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Singaporeans unite for climate action with WWF's Earth Hour, the world's largest grassroots movement for the environment. Earth Hour 2014 © Getty Images.

INTRODUCTION

The theme of this issue is E3 System Modelling and Analysis of Energy and Environmental Policy Reforms in Asia.

Climate change due to greenhouse gas emissions from human activities has drawn worldwide attention since the 1990s. The observed increase in global temperature, rise in sea levels and changes in weather patterns have major impacts, such as accelerated biodiversity loss, aggravated coastal erosion and more frequent extreme weather events. In order to prevent the acceleration of climate change, many countries have launched climate change policy packages, which include introduction of carbon pricing, policies to raise energy efficiencies, test-bedding of low-carbon technologies, development of renewable and clean energy, and so on. In addition to emissions reductions, efforts are also underway to explore suitable adaptation solutions. Sustainable development is the ultimate goal of all the actions.

In recent decades, modelling has gained popularity as an important tool for energy and environmental policy analysis, as simulation results under alternative assumptions can provide policy-makers with quantitative insights into carbon mitigation pathways and potential impacts of proposed policies for economic development, energy consumption and ecosystem sustainability. While national models are widely used to analyse local issues, multi-country models have also been developed to analyse regional or global issues that require multilateral cooperation.

This issue of the *Bulletin* is a compilation of the presentations delivered at ESI's *2nd Asian Energy Modelling Workshop on Climate Change and Sustainable Development*, held in Singapore on 23 July 2015. Featuring eight speakers from Austria, China, France, Japan, Singapore, Switzerland and the United Kingdom, the presentations focussed on quantitative analysis of climate change mitigation and adaptation policies around the world, and their implications for Asian countries.

Prof. Chen Wenying, Deputy Director of the Institute of Energy, Environment and Economy at Tsinghua University, presented "National and Regional China TIMES Modelling to Address Climate Change and Sustainable Development". China's MARKAL model was first developed in 2000 while the TIMES model was developed based on the MARKAL model in 2009. The models that include 40 end-use subsectors and more than 400 technologies are updated continually and are successfully applied in about 20 projects, at both the national and international levels. Prof. Chen

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explained the models' structures, energy service demand projections, scenario settings and modelling results for climate change and sustainable development research. The China MARKAL/TIMES models discussed included the standard MARKAL/TIMES, MARKAL/TIMES-ED, MARKAL-MACRO, Five-region TIMES-Water, and Fourteen-region Global TIMES models.

Dr Gabrial Anandarajah, Senior Lecturer at the Energy Institute, University College London (UCL), presented "Modelling Endogenous Technology Learning in a Multi-Region TIMES Model". The relationship between cumulative deployment and capital cost is a well-characterised concept used as a "learning curve" in the economics of innovation. Learning in one technology often enables cost reductions in other closely related technologies. Dr Anandarajah presented a case study exploring a multi-cluster learning approach using the multi-region TIAM-UCL global energy system model, specifically the competitive and/or complementary relationship between hydrogen and electricity as low-carbon transport fuels. Many key technologies (fuel cells, automotive batteries and electric drive trains) are shared across a set of transport modes (cars, buses and large goods vehicles [LGVs]) and technologies (hybrid and plug-in hybrid fuel cell vehicles, battery electric vehicles, hybrid and plug-in hybrid petrol, and diesel vehicles).

Mr Shigeru Kimura, Special Adviser to the President on Energy Affairs, at the Economic Research Institute for ASEAN and East Asia (ERIA), presented "Estimation of Policy Basis Energy-Saving Potential in the East Asia Summit (ASEAN+6) Region Applying the Energy Outlook Approach". The energy outlooks of each East Asia Summit country were produced using the econometric approach. Every outlook has a business-as-usual scenario and an alternative policies scenario which consist of ambitious energy-saving targets. From these two scenarios, energy-saving potentials can be calculated as the differences between the two scenarios. Mr Kimura first explained the energy outlook modelling techniques, then discussed the energy outlook results for the East Asia Summit countries, including energy supply and demand, energy savings and carbon reductions from 2012 to 2035. Many policy implications can be derived from the modelling results: for example, the use of low-carbon energy technologies is another important option in addition to ambitious energy efficiency targets.

Dr Liu Yang, Energy Analyst at the International Energy Agency (IEA), presented "Modelling Macroeconomic Impacts of Energy Efficiency Improvement: An Application to Emerging Economies". Emerging economies have become the major drivers of global energy demand and resulting carbon emissions. In order for these countries to follow a sustainable development path, they require a powerful and cost-effective solution to improve energy efficiencies. This will simultaneously promote economic growth as well as reduce emissions. However, the expected impacts of the energy efficiency policies still need to be investigated in regard to macroeconomic effects, rebound effects and multiple policy combinations. Dr Liu additionally shared his insights on: (a) how energy efficiency targets can determine the climate policy ambitions of large emerging economics; (b) understanding the heterogeneity of energy efficiency policy impacts; and (c) modelling technology innovation using a systemic approach.

Dr Florian Kraxner, Deputy Director of the Ecosystems Services and Management Program at the International Institute for Applied Systems Analysis (IIASA), presented "Reconciling Top-Down versus Bottom-Up Modelling for Renewable Energy Systems". He discussed how a large suite of scenarios from various energy models is projecting a steeply increasing share of renewable energy for this century. However, all emissions technologies have limits/downsides. This aspect requires governments to aim for a portfolio that respects the limits and trade-offs with other policy goals, but also to seize opportunities to make trade-offs and synergies between land-based mitigation strategies and combining carbon-neutral bioenergy with carbon capture and storage. Dr Kraxner highlighted the different combinations of scenarios for global feedstock supply in the production of bioenergy, and demonstrated bioenergy modelling at various scales, using global, regional and local case studies.

Mr Ramachandran Kannan, Senior Scientist in the Energy Economics Group at the Paul Scherrer Institute (PSI), presented "Development and Application of Energy-Economic Models for Switzerland's Climate Change Mitigation Scenarios". Energy-economic models have emerged as a useful methodology for energy research aimed at evaluating future energy supply options and their associated uncertainties, as well as generating insights for public policy design. In Switzerland, energy models covering a wide range of analytical approaches have been developed. The PSI is working on a range of technology-rich, bottom-up TIMES models to understand the long-term energy transition pathways. Mr Kannan gave a broad overview of the application of the TIMES family of energy models for mitigation research in Switzerland, and analysed a set of low-carbon scenarios using the Swiss TIMES energy system model.

Dr Liu Yu, Associate Professor at the Institute of Policy and Management, Chinese Academy of Sciences (IPM-CAS), presented "A Multi-Regional CGE Analysis of a Linkage in Carbon Markets between Hubei and Guangdong". China is the largest carbon emitter in the world and has set a few emissions targets for future developments. To reduce carbon emissions, seven market-based emissions-trading pilot schemes were launched in China in 2013. Dr Liu discussed the use of the Chinese multi-regional computable general equilibrium (CGE) model to simulate the economic impacts of the separate carbon trading that occurs in Guangdong and Hubei, as well as inter-provincial carbon trading. The empirical study shows that regional emissions trading can help reduce the average abatement costs dramatically. But not all parties can benefit from emissions trading: going forward, the selection of the regions for emissions trading will require special attention as the trading regions will suffer losses. But promoting emissions trading will improve the structure of domestic demand and transform the patterns of economic developments.

Dr Li Yingzhu, Research Fellow at the Energy Studies Institute (ESI), presented "The Economic and Social Impacts of Climate Policy on Singapore". As a small open economy that is highly exposed to international markets and which depends heavily on international trade, Singapore can be affected by other countries' climate policies. Further, it can be threatened by the impacts of climate change, such as a rise in sea levels and ambient temperatures, as well as accelerated coastal erosion. It is thus important for Singapore to quantitatively evaluate both foreign and domestic climate policy instruments and subsequently examine the implications of policy designs that could be used to alleviate the negative impacts. Dr Li illustrated the CGE framework built at ESI for Singapore and applied the CGE models (single-region and two-region CGE models) to evaluate the impacts of domestic and foreign carbon taxes, and the tax revenue recycling mechanism in different scenarios.

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

Dr Su Bin, Senior Fellow
(On behalf of the ESI Bulletin Team)

National and Regional China TIMES Modelling to Address Climate Change and Sustainable Development

Prof. Chen Wenying, Deputy Director of the Institute of Energy, Environment and Economy, Tsinghua University, China

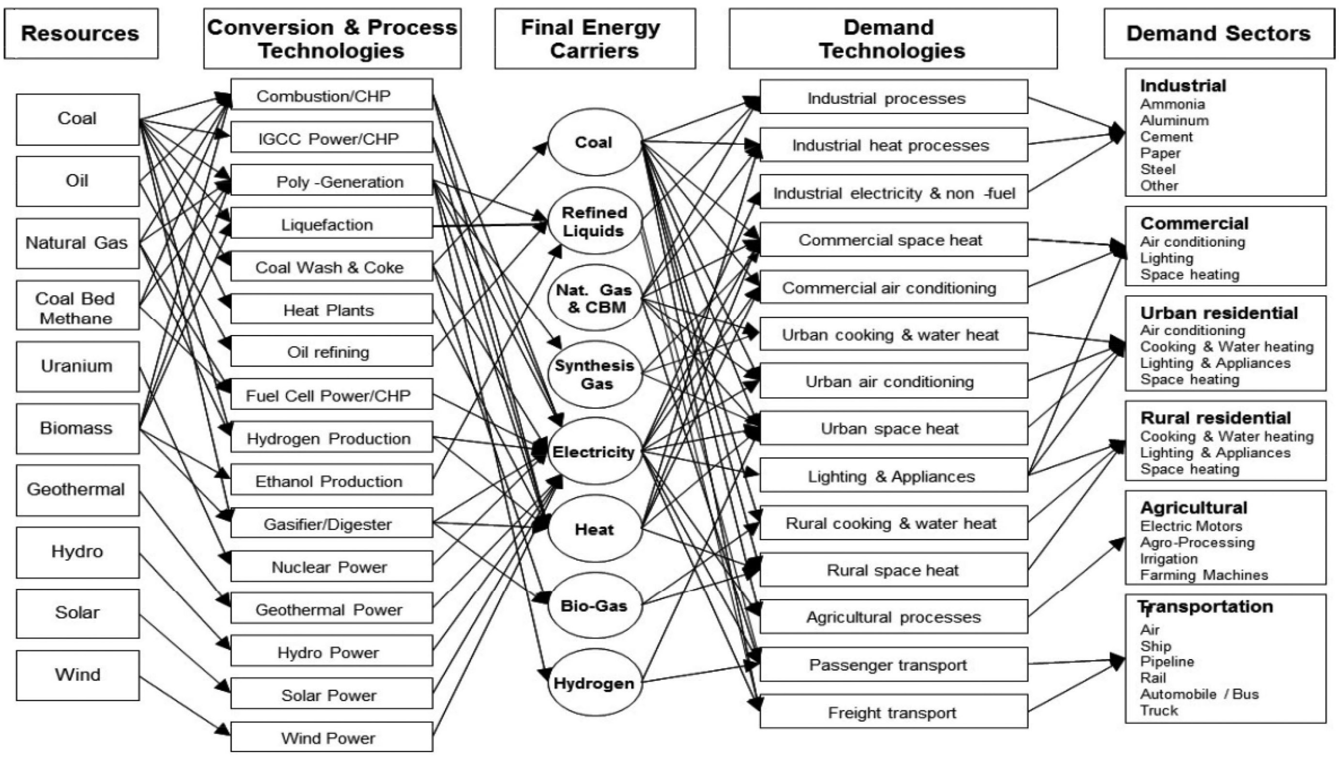
Write-up by ESI's Jacqueline Tao

The TIMES Model

The TIMES model is a dynamic energy, environment and economic model, which is a combination of the MARKAL (Market allocation) and Energy Flow Optimization Model (EFOM) developed by the International Energy Agency. The TIMES model optimises energy systems with cost-minimising objectives over specified periods to meet exogenous energy service demand. The China MARKAL/TIMES model, developed in 2000 as a tool to assess China's future energy development scenarios and study its mitigation strategies, is being continuously updated and used in various interdisciplinary assessments.

The China TIMES model integrates the conventional MARKAL/TIMES model with China's Energy Service Demand Projection Model (ESDPM), and was developed in five-year intervals extending to 2050. The model provides a holistic representation of the Chinese energy system, inclusive of the full range of energy processes, from exploitation to distribution and end use. The model also includes a variety of primary energy sources (a mix of both conventional fossil fuel sources and renewable sources), and energy conversion processes and technologies.[1] Demand sectors are divided into six main sectors, then further divided into 43 subsectors. The above-mentioned inputs feed into a simplified reference energy system illustrated below (Figure 1).

Figure 1: Simplified Reference Energy System

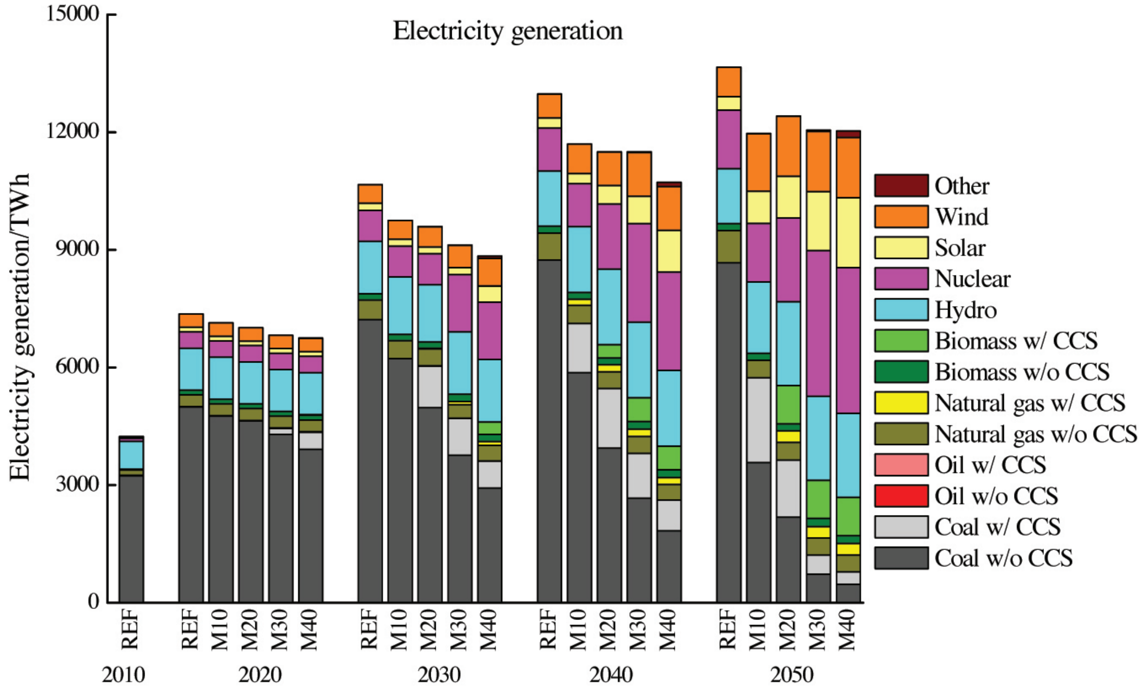


The Energy Service Demand (ESD) inputs for each of the sectors were derived from macro-economic assumptions of GDP growth, population growth, industrial structure and urbanisation rate. The derived ESD inputs were then inserted into the model to create the Reference scenario. Key historical and planned policy considerations were also incorporated into the Reference Scenario. A total of four alternative scenarios (M10–M40) were developed, each representing a cumulative 10 to 40 per cent reduction of carbon from the reference scenario.

Under the Reference Scenario, China's emissions in 2050 are close to the 15 gigatonnes (Gt) mark (Figure 2). A shift to the M40 scenario would reduce the emissions level to under 5 Gt. While coal will dominate the power generation sector in the short to medium term (2020–30), its share will likely decrease in the long term. Carbon capture and storage (CCS) is to start in 2020, though the shifting to more aggressive targets will force reductions in the use of coal (with and without CCS) in power generation altogether. The shift to more aggressive targets will not significantly affect demand for electricity generation, with the increased use of renewable energy sources displacing coal. The institutionalisation of more stringent targets will also generate co-benefits in terms of reduction of other pollutants, such as SO_x, NO_x and PM 10 and PM 2.5.

To achieve the overall mitigation targets, it is expected that different sectors will adopt different emissions pathways, each peaking at a different time period. While the industry sector is expected to peak earlier (around 2020), the building and transportation sector is likely to peak around 2035. The mitigation cost for M40 is much higher than M10 and M20.

Figure 2: Share of Technologies in Power Generation



To account for regional disparities in water endowments, and their relation to power generation, regional water consumption information is integrated within the China TIMES model to create the Five-region China TIMES-Water Model. The TIMES-Water model incorporates regional water consumption and supply curves to the TIMES model, thereby creating an additional matrix of water-related costs into the traditional TIMES model. This extra dimension provides further clarity to the regional power generation capabilities and associated costs.

An extra global model was created to include international trade activities in the China TIMES model. The 14-region Global TIMES model divides the world into 14 regions. Similar projections were created to estimate the ESD for each region, and these were fed into the global model, thereby generating the reference scenario. Alternative scenarios, levying an annual 5 per cent incremental carbon tax of USD 20 (Carbon Tax 1) and USD 30 (Carbon Tax 2) from 2015, were developed respectively.

Under Carbon Tax 1, the immediate short- to medium-term reductions in emissions are not significant, with emissions reduction only picking up in the period 2040–50. Global emissions under the Carbon Tax 1 scenario are still seen to be gradually increasing, though at a lower rate as compared to the reference scenario, throughout the period 2010–50. On the other hand, under the Carbon Tax 2 scenario, the institutionalisation of a carbon tax increasing from USD 30 in 2015 to around USD 165 in 2050 creates an immediate effect on global emissions, causing a dip in global carbon emissions from 2020, after which the depressed global emissions are sustained through to 2050. The power generation sector offers the highest potential for emissions reduction, with the sector accounting for a large proportion of the emissions reductions under the alternative scenarios.

1 For details of the China TIMES model, see W. Chen, X. Yin and H. Zhang, "Towards Low Carbon Development in China: A Comparison of National and Global Models", *Climatic Change* (forthcoming).

Modelling Endogenous Technology Learning in a Multi-Region TIMES Model[1]

Dr Gabrial Anandarajah, Senior Lecturer at the Energy Institute, University College London

Write-up by ESI's Hari Malamakkavu Padijare Var

Introduction

Hydrogen and fuel cell technologies have great potential to decarbonise road transport. However, widespread use of these technologies is currently limited due to their prohibitive cost. Technologies advance by a continuous investment in R & D, and by improvements in economies of scale and efficiency of supply chains. This is known as "learning-by-doing", a key concept in the economics of innovation. Empirical estimation of learning curves can quantify the rate at which capital cost and performance of a technology improves as a function of cumulative investments and installed capacity. Using the model-based approach to evaluate the evolution of importance in decarbonisation technologies, most bottom-up models (TIMES/IAM/MARKAL) use exogenous forecasts of technological development. This approach presumes a level of technology adoption, and ignores the learning costs (improvement costs of technology through continuous R & D investment, and economies of scale). In this vein, endogenous modelling of technological change allows for the model to suggest technologies that may not be adopted initially due to higher cost, but which become cost-effective and highly significant in future decarbonisation pathways due to the effect of learning-by-doing.

This study applies a multi-cluster approach whereby many key technologies (hybrid technology, battery, fuel cells, etc.) are shared across a set of transport modes. In this way, the synergies and interactions between different technologies and the competitive or complementary relationship between hydrogen and electricity are explored using the TIAM-UCL model.

Overview of Modelling

Authors have used TIAM-UCL, a 16-region linear planning (LP) cost optimisation perfect foresight model (based on ETSAP-TIAM), which minimises the total discounted energy system cost as well social welfare for the period 2005–2100. Each region has its own energy systems and can trade fuel resources and emission credits. The model, has detailed classification of fuel resources for each region with projected energy services demand as a function of GDP, population, energy intensity, and so on. Renewable energy sources and alternative technologies for synthetic fuel production, as well as alternate pathways to hydrogen production, are also considered in the supply side of the model. The model has improved representation of hydrogen infrastructure with carbon capture and storage (CCS).

A multi-cluster approach is used to endogenously model related technologies, with the "key technologies" as the shared components acting as the driver for learning together. Three key technologies explicitly modelled are: i) fuel cell systems; ii) electric drivetrains; and iii) automotive battery systems where investment costs are modelled for learning. Efficiency and operations and management (O & M) improvements are modelled as attributes of the vehicles.

Daimler AG hydrogen fuel cell vehicle, based on the Mercedes-Benz A-Class. Photo by Robert Couse-Baker. (Permission under CC BY 2.0)

Key assumptions of Endogenous Technology Learning (ETL), such as initial cost, learning rate, floor cost and cumulative investment, are taken from technology literature. Non-linear learning cost curves are linearised to be modelled in LP-based TIMES. The following scenarios are examined to analyse the role of learning in determining the optimality of hydrogen in the global transport sector:

- i) Reference Scenario
- ii) Low-Carbon Scenario
- iii) Five Low-Carbon ETL Scenarios, namely: a) Static Technological Development; b) ETL Base Case, where hydrogen vehicle roll-outs are minimal until they are cost-effective; c) ETL early adoption which is itself further divided into three sub-scenarios with respect to the number of hydrogen vehicles on the road by 2015; d) ETL no CCS scenario; and e) ETL late action scenario, where the global action to reduce emissions starts from 2020.

However, using a single-learning rate has some deficiencies in modelling, such as the following:

- i) Historical learning rates are not predictors of future learning rates
- ii) Learning rates are typically not the same throughout the life-cycle of the technology
- iii) Learning relationships could be more complex
- iv) Single-factor learning models have longer learning times in comparison to multi-factor models

Results

In the Reference Scenario, at least one-fifth of the global GHG emissions will come from China by the end of the century. However, in the Low-Carbon Scenario, it is observed that per capita CO_2 emissions converge over the planning horizon. The share of diesel in the energy mix for transportation decreases while that of natural gas increases. In the Static Technological Development Scenario, the role of hydrogen and electric vehicles (EVs) is negligible in the transport sector even under the Low-Carbon Scenario. Without significant learning, the potential for hydrogen and EVs to mitigate climate change efforts is negligible. In the Endogenous Technology Learning Scenario (ETL), hydrogen (fuel cell based technology) and EVs both play a substantial role in decarbonisation of the transport sector. Natural gas and diesel also have key roles in the public transport sector. The share of hydrogen increases from 3 per cent (Light Goods Vehicles or LGVs) in 2030 to more than 20 per cent (LGVs and passenger cars) in 2050, while biofuels play a minor role. The passenger car market evolves from conventional internal combustion engine (ICE) vehicles to a mix of ICEs and hybrids, and finally to a mix of EVs and fuel cell vehicles by 2100.

In the Early Adoption Scenarios, the model still prefers hybrid and natural gas vehicles in the near-term future (2030) as per base case, while the Later Action Scenario results in increased transport sector hydrogen consumption in the medium and long term (with ETL). This accelerated use of hydrogen is due to a more aggressive rate of decarbonisation resulting from late adoption of the CO_2 target. The No CCS Scenario is also broadly similar to the Later Action Scenario in accelerated use of hydrogen technologies to reduce emissions. The investment (discounted to base year 2005) over the 15 years from 2015 to 2030 is USD 64 billion (required to have a cumulative installed capacity of around 1,860 GW of fuel cell by 2030). However, this cost is offset by the avoided investments in the conventional technology: petrol and diesel engines. As a result, the additional "learning investments" required to bring down fuel cell costs are rather small: around USD 33 billion (discounted to base year 2005) for the 15 years. In the medium term, there appears to be synergy between vehicles using hydrogen and electricity as fuels. In the long term, in this heavily decarbonised transport sector, hydrogen and electricity become competitors in the sense that scenarios that have more of one have less of the other.

Electric vehicles outside the National Environment Agency Office, Singapore, March 2015. Photo by Anton Finenko.

Conclusion

It can be concluded that hydrogen and EVs can play a critical role in decarbonising the transport sector if we apply an ETL model to study the pathways of technology adoption. They emerge as complementary transport fuels, rather than strict competitors in the short and medium term. However, in the very long term, technology competition between hydrogen and electricity does arise.

1 G. Anandarajah, W. McDowall and P. Ekins, "Decarbonising Road Transport with Hydrogen and Electricity: Long Term Global Technology Learning Scenarios", *International Journal of Hydrogen Energy* 38, 8 (2013): 3419–32.

Estimation of Policy Basis Energy-Saving Potential in the East Asia Summit (ASEAN+6) Region Applying the Energy Outlook Approach

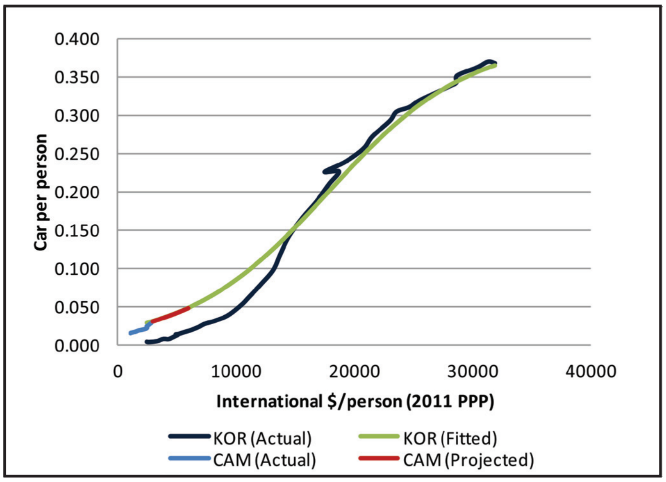
Mr Shigeru Kimura, Special Adviser to the President of ERIA on Energy Affairs, Economic Research Institute for ASEAN and East Asia (ERIA)

Write-up by ESI's Melissa Low

Energy Outlook Modelling Techniques

Modelling involves huge amounts of data, including energy data from energy balance tables; macroeconomic data such as world development indicators from the World Bank; and national activity data. For example, to arrive at the curves in Figure 1, International Energy Agency (IEA) Balance Tables were supplemented with national data.

Figure 1: Korea's Historical Data Used in a Logistic Function to Forecast Cambodia's Car Ownership



Energy Outlook Results

For the Energy Outlook Results of the East Asian Region (EAS), the data were found in official documents such as national reports or submissions to international bodies. As for those that were not publically available, some were obtained from the Economic Research Institute for ASEAN and East Asia (ERIA) Energy Unit. The energy-saving goals and action plans for each country under analysis are regularly updated on the Asia Energy Efficiency and Conservation Collaboration Center (AEEC) website.

The study also included a primary power development plan, conducted in 2014. Oil and gas will continue to feature in final energy consumption in most of the EAS region countries as their share appears to increase. Oil marks the largest growth from 2012 to 2035, followed by electricity and gas (Figure 2). Other forms of energy—mainly traditional biomass—will not increase significantly. The results of ERIA's work shows greater diversification from traditional biomass to conventional energy, such as petroleum products and electricity. Renewables will experience a slow increase and the adoption of nuclear energy presently seems very ambitious.

The transport sector's share will grow from 17 per cent in 2012 to 22 per cent in 2035, but the share of industry in final energy consumption will remain dominant in 2035 at about 38 per cent.

As for power generation, from 2012 to 2035, nuclear power will have the highest growth at 8.5 per cent per annum, followed by new and renewable energy (NRE) (6.7 per cent), geothermal (5.7 per cent) and gas (3.3 per cent). Power generated from oil will, however, decrease. Consequently, the nuclear share will rise from 3 per cent in 2012 to 11 per cent in 2035, followed by NRE (3 per cent to 7 per cent) and geothermal (0.3 per cent to 0.6 per cent), but gas will maintain its share of 12 per cent until 2035. Coal-fired generation will still dominate and its share will remain at about 60 per cent in 2035.

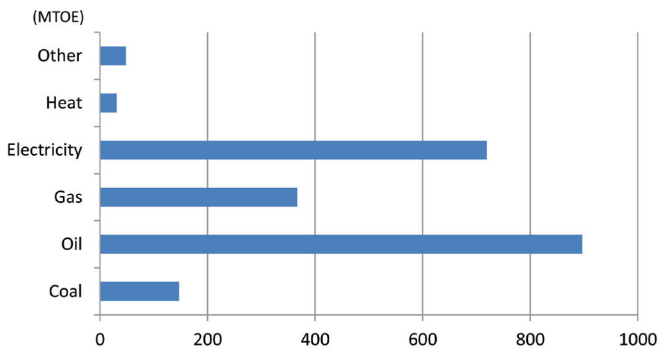
With respect to primary energy supply, nuclear will see the highest growth at 8.5 per cent per year, followed by geothermal, gas, oil and hydro during the period 2012–35. In these same years, the nuclear share will increase from 2 per cent to 6 per cent, while the share of gas will also grow from 9 per cent in 2012 to 13 per cent in 2035. The period 2012–35 will also see the shares of oil and geothermal rise slightly from 23.6 per cent to 24.7 per cent, and 0.7 per cent to 1.1 per cent, respectively. The share of coal will decline from 52 per cent in 2012 to 45 per cent in 2035, but will still be the largest.

The results show that the share of coal will increase the most from 2012 to 2035, followed by oil, gas and nuclear. That of traditional biomass will taper, but that of new and renewable electricity will increase rapidly. Traditional biomass use will decline from 90 per cent in 2012 to around 70 per cent in 2035.

Energy-Saving Potential

In terms of energy-saving potential in final consumption, oil will have the largest potential savings, followed by electricity, coal and gas in 2035. Electricity savings will contribute to a reduction of thermal power generation. In the primary energy supply sector, coal will see the largest potential savings, followed by oil and gas. On the other hand, hydro, nuclear, geothermal and others will have negative savings (increase) due to NRE and the low-carbon policies of the EAS countries.

Figure 2: Final Energy Consumption Increment, 2012–35



Source: ERIA, *Energy Saving Potential (ESP) Working Group Report* (Jakarta Pusat: ERIA, 2014).

Policy Recommendations and the Way Forward

The formulation of energy efficiency laws and regulations such as Energy Efficiency Acts, and announcements of energy-saving targets and action plans within each final sub-sector are ways to promote efficiency. Financing energy efficiency improvements can be addressed through the establishment of funds or incentive schemes such as tax credits or soft loans.

The deployment of renewable energy can be enhanced through the formulation of renewable energy laws and regulations, and appropriate policies. However, feed-in-tariffs and net-metering tools still need to be studied for their applicability, and governments should seek public–private partnerships in these efforts.

For power generation, the main policy recommendation was to improve thermal efficiency by using combined cycle gas turbine (CCGT) and clean coal technologies together with carbon capture and storage (CCS). Governments need to address public acceptance of coal and nuclear power plants, and study power grid interconnections for greater diversity and stability in their grids.

Energy pricing in the EAS region should also undergo some reforms, including removal of all energy subsidies on petroleum products. Market-based electricity pricing is the preferred option because it encourages competition, and resulting cost savings can be passed on to consumers. On technology transfer and capacity-building, financial support remains the greatest challenge. Capacity-building is underway through the ERIA's energy efficiency and conservation (EEC) programme. Governments can also consider opening domestic petroleum markets to foreign private companies.

Conclusion

In conclusion, a bottom-up approach (end-use type model) could be used to break down energy consumption by subsectors to end-use. For instance, this would be particularly useful when applied to electricity in the residential sector to analyse the consumption levels of household lighting, space cooling or heating, water heating, refrigeration, and so on. For fuel consumption in the road transport sector, a bottom-up approach would examine the number of registered vehicles by type, average driving mileage by type, fuel economy by type, and provide the necessary information to formulate policies. The use of end-use energy consumption data is particularly important. An energy consumption survey (sampling) of residential and commercial sectors is one way to collect accurate data for this purpose.

Modelling Macroeconomic Impacts of Energy Efficiency Improvement: An Application to Emerging Economies

Dr Liu Yang, Energy Analyst at the International Energy Agency

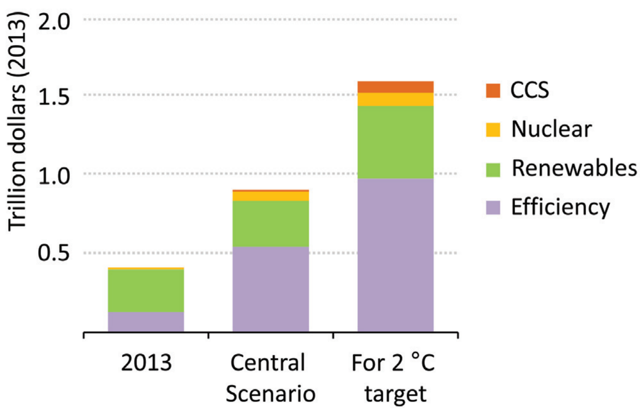
Write-up by ESI's Victor Nian

Role of Emerging Economies in the Global Energy Landscape

Global energy demand is projected to increase by more than 30 per cent by 2035, with emerging economies contributing up to 96 per cent of the growth. With the slowdown of China's economy, India, Southeast Asia, the Middle East, and parts of Africa and South America will become the main drivers of global energy demand growth beyond 2020. Under the New Policy Scenario developed by the International Energy Agency (IEA), the increase in primary energy demand is seen primarily in the non-OECD countries despite a sharp decline in their energy intensity, expressed as the ratio of total primary energy supply to gross domestic product (GDP). Given the current momentum in primary energy demand, the world is quickly running out of its CO_2 budget under the 2C scenario.

Under the IEA's Central Scenario, 50 per cent of the CO_2 budget for the 2C target at 2100 was already used up from 1900 to 2012. Going by the current growth momentum of global primary energy demand, the world will exhaust its CO_2 budget by as early as 2040. Achieving the 2C target requires a fourfold increase in investment on low-carbon options, including energy efficiency, renewables, nuclear, and carbon capture and storage (CCS) technologies (Figure 1). Energy efficiency improvement was identified as the primary driver for emissions reduction. Among the portfolio of options, 38 per cent of the CO_2 emission reductions come from end-use fuel and electricity efficiency improvements; 14 per cent from CCS, 9 per cent from end-use fuel switching, 30 per cent from renewables, 2 per cent from power generation efficiency improvements and fuel switching, and 7 per cent from nuclear. According to the IEA decomposition analysis, economic and population growth, structural change and energy efficiencies are the three main factors influencing energy demand. The United States and Europe have the potential to greatly improve their building sectors' energy efficiency, while China and India can both advance their industrial and transport energy efficiencies.

Figure 1: Average Annual Low-Carbon Investment, 2014–40



Economic Implications of Energy Efficiency Policy under Climate Targets

To achieve a certain level of emissions reduction, carbon pricing policy may not be effective when there is a huge potential of cost-effective energy efficiency opportunities. This is because a carbon price may not directly address the energy efficiency gap, but will increase marginal cost of electricity generation, thus negatively impacting economic growth. On the other hand, an appropriate energy efficiency policy can decrease energy demand, leading to reduction in overall energy cost. It is worthwhile to understand this interaction between energy efficiency, renewable energy and climate policies in the context of emerging economies. Most emerging economies have adopted a relative climate target in terms of unit of emissions per GDP or related abatement target to their business-as-usual emission levels. Hence, easily achievable energy-efficiency abatement opportunities can make the emissions intensity targets non-binding alongside a rapidly growing economy. This calls for coordination between energy efficiency and climate policies in such a context.

Furthermore, from the perspective of Intended Nationally Determined Contributions (INDCs), energy efficiency can play an important role in the near term, while saving time for a transition towards a low-carbon energy mix, which will take over in the long-term for China's case.

To better illustrate policy insights with respect to energy efficiency and climate change, a Computable General Equilibrium (CGE) model for Global Responses to Anthropogenic Change in the Environment (GRACE) was used to analyse the economic implications of both climate and energy policy instruments on linking an emissions trading scheme (ETS) between the European Union and China if China's relative climate target is not binding when its carbon intensity declines due to economic growth being surpassed by energy efficiency improvement. Figure 2 provides the impacts of renewable and climate policies from key policy-relevant dimensions. These include mitigation and cost effectiveness, energy transition, equity and competitiveness in a joint EU–China carbon market.

This analysis concludes that as long as an absolute emissions cap is missing in China and a carbon intensity target is not binding due to GDP growth and energy efficiency improvement, a joint ETS is not attractive for mitigation, though the country can meet its renewable energy target of reduced emissions.

Figure 2: Findings from the GRACE Model

Mitigation effectiveness	➢Total abatement in both regions decreases markedly in the joint ETS cases to around **one-half** of that in the independent ETS cases. ➢The renewable energy subsidies **do not contribute** to total abatement in the case of interlinked ETS.
Mitigation cost	➢ Renewable subsidies have **different implications** on GDP loss in Europe and China.
Energy transition	➢A joint ETS generates **opposite** energy-transition incentives in Europe and China.
Equity	➢The financial transfer through the joint ETS remains **marginal** compared to China's demand for renewable energy subsidies.
Competitiveness	➢ There is **no major concern with respect to competitiveness** faced by EU's emissions intensive industries.

Challenge of Modelling Heterogeneity of Consumer Behaviours

The impact of energy efficiency policy is highly correlated to behaviour change. There exists a knowledge gap on how energy modelling exercises can better reflect the heterogeneity of consumer behaviour change within different population segments. In emerging economies, where there is much disparity in development between urban and rural regions, it is highly important to conduct research in this area.

In China's efforts towards increasing energy efficiency, the country introduced a nationwide subsidy programme for energy-efficient home appliances. Consumers were given a cash rebate ranging from USD 16–64 from June 2012 to June 2013 for five categories of home appliances (air conditioners, TVs, refrigerators, washing machines and water heaters). In addition, the Chinese central government financed about USD 2 billion while consumers spent about USD 41 billion on 65 million units of energy-efficient home appliances. Based on this programme evaluation, the elasticity of electricity consumption was influenced by a number of factors, such as income, age, education level, and energy-saving awareness. Essentially, the richest urban population and poorest rural population demonstrated the least sensitivity to the energy-efficient appliance incentivising scheme, while the middle-class population was significantly influenced by the incentivising scheme. These results suggest that the disparity between urban and rural regions, and targeted consumer behaviour changes should be taken into account to ensure the effectiveness of future energy-efficient subsidy programmes.

Challenge of Modelling the Endogenous Technology Adoption Process

Another important area in energy systems modelling is that of modelling technological innovation and adoption under the influence of multiple policy instruments. Essentially, it is necessary to take into consideration the market and non-market intermediated effects. The market intermediated effect, or the profitability effect, enhanced the profitability and enlarged the market opportunities for new technologies through measures such as feed-in tariffs, carbon prices, capital subsidies and low-interest loans. The non-market intermediated effect, or the epidemic effect, came about with the impact of a national system of innovation and a given regulatory framework. Through a network of institutions coordinated by the government, the national system of innovation and regulatory arrangements played a role in influencing human capital development, research capacity, proximity between user and supplier, and absorptive capacity of new technologies. Both effects were modelled simultaneously in a unifying theoretical framework and simulated with the support of the data from China's wind power sector.

This modelling work finds that the epidemic effect may significantly influence the pattern of clean technology diffusion. It implies that policy instruments can internalise positive (learning-by-doing) and negative (carbon emissions) externalities to obtain an overall effect on adoption that is greater than its direct effects, since the new adopters induce others to adopt as well. The cumulative impact of subsidies in the forms of financial incentives will be significantly greater than their immediate impact. Thus, optimal social welfare can be enhanced. The outcome of this work supports a systemic approach of endogenously modelling the penetration rate of energy efficiency and renewable technology diffusion in energy system models.

In conclusion, understanding the interaction of multiple policies, assessing consumer behaviour heterogeneity and forecasting energy-efficiency technology diffusion continue to be areas of further research in energy system modelling.

Reconciling Top-Down versus Bottom-Up Modelling for Renewable Energy Systems: IIASA Integrated Model Cluster and Multiple-Scale Case Studies

Dr Florian Kraxner, Deputy Director of the Ecosystems Services and Management Program, International Institute for Applied Systems Analysis, Austria

Write-up by ESI's Anton Finenko

The International Institute for Applied Systems Analysis (IIASA), based in Austria, was founded in 1972 to decouple the political dissent, between the United States and the Soviet Union, from scientific collaboration. With currently 23 international member countries, the IIASA's mission is to provide insights and guidance to policy-makers worldwide by finding solutions to global and universal issues concerning energy, climate change, food and water through applied systems analysis, in order to improve human and social well-being and to protect the environment.

The world is still heavily reliant on fossil fuels. How we decide to design our global future energy mix will result in different trajectories of temperature rise. In order to achieve the minimal target of $2^{\circ}C$, mankind would need up to a 3.6-gigatonne (Gt) reduction in carbon equivalent by the end of the century. To reach this target, bioenergy, reforestation, and carbon capture and storage play crucial roles. It is unclear, however, where the global bioenergy production should be located. While the most favourable areas for bioenergy are situated along the inner tropical belt, it is equally important to protect flora and fauna in those regions. This dilemma highlights the problem of the ostensibly available land resources, from which only a tiny fraction can be used as cultivated land. Land and water used for food production regularly compete with other ecosystem services. Ignoring such conflicts over resource use can lead to unsustainable exploitation, environmental degradation and avoidable long-term social costs.

Together with its partner institutions, IIASA has developed a system that enables rational land-use planning based on an inventory of land resources, and evaluation of biophysical limitations and production potentials. IIASA's approach is based on a combination of top-down and bottom-up assessment models as shown in Figure 1. The top-down assessment helps us to identify the necessary global sustainability and climate targets, while the bottom-up analysis helps translate these objectives into the regional scale of land use and also informs policy-makers about possible development options. Some of the top-down models used by the IIASA include: the Global Forestry Model (G4M),[1] and a global agricultural management model (EPIC),[2] which provide inputs for the global economic and land-use model (GLOBIOM).[3] GLOBIOM is a partial equilibrium model which can be linked to macroeconomic or energy models to capture drivers and also provide feedback on, for example, population, GDP, carbon prices and bioenergy demand. It can also be linked with smaller, bottom-up models, like the renewable energy systems optimisation model, BeWhere.[4] Depending on the scope of the analysis, the models can provide results as a combined tool or be used independently for various specific assessments.

Figure 1: Top-Down and Bottom-Up Modelling Tools at IIASA

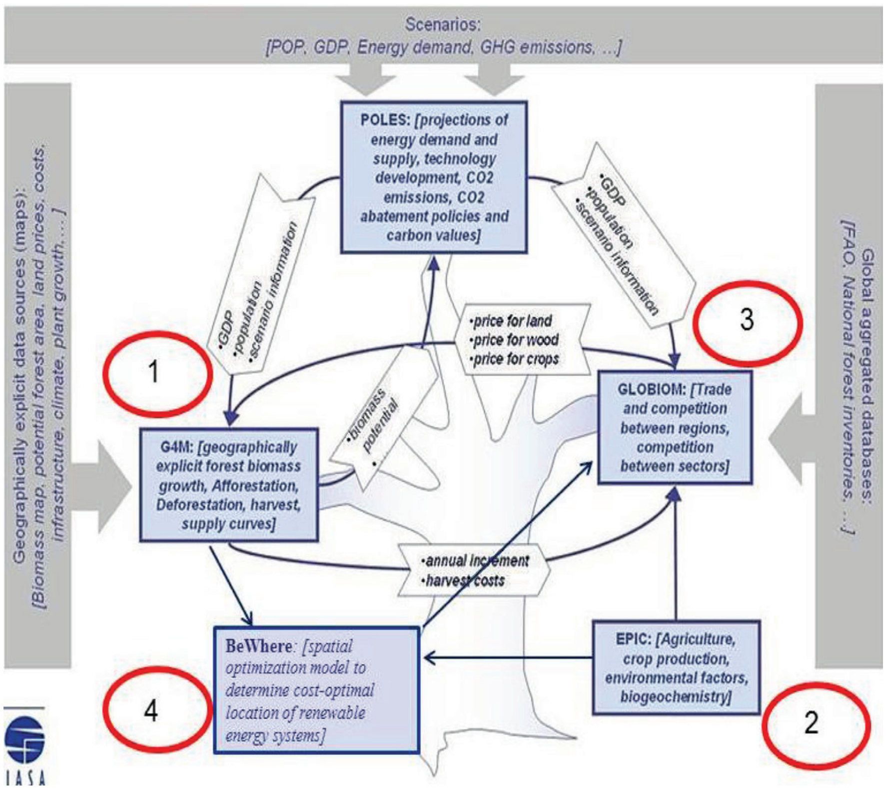
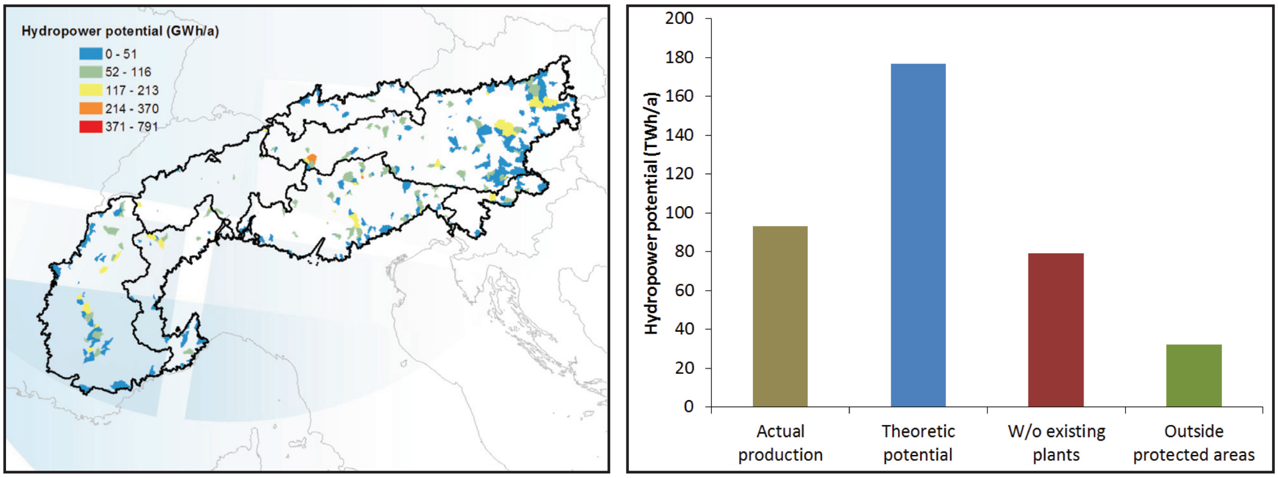


Figure 2: Theoretical vs. Actual Hydropower



Several work examples carried out by the IIASA and its partners using the combined top-down and bottom-up approaches were highlighted. One such work included a joint collaboration with the World Wildlife Fund that investigated different combinations of scenarios for global feedstock supply for the production of bioenergy under specified social and environmental safeguard provisions. Results from this collaboration with WWF, applying inter-alia the GLOBIOM and G4M models, highlighted the fact that it is possible to avoid large-scale deforestation, even under expanded bioenergy production. However, a number of scenarios showed severe impacts on different land-use types and water resources across the world, if no conservation targets are implemented.

Another example included an analysis done with the BeWhere model for the Alps region in Europe. The background premise of this research was to address the question of whether or not various forest management targets could be met while preserving ecosystems services. For instance, harvesting forests for bioenergy production can provide more clean energy, but at the same time reduce their potential as carbon sinks. Moreover, choosing between distributed or concentrated areas for forest harvesting can affect the potential for bioenergy production. In another important example, the theoretical and actual renewable energy potentials of a region were compared. While many areas seem very favourable based purely on the biophysical-geographic assessment, other factors such as land protection policies can severely restrict such potentials. For instance, it was shown that the total hydropower potential of the Alps reaches almost 180 gigawatt-hours per annum (GWh/a), whereas actual production outside of the restricted area is less than 40 GWh/a. Also, the cost of power production—under specific scenario assumptions for the Alps—increases by about four times when applying a high protection level. The findings are illustrated in Figure 2.

Another ongoing application of BeWhere and G4M helps with estimating the biomass and BECCS (Bioenergy combined with Carbon Capture and Storage) potentials for Indonesia. Several previous assessments have identified the biomass potential within conservation and protected forest areas that may be inaccessible for harvesting. Using, for instance, the spatial data provided through IIASA's scientific crowdsourcing platform, Geo-Wiki,[5] the biomass potential could be downscaled to those regions outside of the protected areas.

In conclusion, it is important to differentiate between the theoretical or natural sustainable potential of land use and the actual one, based on the socio-economic features of the region. In many cases, the natural potential will be more accurate as it reflects a more complete picture of the land resources.

1. For more information, see http://www.iiasa.ac.at/g4m.
2. For more information, see http://www.iiasa.ac.at/epic.
3. For more information, see http://www.iiasa.ac.at/globiom.
4. For more information, see http://www.iiasa.ac.at/bewhere.
5. For more information, see http://www.geo-wiki.org.

Development and Application of Energy-Economic Models for Switzerland's Climate Change Mitigation Scenarios

Based on a presentation given by Mr Ramachandran Kannan, Senior Scientist at the Energy Economics Group, Paul Scherrer Institute, at the *2nd Asian Energy Modelling Workshop on Climate Change and Sustainable Development*, held in Singapore on 23 July 2015.

Write-up by ESI's Liu Xiying

Swiss Energy System Overview

In 2013, Switzerland spent CHF 32.86 billion on its energy, accounting for 5.4 per cent of its GDP. Among its 896 petajoules (PJ) of final energy consumption, 52 per cent was oil and 14 per cent was natural gas, both of which had to be imported. The total cost of energy imports was CHF 11.56 billion and energy import dependency stood at 77.10 per cent.

Of the final energy demand mix, 24 per cent is electricity generated mainly from hydro power plants and nuclear power plants. The three largest electricity consumers were the industry (32 per cent) sector, the residential sector (31 per cent) and the service sector (27 per cent). Electricity trading was important in terms of power system balance and revenue (CHF 442 million in 2014).

Looking ahead, Switzerland is facing several key challenges in its energy system transformation. First, the Swiss government has decided to phase out all of its nuclear power plants by 2034. Thus, other sources of electricity generation need to be developed to replace the nuclear component in the electricity generation mix. Second, the proportion of renewable integration into the power system is expected to increase for climate change mitigation purposes. Third, though Switzerland is self-sufficient in electricity generation on an annual basis, it is still dependent on imported electricity for seasonal demand. Thus it needs to address the issue of electricity system balancing for large seasonal and diurnal variation in both demand and supply. Fourth, in order to supply the increasing use of electric vehicles, heat pumps, etc., electricity demand is expected to rise and the demand profile will be changing. Fifth, Switzerland's energy system transformation needs to meet the requirements of availability, reliability and security in light of nuclear/climate policies in cross-bordering countries. Finally, if flexible hydro power plants are used to balance a power system with higher renewable integration, there may be large revenue losses from electricity trading.

Energy-Economic Models

Energy-economic models are used to improve the understanding of energy transition pathways and policy strategies for creating sustainable long-term energy systems. Although models are not truth machines, they are helpful in various ways, including: 1) doing large and complex calculations/optimisation; 2) generating insights under a range of assumptions; 3) understanding complexities, cross-sectoral interactions, and so on; and 4) testing hypotheses (technology portfolio, scenario visions, etc.). In the analysis of energy-economic models, scenarios are widely used to explore and understand different ways that future energy systems might evolve.

Existing Analytical Tools in Switzerland

Currently, there are various analytical energy-economic models in Switzerland, each with different advantages and disadvantages. Macro-economic models[1] consider the entire economy (labour, capital, non-energy materials), but highly simplify the energy sector and sometimes cannot be explicit with technologies. Energy systems models, such as MARKAL, ETEM and TIMES, can include cross-sectoral interactions, and adopt detailed technology and infrastructure depiction, energy resource supplies, etc. However, there is no interaction with the economy, so they are only partial equilibrium models. In addition, end-use sectors are also aggregated and the load curve is simplified.

Electricity models can introduce high intertemporal disaggregation and use detailed technology characterisation, i.e., the MARKAL electricity model, electricity trade model, system dynamics model, etc. Sectoral models are not only technology-specific, but can also build in stocks, social and behavioural characteristics, etc. However, neither electricity models nor sectoral models can include cross-sectoral interaction, introduce resource competition, or use exogenous demand assumptions. Thus, when research objectives and scope are considered, there are always trade-offs between energy-systems approaches, sectoral models and macro-economic models.

The TIMES Family of Models

The Swiss TIMES electricity model (STEM-E)[2] is a single-region model, which combines a long model horizon (2010–2100) with an hourly representation of weekdays, Saturdays and Sundays in four seasons. STEM-E is built to explicitly depict plausible pathways for the development of the electricity sector, while dealing with inter-temporal variations in demand and supply.

The Swiss TIMES energy system model (STEM)[3] is further developed to depict the full energy system in Switzerland, from resource supply to end-use energy service demands (ESDs). The model is used to identify the least-cost combination of technologies and fuels to meet future ESDs (which are given exogenously based on a set of scenario drivers), while fulfilling other technical, environmental and policy constraints (e.g. CO_2 mitigation policy). It includes several unique features that make it particularly suitable for Switzerland, including its ability to depict certain technologies in more detail, represent more dynamic electricity load curves, and account for real-world factors in technology deployment and economic risk.

The cross-border Swiss TIMES Electricity Model (CROSSTEM) is a detailed bottom-up model of the electricity system of Switzerland and its neighbouring countries (Austria, France, Germany and Italy). CROSSTEM is also built based on the TIMES framework. It represents bilateral interconnectors, and trade between Switzerland and the four neighbouring countries—subject to interconnector availability, losses, trading costs and other constraints.

Conclusions

Energy models can be helpful in understanding the dynamics of energy transition pathways, and scenario analyses can be tailored to specific research and policy questions. However, there is no "one-size-fits-all" approach. Thus, ideally, in order to carry out a comprehensive study, several models should be employed. Finally, as models are data-intensive in nature, complete transparency of model inputs is critical in the building of trust.

1. CGE, CITE, Geneswis, GEMINI-E3, GEM-E3, MultiSWISSEnergy, MERGE, Global Trade Analysis Project (GTAP), SwissOLG, SwissGem.

2. R. Kannan and H. Turton, *Documentation on the Development of the Swiss TIMES Electricity Model* (Switzerland: Paul Scherrer Institute, 2011). http://www.psi.ch/eem/PublicationsTabelle/2011_Kannan_STEME.pdf.

3. R. Kannan and H. Turton, *Switzerland Energy Transition Scenarios—Development and Application of the Swiss TIMES Energy System Model (STEM): Final Project Report* (Switzerland: Paul Scherrer Institute, 2014). http://www.bfe.admin.ch/forschungewg/index.html?lang=de&dossier_id=02886.

A Multi-Regional CGE Analysis of a Linkage in Carbon Markets between Hubei and Guangdong

Assoc. Prof. Liu Yu, Institute of Policy and Management, Chinese Academy of Sciences

Write-up by ESI's Su Bin

China is the second largest economy and largest carbon emitter in the world. In 2014, its carbon emissions reached 9.8 gigatonnes. The government has set a few emissions targets, such as the "1617" target, which aims to reduce energy intensity and carbon intensity by 16 and 17 per cent, respectively, as stated in the 12th Five-Year Plan (2011–15). Additionally, the "4050" target is one that aims to decrease carbon intensity (emissions per unit of GDP) by 40–45 per cent in 2020 compared with 2005 levels. Carbon emissions are expected to peak around 2030.

To reduce carbon emissions, the market-based mechanism has also been considered. To date, China has launched seven pilot emissions-trading schemes (Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong and Shenzhen), and intends to gradually establish the national emissions trading schemes (ETS) in 2016.

Previous literature focuses on using the IO/CGE, energy technology and optimisation methods to study the carbon tax, marginal abatement cost, quota allocation, emissions trading among countries, and trading across regions within one country. Our study uses the multi-region CGE model (CASIPM-R model) to study China's regional emissions-trading schemes (ETS). Some key questions include:

(a) Does the ETS policy lead to substantial impacts on the regional economy?

(b) What is the marginal abatement cost for the pilot regions?

(c) What is the effect of emissions reduction policies on different industries?

The CASIPM-R model is a multi-regional general equilibrium model based on the TERM model developed by CoPS. The static version includes 31 provinces and 193 sectors, while the dynamic version comprises 31 regions and 45 sectors. Not only can it analyse the impact of regional demand-side shocks, it also simulates regional supply-side shocks. The databases used are the 2007 Chinese national and provincial input–output tables and the 2007 energy statistics data. Two sub-models, namely a carbon tax module and an emissions-trading module, are also developed.

The analysis focuses on two of the pilot ETS regions: the provinces of Guangdong and Hubei. Two scenarios are considered in the emissions-trading module. The first is the "no-trading" scenario, while the second is the "trading" scenario. Under the "no-trading" scheme, there is no trading between regions. Therefore, the actual emissions in each region will equal its emissions quota, and the equilibrium prices of carbon in the two regions are not the same. Under the "trading" scheme, the two regions can achieve their reduction targets through trading. Thus, there is an equilibrium price of carbon for both regions. For both scenarios, the carbon emissions caps are determined by the GDP growth rate and energy intensity, and the emissions quotas are allocated using the auction method. For the revenue generated from emissions trading, we chose the direct income subsidy to the households.

Figure 1 shows the simulation results of the two scenarios. For the "no-trading" scenario, the carbon price in Guangdong is 103 RMB/tCO_2, while that of Hubei is only 15 RMB/tCO_2. For the "trading" scenario, the equilibrium carbon price becomes 35 RMB/tCO_2. In this case, Guangdong will buy a 23-million-tonne CO_2 quota (i.e. RMB 0.8 billion) from Hubei.

Figure 1: Simulation Results of the Two Scenarios

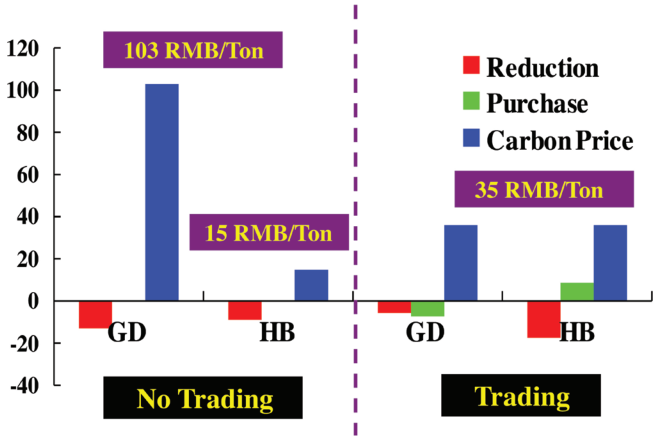


Table 1 lists the impacts to the macro-economy of the two scenarios. In general, Guangdong's economy becomes smaller while Hubei's gets larger. In other words, Guangdong will benefit from the carbon market, but Hubei will not. However, from a welfare perspective, both regions improve (see the private consumption indicators in Table 1). When calculating the average cost of carbon abatement for the two regions, Guangdong's average abatement cost drops from 1,342.7 RMB/tCO_2 (no trading) to 479.1 RMB/tCO_2 (trading), while Hubei's average abatement cost increases from 310.5 RMB/tCO_2 (no trading) to 706.3 RMB/tCO_2 (trading). If the two individual regions are combined as a carbon-trading zone (Guangdong–Hubei), the group average abatement cost falls dramatically from 972.4 RMB/tCO2 (no trading) to 567.9 RMB/tCO_2 (trading).

In summary, market-based measures can play an important role in emissions reduction as they can decrease the cost of emissions reduction sharply. Our analysis indicates that not all parties can benefit from emissions trading. Thus, it is important to build a system that encourages all parties to participate in the trading. The Chinese government should also be careful in its selection of regions for emissions trading since the trading regions will suffer losses as a whole. However, promoting emissions trading will improve the structure of domestic demand and transform some patterns of economic development.

Table 1: The Two Scenarios' Impacts on the Macro-Economies

Unit: %	Guangdong		Hubei	
	No trading	Trading	No trading	Trading
GDP	−2.13	−0.76	−1.13	−2.57
Private consumption	−0.31	−0.19	−0.05	0.02
Investment	−3.41	−1.27	−1.93	−4.29
Export	−0.74	−0.23	−0.64	−1.39
Import	−1.57	−0.57	−1.74	−3.92
CPI	0.37	0.11	0.09	0.17
Employment	−1.40	−0.48	−0.52	−1.15
Capital	−2.74	−1.01	−1.75	−3.92

The Economic and Social Impacts of Climate Policy in Singapore

Dr Li Yingzhu, Research Fellow, Energy Studies Institute

Singapore is a wealthy and small open economy which emitted just over 45 million tons of CO_2 in 2010. Although these emissions account for less than 0.2 per cent of global GHG emissions, this non-Annex I country nonetheless has plans to reduce its emissions. In 2009, the Singapore government announced a target of constraining national emissions at 7–11 per cent below the 2020 Business-As-Usual (BAU) level. In July 2015, the government submitted its "Intended Nationally Determined Contribution" (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC), pledging to reduce its emissions intensity to 36 per cent below the 2005 level by 2030.

Why does Singapore join in combating climate change? First, this coastal country is threatened by sea-level rises, accelerated coastal erosion and disruption to global food supply chains arising from climate change. Second, Singapore would like to act as a responsible nation and make joint efforts with other countries to mitigate climate change. Third, its small open economy is highly vulnerable to foreign policies. For instance, to prevent carbon leakage and also to protect domestic industries, several countries have proposed imposing border-carbon-adjustments (BCA) on products from countries without comparable emissions-reduction commitments.

Currently, more than 90 per cent of Singapore's electricity is generated by natural gas, and it is difficult for the country to develop renewable energy due to its size and tropical location. As a result, Singapore's main strategy for emissions reduction is to improve energy efficiency, promote investment in R&D of low-carbon energy technologies, encourage energy conservation, as well as to urge its citizens to reduce road vehicles by taking public transportation. Carbon pricing was mentioned in the *2012 National Climate Change Strategy* as a potential instrument. However, the economic and social impacts of climate policy on Singapore seem to have caused its government to hesitate. Thus, ESI researchers decided to quantitatively analyse this issue in an attempt to gain greater understanding and clarity.

A computable General Equilibrium (CGE) model was adopted to support the analysis. A single-region Singapore model was first developed, and then extended into a two-region model: Singapore (SG) and the rest of the world (ROW). Singapore's 2007 input–output table and other statistics were used to construct its social accounting matrix, while the Global Trade Analysis Project (GTAP) database was used for the ROW. The economy was broadly disaggregated into 11 sectors. In the production process, fossil fuels, electricity, capital, labour as well as non-energy intermediate goods were all used. The final output was differentiated into domestic goods and exports. Domestic goods were subsequently distributed for household consumption, government expenditure, investment and intermediate use.

Theoretically, it is easier to handle a single-region model. However, having a single-region means having no player on the other end of international trade. Thus, the prices of imports and exports have to be set exogenously. Developing a multi-region model is more complicated, but the prices of traded goods can be determined by demand and supply in the international markets. As an important player in the international markets for many products (e.g. semiconductors and electronics), Singapore can partially pass increased costs to foreign importers. Therefore, the SG–ROW framework is expected to provide "better" results given the same carbon price. To visualise the difference, three scenarios (A1–A3 in Table 1) were simulated. It was found that macroeconomic indicators (e.g. GDP, household consumption and total exports) tended to be affected much less under the SG–ROW framework than expected. Accordingly, emissions reduction was less pronounced.

Another four scenarios (B1–B4 in Table 1) were then performed under the SG–ROW framework. It was found that if ROW unilaterally imposes the carbon tax, Singapore's GDP and household consumption decline slightly, but total exports increase due to price advantage. Of particular note is that a "carbon linkage" from the ROW to Singapore would emerge (see light blue columns in Figure 1). If both the ROW and Singapore impose the carbon tax, Singapore's GDP and household consumption would decline a bit more, and total exports would benefit less due to a smaller price advantage. Nevertheless, Singapore's carbon emissions would drop significantly by 2 per cent (see dark blue columns in Figure 1). Generally, refunding carbon tax revenue would alleviate the negative impacts, but meanwhile weaken the effectiveness of a carbon tax on emissions reduction.

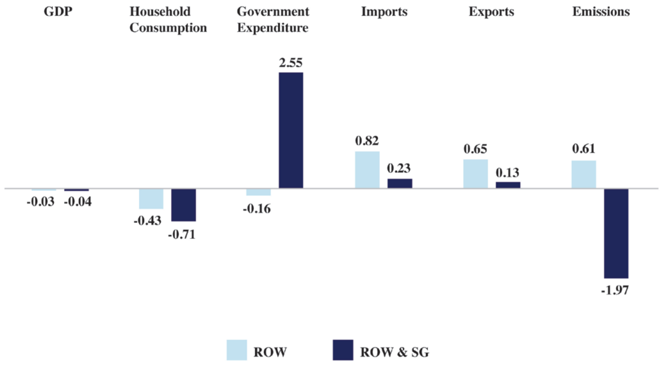
ESI's CGE project started in April 2014, with the initial aim to develop an environmental CGE framework to support

Table 1: Scenario Designs

Scenario	Description
A1	SG carbon tax of S$30/t$CO_2$ on energy, manufacturing & transport sectors
A2	A1 + carbon tax revenue refunded to households
A3	A1 + carbon tax revenue refunded to firms
B1	ROW carbon tax of S$30/t$CO_2$ on energy, manufacturing & transport sectors
B2	ROW & SG carbon tax of S$30/t$CO_2$ on energy, manufacturing & transport sectors
B3	B2 + SG carbon tax revenue refunded to households
B4	B2 + SG carbon tax revenue refunded to firms

policy analysis of energy and environmental issues for Singapore. In the next phase, ESI researchers will work on extending the current SG–ROW framework to a multi-region framework which includes Singapore's major trade partners and ASEAN neighbours. To presume that other countries will collectively implement a certain policy is fairly unrealistic. Therefore, evaluating the potential impacts of domestic carbon pricing and foreign BCA based on a multi-region framework can provide more precise insights for Singapore producers and policy-makers. Additionally, a multi-region framework will allow us to address issues that require regional cooperation. The ESI research team plans to deepen the analysis of carbon pricing in the short term, but is open to other energy and environment-related policy questions that are important to Singapore and the ASEAN region.

Figure 1: Impacts (%) of ROW Carbon Tax (B1) and ROW & SG Carbon Tax (B2)



Staff Publications

Internationally Refereed Journals

Xunpeng Shi, "Application of Best Practice for Setting Minimum Energy Efficiency Standards in Technically Disadvantaged Countries: Case Study of Air Conditioners in Brunei Darussalam", *Applied Energy* 157 (2015): 1–12.

Yu Sheng, Yanrui Wu, Xunpeng Shi et al., "Energy Trade Efficiency and Its Determinants: A Malmquist Index Approach", *Energy Economics* 50 (2015): 306–14.

Book Chapters

Melissa Low and Lim Lei Theng, "Past and Contemporary Proposals on Differentiation and Equity: Shaping the 2015 Climate Agreement", in *Sustainability Matters: Environmental and Climate Changes in the Asia-Pacific*, ed. Lin-Heng Lye, Victor R. Savage, Harn-Wei Kua et al. (Singapore: World Scientific Publishing, 2015), pp. 503–28.

Philip Andrews-Speed, "China's Energy Needs and Energy Security", in *Sino-U.S. Energy Triangles: Resource Diplomacy Under Hegemony*, ed. David Zweig and Yufan Hao (New York: Routledge, 2015), pp. 38–54.

Philip Andrews-Speed and Sufang Zhang, "Renewable Energy Finance in China", in *Renewable Energy Finance: Powering the Future*, ed. Charles W. Donovan (London: Imperial College Press, 2015), pp. 175–94.

Xunpeng Shi and Hari Malamakkavu Padinjare Variam, "China's Gas Market Liberalisation: The Impact on China–Australia Gas Trade", in *China's Domestic Transformation in a Global Context*, ed. Ligang Song, Ross Garnaut, Cai Fang and Lauren Johnston (Canberra: ANU Press, 2015), pp. 137–74.

Reports

Philip Andrews-Speed, "Mixed Motivations and Mixed Blessings: Chinese Investments in Southeast Asian Energy and Mineral Resources", *ISEAS Perspective* 40 (2015).

Su-Ann Oh and Philip Andrews-Speed, "Chinese Investment and Myanmar's Shifting Political Landscape", *ISEAS Trends* 16 (2015).

Staff Presentations and Moderating

29 September Anton Finenko participated as a panellist at the *Renewable Energy Policies in Southeast Asia Panel Discussion* organised by the American Chamber of Commerce in Singapore, AmCham Office, Singapore.

22 September Elspeth Thomson moderated, "GCC Economic and Political Outlook: Challenges in Transitioning to Sustainable Development under a Low Oil Price Environment", a seminar delivered by Dr Adnan Shihab-Eldin, Director General of the Kuwait Foundation for the Advancement of Sciences, organised by the Middle East Institute, National University of Singapore.

21 September Melissa Low presented, "Engaging with Singapore's Climate Change Policies", at a Roundtable organised by the National University of Singapore's Faculty of Arts and Social Science's "Social Science & Policy" (SSP) Cluster, held at NUS.

14 September Xunpeng Shi presented, "Potentiality and Reality of Regional Cooperation and Connectivity: ASEAN Examples", at the *Expert Group Meeting on Energy Integration for Sustainable Development in Asia and the Pacific*, organised by the UN Economic and Social Commission for Asia and the Pacific (ESCAP), Irkutsk, Russia.

14 September Xunpeng Shi presented, "Assessment of Instruments Facilitating Investment in Off-Grid Renewable Energy Projects", at the *Expert Group Meeting on Energy Integration for Sustainable Development in Asia and the Pacific*, organised by the UN Economic and Social Commission for Asia and the Pacific (ESCAP), Irkutsk, Russia.

11 September Xunpeng Shi presented, "Panel Discussion on the Developing APEC Sustainable Energy Development Agenda" at the *Asia Pacific Sustainable Energy Development Forum*, organised by the APEC Sustainable Energy Center, Tianjin, China.

28 August Philip Andrews-Speed moderated the panel on "China's Overseas Energy Engagements: Interests and Diplomacy", at the workshop, *Perspectives on China's Rise as a Maritime Power and Quest for Energy Security*, Singapore.

27 August Christopher Len moderated the panel on "China's Foreign and Security Environment: Xi Jinping and China's Changing External Environment", at the workshop, *Perspectives on China's Rise as a Maritime Power and Quest for Energy Security*, Singapore.

27 August Philip Andrews-Speed moderated the panel on "Securing China's Overseas Energy Interests", at the workshop, *Perspectives on China's Rise as a Maritime Power and Quest for Energy Security*, Singapore.

27 August Yao Lixia presented, "Energy Security in Resource-Poor Countries: A New Paradigm of Conceptual Framework", at the *18th International Academic Conference,* London, UK.

29 July Xunpeng Shi presented, "Policy Implications for Enhancing Global Energy Governance", at *The Impact of Low Oil Prices and the Role of the G20 in Global Energy Governance International Conference,* organised by the Shanghai Institute for International Studies.

27 July Philip Andrews-Speed presented, "What Role Can the G20 Play in Global Energy Governance, and How Can China Use Its Presidency in 2016?", at *The Impact of Low Oil Prices and the Role of the G20 in Global Energy Governance International Conference,* organised by the Shanghai Institute for International Studies.

26 July Melissa Low moderated the panel on "Implementing Environmental Education: A Comparative Case Study", at the *ASEAN Power Shift 2015* held at the United World College Southeast Asia Campus, Singapore.

25 July Melissa Low moderated the panel on "Understanding INDCs and What It Means for ASEAN" at *ASEAN Power Shift 2015,* held at United World College Southeast Asia Campus, Singapore.

22 July Xunpeng Shi presented, "Discussion on the Report of the 2nd ERIA Multilateral Joint Study for the LNG Market", at the *2nd ERIA Multilateral Joint Study for the LNG Market*, held in Tokyo, Japan.

16 July Christopher Len presented, "Singapore and the Arctic", at the conference, *Ensuring Maritime Stability, Security and International Collaboration in a Changing Arctic*, jointly organised by Daniel K. Inouye Asia-Pacific Center for Security Studies and the Ocean Policy Research Institute–Sasakawa Peace Foundation, held in Tokyo, Japan.

13 July Xunpeng Shi presented, "China's Gas Market Liberalisation and Its Global Impact", at the *27th Annual Conference of Chinese Economics Society Australia* (CESA), held in the University of Wollongong, New South Wales, Australia.

10 July Christopher Len presented, "Unconventional Gas Developments in Asia: Lessons from the US Shale Gas Revolution", at the *4th AEEPRN Annual Conference: Energy Transition in Asia and Europe*, jointly organised by Korea University's Green School, the Graduate School of Energy and Environment, and the Korea Energy Economics Institute, Seoul, Korea.

10 July Philip Andrews-Speed presented, "Asia's Energy Future: Will Asia's Developing Economies Make the Switch to Clean Energy?" at *DBS Asian Insights Conference*, Singapore.

10 July Xunpeng Shi presented, "China's Gas Market Liberalization and Its Impact on China–Australia LNG Trade", at *ANU China Update*, Canberra, Australia.

8 July Xunpeng Shi presented, "Panellist on China's Gas Market Liberalisation", at *China Symposium: China's Domestic Transformation in a Global Context*, jointly organised by the University of Melbourne's Centre for Contemporary Chinese Studies and Faculty of Business and Economics, held in Melbourne, Australia.

7 July Philip Andrews-Speed presented, "Global Engineering Debate: Energy Resources in Southeast Asia", at the Institute of Mechanical Engineers and Engineering Alumni, Singapore.

7 July Philip Andrews-Speed presented, "Southeast Asia's Food Water and Energy Nexus in 2030", at the *1st Asian Undergraduate Summit*, held at the National University of Singapore.

6 July Philip Andrews-Speed presented, "The Global Resource Nexus: Market, Strategic and Local Realms", at the *1st Asian Undergraduate Summit*, held at the National University of Singapore.

1–3 July Melissa Low presented, "Intended Nationally Determined Contributions", at the *ASEAN Working Group on Climate Change Negotiations,* held at the Asian Institute of Technology (AIT) Campus, Bangkok.

Staff Media Contributions

Philip Andrews-Speed was interviewed by *Radio Durian FM* on China's Energy Vision for Asia, 21 September 2015.

Philip Andrews-Speed was interviewed by *TV Channel Russia 24* on Reform of China's Oil Sector, 16 September 2015.

Philip Andrews-Speed was interviewed by the *Wall Street Journal* on China's Power Sector Reforms, 10 September 2015.

Philip Andrews-Speed was interviewed by *Radio Free Asia* on China's Electricity Consumption, 31 August 2015.

Philip Andrews-Speed was interviewed by *Reuters* on the Significance of the IEA in Asia, 28 August 2015.

Recent Events

23 September, Overview of the Shipping Industry and Its Challenges to Reduce Their Greenhouse Gases and Contribute to a Green Ship and Green Port Environment
Dr Carol Anne Hargreaves, Chief of the Business Analytics Practice at the Institute of Systems Science, National University of Singapore discussed the many challenges that the maritime industry faces in its efforts to comply with new regulations introduced in January 2013, including the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), which are mandatory for all ships of 400 gross tonnage and above. Furthermore, from 2015, ships operating in Emissions Control Areas are required to use fuels with 0.1 per cent or less sulphur content (versus 1 per cent previously). From next year, a new threshold will also apply to nitrous oxide emissions. Dr Hargreaves explained the ways in which shipping owners can overcome these challenges and contribute to a green ship and green port environment.

27–28 August, Perspectives on China's Rise as a Maritime Power and Quest for Energy Security
ESI, in cooperation with the China Strategic Culture

Promotion Association (CSACPA), organised a one-day workshop and half-day forum examining China's rise as a maritime power and quest for energy security. Presently, Chinese national oil companies have assets across the world: in the Middle East, Africa, North America, Latin America and Asia. China relies on seaborne deliveries for much of its oil and, increasingly, natural gas. Beijing also has plans to undertake deep-sea and frontier oil and gas explorations and mining. These energy interests—as well as the Chinese leadership's pronouncements on developing China as a maritime power and the creation of a 21st-Century Maritime Silk Road—will significantly affect how China behaves diplomatically, militarily and commercially, with regional and global implications. To this end, ESI and CSCPA brought together Chinese, as well as international and Singapore-based experts from different backgrounds, to share their personal views and perspectives. Both the workshop and forum were by-invitation only and held under the Chatham House Rule.

18 August, China's Carbon Emission Status, Derivation Trend and Emissions Performance

Dr Dong Feng, Associate Professor at the School of Management, the China University of Mining and Technology (CUMT) introduced China's 12th Five-Year Plan and its recently submitted Intended Nationally Determined Contribution (INDC). He went on to evaluate regional emissions reduction performance by employing a number of quantitative indicators and models such as the Theil Index, Variation Coefficient, Gini Coefficient and Cluster Analysis. He then described the factor decomposition and dynamic simulation process used to evaluate China's carbon emissions reduction efforts. Dr Dong presented the empirical results from his study and concluded with some policy recommendations.

29 July, Risk Governance in Nuclear Development: The Why's and How's of Multi-Stakeholder Engagement

Dr Catherine Mei Ling Wong, Senior Research Officer at the Cairns Institute, James Cook University, Australia presented a Hybrid Risk Governance Framework as a format for multi-stakeholder engagement. This model offers a comprehensive set of procedures that corporations, policy-makers, risk managers, etc., can use to navigate the participatory process at various stages of a project. She also discussed a case study of a nuclear power plant in India after the Fukushima disaster.

21 July, Bond Financing for Renewable Energy

Mr Thiam Hee Ng, Senior Economist at the Asian Development Bank, provided an overview of financing mechanisms for Asia's growing energy needs, and noted that funds will have to be mobilised from the private sector to supplement government and sovereign funds. To do this, governments need to provide long-term supportive policy frameworks in order to promote investment in renewable energy capacity. Mr Ng highlighted that Asia has a large pool of funds available for investments as it remains a capital surplus region. Being more familiar with the region might lead Asian investors to assess the risks and returns on renewable energy projects in the region differently from investors from advanced economies. He gave examples of how some bond markets in the region have attained sufficient depth to tap into the financing of large renewable energy projects.

20 July, Revisiting Environmental Kuznets Curves (CO_2 and SO_2) with Endogenous Breaks Modelling for Individual OECD Countries

Dr Brantley Liddle, Special Advisor at the Asia Pacific Energy Research Centre (APERC), Tokyo, delivered a presentation that examined the relationship between CO_2 and SO_2 emissions per capita and real GDP per capita for 23 and 25 OECD countries for each type of pollutant, respectively. For 15 of the 23 countries studied, the carbon emissions–income relationship showed either: (i) decoupling, where income no longer affects emissions in a statistically significantly way; or (ii) saturation, where the emissions elasticity of income is declining, less than proportional, but still positive. The emissions–income relationship was negative for only four countries. In contrast, the predominant income–sulphur emissions relationship—the case for 24 of the 25 countries studied—was either: (i) inverted Vs, where the emissions-income relationship became negative, or (ii) decoupling. Dr Liddle also discussed carbon emissions elasticities between income and population for 26 OECD and 54 non-OECD countries.

2 July, CNG Conversion of Vehicles in Dhaka: An Analysis of Air Quality, GHG and Congestion Impacts

Dr Zia Wadud, University Research Fellow in Transport and Energy, based at the Centre for Integrated Energy Research (CIER), the University of Leeds, discussed the background of the CNG conversion policy in Dhaka, Bangladesh, then explained the modelling of Dhaka's air quality and climate impacts using the impact pathway model. He also addressed the potential congestion and overall social impacts.

Contact

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

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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.

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