methodology and applications. It also provided insights into what and how strategic questions related to energy technology can be formulated and attempted through modelling analysis.

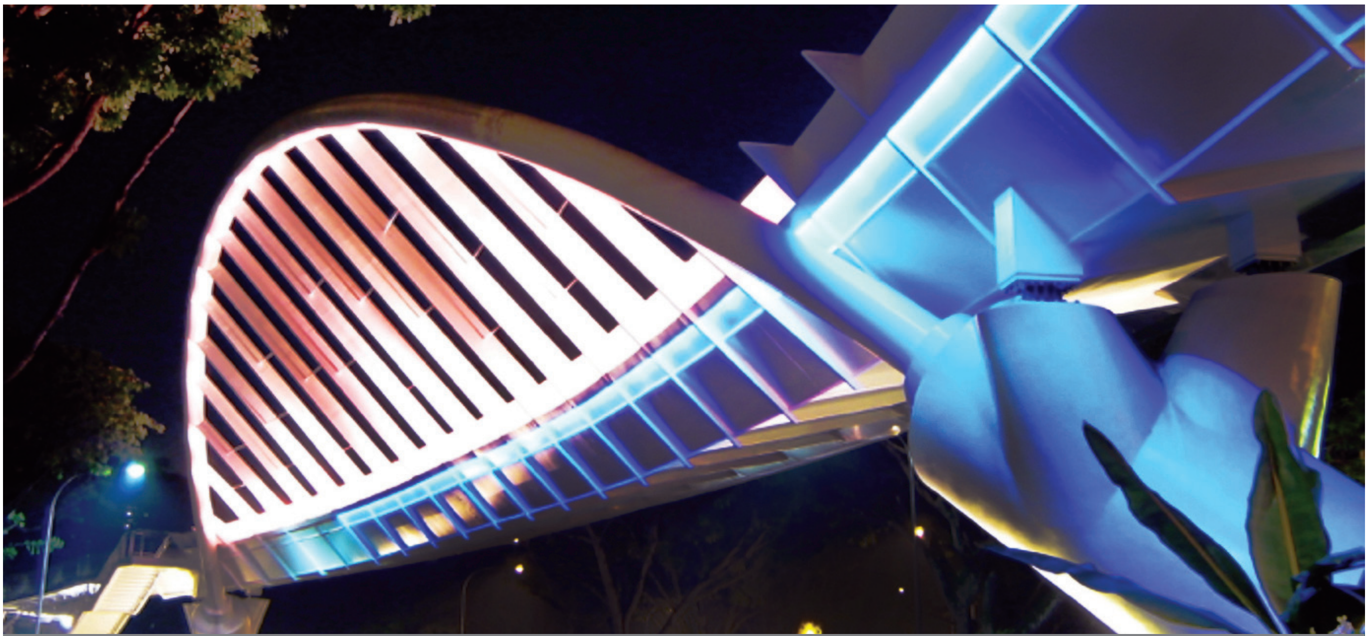
We hope you find these presentation summaries of interest and welcome your views and comments.

Dr. LI Yingzhu, ESI Research Fellow, and Dr. SU Bin, ESI Senior Fellow
(On behalf of the ESI Bulletin Team)

Youbike Station at Changhua Railway Station, Changhua City, Taiwan, June 2014. Photo by Jeffreyjhang (Permission under CC BY-SA 3.0).

Estimation of Global Rebound Effect Caused by Energy Efficiency Improvements

Dr. Taoyuan WEI, CICERO Center for International Climate Research, Norway



Alexandra Arch at Alexandra, Singapore, 2009. Photo by Kok Leng Yeo (Permission under CC BY 2.0).

The rebound effect suggests that a series of behavioural responses may distort the initial response to energy efficiency improvements (see Figure 1). At one extreme, consumers may reduce energy consumption by more than the energy efficiency improvement, leading to super-conservation. Alternatively, consumers may consume more energy than the stipulated energy efficiency improvements, leading to energy efficiency backfire. Mostly, there will be a situation of partial rebound.

While the rebound effect has been much studied in existing literature, there remains a lack of focus on global and general equilibrium rebound. This study examines the size of the global rebound effect on energy use and related emissions in the long term using the Global Responses to Anthropogenic Change in the Environment (GRACE) Model.

GRACE is a global, recursive and dynamic computable general equilibrium (CGE) model. It divides the world into eight regions: the United States, European Union, Japan, Russia, China, India, Brazil and the rest of the world. The model is calibrated using the Global Trade Analysis Project (GTAP) version 9 database, with the base year of 2011. Development pathways up to 2040 follow the scenarios set forth in the 2015 *IEA World Energy Outlook* New Policies Scenario. An alternative Energy Efficiency Improvement Scenario was developed under the assumption that the world economy will be 10 per cent more efficient in 2040 in all non-energy sectors compared to the BAU, equivalent to an annual energy efficiency improvement of 0.38 per cent.

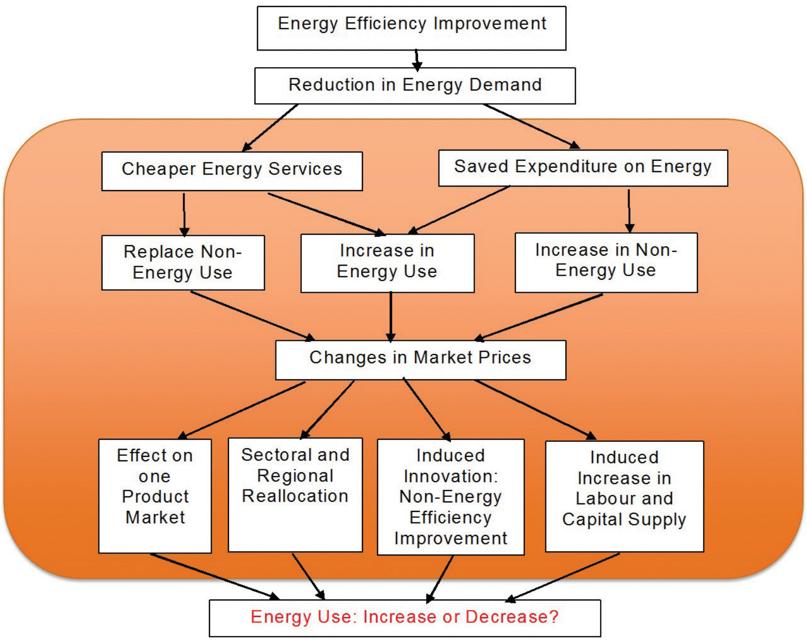
Simulation results indicate that there is a considerable long term rebound effect in energy, ranging from 55 per cent in Brazil to close to 80 per cent in India, with the global effect close to 70 per cent by 2040. Although at first glance such estimates may seem high, the results are broadly in line with previous estimates (e.g., Barker et al., 2009), which set the global rebound effect in energy to be 31 per cent by 2020 and 52 per cent by 2030.[1] The rebound effects in terms of emissions are significantly higher at between 75 per cent (Russia) to 98 per cent (China) and the global estimate is at 90 per cent. As energy efficiency is introduced as a parallel increase in all sectors in the model, fossil fuels, which are cheap compared to renewable energy sources, will only become cheaper, thereby inducing increased consumption of these emission-intensive sources.

The results also illustrate that labour mobility contributes positively to the rebound effect. In fact, when the labour supply is fixed, the global rebound effect on energy falls from 70 per cent to 60 per cent. Interestingly, the rebound effect dropped significantly when the labour supply was fixed in developed countries and China, while experiencing little change in the case of India. This may imply that the labour supply fulfils different roles in different regions.

The model can also be extended for a more detailed regional analysis on the rebound effects of different energy sources. For China, two observations can be made. Firstly, the rebound effect for crude oil is always the highest, which may be explained by the historical low consumption of the fuel. Secondly, backfire (whereby the rebound effect is more than 100 per cent) is experienced in both the agriculture and services sectors. Thus, policy-makers should be cautious when initiating energy efficiency in these sectors to reduce energy use/emissions, given that these labour intensive sectors may see increased economic activity when energy constraints are removed. In a similar vein, energy efficiency policies may be the most effective in the energy-intensive sectors.

The results of this study have several important implications. Firstly, stand-alone energy efficiency improvements may not be an effective policy for emissions abatement and reduction in global energy use. However, energy efficiency remains a significant contributor towards promoting economic growth and social welfare, as seen from its contribution in increasing the supply of labour and capital in the long run. Secondly, policies targeting the improvement of energy efficiency in renewables are expected to be more effective in promoting renewable energy production and emissions abatement than energy efficiency measures. Lastly, efficiency improvements are more effective in the energy-intensive sectors, thus more policy attention could be directed to these sectors.

Figure 1: Rebound Effect Mechanisms



Source: Dr. Wei's presentation slide.

Further studies are needed to examine the reasons behind the significant long-term global rebound effect. These studies could perhaps include comparatively cheaper fossil fuels, sectoral or regional reallocation, induced capital supply, key substitution parameters and investment costs to obtain energy efficiency improvements. More importantly, further studies are needed to validate the model using historical data from databases such as the World Input-Output Database (WIOD). Such examinations would allow differentiation between historical and current rebound effects, thereby enabling better estimates of the long-term global rebound going forward.

This summary of Dr. WEI's presentation was written by ESI Research Associate, Jacqueline TAO.

1 T. Barker, Dagoumas, A. and Rubin, J., "The Macroeconomic Rebound Effect and the World Economy", *Energy Efficiency* 2 (2009: 411).

From Efficiency Priority Strategy to Total Control Strategy in Beijing: Urban Transformation as an Adaptation to Resource and Environmental Constraints

By Zhuoying ZHANG (Assistant Professor at the Academy of Mathematics and Systems Science, Chinese Academy of Sciences) Xiaoling ZHANG (Associate Professor, City University of Hong Kong), Minjun SHI, (Professor, School of Economics, Renmin University of China)

Over the last 25 years, the population of Beijing has doubled while its GDP has risen over 40 times. The result has been a severe stress on water resources with average yearly water consumption at only 1/60th the world average. As the population and GDP of Beijing are expected to continue growing for some time, the question of optimising usage of water resources for a level of economic growth is highly pertinent. To this end, the authors of this study sought to determine the optimal industrial structure in Beijing under water resource constraints.

The potential of industrial restructuring for water saving and economic growth was analysed by applying three different objectives in an optimisation model for different time phases in Beijing: 1) optimising for maximum GDP growth for a given level of water usage; 2) optimising for minimum water usage for a level of GDP; and 3) optimising for a minimum level of intensity of water use for a given level of GDP and industrial structure. Using data from input-output tables, the model was set up as an optimisation problem subject to the constraints of Beijing's industrial structure and total water supply, setting a lower limit of agriculture production to allow for a level of essential agriculture production.

The results of the optimisation for maximisation of GDP indicated that the current level of optimised water use can support a higher level of GDP growth. Figure 1 shows that: 1) the economic benefits gained through industrial restructuring aimed at enhancing economic growth under water constraints are positive, and 2) less water is needed to support the present level of economic activity. This is confirmed by the second objective of optimisation for less water use. The results showed that the water use necessary for sustaining the present level of GDP is only 50 per cent of the current water usage (see Figure 2). The results from the third optimisation exercise to minimise the intensity of water usage found that optimised water use for the same level of GDP is 45 per cent less than the current water use (see Figure 3). This means that the effects of making changes to Beijing's industrial structure in order to minimise water intensity are similar to the effects of minimising the amount of total water use.

In each period, the most predominant factors involving water resources in Beijing's industrial restructuring were the economic factor in 1992, the water use efficiency factor in 2002, and the water use quantity factor in 2012. Over the period in question, urban transformation in Beijing as an adaptation to water resource constraints would have gone through a process of efficiency priority strategy to total control strategy. This is due to the fact that a total control strategy provides stringent control over the scale

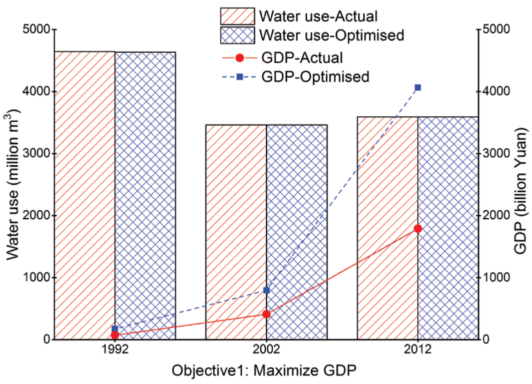
Industrial Area in Beijing at Night, China, 2005. Photo by Peter Morgan from Beijing, China (Permission under CC BY 2.0).

of production and greater water saving effects than an efficiency priority strategy. This can be seen from the scale of optimised production where objective 2 is lower than that in objective 3, with the difference increasing over the target years. The optimised total water usage with objective 2 is also lesser than that for objective 3, with the former measured at approximately 30 per cent to 40 per cent less than in the latter. For the high water intensity sectors, their predicted scale of production is significantly reduced by optimisation, especially with the optimisation of objective 2.

In conclusion, the results of this study confirmed the potential utility of industrial restructuring aimed at water saving and economic growth in Beijing. They helped identify the ideal industrial structure and clarify the pathway of Beijing's urban transformation as an adaptation to water constraints. The selection of either a total control strategy or an efficiency priority strategy for industrial restructuring is relevant to the problem of severe water resource constraints in the region's socio-economic development. The former is more powerful than the latter in reducing water use, but requires stringent control over the scale of production. Going forward, Beijing's achieving sustainable development under water resource constraints pivots on fundamental changes being made to its mode of economic growth, namely: (1) carrying out some profound internal industrial restructuring, and (2) shifting some industries to surrounding areas. The use of this analytical approach indeed has the potential to deepen our understanding of Beijing's urban transformation and the role of water resources in the process, providing inputs for policy-makers to maintain the region's future sustainable development.

This summary of Zhuoying ZHANG et al.'s presentation was written by ESI Research Associate, Hari M.P.

Figure 1: Optimise for Maximum GDP (Objective 1)



Source: Dr. Zhang's presentation slide.

Figure 2: Optimise for Minimum Water Use (Objective 2)

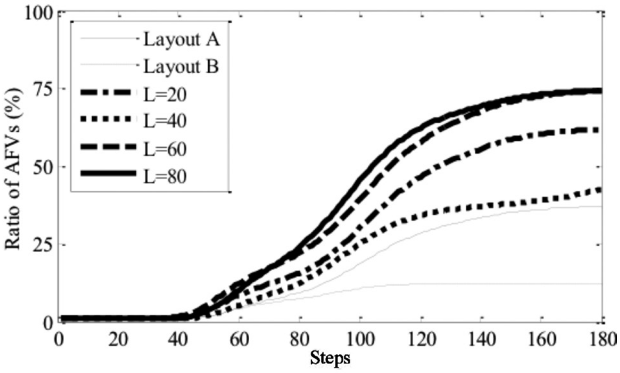
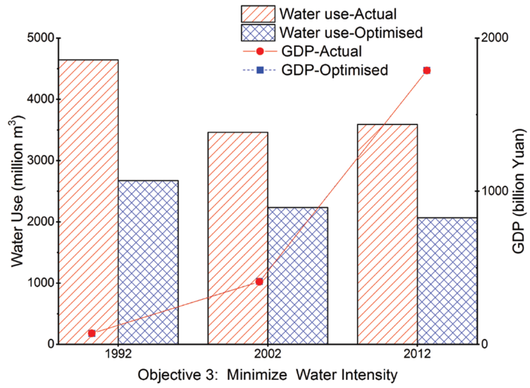


Figure 3: Results from Optimisation for Minimum Water Intensity (Objective 3)



Developing an Integrated Energy Strategy for a Sustainable Transition Using a TIMES-Based Model

Mr. Rocco DE MIGLIO, Energy Engineering Economic Environment Systems Modelling and Analysis (E4SMA), Team of InSmart, Cesena, Italy

Panoramic View of Cesena, Italy, 2009. Photo by Uomodis08 (Permission under CC BY-SA 3.0).

To be an ideal energy model, it must meet several criteria. For instance, the model should include technology explicitness, microeconomic realism, macroeconomic robustness, consumer behaviour, regulatory instruments and financial incentives. Equally important, the model should be integrated and participative. For several reasons the Integrated Markal-Efom System (TIMES) is a commonly used energy model. Firstly, it is an integrated, linear programming bottom-up energy model. Secondly, it can provide a prospective analysis on a long term horizon and the energy demand is driven by energy service demands which are exogenously defined and (generally) expressed in physical units. A "responsive or elastic" energy demand mode can also be used. Thirdly, it can be used to select optimal technologies with an objective function as the maximisation of the net social surplus (mono-objective) and several environmental constraints (e.g., GHG emission limits). Finally, TIMES can compute an economic equilibrium for energy markets, from supply to end-use services.

Energy models can be used for scenario analysis. Energy scenarios are not meant to be predictions of the future, but rather points of comparison to evaluate sensitivities and alternative outcomes. To use energy model scenarios in policy-making, there are two approaches: (1) one which includes targets which must be met in the scenarios (e.g., energy efficiency targets or emission targets); and (2) one which includes a set of policy mechanisms (e.g., CO_2 tax, feed-in-tariffs and standards) and examines their effect on the development of the energy system.

In the first approach, the model is run with the targets to be achieved, then the technologies and energy mix of the cost-optimal path in the model solution are identified to achieve the target. After that, how to achieve the cost-optimal path through policy instruments is identified. The policy instruments include regulations, awareness-raising actions, market reforms and longer term options. Finally, the action plans with detailed and clear measureable targets, activities, timeframes, tasks, responsibilities, resources allocation, milestones and performance measures can be produced.

In the second approach (Figure 1), the first step is to run the model with the actions (policy instruments) included. Then the model solution will show the effect of the policies on the energy system development. After that, the output is compared with the desired state of the energy system in the future. Finally, the action plans can be produced.

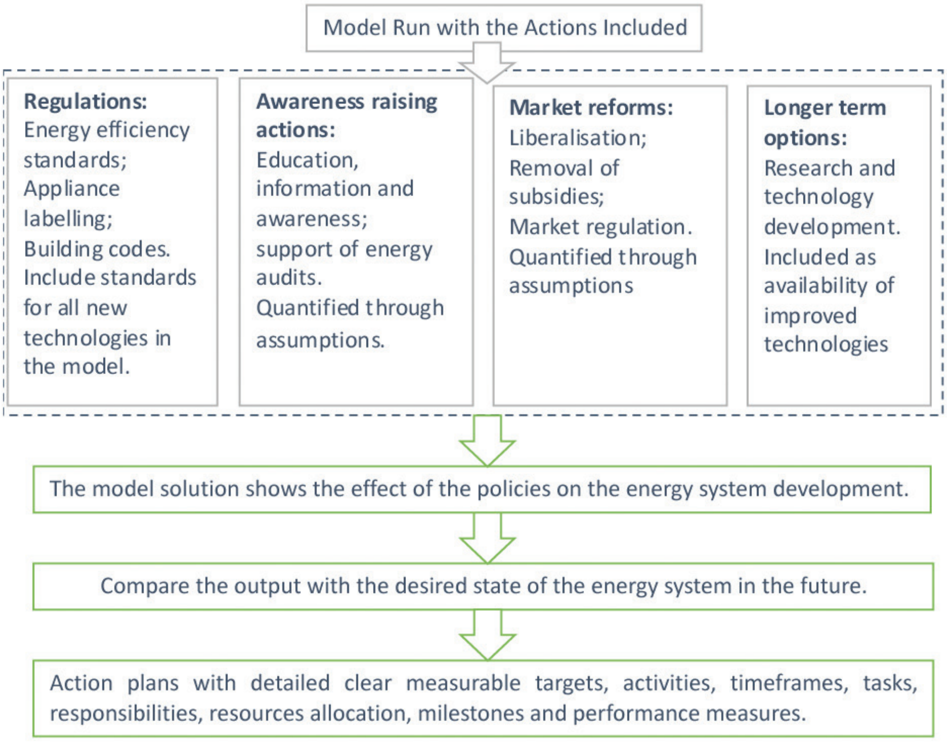
The goal of both approaches is to use the output from the scenario analyses to design and implement national policies. In order to identify the required actions necessary for moving the system towards desired evolutions (or at least be able to avoid undesired developments), the backward approach can be used. The backward approach means working from the scenario results to the existing situation (base year) to identify pathways, bottlenecks and complexities in the concrete actions suggested by the modelling exercise. Note that the perfect foresight of some models may depict a pathway towards the final (desired) outcome which is not easy to implement. Analysis of the results (identification of key turning points and changes) is always needed to design the set of actions and timeline.

In recent years, the TIMES model has been employed to analyse a wide variety of activities. In this study, it is applied to four municipalities in the European Union (EU), where the key goal is the identification of an optimum mix of applicable measures and technologies that will lead the way towards the achievement of the municipalities' sustainable targets. Compared to the existing (common) planning methods, the outputs indicate that the key advantages of the proposed approach are that multiple future energy scenarios can be analysed and cross-compared, and integrated strategies can be identified. Furthermore, stakeholders' engagement is used to generate alternative planning hypotheses. The stakeholders' engagement involves two steps: (1) identification of an optimum mix of applicable measures and technologies that will pave the way towards the achievement of the sustainable targets of the municipality of Cesena, Italy; and (2) comparison of performance criteria (both quantitative and qualitative) to rank the alternatives.

In this case study, six alternatives were identified and nine criteria were compared using the Hinkle's method. The results provided the best alternative, and also quantitative information (right technologies, right places, right time) for the preparation of the implementation plan. The results also indicated that in 2030, emissions covered by the present analysis were reduced by about 17 per cent based on 1995 values, and per capita emissions were reduced to 3.2 t/capita in 2020 and 2.5 t/capita in 2030. In summary, urban planning and energy planning were carried out together in an integrated manner, and the participation of the municipalities' staff and a broad stakeholder group was incorporated.

This summary of Mr. DE MIGLIO's presentation was written by ESI Research Fellow, Jun YUAN.

Figure 1: Approach for Energy Model Scenarios Used in Policy-Making



Source: Rocco De Miglio's presentation slide.

Power Mix Scenario Analysis for Carbon Reduction Targets in Taiwan Using an INER-TIMES Model

Dr. Jyh-Jun CHEN, Center of Energy Economics and Strategy Research, Institute of Nuclear Energy Research, Taiwan

Main Stadium at the World Games 2009, Kaohsiung, Taiwan, 2009. Photo by Peellden (Permission under CC BY-SA 3.0).

This study evaluated Taiwan's electricity generation mix and CO_2 emissions from 2015 to 2050 on the basis of the Institute of Nuclear Energy Research's (INER) Integrated MARKAL-EFOM System (TIMES) model. The INER-TIMES is a type of bottom-up, technology-rich and cost optimisation model whose purposes are to determine decarbonisation pathways and to assess technologies. This energy system model is useful in that, given the different power technologies in any given economy, it allows for better assessment of CO_2 reduction in the medium and long terms, and also

Table 1: Description of Technologies, CO_2 Reduction Targets and Scenario Assumptions

Tech	Time	Reference	Advanced	Moderate
Coal-fired, Gas-fired, Oil-fired	2016-2027	Up-Bound set as 10505 TPC Project of Power Development Planning		
	2028-2050	Coal-, gas- and oil-fired annual growth rate set as 3.4%/year , 5.6%/year and 0%/year, respectively		
CCS	from 2035	Owner-defined Up-Bound		
Renewable	2016-2025	Up-limit set as the BOE planning		
	from 2026	Up-limit set as Advanced Scenario		Up-limit set as Moderate Scenario
Nuclear	from 2016	Nuke 1-3 decommission as scheduled / Nuke 4 Halt		
Co-gen	2020-2050	Up-limit referred to statistics of Bureau of Energy		
CO_2 Reduction Target	2020	N/A	Equal to the amount in 2005	
	2030		INDC	
	2050		Legislation Target	

Source: Dr. Chen's presentation slide.

gives reference to policy-makers for power generation and CO_2 reduction planning.

The scenarios were based on the planning of three Taiwan government agencies: the Taiwan Power Company (TPC), Bureau of Energy (BOE) and the Environmental Protection Agencies (EPA). The inputs of the overall modelling framework consisted of energy demands, cost parameters, technical parameters and policy targets, while the outputs were energy cost, CO_2 emissions, energy mix and energy roadmap. The modelling analysis consisted of three scenarios: Reference, Advanced and Moderate. The global model included seven technologies. The detailed scenario assumptions are shown in Table 1.

The results of the Reference Scenario found that after 2025, when there is to be no nuclear power, the generation portfolio of coal and gas increased gradually, but the increase in renewables was limited without a target for reducing emissions. The average annual growth rate of electricity consumption was 1.2 per cent from 2016 to 2025 but dropped to 0.68 per cent from 2026 to 2050 due to a shrinking of the population and slowing down of GDP growth.

In the Advanced Scenario for CO_2 reduction targets, an obvious turning point occurred in 2025. Before 2025, as coal generation was still used as the base power, it accounted for a considerable proportion in the whole generation portfolio. However, after 2025, coal was gradually replaced with low-carbon and zero-carbon technologies. In 2040, the proportion of net generation for coal was almost zero while the proportion of CCS increased rapidly. The daily load curves in this scenario for 2050 were analysed and compared in the summer and winter seasons. Due to the summer's higher intensity of sunlight, PV power generation was significantly higher compared to what was generated in the winter. Due to the monsoon, winter offshore wind power generation was significantly higher than in the summer. Storage and gas-fired generation played important roles in maintaining a stable power supply.

In the Moderate Scenario, the generation portfolio of PV was smaller than in the Advanced Scenario. Hence, the demand for electricity was reduced to achieve the same emissions reduction target after 2025. The balance between generation and demand was adjusted by conventional pumped-storage hydroelectricity and gas-fired generation, while the development of chemical energy storage technologies, such as flow batteries, was quite limited. Compared with the *Energy Technology Perspectives (ETP) 2016*,[1] the reduction of emissions for the medium term in Taiwan were more dependent on solar and gas-fired generation due to the lack of nuclear, CCS and biomass. For the long term, more CCS and enhanced geothermal were needed. In 2025, the generation of solar and wind power reached 15 per cent in total, which was notably higher than the 9 per cent in the New Policies Scenario and 11.4 per cent in the 450 Scenario in the International Energy Agency's *World Energy Outlook 2015*.[2] This reveals that the technologies for emission reductions are quite limited in Taiwan.

In conclusion, the INER-TIMES model was able to simulate how storage technologies perform with large-scale intermittent renewable energy integration. Based on the results from the Advanced Scenarios, the author suggests that the government of Taiwan build 2.1 GW of pumped-storage and 3.8 GW of flow batteries prior to 2035 and 2050. The 28 GW of gas-fired generation will continue to meet the daily load. Compared with the *ETP Perspectives 2016*, due to the lack of nuclear and biomass, in the medium term Taiwan will be more dependent on solar PV and gas-fired generation, while in the long term, more CCS and enhanced geothermal will be required.

This summary of Dr. CHEN's presentation was written by ESI Visiting PhD student, Ms. Cuixia GAO, from Jiangsu University.

1 International Energy Agency (IEA). *Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems* (Paris: OECD/IEA, 2016).

2 IEA. *World Energy Outlook 2015* (Paris: OECD/IEA, 2015).

Assessment of Energy Technologies from a Whole System Perspective

Dr. Victor NIAN, Research Fellow, Energy Studies Institute, NUS

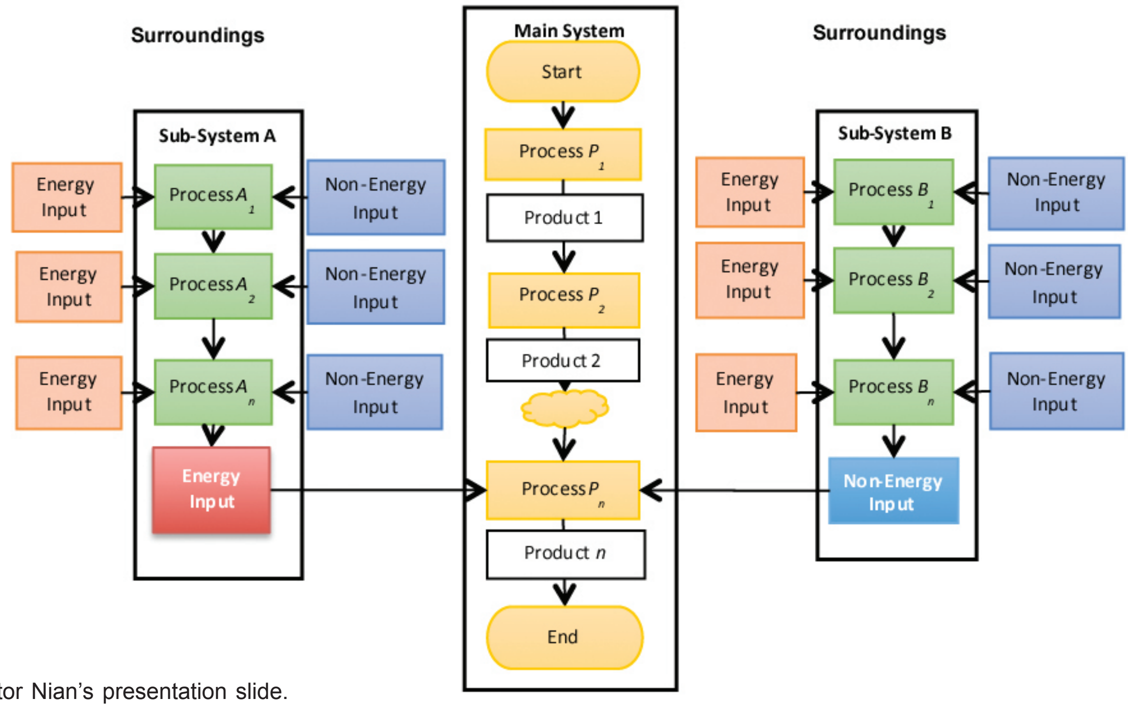
Panian Coal Mine on Semirara Island, Caluya, Antique, Philippines, 2005. Photo by TJCERAME (Permission under CC BY-SA 3.0).

Accompanying their growing economic development, the countries of Southeast Asia are all experiencing rising energy demand and rising energy intensity of demand.[1] The forecast in 2013 showed that fossil fuels will continue to play an important role for many years to come. The goal to reduce carbon emissions in this part of the world is challenging given that the demand for coal is still increasing. The International Energy Agency (IEA) predicts that as the Southeast Asian countries increasingly become net energy importers, they must "use the money in the right places" in terms of energy infrastructure investments if they are to accomplish their decarbonisation targets. However, the various countries use different types of electricity generation.

Thus, the purpose of this presentation was to discuss the development of methodologies that capture the advantages of the existing methods of power generation as well as their potential for carbon reductions. These methodologies can be used as generic tools for the life cycle analysis of carbon emissions from other power generation technologies and systems.

When conceiving this methodology, the primary considerations were: benchmarking the performance of energy technology systems, understanding the impacts of decisions on the energy system, evaluating the alternative pathways to achieve policy objectives and analysing different levels of energy systems flexibly. The first methodology is based on the energy balance principle. The system may comprise a number of processes, some of which may interact with other systems as shown in Figure 1. It encompasses a generic system, input–output and boundaries definitions. The boundaries facilitate the use of Kaya Identity and decomposition techniques to identify carbon emission streams.

Figure 1: A Conceptual Depiction of a Life Cycle System and Its Interactions with Its Surroundings



Source: Victor Nian's presentation slide.

Coal-Briquettes Distributor in Hanoi, Vietnam, 2011. Photo by CEphoto (Permission under CC BY-SA 3.0).

However, the conventional system and boundary formulations developed for the life cycle of an individual energy system cannot be directly applied to a life cycle of interconnected energy systems. To address these inherent issues, a new life cycle analysis (LCA) using the process chain analysis (PCA), called an LCA–PCA methodology, is developed. A new concept of partial temporal boundary is introduced through a quantitative formulation. The interconnecting systems are synchronised through the partial temporal boundary.

The cost drivers for learning-by-doing can be divided into internal drivers and external drivers. Specifically, the internal cost drivers contain learning by doing cluster learning, economies of scale, economies of repetition and batch production and others. The external cost drivers contain technology transfer, spill-over effects, severe accidents, extreme external events (e.g. natural disasters and terrorism activities), policy and regulatory changes and others. The application of this methodology can be used to assess environmental impacts on the solar PV industry,[2] woody biomass and coal industries.[3]

On the flexible system representation front, the methodology allows for an energy system to be represented as a particular engineering process, a general or macro economy of a country, or the whole world. A flexible system formation can facilitate flexible input and output definitions. The input and output of a process can be energy, material, cost and any other quantifiable variables that are relevant to the overall objective of an analysis.

In summary, the current state of methodology development can be summarised as follows. A generic multi-process system can be evaluated on the basis of cradle-to-grave. A generic multi-system formation can be evaluated using the synchronisation principle recently developed in the LCA literature. Accounting for non-quantifiable variables (such as social behaviour, geopolitics and international relations), extension of system and process definitions, and interactions with macroeconomic modelling frameworks are pending further development.

This summary of Dr. Victor NIAN's presentation was written by Ms. SHI Min, a doctoral candidate at the Research Institute of Economics and Management (RIEM) of Southwestern University of Finance and Economics, China.

1 International Energy Agency, *Southeast Asia Energy Outlook 2015* (Paris: OECD/IEA, 2015).

2 Victor Nian, "Impacts of Changing Design Considerations on the Life Cycle Carbon Emissions of Solar Photovoltaic Systems" *Applied Energy* 183 (2016: 1471-87).

3 Victor Nian, "The Carbon Neutrality of Electricity Generation from Woody Biomass and Coal, a Critical Comparative Evaluation" *Applied Energy* 179 (2016: 1069-80).

Staff Publications

Internationally Refereed Journals

Xunpeng Shi, **Hari Malamakkavu Padinjare Variam**, "East Asia's Gas Market Failure and Distinctive Economics: A Case Study of Low Oil Prices", *Applied Energy* 195 (2017): 800-809.

Brantley Liddle and Perry Sadorsky, "How Much Does Increasing Non-fossil Fuels in Electricity Generation Reduce Carbon Dioxide Emissions?", *Applied Energy* 197 (2017): 212-21.

Books and Book Chapters

Ho Juay Choy, **Melissa Low**, **Gautam Jindal**, Dora Almassy, *Handbook For ASEAN Government Officials on Climate Change and SDGs*, Asia Europe Environment Forum, April 2017.

Staff Presentations and Moderating

3 May Christopher Len and Philip Andrews-Speed presented "Energy and Sustainable Development" at the National University of Singapore – University of Tromso workshop, jointly organised by ESI and Innovation Norway Singapore.

26 April Philip Andrews-Speed presented "Governing the Energy-Water-Food Nexus in China: An Institutional Analysis" at China University of Mining and Technology Beijing, Beijing.

18 April Anthony D. Owen presented "The Southern African Powerpool" at the *HAPUA – UNESCAP Workshop on ASEAN Electricity Exchange*, Jakarta.

18 April Anthony D. Owen presented "The Greater Mekong Sub-Region" at the *HAPUA – UNESCAP Workshop on ASEAN Electricity Exchange*, Jakarta.

3 April 2016 Philip Andrews-Speed presented "Nitrogenous Chemical Fertiliser in China's Water-Energy-Food Nexus: An Institutional Analysis" at *Energy Research and Social Science Conference*, Sitges, Spain.

22 April Melissa Low presented "Actions on Adaptation and Resilience in a Densely-Populated City: Singapore" at the *4th International Conference on Climate Change* at Hong Kong Polytechnic University, Hong Kong.

6 April Melissa Low moderated the panel discussion at "Optimism in a Time of Uncertainty: Before the Flood" organised by ESI and held at the University Hall Auditorium, NUS.

Staff Media Contributions

Philip Andrews-Speed was interviewed by *Radio Free Asia* on China's clean air plan, 4 April 2017.

Recent Events

4 May, International Legal Framework for Nuclear Liability: A Coastal State Perspective (Joint ESI-Centre for International Law Seminar)

Mr. Julian Ludbrook, career diplomat from New Zealand and one of the original members of the Group of International Legal Experts appointed to advise the Director-General of the IAEA on international nuclear liability issues delivered a presentation on international nuclear liability from New Zealand's perspective. He began by stating that New Zealand has no nuclear energy industry and is not a user of energy produced from nuclear reactors. He viewed the country as a potential victim of damage from an accident involving the transport of radioactive materials near its territory or exclusive economic zone (EEZ). Mr. Ludbrook expressed concern over the possibility of contamination to the Pacific Ocean from damage sustained to a reactor located in another country. The contamination could cause environmental damage to nearby Pacific waters and adversely affect migratory fish species caught in New Zealand's EEZ or in the waters of the South Pacific affecting some of New Zealand's Pacific neighbours' economies.

3 May, NUS-UiT Workshop on Research Collaboration (Joint ESI-Innovation Norway Singapore Workshop)

This half day workshop was co-organised for a delegation visiting from The University of Tromsø - The Arctic University of Norway (UiT). Its purpose was to discuss potential collaboration between the National University of Singapore and the UiT.

Following welcome remarks by the Norwegian Ambassador to Singapore, Mr. Tormod Endresen, the UiT Rector, Professor Anne Husebekk, and the Executive Director of ESI, Professor Chou Siaw Kiang, introduced their respective

NUS-UiT Workshop co-organised by ESI and Innovation Norway Singapore (Photo by ESI Staff).

organisations. Then several participants made brief presentations to introduce their Arctic research interests, in the areas of Engineering and Maritime Research, Law of the Sea, Energy and Sustainable Development, and Sustainable Arctic Tourism. Professor Husebekk also highlighted UiT's work on Biomedicine and Infrastructure Research. In addition to potential collaborative research, the two sides also discussed potential student exchanges between the two universities.

NUS was represented by Professor Chou Siaw Kiang (Executive Director, Energy Studies Institute), Professor Chow Yean Khow (Executive Director, Centre for Offshore Research and Engineering and Maritime Institute@NUS), Associate Professor Robert Beckman (Head, Ocean Law and Policy Programme, Centre for International Law), Dr. Philip Andrews-Speed (Head of Energy Security, Energy Studies Institute), Dr. Christopher Len (Senior Research Fellow, Energy Studies Institute) and Dr. Sun Zhen (Research Fellow, Centre for International Law).

The UiT participants were Professor Anne Husebekk (Rector), Professor Wenche Jakobsen (Pro-rector for Education), Professor Tore Henriksen (Faculty of Law), Sigrid

From left to right: Associate Professor Robert Beckman, Ambassador Tormod Endresen, Professor Chou Siaw Kiang, Professor Anne Husebekk, Professor Chow Yean Khow and Professor Wenche Jakobsen (Photo by ESI Staff).

Ag (Director/Section for Internationalisation of Studies), Professor Young-Sook Lee (Tourism and Arctic Studies), Professor Tone Bleie (Faculty of Law), Professor Peter Wide (Engineering and Safety), Associate Professor Balpreet Singh Ahluwalia (Faculty of Science and Technology), Associate Professor Bjørn-Morten Batalden (Faculty of Science and Technology), Geir Gotaas (Senior Advisor-Rectors Office), Karine Nigar Aarskog (Senior Advisor-Section for Communication) and Jan Solski (K.G. Jebsen Centre for the Law of the Sea and Visiting Fellow at the NUS Centre for International Law).

Torunn Aass Taralrud and Dr. Per Christer Lund represented Innovation Norway, Singapore, and there was also representation from the Ministry of Foreign Affairs, Singapore.

Later that day, some of the UiT delegates also met with Professor Meng Qiang and other research colleagues from the NUS Department of Civil and Environmental Engineering to discuss mutual research interests related to Arctic shipping.

7 April, Radioactive Sources: What Could Go Wrong? (Joint ESI-CIL Seminar)

Mr. Steven McIntosh, Senior Manager of Government and International Affairs at the Australian Nuclear Science and Technology Organisation (ANSTO) and Chair of the International Atomic Energy Agency (IAEA) International Expert Group and Nuclear Liability (INLEX) noted the need to ensure the safety and security of these radioactive sources. Citing the regulatory infrastructures established by IAEA's member states, he noted that the IAEA developed the *Code of Conduct on the Safety and Security of Radioactive Sources* in 2003, which now forms the basis of much national and international regulation of the use of radioactive sources. On-the-ground efforts also strengthen the security of radioactive sources. These efforts include the *Regional Radiological Security Partnership in Southeast Asia*, which brought together regional states (including Australia), the United States and the IAEA to revise legislation and regulations, provide training to regulators and operators, and install enhanced security measures at particular facilities.

The *ESI Bulletin on Energy Trends and Development* seeks to inform its readers about energy-related issues through articles on current developments. Our contributors come from ESI's pool of researchers, local and overseas research institutes, local government agencies and companies in the private sector. You can download past issues from www.esi.nus.edu.sg.

We welcome your feedback, comments and suggestions. The views expressed in each issue are solely those of the individual contributors.

Professor S. K. Chou, Ms. Melissa Low, Ms. Rachel Ooi, Mr. Leon Toh, Mr. Sandeep Chamling Rai, Ms. Amy Ho and Ms. Nikolina Kulidzan. (Photo by ESI Staff).

6 April, Optimism in a Time of Uncertainty: *Before the Flood* Film Screening and Discussion (Joint ESI/U.S. Embassy in Singapore/Singapore Office of Environmental Sustainability (OES) event)

The film *Before the Flood* by long-time environmental advocate Leonardo DiCaprio, was screened in commemoration of Earth Day (22 April) and to raise awareness about climate change from a global perspective. In his welcome address, ESI's Executive Director, Professor Chou Siaw Kiang noted recent developments in Singapore's climate policy and the commitment of our Government to fulfilling its pledge under the Paris Agreement. In her opening remarks, Ms. Nikolina Kulidzan, Deputy Public Affairs Officer of the U.S. Embassy in Singapore highlighted the importance of bringing attention to the issue of climate change. On the panel, moderated by ESI Research Fellow, Ms. Melissa Low, were Mr. Sandeep Chamling Rai, Senior Advisor for Adaptation Policy, WWF International; Mr. Leon Toh, Executive Director of Damson Capital; and Ms. Rachel Ooi, second year Environmental Studies major at Yale-NUS College. They discussed the realities of climate change, the need for climate leadership in a time of uncertainty, the Paris Agreement and their hopes for the future.

Contact

- Collaboration as a Partner of ESI (research, events, etc)
- Media Enquiries
- ESI Upcoming Events
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