An Integrated Analytical Framework of Sustainable Energy for All:
Developing Asia Perspective

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Doctoral Dissertation

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March, 2015

Acknowledgement

I would like to express my sincere and special appreciation and thanks to my advisor Professor Dr. Tetsuo Tezuka, you have been a tremendous mentor for me throughout my doctoral study in Kyoto University. I would like to thank you for encouraging my research and for allowing me to come up with unique research plan and to grow as a matured research scientist. Your advice on both research as well as on my career have been priceless. I would also like to thank my committee members, Professor Unesaki, Professor Benjamin McLellan, for being my committee members. My dissertation would not have compiled had I not got the support from my previous organization Institute for Global Environmental Strategies (IGES) who allowed me to do research and publish papers towards fulfilment of my doctoral research requirement. I am grateful to my director Dr. Satoshi Kojima from IGES, who supported me relentlessly during my initial days of learning of economic analysis and modelling in energy sector. Without his support I could not have completed my thesis indeed. I am also indebted to IGES authority especially Professor Hironori Hamanaka, Chair of the Board of Directors of IGES and Mr. Hideuki Mori, President of IGES for their continuous moral support to continue my doctoral research even during the difficult days of extreme busyness.

I would also like to extend my special thanks to my family. Words cannot express how grateful I am to my beloved wife Tania, who relentlessly advised, supported and helped me to overcome various difficult situations during the entire period of my doctoral study. Without her support it was rather impossible to manage the work, life and study balance. I am also indebted to my love my little princesses Audrija (age 7) who continuously supported me by hug and kisses whenever I felt tired working overnight. Last but not the least, I am indebted to my parents who are my motivations from the day one of my life and kept inspiring me to complete my journey to obtain the highest academic degree come whatever in my path. I would also like to thank all of my friends who supported me in writing, and inspired me to strive towards my goal.

Abstract

Having a secured and robust energy distribution system is a more challenging task than handling the concerns of energy resources availability. Sustainable Energy for All (SE4ALL) is a global program dedicated to enhance the access to clean, efficient modern energy to the global community especially to the underprivileged people living in the developing countries. Given the increasing complexity in socio-economic condition followed by increasing dynamism in demographic condition and increasing level of political uncertainties including international terrorism, having sustainable energy supply chain is becoming a tougher challenge to the countries. World has enough coal for another two hundred years, oil for another seventy years and with new discovery of shale gas, this particular fuel type is almost unlimited. As a matter of fact, energy resource scarcity is not a big threat to the mankind. Nevertheless, energy poverty is grasping the world aggressively where the Developing Asia region is the most vulnerable one. Being poor in indigenous fossil fuel resources and backward in technology and financial resources, the region has become perennial net energy importer. Unfortunately, the region is also having the highest population growth rate and house one third of world population (more than 2 billion) having lowest level of par capita income in the world (less than 1.51 USD/day). As a result, people of Developing Asia are unable to pay for high cost imported energy to meet their energy demand adequately. Due to lack of technology and financial resources neither these countries are able to develop their own energy market which can sufficiently supply energy to meet the increasing demand, nor they are able to afford to pay increasing price of imported energy from the international market to meet the demand gap.

Given the background of the socio-economic and environmental condition of the Developing Asia region with high level of diversity, implementation of SE4ALL is of great challenge. Taking note of the experiences of implementation of MDG program over a decade it has been understood that a comprehensive and inclusive growth oriented indicator based monitoring mechanism can enhance the potentiality of the success of the program. SE4ALL program has developed a global tracking tool based on the three pillars of energy access, renewable energy and energy efficiency. Given the categorization of the indicators it has been further understood that the prevailing tracking tool needs to be further strengthened by incorporating the factors those are backward linked to the front liner indicators which are easily observable and measurable. As a matter of fact, unless the causal relationship is identified, measured and monitored, success of achieving the target set under SE4ALL program is unsecured. Based on this this principle, we have developed this thesis first to identify the potential backward linkages of each indicators which are crucial for the success of the indicator's target and second, to identify certain additional indicators to be monitored which are expected to enhance the potentiality of the success of the SE4ALL targets. In terms of determining the backward

linkages of the major indicators of SE4ALL like energy access, energy efficiency and renewable energy, we have used a unique approach of analyzing the inter-resource nexus in the context of long term energy supply in the system. . Here we considered three different agents in the economy working in harmony to provide required output per indicator. The agents are natural resources, market and society & government. It has been observed that for energy access and promotion of non-solid fuels, understanding of resource nexus is essential. Water and energy contain a crucial nexus for the overall success of creating sustainable energy supply and demand situation which is elaborated here in this thesis. In the context of market, we have discussed the issues of regional cooperation and energy pricing as mechanisms to promote energy efficiency and renewable energy. A unique methodology has been developed to estimate the subsidies embedded in the energy prices and how to reduce distortion in the energy market by eliminating subsides to bring overall economic benefits in the region. It has been observed that market plays an important role in terms of promoting energy efficiency and renewable energy supply and it is essential to monitor and report the progress towards market maturity in the region for the achievement of SE4ALL objectives. In the context of society and government, we have discussed the issue of innovative investment policy for renewable energy by introducing the concept of investment risk optimization in power sector to promote investment in renewable energy to mitigate the risk of investment in fossil fuel technologies. Thus a unique methodology has been developed to promote sustainable investment in renewable energy sector by prioritizing investment risk over cost of capital base decision making process by the investors. While the objectives of SE4ALL are to promote energy access, increasing renewable energy supply and improving energy efficiency in the market, ultimately it is to improve modern energy and renewable energy supply adequately so that it can meet all demands. We demonstrated that for the successful implementation of SE4ALL in the region, it is important to have a comprehensive tracking indicators which will not only track the final objectives but can also ensure the good progress of the supporting activities required to finally achieve the overall objectives. Finally we have identified additional tracking indicators on top of the existing indicators, which are fundamentally based on the principles of resource, market and society linkages of energy supply and demand and can enhance the probability of successfully achieving the set targets of SE4ALL program.

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List of Abbreviation

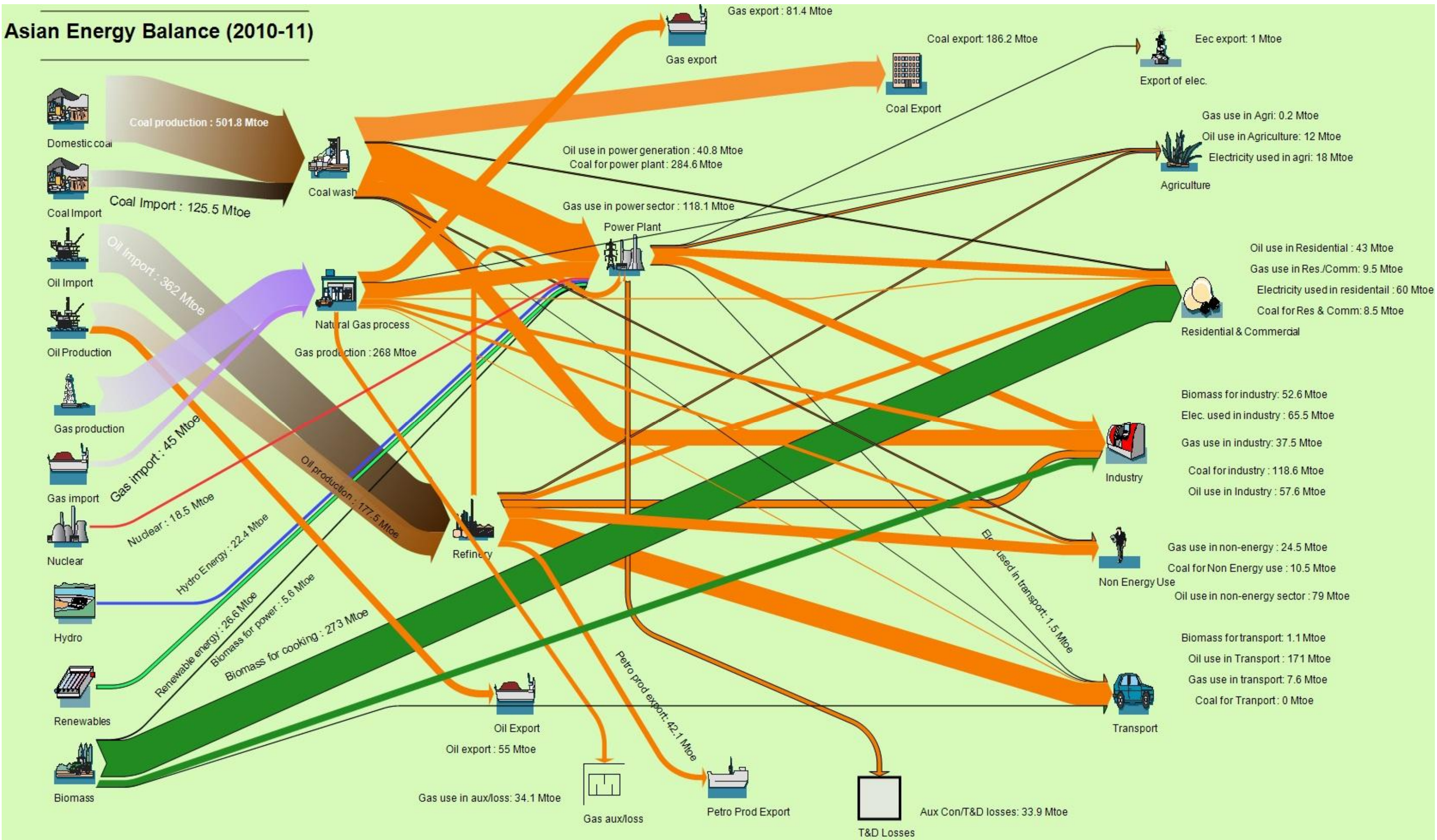
ADB Asian Development Bank
ASEAN Association of South East Asian Nations
BCM Billion Cubic Meter
CCGT Combined Cycle Gas Turbine
CEA Central Electricity Authority
CGE Computable General Equilibrium Model
CPU Compression and Purification Unit
CWC Central Water Commission
DG Diesel Generator
DM Demineralized
DWR Department of Water Resources
EAS East Asia Summit
EJ Exajoules
EPPO Energy Policy and Planning Office
FAO Food and Agriculture Organization
GCM Global Circulation Model
GHG Green House Gases
GMS Greater Mekong Sub-Region
GIS Geographic Information Systems
GTAP Global Trade and Analysis Program
GWh Gigawatt Hour
IEA International Energy Agency
IGES Institute for Global Environmental Strategies
IIASA International Institute for Applied Systems Analysis
IPCC Intergovernmental Panel of Climate Change
IWMI International Water Management Institute
MCM Million Cubic Meter
MoEF Ministry of Environment and Forests
MW Megawatt
MWh Megawatt Hour
NCIWRD National Commission on Integrated Water Resource Development
RCM Regional Circulation Model
SAARC South Asian Association for Regional Cooperation
SE4ALL Sustainable Energy for All
TFP Total Factor Productivity
TLFS Thailand's Load Forecast Subcommittee
TWh Terawatt Hour
UNESCO United Nations Educational, Scientific and Cultural Organization
UNFPA United Nations Population Fund
USA United States of America
WRG Water Resource Group
WSL Water Stress Level

Chapter 1
Asian Energy Perspective

1. Introduction

In Asia mainly the South and South East regions are the most economically promising areas. The countries of these two sub-regions have their differences both inter- and intra-subregionally in terms of size, structure of their economies and cultures, but nearly all of them have grown quite rapidly amidst an era of fragile global growth (ADB/ADBI 2013). On an average, the two sub-regions have marked an average growth rate of around 5% since 1990, and have a prospect of continuing to grow at a rate of 5.4% until 2030. The rapid growth has resulted in much progress in terms of human development, but the two sub-regions still remain the largest home of the world's poor with lack of basic developmental amenities. Addressing these challenges will require these countries to sustain their economic growth. In the context of narrowing the developmental gaps and improving the economic efficiency as a whole with the goal of sustainable development, it is imperative to address the issues of regional diversity in the areas of economy, society and environment, resource endowment and technology as well.

Energy supply is of fundamental significance for economic development because most forms of economic activity rely on some form of energy. The impressive growth of South and Southeast Asian economies in recent decades has already caused a huge increase in the energy demand for these sub-regions as a whole as well as for individual countries. Corresponding to their growth, energy demand has increased at a rate of 6 to7% per annum. It has been estimated that around USD 1 to 2 trillion of investment are required in the regions' energy sector itself. More than USD 100 billion per year for the South Asia region and around USD 35 billion for the South East Asia region are required to develop the energy sector at par to support the corresponding economic growth. It has been further estimated that, the regions' historic investment categorization would require to be changed over the period of time based on it structural changes in energy resource ownership. South East Asia is soon going to be net energy importer in total compare to its position a decade ago (of net energy exporter). South Asia region mainly driven by Indian economic growth will require significant investment to reduce it's over dependence on energy import and improve its energy security condition. Figure 1.1 below shows the Asian Energy Balance (without China) in a sanky diagram which clearly indicates coal in the single largest source of energy in the region followed by oil, natural gas and biomass. In terms of energy use, residential and commercial, industry and transport sectors are the big consumers in the region.

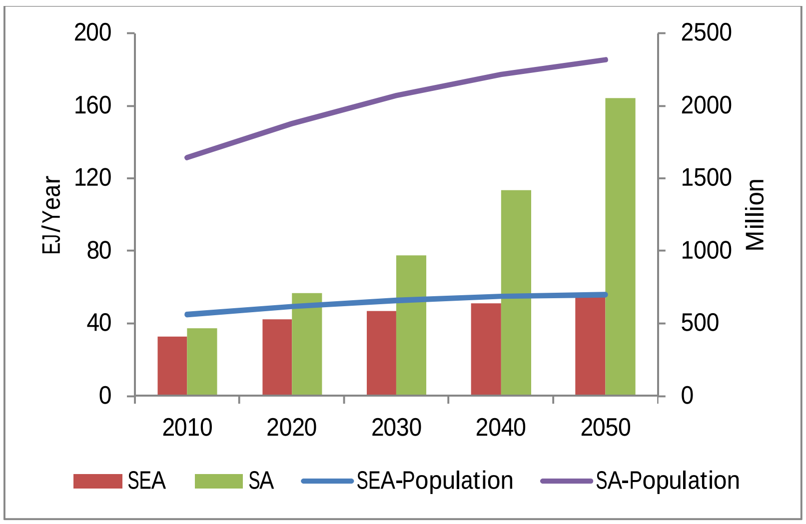


Source: Author estimated using energy balance of Asia (excluding China) from IEA 2010 World Energy Outlook.

Figure 1.1: Asian Energy Balance (2010-11)

1.1 Regional diversity in energy supply

Within Asia, the regions including South (SA) and South East Asia (SEA) differ widely in various aspects of energy sectors like energy supply, demand and trading pattern. In fact, such stunning differences pave the path for cooperation and integration for better economic, social and environmental development in the region. Population is also widely varying over the period of time. Primary energy supply increases by three fold in the South Asia region compared to Southeast Asia by 2050 while population increase is about four folds in case of South Asia compared to Southeast Asia (Figure 2.1)



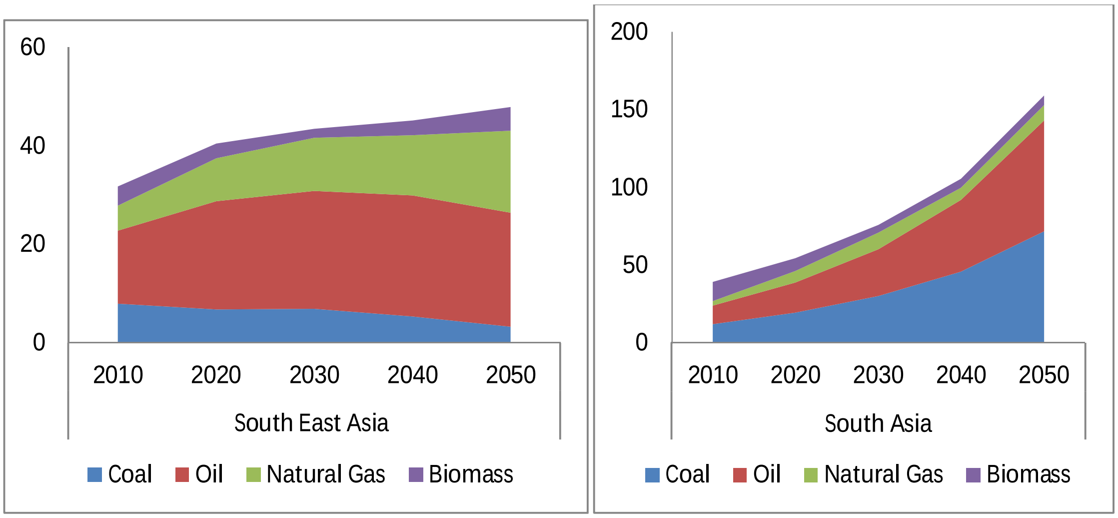
Source: Compiled from Global Energy Assessment Report, IIASA, (Riahi et.al.2012)

Figure 1.2: Total Primary Energy Supply comparison between two regions

In the context of major primary energy supply like coal, oil, natural gas and biomass resources, the Asian regions differ a lot, too. Coal supply increases for the South Asia region while it decreases for the other. Similarly, oil supply increases in the South Asia region compared to declining trend in the South East Asia region. Natural gas is a big source of primary energy supply in the South East Asia region compared to the South Asia region though the supply of gas slightly decreases over the period of time in the region (Figure 1.3)

In the context of energy supply augmentation and energy security concerns, and the need to use cleaner forms of energy, there has been increased focus on natural gas—an interest in increasing its supply in some SAARC member states (SMSs) and as an attractive option to diversify the current fuel mix in other SMSs. Natural gas is an economically attractive substitute for diesel based power generation. Natural gas-based electricity generation for localized use and for bulk transmission through intra-regional power interconnections is an important electricity supply option.

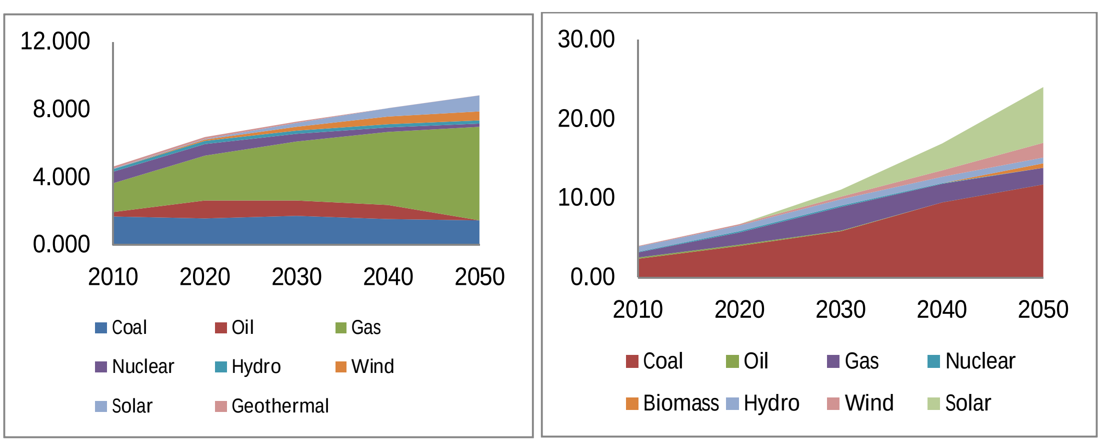
The long-distance transport of natural gas (beyond 2,000 km) over oceans is most economically carried out in the form of liquefied natural gas (LNG)— natural gas cooled to minus 160 degrees centigrade and occupying 1/600th the gaseous volume.



Source: Compiled from Global Energy Assessment Report, IIASA, (Riahi et.al.2012)

Figure 1.3: Projected Total Primary Energy supply status in Asia

In terms of electricity supply, the region is varied in nature. South Asian sub region is heavily depending upon coal based power generation while the South East sub region is depending on gas based power supply. Renewable energy is also going to play an important role in the region. Especially for the South Asia region solar energy is expected to play a significant role in terms of rural and decentralized electricity supply. Geothermal is expected to play an important source of energy in the South East Asian region which is partly falls within the Ring of Fire in the Pacific. The figure 1.5 below shows the long term projection of electricity supply situation in Asia.



Source: Compiled from Global Energy Assessment Report, IIASA, (Riahi et.al.2012)

Figure 1.4: Projected electricity generation in Asia

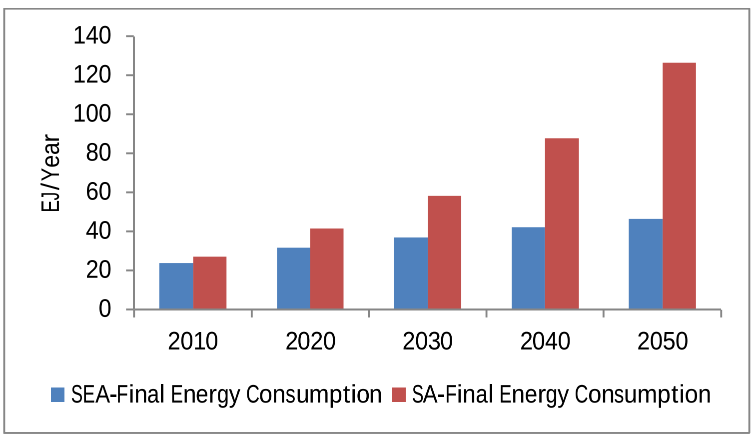
1.2 Regional diversity in energy consumption

Strong economic growth and rapid urbanization accelerate Asia's primary energy demand at more than twice the global average in the Outlook to 2035. As per new policy scenario, especially South Asia's energy demand rises by 83% between 2011 and 2035, which is representing over 10% of the growth in energy use worldwide. Per-capita energy demand increases from around one-fifth to one-third of the OECD average over the period. The amount of energy used to generate a unit of GDP declines by almost two-fifths. Very significant rise found in Coal demand from a 16% share of the primary energy mix in 2011 to 28% in 2035, consistent with the trend in recent decades in its larger neighbours, China and India. Demand for oil rises from 4.3 mb/d to 6.8 mb/d, representing almost one-fifth of the growth in global demand. Gas demand increases about 80% to 250 bcm. The share of renewables in the primary energy mix falls as rapidly increasing use of modern renewables – such as geothermal, hydro and wind – is offset by reduced use of traditional biomass for cooking (IEA/ERIA, 2013).

The power sector is fundamental to the energy outlook for Southeast Asia. Electricity demand increases by half by 2020 and to almost 1900 TWh by 2035, a level equivalent to the combined current demand of Japan and Korea. Gross capacity additions of almost 300 GW are required. Coal emerges as the fuel of choice in the power sector as it is relatively cheap and abundant in the region. A shift towards coal is already underway: some three-quarters of the thermal capacity now under construction is coal-fired. Gas for power generation will increasingly come from LNG, which in most cases is set to be more expensive than the gas historically used in the region. Power sector investment of almost $1 trillion is required over 2012-2035.

Final energy consumption rises by 76% in 2011-2035. Industry remains the largest end-user, with its demand growing just over 90%. Strong growth in the vehicle stock pushes energy demand up by 88% in the transport sector. Buildings sector energy use rises at a more moderate rate, dampened by an ongoing switch to modern, more efficient sources of energy away from traditional biomass. The region's energy-related CO_2 emissions almost double, reaching 2.3 Gt in 2035. Growth is faster than in primary energy demand, reflecting the pronounced increase in the share of fossil fuels in the energy mix. Carbon intensity — the amount of CO_2 emitted per unit of GDP — improves significantly, falling by 33% over 2011-2035. Industry is presently the largest end-use sector and its energy demand grows at 2.7% per year on average over 2011-2035. From the view point of end user total final energy consumption grows at an average annual rate of 2.4% through 2035, rising from 398 Mtoe in 2011 to just over 700 Mtoe in 2035, behind this rise in consumption major factor is industry is driven by a continued structural shift from labor-intensive activities to more energy-intensive ones (IEA/ERIA, 2013).

Energy demand in the buildings sector increases 1.8% per year, rising by 52% overall during the period. This growth is quite modest, this growth results from an ongoing switch from traditional biomass combusted in inefficient devices to modern (more efficient) forms of energy. Transport sector energy demand nearly doubles over 2011-2035, growing by 2.7% per year. This rapid increase is underpinned by rising incomes, often low or subsidized oil product prices and, in some cases, a lack of public transport. Oil-based fuels continue to dominate in transport, meeting 90% of demand in 2035, passenger light duty vehicle (PLDV) ownership rates remain low relative to the world average, rising to 71 per 1000 people in 2035. The PLDV stock rises from 22 million in 2011 to 53 million in 2035, with most of the growth in Indonesia, Malaysia, Thailand and the Philippines. (IEA/ERIA, 2013). Thus the region also differs in final energy consumption with wide difference (Figure 1.4). Until 2020 final energy consumption remains almost same for both the regions but it suddenly changes for the South Asia region when it surpasses Southeast Asia region by almost two fold by 2040.



Source: Compiled from Global Energy Assessment Report, IIASA, (Riahi et.al.2012)

Figure 1.5: Projected energy consumption in Asia

Though an increasing trend of energy consumption is forecasted for this region ,but In 2011, it was found that average per-capita energy consumption in Southeast Asia was 0.9 tonnes of oil equivalent (toe), which is around one-fifth of the OECD average. However level of average per-capita energy consumption vary significantly across the region: for example per-capita consumption in Myanmar, for example, is 33 times lower than in Brunei Darussalam.

Southeast Asia's energy intensity – primary energy demand per unit of GDP measured in market exchange rate (MER) terms – is projected to decline at 1.9% per year between 2011 and 2035, as a shift in economic structure to more energy-intensive industrial activities in some parts of the region is offset by improvements in energy efficiency at both the end-use and conversion levels.

As a matter of fact, strong intra and inter regional disparity in terms of energy consumption and pattern are observed and predicted for next several decades.

1.3 Importance of Sustainable Energy for All in Developing Asia region

As discussed in the previous sections that the Developing Asia region is diverse in energy resources availability, with varied supply and demand pattern of energy commodities in the market, it is important to have a uniform and harmonized energy market in the region for sustained growth and development (Bhattacharya, Kojima, 2010). With increasing economic growth and social sector development activities in the region, energy is becoming one of the major factor inputs though the region is the net energy importer. Due to financial and technical reasons the region is also suffering lack of growth in the energy sector per say which is invariably taking toll on its development rate. On one hand the region needs continued economic growth to pull out millions of poverty ridden people from disgrace and on the other hand it needs uninterrupted and reliable supply of energy at an affordable price though the availability and price of energy commodities are not easy to control. It has been observed over several research and observations that energy supply plays an important role in terms of changing lifestyle of society, its economic status though income generation and social development. In the UN Sustainable Energy for All Forum in June 2014, it has been further discussed that sustainable energy supply is also having numerous positive impacts including women and child health, women development and empowerment and also education. It has been estimated that the countries with high Human Development Index (HHD) consume more energy than medium and low HDI (MHD and LHD) countries in the world. The HHD countries consume around 48% of total world energy while their population is only 17% of the world. On contrary, LHD countries are consuming only 3% of the world energy with 15% of world population. MHD countries also consume 48% of world energy with 67% of world population. In terms of world GDP share HHD, MHD and LHD are having 53%, 43% and 4% respective (Wu et.all, 2012). In terms of distribution of countries in the Developing Asia region, most of them are either MHD or LHD countries. As a matter of fact, the region needs to have robust energy supply and distribution system in place to act upon the issues of human development and growth. Given the primary objectives of the SE4ALL, which are to address the basic needs of the people, the program is envisaged to change the existing severe inequality in income distribution, resource consumption and human development. SE4ALL is thus expected to play an important role to achieve the target. Reiterating the objectives of this thesis here, we would like to mention that the purpose of this work is to enhance the potentiality of the SE4ALL to achieve its targets within the given timeline for better future of mankind.

Chapter-2
Analytical Framework and Models

2. Introduction to generic framework of Sustainable Energy for All (SE4ALL)

The world made major advances on the energy front during the last 20 years. An additional 1.7 billion people (equivalent to the combined population of India and Sub-Saharan Africa) gained the benefits of electrification, while 1.6 billion people (equivalent to the combined population of China and the United States) secured access to generally less-polluting nonsolid fuels. On the other hand, Energy intensity has dropped significantly, which has created avoided generation capacity of 2,300 exajoules of new energy supply over the past 20 years. This advancement has also cut down cumulative global energy demand by more than 25 percent over last couple of decades (1990–2010), and leaving 2010 consumption more than a third lower than it would otherwise have been. Renewable energy supplied a cumulative total of more than 1,000 exajoules globally over 1990–2010, an amount comparable to the cumulative final energy consumption of China and France over the same period (IEA & The World Bank, 2014).

The Global Tracking Framework has been developed by a group of international experts and organizations in 2012 which is the first attempt to develop a measuring framework of progress on achieving the target of sustainable energy for all. In terms of measuring indicators of SE4ALL and setting the targets the GTF has identified the following three indicators:

i) The rate of access to electricity and of use of non-solid fuel as the primary fuel for cooking will have to increase from their 2010 levels of 83 and 59%, respectively, to 100% by 2030.

ii) The rate of improvement of energy intensity will have to double from –1.3 % for 1990–2010 to –2.6% for 2010–30.

iii) The share of renewable energy in the global final energy consumption will have to double from an estimated starting point of at most 18 % in 2010, implying an objective of up to 36 % by 2030.

The Figure below shows the schematic diagram of existing framework of Sustainable Energy for All at a global scale.

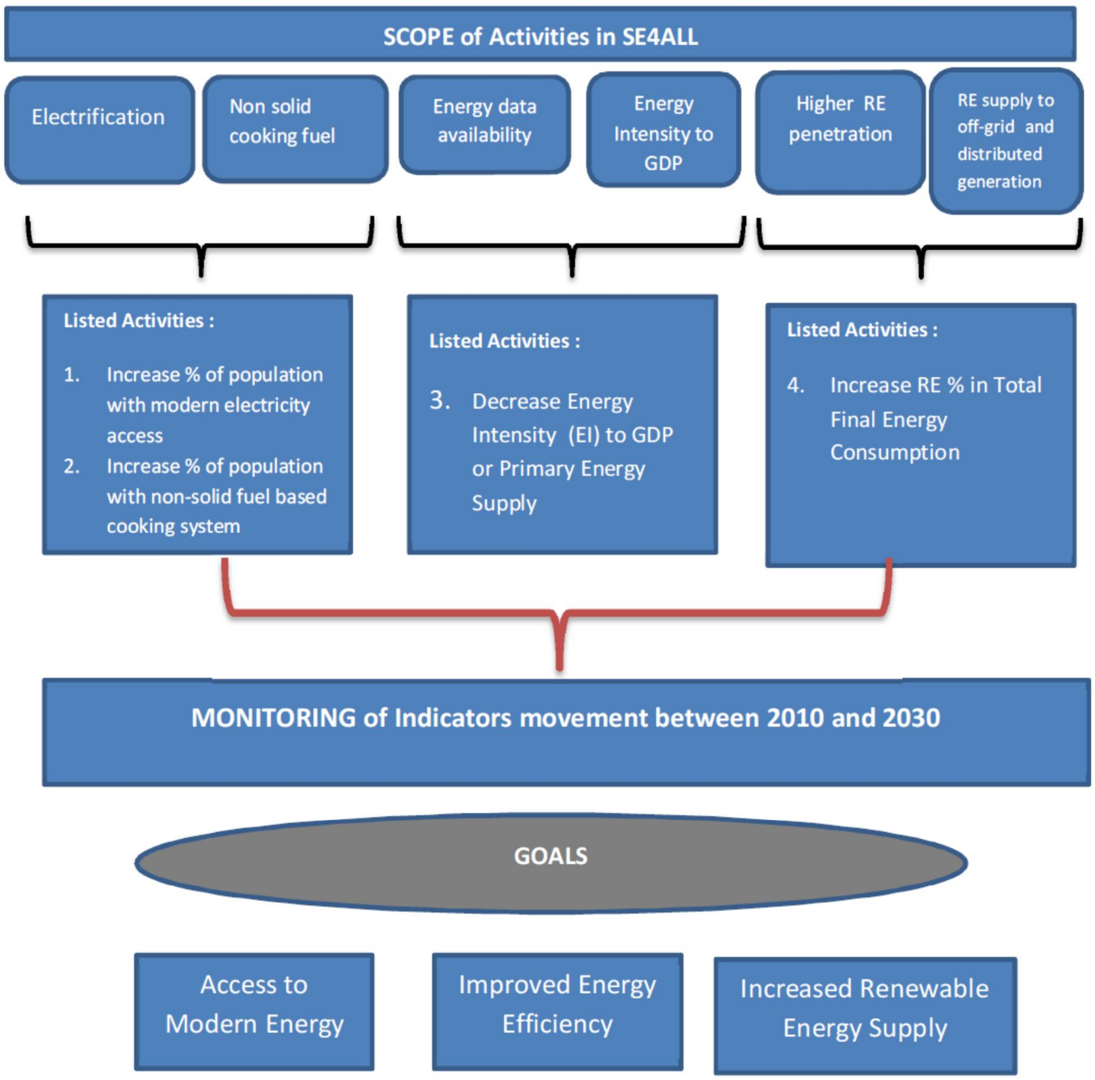


Figure 2.1: Schematic diagram of existing SE4ALL Analytical Framework

The existing SE4ALL global monitoring framework sets 2010 as the base year against which the progress of the initiative will be measured. The framework provides an initial system for regular global reporting, based on indicators that are technically rigorous and at the same time feasible to compute from current global energy databases and that offer scope for progressive improvement and monitoring over time. For energy access, household survey evidence is used to determine the percentage of the population with an electricity connection and the percentage with access to non-solid fuels. Here the solid fuels are defined as both traditional biomass (wood, charcoal, agricultural and forest residues, dung, and so on), processed biomass (such as pellets and briquettes), and other solid fuels (such as coal and lignite). As a proxy for energy efficiency, the framework takes the compound annual growth rate of energy intensity of gross domestic product (GDP) measured in purchasing power parity (PPP) terms, complemented by supporting analysis of underlying factors as well as sectoral disaggregation. For renewable energy, the framework indicator is the share of total final energy consumption deriving from all renewable sources (bioenergy, aerothermal, geothermal, hydro, ocean, solar, wind).

2.1 Methodological issues of existing SE4ALL framework

The existing form of the framework is based on three basic pillars of sustainable energy supply and demand in the market: energy access, energy efficiency and renewable energy. The fundamental ideas of the framework is to ensure uninterrupted and reliable energy supply to the users at a mass scale which can improve the quality of life in one hand and on the other hand can strike a balance between supply of exhaustible energy resources and ever increasing demand due to population growth in an environmentally conducive manner. It has been identified that energy use is the single largest source of Green House Gas emissions in the world which is causing the increase in average global temperature beyond the sustainable limit. Though it is a hard challenge to define the indicators of energy access, efficiency and renewable energy at a global scale in an exclusive manner, but SE4ALL Framework has attempted to prepare a generic definition of these indicators which could be measured under several subcategories of indicators. The idea is to come up with a cumulative measure of development under each category based on improvements recorded with respective sub-categories of indicators. Figure 2-1 above thus tries to create a tree of decision making processes under the SE4ALL generic framework. However, understanding the complexity and vastness of the situation spread across world with more than 6 billion people, SE4ALL generic framework kept the provision of gradual development towards more complex system of operation and monitoring as the world progresses towards the final goals of the SE4ALL. The framework also divided the entire monitoring system into two categories of Global and Country Level with 0-5 Tier of tracking. Tier-0 starts with very basic level of information and statistics and Tire-5 is very advanced level of statistics (Banerjee,2013)[1]. The entire framework of tracking depends on data and statistics collection and putting the figures in a stylized manner to evaluate the progress. The existing framework is fundamentally based on tracking of energy demand side activities to the maximum extent possible. However, energy supply side tracking is a weakness of this framework. Nevertheless, the current structure and framework of SE4ALL lacks in specificity in terms of how and at what cost to achieve the targets. Unless, the framework deals with the process of achieving the targets, the success of the framework remains inconclusive.

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[1] The Global Tracking Framework for SE4ALL Volume 3. Link: http://documents.worldbank.org/curated/en/2013/05/17765643/global-tracking-framework-vol-3-3-main-report

2.2 Lesson learned from MDG program

Although the MDGs give an important and much-needed focus to poverty and hunger alleviation, as well as other interrelated issues such education, gender equity, the environment, maternal and child health and other health problems, the Goals do not say how meeting such targets will be financed. Here the approach of the MDGs neglects the question of which economic policies are necessary for a dynamic and transformational process of economic development. In fact, the MDGs were focused on global targets indeed with limited consideration for national and regional circumstances. The framework did not consider the issues of vulnerability to natural hazards and other external shock which might have caused the setbacks in MDG target. The MDG goals also overlook the importance of cross cutting issues.

2.3 Scope of improvement in SE4ALL Framework

Taking the lessons learned in the implementation failure of MDG program at a global scale and further understanding the structure of the current SE4ALL framework, in this section we would like to propose the scope of potentiality improvement of the success of SE4ALL first and then would like to demonstrate why these additional building blocks are required to enhance the potentiality of success for this program in the subsequent sections. The major emphasis is given on the supply side of energy in the system. It is understood that unless there is sufficient and uninterrupted quality supply of energy in the market, it would be impossible to meet the target of energy access and subsequently energy efficiency and renewable energy supply. However, as mentioned in the SE4ALL document that having the framework at a global scale is always a big challenge, it therefore, important to address the issues in a regional manner before even going at a national scale. In this thesis we would like to introduce a regional scale analysis between global and national scale as an intermediary step of analysis before building additional blocks of analysis to improve the rate of success of the targets set under the SE4ALL program.

Given the fact of high economic growth rate potential with massive scale of disparity in income, availability of natural resources and cultural diversity, South and South East Asia region (excluding China) is the home of more than 700 million people of without modern access to energy, around 273 Mtoe of solid biomass energy is used for cooking and only 24 Mtoe of renewable energy is used for power and other direct energy use. As a matter of fact, this Developing Asia region is a classic case of experiment and analysis under the framework of SE4ALL. In this study, South and South East Asia regions are merged together and nomenclature as Developing Asia.

2.3.1 Multi-point backward linkage in electricity access

Electricity access is considered to be the key for sustainable energy for all. It is envisaged that for improvement of access to energy there are several backward linkages which need to be in place. Unless these linkages are working right, there will not be sufficient amount of electricity available to enhance the access through wider distribution network. It has been observed that in the Developing Asia region around 75 to 85% of population has access to modern electricity supply and among that only 74 % rural people has access to electricity. Figure 2-2 below shows the backward linkages of "Access to Electricity" which vouch for additional information for better measurement of the electricity access percentage in the market.

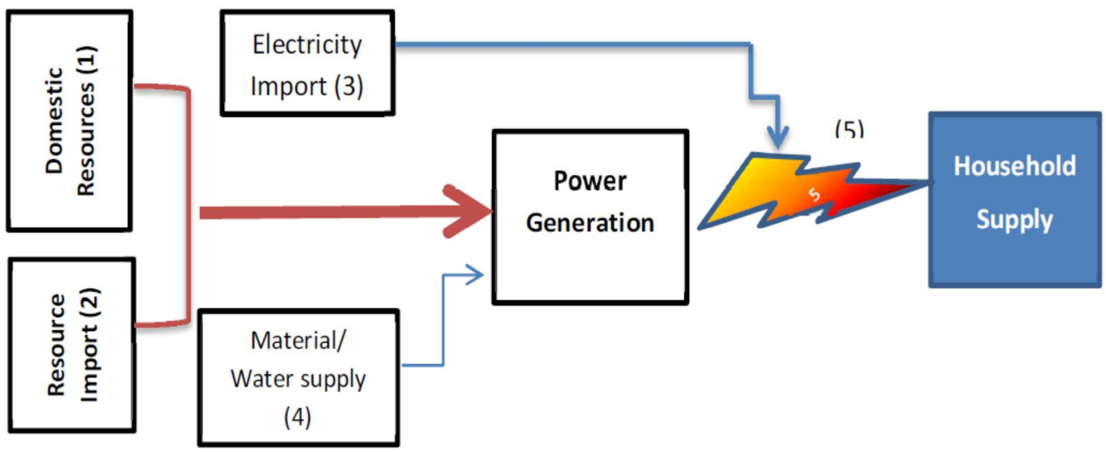

Figure 2.2: Backward linkages of electricity access

There are five (5) important linkages in the electricity supply system which has impact on unit of electricity available in the network and subsequently achieving the target percentage of electricity access. Link 1 is for domestic availability of energy resources including coal, oil, natural gas, hydro, uranium and other renewable resources (solar, wind, geothermal etc) which are easily available to generate power. Link 2 is the region's and country's external resource procurement facility through import. In the developing Asia region, energy resources availability is scattered and insufficient in terms of meeting the growing demand. Therefore, energy import is an important issue of this region to achieve the target percentage of electricity access. Currently the region is a net energy importer and the import dependency is envisaged to grow given the widening demand and supply gap. Similarly, Link 3 in the backward linkages is about other resource availability for power generation. Electricity is generated not only by energy resources but also need huge amount of water in the process and other metals for construction of plants. As a matter of fact these resources are also getting scarce in the region due to increasing conflict between different end users of the same resources. It has been observed that water is going to be scarce resource in the region especially under the long term impact of climate change and global warming (Bhattacharya and Mitra, 2012). Finally the Link 5 is all about transmission and distribution system in the region. Given the current T&D facilities available in the region, it is imperative, that massive up-gradation is required to facilitate the expected incremental flow of power in the network

2.3.2 Multi-point root-cause analysis of access to modern cooking energy

Access to modern cooking energy is one of the key targets under the SE4ALL. In the Developing Asia region access to modern cooking fuels especially LPG and electricity are very limited. The region is still depending heavily on solid fuels like biomass (fire woods/ cow dung etc) and very low grade coal. In 2010 it has been estimated that around 50% of the regional population is depending on solid fuels for cooking. Solid fuels are the sources of all sorts of local air pollutants including particulate matters, back-carbons etc. In the SE4ALL tracking framework it has been captured as a single point monitoring and improvement objective. However, given the condition of energy supply, demand and distribution system in the region, it is hardly possible to get success on improving percentage of population using modern energy for cooking unless the backward linkages are set properly. Though in Tire 5 monitoring technique it has been mentioned about advanced level of indicators but there is no such specific mention about the type and category of indicators required to be monitored.

In this study it has been explored different linkage points which need to be observed and monitored as well to ensure the success of the target. The objective is to identify the important parameters for monitoring to enhance the chance of achieving the target set under this major indicator in SE4ALL.

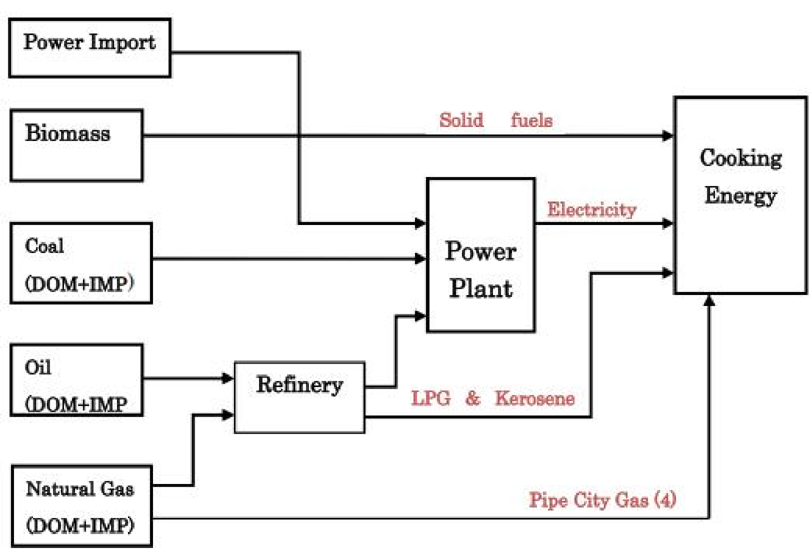

Figure 2.3: Backward linkages of non-solid cooking energy supply

In the context of improved non-solid fuel use in domestic cooking in the region, we have identified the major backward linkages in addition to biomass link. It is shown (Fig 2-3) in the figure above that to substitute 273 Mtoe of biomass energy in cooking and heating purposes in the region, electricity, liquid fuel and gas supply need to be enhanced significantly. Referring to the Asian Energy balance, we can say that electricity supply to domestic use (60 Mtoe) needs to be at least doubled and gas supply which is around 10 Mtoe now also needs to be increased by many folds to substitute even the half of solid fuel use in the region. As a matter of fact, achieving the target of non-solid fuel use in cooking sector needs substantial follow up in the sectors of alternative fuel supply as well. Use of non-solid fuel in cooking needs sufficient supply of electricity, LPG, Kerosene and pipe gas which can further displace biomass based cooking fuel. It is therefore, important to keep close watch on supply and demand situation of these fuels in the context of cooking energy supply.

2.3.3 Things to watch for enhance modern energy access in Developing Asia

Based on the above mentioned analysis for multipoint monitoring system for successful implementation of SE4ALL in the Developing Asia region, three important indicators have been identified by the author here for further monitoring and reporting. The indicators are:

a) Domestic energy resource availability
b) Robust power generation and transmission & distribution capacity
c) Energy supply security through energy trade

Domestic energy resource and reserve is a given condition to a country and the region as a whole. Human interference to improve the domestic resource and reserve is limited with the existing available technology. Improved technology in resource exploration and subsequent use of advanced technology in resource extraction can further enhance domestic resource availability by certain extent. However, developing the generation, transmission and distribution capacity within the region is one the most important actions to achieve the target of improved energy access. Therefore, developing a sustainable power supply system is an important task ahead and needs to be monitored in a regular basis. Sustainable power supply system incorporates long term planning of technology development and consideration of non-energy resources availability required for power generation as well. Capacity addition is fully controlled activity in the system compared to domestic resource availability which is uncontrolled variable for the regional energy supply system. The supply of energy can also be improved by systematic improvement in energy commodity trade either in terms of primary energy commodity (coal, oil, gas) or in terms of electricity via cross border grid interconnection.

2.3.4 Multi-point root-cause analysis of energy efficiency improvement

Energy efficiency improvement is one of the three major objectives set under the SE4ALL program. The primary objective of this target is to reduce the energy intensity to economic activities and primary energy consumption by the world. In the context of doing so, SE4ALL framework has identified and addressed the issues of multidimensionality of energy efficiency improvement, issues related to intensity and efficiency, valuing of energy in product development, issues of primary energy versus final energy and finally volatility of efficiency measures. In terms of dealing with these practical issues SE4ALL framework suggested to have two dimensional measures of energy intensity of emerging economies and energy efficiency of major energy industries. However, the issue still lies with the national scale energy intensity to GDP especially for the emerging economics where GDP is growing at a faster rate compared to energy consumption growth rate. As a result countries are showing declining energy intensity to GDP (EI/GDP) over the period of time. India for example (See Fig. 2-4) showing a declining rate of energy intensity to GDP since early 1990 compared to other countries (Bhattacharya, 2012).

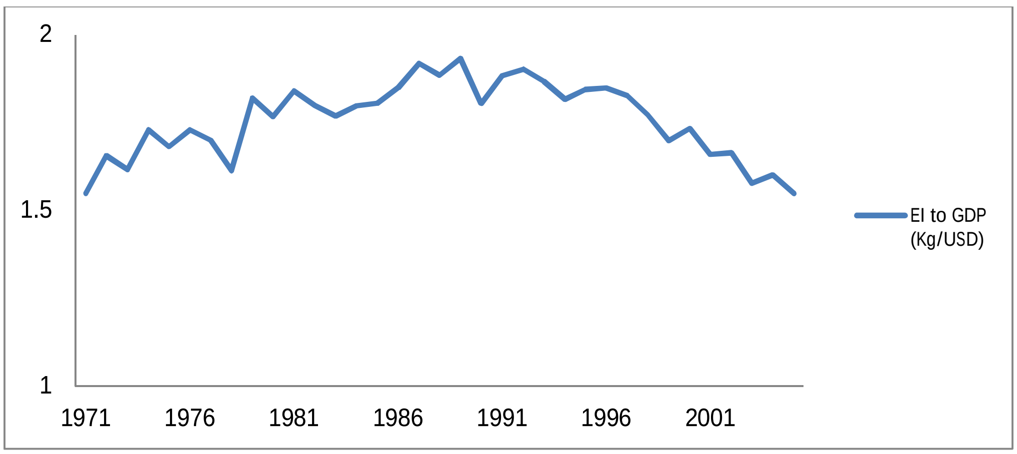

Figure 2.4: Historic emissions intensity of GDP in India

In terms of valuing the energy input in the product development, SE4ALL mainly focuses on the purchasing power parity measure to capture the value added economic output. In the context of primary and final energy consumption issues, the framework suggested tracking global energy intensity compared total primary energy supply and sectoral energy intensity to final energy consumption. Nevertheless, in the developing Asia region the market of energy efficiency also depends on two very important factors; technology and market condition. The following schematic diagram (Fig.2-5) shows the root causes or backward linkages of various factors under technology and market that are influencing the process of energy efficiency improvement in the region.

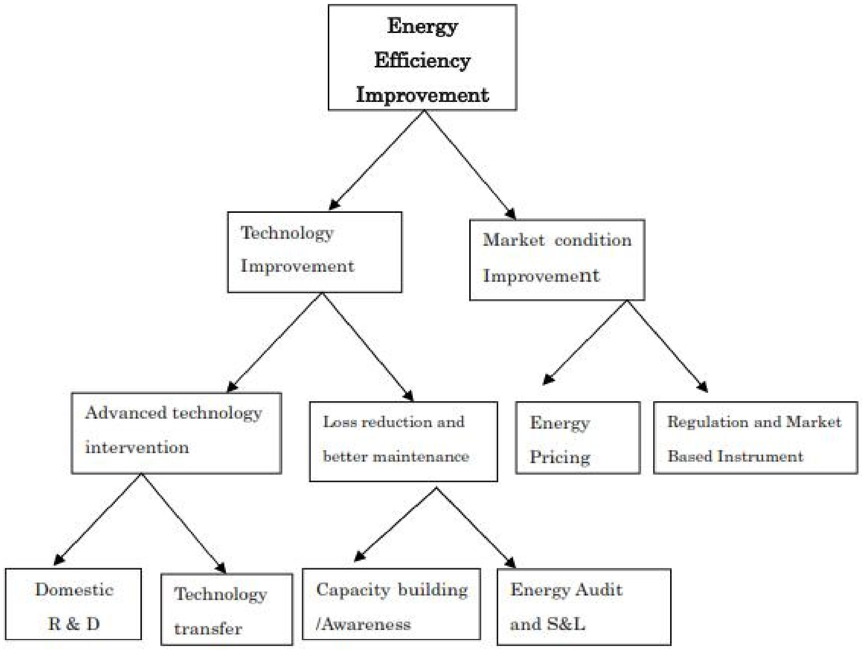

Figure 2.5: Backward linkages of energy efficiency improvement

Based on the root-cause analysis of energy efficiency improvement at a global scale it has been identified that there would be two main activities required to be monitored on a regular basis to improve the potentiality of achieving the target set under this pillar of objectives in SE4ALL.

First, the enhanced trade and collaboration in energy equipment trade in the region. Since the Developing Asia region is under-performing in terms of technology innovation and development, therefore, the region needs sufficient amount of intra and inter regional equipment and goods trade in the energy sector. This trade is envisaged to increase the use of advanced technology in the market and is envisaged to reduce energy consumption and subsequently energy intensity.

Second, the energy price reform and subsidy removal from the regional energy market. Developing Asia region as a whole is reeling under huge energy subsidy and underpricing of energy commodity in the market since last several decades. It has been observed that energy price reform in the region can help the region to have better supply of energy at no or low additional cost to the economy as a whole.

2.3.5 Multi-point root-cause analysis of renewable energy promotion

In the framework of SE4ALL, renewable energy is playing an important role. It has been envisaged that the program should promote renewable energy in the world so that its supply can be doubled by 2030 compared to the current level of supply percentage of RE to Total Final Energy Consumption.

It has been estimated that the Developing Asia region is having more than 30% of total final energy consumption as renewable. As a matter of fact, this ratio is far better than other developed regions of the world. Nevertheless, the main contribution of this renewable energy is coming from biomass use in cooking purpose which is otherwise a negative trait in the context of non-solid fuel based cooking system indicator in the SE4ALL framework. In the region out of 30% of renewable energy supply, around 25% is coming from biomass. In terms of electricity generation, total renewable energy based supply is around 14% of total power supply compared to 26% in Europe, 16% in North America, 56% in Latin America and 19% of World Average (Global Energy Assessment Report, 2013). This further indicates that the Developing Asia needs significant amount of power generation from renewable energy resources and needs to reduce direct use of biomass for cooking and heating purpose. Therefore, indicator of RE percentage use in Total Final Energy Consumption alone cannot serve the purpose of promoting renewable and green energy supply in the grid. The figure 2-6 below further elaborates the backward linkages of renewable energy sector which are required to be in place to have enhanced level of RE supply in the market.

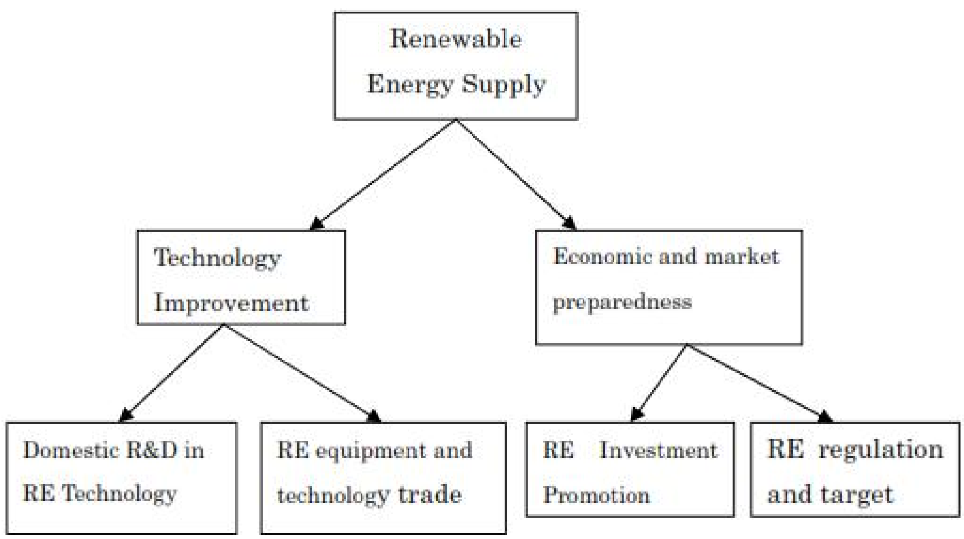

Figure 2.6: Backward linkages of renewable energy supply

Analyzing the root causes of renewable energy supply in the market, it has been identified that there are two major linkages that need to be in place for successful penetration renewable energy in the system. Easy access to renewable energy technology at a lower cost and market preparedness to deal with the special characteristics of renewable energy supply system are the two major issues to promote renewable energy supply mix in the world.

In terms of RE technology development, there are two important factors need to be considered: a) promotion of domestic research and development in new and renewable energy technology and b) promotion of renewable energy equipment trade and promotion. Domestic R&D is essential to develop a low cost indigenous RE supply technology and to develop distributed generation system for better and wider use of renewable energy. Similarly, RE equipment trade among the nations in the region can further enhance the access to new and advanced technology of RE power generation at a lower cost and with less time (Moinuddin and Bhattacharya, 2013).

In terms of RE economics and market preparedness, there are two important issues need to be considered in detail; a) promotion of renewable energy investment and b) creating regulatory and policy enabling environment to promote renewable energy generation and supply in the region. It has been observed that renewable energy sector investment globally follows a boom-bust cycle commensurate with the international oil price. The figure 2-7 below shows the correlation between oil price movement and corresponding year's investment in renewable energy technology.

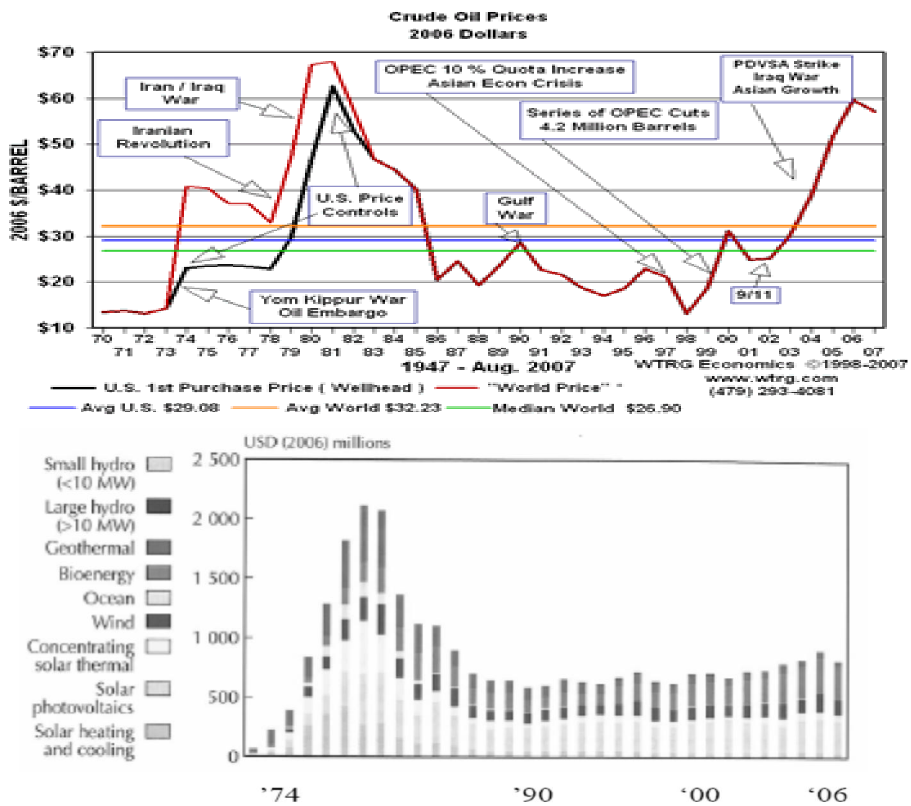

Figure 2.7: Renewable energy R&D budget compared to the crude oil price

Source: Adopted from Kobos et.al 2006 and Bhattahaya, 2010, IGES Policy Brief

Asian energy sector investors should think of an effective alternative to reduce the risk of international fossil fuel price fluctuation and its negative economic and financial consequences on the decision making process. Risk-covering financial instruments like forward contracts and options which sometimes account for half of the total supply cost often play a decisive role in investment planning in the highly price-sensitive energy market. Risk explicit cost benefit analysis of the power sector investments can influence the investors in favor of renewable energies even though they are apparently more expensive than the conventional sources.

In terms of promoting renewable energy in the market, a steady and consistent policy and regulatory environment is required. It has been observed that in the Developing Asia region renewable energy related regulations and policies are not steady and changes frequently based on changes in government priority and international energy price movement.

2.4 Goals and objectives of the thesis

Analyzing the existing situation of the Developing Asia region in terms of its economic, social, environmental followed by the overall human development status, it has been understood that developmental inequality is the root of all troubles in the region. Such inequalities are observed in economic condition including availability of finance, in social condition in terms of widening development gaps covering issues like health, education, sanitation and livelihood etc. Given the observed and established positive correlation between human development and use of modern energy (Amie Gaye, 2007), the goal of this thesis is to contribute to the process of narrowing the development gaps, reducing the developmental inequality in the Developing Asia region by enhancing the potentiality of the success of SE4ALL. We believe that the success of SE4ALL can eradicate poverty at large and can bring parity in development across the world.

Based on our understanding and analysis of the existing framework of SE4ALL and the lessons learned from other international development initiatives like the Millennium Development Goal, we propose certain complementary and additional analysis of the existing framework and its related monitoring activities of the set targets under the SE4ALL program in the region. The proposed set of additional monitoring indicators are envisaged to improve the potentiality of the achieving the overall targets and goals of SE4ALL. These additional indicators are indentified based on integrated assessment of multiple resources availability, constraints and their impacts on economy, society and environment to determine the progress of the corresponding indicator. Instead of single point monitoring of the indicator the improvement suggests to have multi-point monitoring based on its root-cause linkages.

We have discussed various aspects of energy as a vital input resource for Asian economic, social and environmental development in a long term manner. One of the biggest advantages of Asian developing economies is, it still have the opportunity to have sustainable energy planning for its balanced growth. Energy sector characteristically has very long technology and investment lock in period. As a result, the sector is quite rigid in terms of introducing any new change. Since Asia needs investment and growth in energy sector, therefore, opportunity is still there for making it sustainable in nature. Given the fact of relative advantages of investment flexibility, we have discussed how Asian economies can introduce policy changes in the areas like energy pricing, energy infrastructure development and also in renewable energy sector for a sustainable energy policy which can support economic and social development and can protect environmental degradation as well. No growth can sustain without considering society and surrounding environment into consideration. Therefore, conventional growth pattern mainly followed by the developed economies over the last couple of centuries are in serious threat which ignored society and environment in large. Finally, this thesis aims to provide an additional set of indicators to monitor and to enhance the potentiality of the success of the program of SE4ALL which are based on robust analytical framework of multi-resource and multi-factor analysis for balanced growth and development in Asia.

Asian developing countries are currently reeling under the problems of lack of analytical tool of their own and demonstration of good practices and results of using those tools for implementable policy development. Hence, the thesis deals with two main objectives: First, identification of required tools for analytical investigation of the complex issues of interlinkages between energy, economy, society and environment and second, how those tools can be used for developing implementable policy recommendations for the region under the overarching umbrella program of SE4ALL.

2.5 Description of the models used

Given the objectives and goal of the thesis we have not only identified the potentially important indicators to be measured and monitored but also demonstrated the impacts of these indicators on economy, society and environment if they do not perform well or do perform well. While developing these demonstration analyses, we have used four different models. First, the Bottom-up energy systems analysis model; second, the Top-down macroeconomic model based on computable general equilibrium framework; third, an econometric model and fourth, a risk analysis model. In the following section we descried the generic structure of each of the models used in this thesis in detail. Nevertheless, each paper specific model details are described in their respective chapters with further detail relevant for that particular study.

a) Bottom-up energy system model: Bottom-up energy models are traditionally technology-driven. It treats energy demand as either given, for example expressed as useful energy demand, or as a function of, for example, energy prices and national income. While the model considers price of energy in the system, it ideally becomes a partial equilibrium model. It indicates that in the model only energy sector of the economy gets balanced in terms of its supply and demand. Energy demand is satisfied by varieties of supply and distribution technologies. Technology change occurs through replacement of existing technology by new technologies if these have better cost performance. Technology change is thus explicitly described in the bottom-up model (NEP, 2012). Here we have used the energy supply model MESSAGE (Model for Energy Supply Systems And their General Environmental impact) which is a dynamic linear programming (DLP) model minimizes total discounted costs of energy supply over a given time horizon. The main purpose of the model is to balance supply and demand of energy in an equilibrium market condition. Model balancing happens at the secondary energy level (electricity supply) through primary energy supply and use of multiple energy technologies. The balancing of the model gets constrained by the important factors like built-rate of different type of energy technologies in the market, domestic and imported energy supply status and technological prospect in terms of efficiency improvement rate in the market. Major features of the model are: a) disaggregation of the time span of energy supply in various load regions for electricity demand, b) disaggregation of resources into different cost categories, and c) consideration of the environmental impact of energy supply strategies. The model output is used to describe scenarios of energy supply and corresponding demand pattern. The energy flows give a consistent picture of the supply/demand balance; and the shadow prices allow for an assessment of the incremental benefit of additional resources, the incremental benefit of new technologies, and the marginal costs of meeting additional demand. The environmental module may be used to model the influence of emission or concentration standards (upper limits) on the model solution (Schrattenholzer, 1981). The water module can also be used to model the influence of water availability constraint by putting the upper bound of water availability per technology basis or as a total water supply to the energy sector.

b) Top-down macroeconomic model: Top down macroeconomic models are mainly computable general equilibrium (CGE) models which try to include the entire economy in which the energy system is a part. The main feature of CGE models is that all markets for goods and services in the economy are in equilibrium and that supply and demand for a certain market is affected by all other markets. CGE models may be static or dynamic with respect to time. Demand and supply are the result of utility-maximization of consumers and profit-maximization of the producers. In the market demand gets cleared by the supply through market clearing prices. Since all markets are in a state of equilibrium, real-life disequilibria such as underemployment and current account imbalance are not captured in the model. This model also considers the zero profit condition of the market as well.

2.6 Major databases used and data validity

In the thesis we have used two major databases for the Top Down and Bottom-up models respectively. For CGE based analysis we have used the GTAP Version 7 database published by the Purdue University. This is a global multiregional database developed under the project called Global Trade Analysis Project established in 1992. The GTAP database comprises of detailed bilateral trade transport and protection data characterizing economic linkages among regions, together with individual country input-output data bases which account for inter-sectoral linkages within regions. The database has 57 sector of economic activities with 113 region.

Agricultural production data for the OECD countries are mainly taken from the EUROSTAT and I-O Table for EU27. Non OECD country data are taken from individual country sources. Macroeconomic data on GDP, domestic and external consumption, savings, reserves and investments are taken from the World Bank database at 2004 base year. Trade related data is taken from the sources like OECD statistics and IMF global economic databases. USDA database like COMTRADE is also being used for trade data base preparation. For trade protection data especially import and export tariffs and subsidies, GTAP Ver7 mainly depends on the OECD statistics for EU and other OECD member countries and for the developing countries to individual researchers. Similar to the GTAP 6 Data Base, the 2004 tariff data in the GTAP 7 Data Base is based on the Market Access Maps (MAcMapHS6) contributed by David Laborde. The MAcMap data base is compiled by ITC and CEPII from UNCTAD TRAINS data, country notifications to the WTO, AMAD, and from national customs information. In GTAP version 7, the 2004 IEA energy volume data has been incorporated and the energy prices for the year 2004 have been updated using price indices and exchange rates (GTAP Ver.7.0 Manual).

In terms of data quality and validity for GTAP Ver 7, it has been mentioned by the developer that highest priority is given to the quality of data. Data have been verified and validated by cross checking the same data from different sources and by peer reviewed by the national and international experts in the same sector. EU, US and other OECD country data are more or less validated by the data providers. The issues of quality is mainly with the data from developing and least developed countries. GTAP database heavily replies on country experts and continuous updating of data on subsequent versions. GTAP therefore, keep updating their database on a regular basis. Finally, this database is one of the most reliable database in the world for Multi regional Input Output Model.

The other major database referred and used in this thesis is the Global Energy Assessment database developed by the International Institute for Applied Systems Analysis based in Vienna in 2012. GEA Scenario Database identifies the options for global as well as regional energy transformation towards the sustainable development ensuring access to modern energy, use of more renewable energy and moving towards energy efficient world while fulfilling the normative goals of reducing air pollution, enhancing energy security and combating climate change. The whole transformation is based upon feasibility of energy supply in reliable manner and cost of energy which are the primary driving factors in today's world. The GEA database includes detailed quantitative information for 41 pathways that fulfil these objectives.

Moving from these objectives to a specific pathway the GEA distinguishes three critical levels with major implications for the nature and direction of the energy transformation. The first level describes alternative levels of energy demand and efficiency improvements, and leads to distinct pathway groups of low, high and intermediate demand (GEA-Efficiency, GEA-Supply and GEA-Mix respectively). The second level of classification in the database explores alternative transformations on the supply-side with the main aim to test the flexibility of different supply-side configurations to fulfil the GEA sustainability objectives. The third level of classification in the database incorporated in the transportation sector to investigate the impacts of fuel shifting, efficiency improvement in transportation system and also use of hydrogen fuels. Figure 2.8 below describes the structure of the GEA database. Here we have used the GEA Mix pathway where the energy supply transformation and energy efficiency improvement targets are set moderate for the world to achieve the sustainable development target. The GEA database has 11 regions covering the entire world (IIASA, 2012).

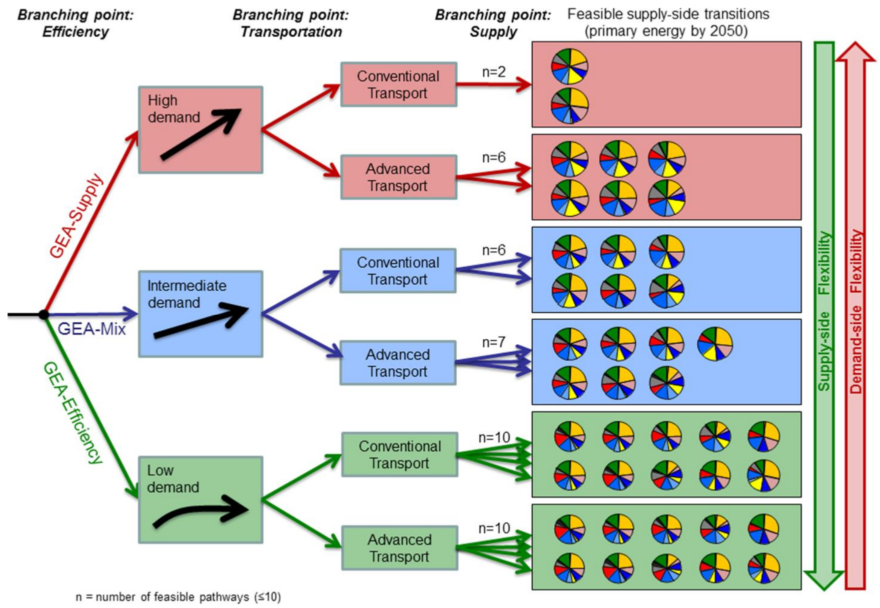

Figure 2.8: GEA Database structure and classification

2.7 Structure of the thesis

Chapter two describes the detail structure of the proposed improved analytical framework which is based on the principle of integrated assessment of resources and multi criteria based decision support mechanism. It is assumed that the success of SE4ALL improves where all of its structural components are interlinked. Figure 2.9 below depicts the fundamental principles of integrated assessment followed in this thesis document

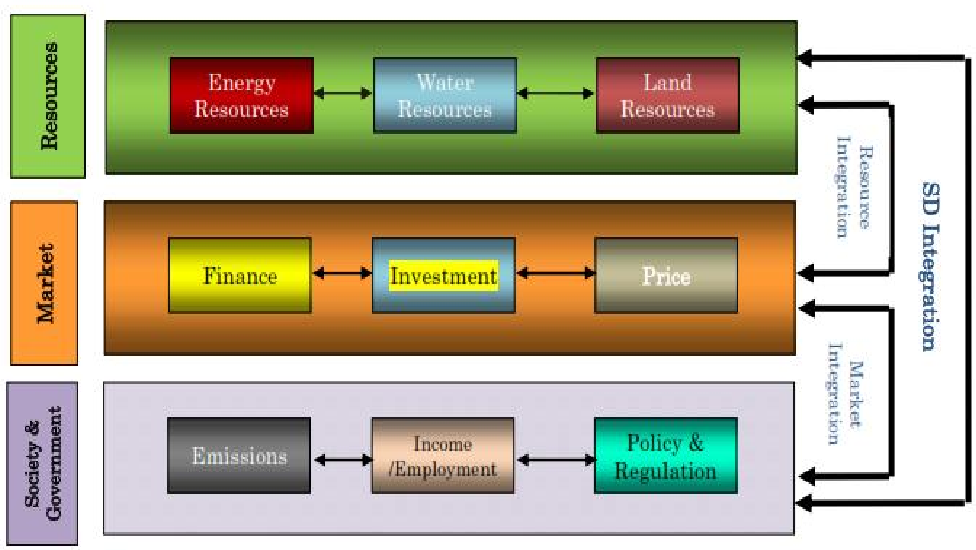

Figure 2.9: Schematic outline of thesis concept

In chapter three, we discuss the issues of resource constraint in the context of long term sustainable energy scenario development for Asia. It is in general assumed that all other natural resources like water will be available with required amount for energy production and generation as long as we need. However, it is now evident that water is becoming more and more scares under the influence of rapid population growth, urbanization and increasing agricultural activities. Climate change is also expected to create impact on water availability especially in a seasonal term. As a matter of fact, water resource constraint may affect the long term energy scenario in Asia and its subsequent use for other development purposes. This chapter highlights the importance of multi-resource integrated assessment to develop policy for sustainable energy for all.

Chapter four discusses the issue of regional energy commodity trade and cooperation to improve energy supply and demand situation to strike balance between affordability, reliability and efficiency of energy use for sustainable development. In the given complexity of energy systems, natural distribution of resources and scattered demand, regional cross border cooperation in energy sector is essential for sustainable development. Importance of seamless energy commodity trade under the liberalized trade environment is important to achieve the target of sustainable energy for all.

Chapter five deals with the issues of energy subsidy and how removal of subsidy can contribute to sustainable development. At the beginning the chapter discusses about the methodological issue of determining net subsidy amount for each energy commodity in the macroeconomic framework and then demonstrates how to use a general equilibrium modeling framework to analyse energy price reform which can bring economic, social and environmental benefits to the countries.

Chapter six deals with the issues of renewable energy equipment trade and regional cooperation in terms of improving renewable energy supply in the market. This chapter first analyses the factors that affect the trading of renewable energy equipment in the regional market and how finally describes how this trade improvement can support the objective of SE4ALL in terms of supplying renewable energy in the network.

The chapter seven discusses a new concept of identification of energy supply portfolio from the investment risk perspective. It has been identified that promotion of renewable energy in the supply mix is subject to investor's decision to investment in green energy. Apart from other enabling environment including national and international policies to promote renewable energy, investor also needs to understand the comparative benefits of investment in renewable energy sector over conventional sector.

Finally, the chapter eight finally concludes and recommends the additional tracking indicators required to enhance the potentiality of successful achievement of the set targets of SE4ALL in the developing Asia region. The chapter describes the mechanism of synthesizing the outputs of seven different indicators of sustainable energy for all in an inclusive manner and to derive certain informed decision making indicators to track the progress of SE4ALL within given timeframe.

2.7.1 Uniqueness of the proposed improvements of the framework

Thus, the purpose of this thesis is to enhance the potentiality of achieving the targets set under the SE4ALL program by proving certain additional measuring indicators and the methodology to use them in the context of Developing Asian. There is a lack of systematic investigation framework of the critical factors of the energy sector development including energy pricing, resource constraint and selection of energy supply portfolio in the region. This work attempts to fill that gap of analytical framework with an integrated assessment tool with all necessary documentary evidences. Standard energy policy development deals with only the sectoral information but given the increasing complexity of the sector and its inter relationship with other sectors, it is important to have certain advanced analytical framework for energy sector which can take care of the issues like multi resources conflicts, maintaining uninterrupted investment flow in the sector, considering the impacts on environment etc. There is no single methodology available so far to conduct such massively complex analysis. Thus, the thesis attempts to bring number of necessary analytical tools and methodologies available under one common goal of increasing the potentiality of achieving the targets set for SE4ALL program.

Chapter 3

Sustainable Electricity Supply under Resource Constrained Condition[2]

3. Introduction

Asia is the driest continent in the world in terms of availability of freshwater. It is less than half of the global annual average of 6,380 cubic meters per inhabitant. The region also has less than one-tenth of the total water available in South America, Australia and New Zealand, less than one-fourth of North America, almost one-third of Europe, and moderately less than Africa per inhabitant. It has been estimated that by 2030 the word will face nearly 40% of supply shortage of water to meet the demand (WRG, 2010). In India total water demand will increase by 100% (750 BCM) and in China it will be around 200 BCM by 2030. 25% of the earth's surface is under severe water stress. Approximately 2.1 billion people live in the water stressed river basins and 50% of them live in South Asia and China (WRG, 2010).

Needless to say, the problem is even more acute in water-stressed countries like India. Table 3-1 shows the projected ratio of water used for power generation to total utilisable water[3].

Table 3-1: Projected ratio of electricity sector water use to the total utilisable water in India

Year	Projected ratio
2010	4%
2025	9%
2050	20%

Source: Authors' estimates (Bhattacharya and Mitra 2012).

Table 3.1 indicates that the ratio of water use for power generation is rapidly increasing over the period of time. Considering the fact that water constraints pose a severe threat to agricultural production in India, the very high projected ratio of electricity sector to water use implies there is a critical trade-off among various water uses (in particular food versus energy). This

[2] Chapter source: Bhattacharya, Anindya and Mitra, Bijon. 2013. *Water Availability for Sustainable Energy Policy: Assessing Cases in South and South East Asia*. Institute for Global Environmental Strategies Research report 2013-01. ISBN 978-4-88788-139-6. Hayama, Japan.

[3] In the countries like India where majority of electricity is generated from thermal sources (coal, oil, gas etc) water is used for thermal cooling in cooling towers. Consumption of water mainly happens due to evaporation of water in the cooling towers. Percentage of water use in power sector compared to the total utilizable water in India is mainly derived using the consumptive water demand in Indian thermal power generation.

trade-off underlines the necessity of long term energy planning that integrates water for India to avoid a severe water crisis in the next couple of decades. However, as shown in Figure 3.1, planning for power plant installation in India is currently done without considering water availability. If this continues, the majority of the future power plants will be built in water scarce regions in India.

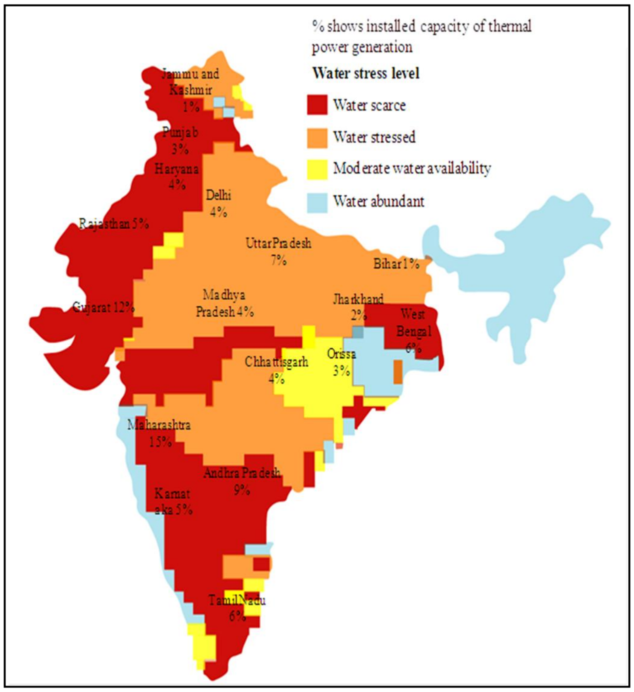

Figure 3.1: India's existing thermal power plant

It has been observed by the authors that the major drivers of future water demand in this region are rapid demographic change (high population growth, rapid urbanization and shift in living standard), economic growth and climate variability. Water demand in domestic sector is expected to grow at an annual rate of 2% until 2025 and water withdrawal rate will be around 11% per annum. Agriculture demand for water will increase at the rate of 0.8% per annum whereas industrial demand is expected to grow at rate of 4% per annum until 2025 (NCIWRD, 2006).[4].

This chapter is focused on Indian case in terms of developing the rationale, methodology and conducting scenario simulation because India is the largest country in the Developing Asia region excluding China. Given the economic and social growth prospect of India along with its huge long term energy demand, country's precarious water availability situation further corroborates the needs of conducting case study on India to demonstrate the importance of resource constraint in terms of sustainable electricity supply in the region.

[4] For further detail please refer to the document: http://www.unicef.org/india/Final_Report.pdf

3.1 Rationale and objectives

Sectoral demand for water including power sector by the year 2050 is expected to exceed the available water resources in India. Under a situation of water stress, given the priority for agricultural and domestic sector over industrial water usage, as mentioned in the national water policy, the industrial sector (including power) may face water availability issues. Spatial and temporal distributions in water availability may further aggravate the situation. In the context of having uninterrupted and sufficient amount of power supply in the grid which can ensure improved access to electricity and can ensure gradual decrease in percentage of population using solid fuel for cooking, an integrated planning for power sector development is necessary. Given the increasing water scarcity in the country, water is envisaged to be a challenge for new and existing thermal power plants in India to produce sufficient power. Therefore, this chapter examines the implication of water resource constraint in the context of sustainable electricity generation in India and how this findings can be further incorporated in the framework of SE4ALL tracking and monitoring.

Water use priority primarily lies with human consumption and agricultural use in the developing Asia region where population is high and agriculture is basis of economy. In India over last couple of National Water Policies (1987 and 2002) the water use priorities were set like human consumption (drinking water), irrigation for food production, hydro power for energy, environment and ecological use and finally industrial and navigational use. Nevertheless, in 2012 Water Policy a drastic change has been introduced in the policy by removing the ranking of priority of different water users. However, it is mentioned that safe drinking water is a pre-emptive need for mankind and cannot be given away. The new policy also introduced the concept of valuing water as an factor input for economic activities and suggested that it should be used based on its marginal value in different sectroal use. This further indicates flexible priority of water use which would be determined on a case by case basis. Departure from conventional fixed priority ranking policy thus ushers the further investigation of all sectroal use of water in greater detail to estimate its demand and cost. This chapter is therefore, contributing to that process of evaluating the demand for water in the energy sector and its mitigation actions and corresponding economic costs.

The Indian power sector is expected to grow from 231 GW to 350-887 GW from 2012 to 2050 (CEA, 2012). Indian power sector is heavily dependent on coal and gas based thermal power plants and is expected to continue to rely on fossil fuels significantly. Fossil fuel based power generation is water intensive. Therefore there is a need to assess the water requirement for thermal power plants over a long term and the policy implications on account of water stress on thermal energy generation. While negative impact of climate change on water resources is expected, water demand will increase exponentially to ensure drinking water for food security for people and to fuel economic growth. As per current statistics of Department of Water Resources, cumulative water demand of domestic, agriculture, and industry is 57 BCM, which indicated water shortage situation as per current water demand and utilizable water storage. Department of Water Resource, Govt. of India estimate showed that water demand will rise to 80 BCM by 2025 (CWC,2010) .

Therefore, main objectives of this chapter are

(i) Establishing resource link between water and energy at the supply side of energy under the framework of energy systems of a country
(ii) Demonstrating the importance of water-energy integrated assessment in energy planning for sustainable development
(iii) Demonstrating the effects of the water availability on long term energy scenario development and subsequent impacts on energy technology choice.
(iv) Updating existing monitoring framework of SE4ALL with resource constraint tracking to ensure sustainable supply of electricity to improve access to electricity and modern source of energy for cooking.

3.2 Methodology

Given the objectives of this chapter, we use three different types of assessment models: i) energy systems model, ii) climate forecasting model (circulation model) and iii) hydrological model. Though the general purposes of these models are different in nature but they are used in a synchronized manner to obtain an integrated assessment output. However, in this chapter three models are not endogenously integrated rather manually fed to each other.

3.2.1 Description of MESSAGE model and water demand assessment for energy sector

Besides, different model integration another major methodological advanced has been made in this chapter in terms of integrating water assessment module to the energy systems model. So far there is no global energy systems model available which can endogenously determine the water demand for the entire energy system. In this chapter it was the first methodological challenge which we overcome by developing a water module for the MESSAGE Model (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) developed by Messner and Strubegger, in 1995. MESSAGE is a multi-region energy system model capable of estimating the least cost supply option of energy in a long term manner under different constraints including climate, resource and costs. In the process of estimating the water demand exclusively for energy supply in the system, we used a newly developed water module synchronized with the rest of the model. This module endogenously determines the total water demand for total energy that needs to be supplied to the system under the optimal condition. For each energy technology that needs water, a unique water use coefficient is assigned in the model which internally interacts with the corresponding technological output in terms of energy unit and derives the total water demand for that particular technology in the system. Finally, each technology based water demand gets aggregated over the period of time (here we derived water demand on an annual basis). For water demand assessment we used water use coefficient for each eligible technology and data has been collected from power plant survey in the country. Figure 3-2 below shows the schematic diagram of the MESSAGE-Water model that is the basis of our Water-Energy Nexus assessment.

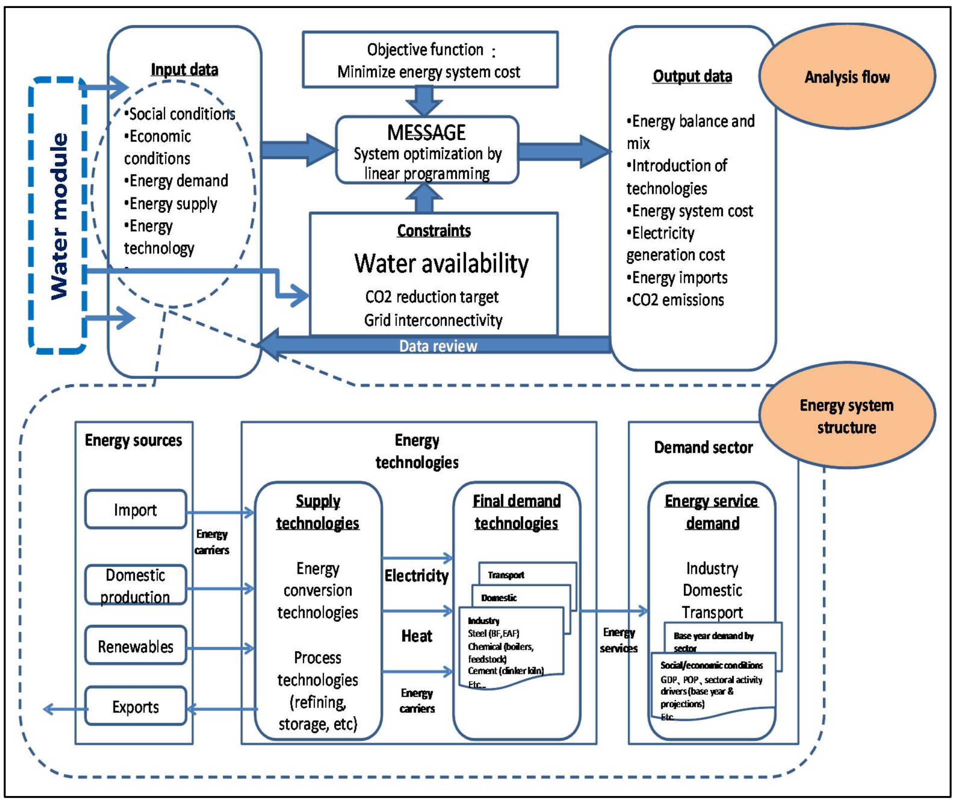

Figure-3.2: Schematic diagram of MESSAGE Model with water module

3.2.2 Integrated use of downscaled climate model and hydrological model

In the context of estimating long term water availability in the region we used two different models i.e global circulation model and hydrological model respectively. The main purpose of adopting two models is to estimate the impacts of climate variation on long term surface water availability which is the major source for energy production. Based on the regional performance and acceptance of Global Circulation Models (GCMs), climate change projections were obtained from ECHAM4. ECHAM4 was used by several regional level and river basin level studies in Southeast Asia

(Chinvanno , 2009; Sharma et al., 2007; Khattak et al., 2011). The most popular two SRES scenarios A2 and B2 were chosen for this chapter. Figure 3-3 below shows the schematic diagram of the flow of the modeling analysis of water demand assessment.

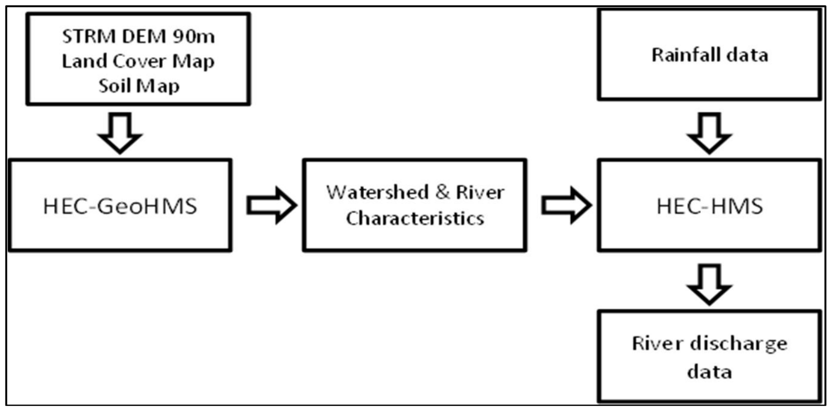

Figure 3.3: Flow chart of water availability assessment exercise

3.2.3 Activity sequence

There are four major steps used to complete the entire quantitative assessment part of in this chapter.

In the first step, we identified the list of all energy technologies use water as one input for process activities. We mainly identified around 70 different energy technologies those are in use in the entire energy systems in this region. This covers the technologies from energy extraction, refining and use. Power generating technologies are given priority here as they are the major water consumers in the South and South East Asia region. Our next task was to estimate the water use coefficients for each selected energy technologies. Here we only considered how much water is withdrawn from the source for energy extraction, refining and conversion (electricity generation). The major problem was region specific data availability. The only source of secondary data was available with Department of Energy, USA based on US power plant and energy sector. To overcome this problem, we conducted power plant survey in India and Thailand both and collected water use data which finally converted to model usable water coefficients.

In the second step, we develop the water module for the MESSAGE global model and running the reference scenario of energy systems to estimate the base water demand.

The third step, is to estimate the long term water availability for energy sector. There is hardly any projection available from a reliable source on energy sector's water demand in the future. The major classifications of water demand categories are agricultural, residential and industrial. In most of the cases energy sector is aggregated under either industrial category or agricultural demand category. In this chapter we first conducted survey for water demand assessment for different sectors and then performed certain statistical analysis using our model determined water demand estimate for energy sector to disaggregate the water demand among energy sector and agricultural sector or industrial sector. The output of this stage is long term water availability for energy sector in the chapter region. As we are also observing the impacts of climate change on water availability, it is assumed that climate change will create some impact on water available energy generation in the future too. Therefore, we conducted the hydrological simulation of net utilizable water in the chapter region under no climate impact, IPCC A2 and IPCC B2 scenarios. However, this assessment we could do only for Thailand at this moment due to time shortage. For India we used pure statistical method to project the energy sectors' water availability until 2050.

In the last step, of this assessment, we used these water availability constraints to estimate impacts on long term energy scenario in the region in terms of technology variation, investment pattern and environmental issues. We also investigated the required options to mitigate the water shortage problem in the region. Figure 3-4 below describes the steps of analysis in sequential manner.

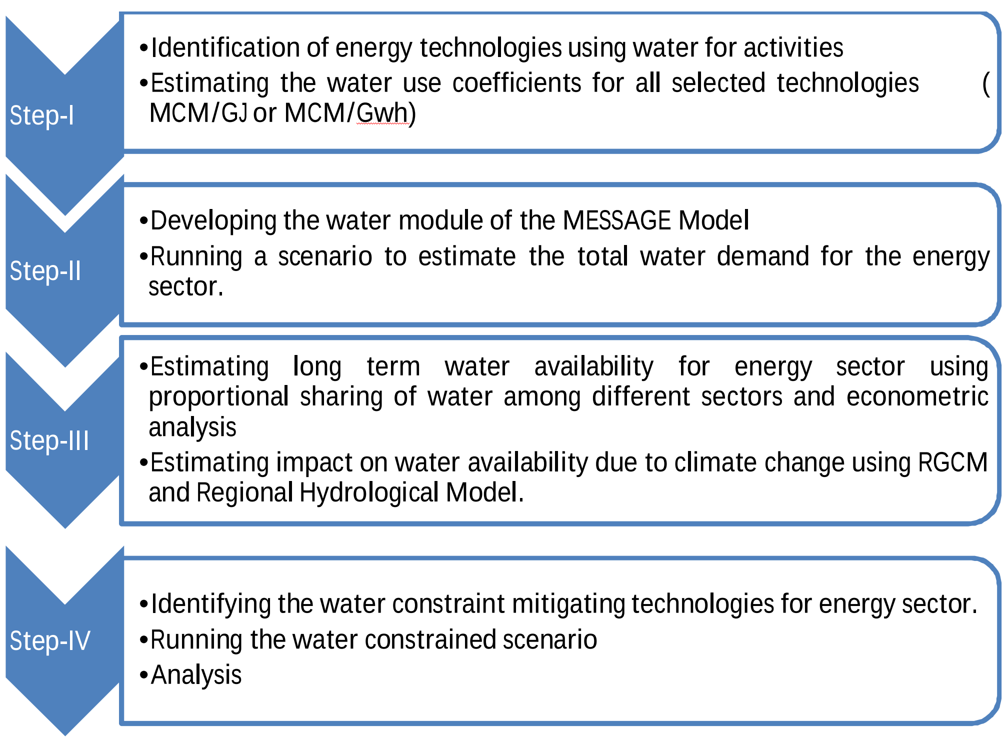

Figure 3.4: Steps of analysis

The following diagram (Figure 3-5) shows how this integrated assessment model is developed and linked to each other.

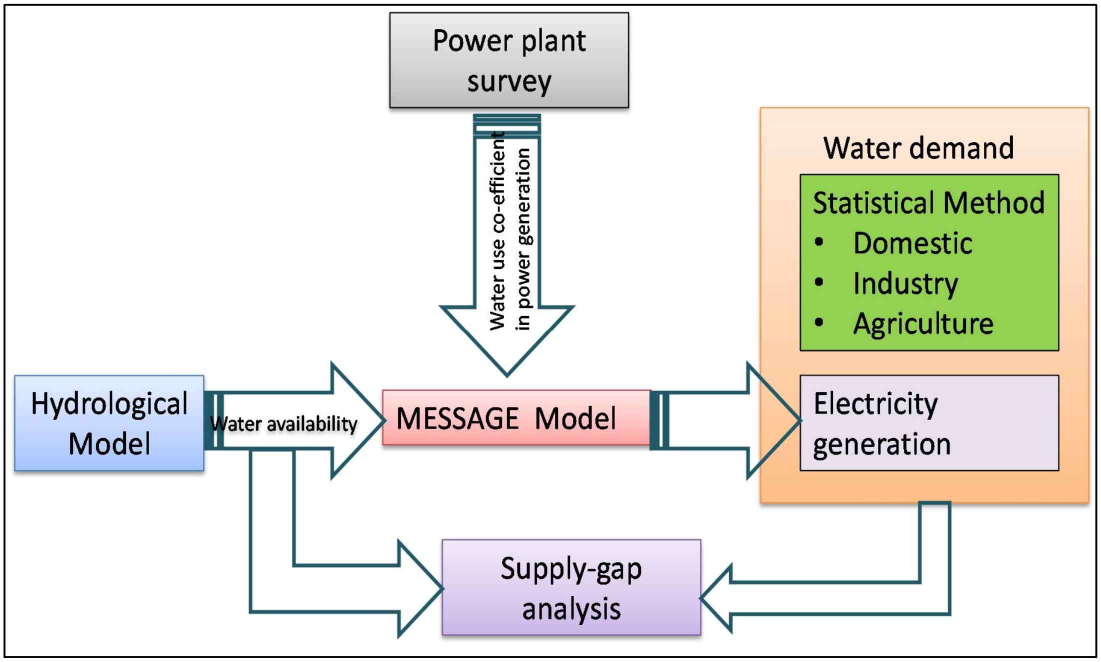

Figure -3.5: Linkages of different models and tools used in this chapter

3.3 Water requirement for primary energy production

Water is needed throughout the energy sector. The water requirements for producing the different primary energy carriers vary; also, there are significant differences between the different types of electricity generation. However, freshwater is required for each step—energy extraction and production, refining and processing, transportation and storage, and electric-power generation itself. Water consumption in primary energy production varies from fuel to fuel whether it is fossil fuel or renewable. More or less, all types of energy production need water at some point of its production cycle. In the following section we will briefly describe about the water foot prints of commonly used energy commodities like crude oil, natural gas, coal and biomass. However, as biomass consists of food and other agricultural residue which has other than energy utilization, it is very complicated to attribute the water demand exclusively for energy production from biomass. As a result, we avoided using the water footprint of biomass as primary energy source. The Table 3-2 below shows the global average of water coefficient of per unit of energy generation from crude oil, natural gas and coal. However, there are now new set of fossil fuels which are promising in the 2050 horizon like shale oil, shale gas etc. but with high water demand. Here in our study region there is no such proven reserve found of such non-conventional fossil fuels and thus we did not include them in our estimation of water demand for energy production in the region.

Table 3-2: Water requirement for primary energy production in Asia

Fuel Type	Water requirement (BCM/EJ)
Crude Oil production	1.058
Natural gas production	0.109
Coal production	0.164

Source: Compiled from Water for Energy Report , WEC, 2010

Based on long term energy supply requirement projection it has been estimated by the authors that in the South Asia region (mainly India) total water required for primary energy production and supply is around 75 BCM per annum by 2050. Figure 3-6 below shows the total water requirement for this region to produce primary energy.

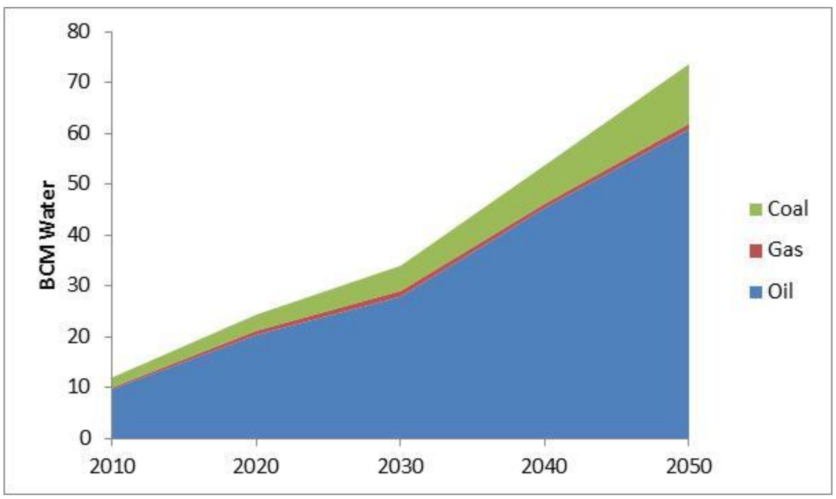

Figure 3.6: Water demand in South Asia for primary energy production

3.4 Water requirement in thermal power plant

The water requirement in power plants depends on the type of technology employed for power generation, type of cooling systems employed, quality of raw water, quality of coal and ash disposal system. The typical power plant water requirements for coal based thermal power plant can be broadly divided into following categories

a) Cooling water – Cooling water is required for condensing steam in the condenser to convert steam back to water. The cooling water has other applications in the thermal power station including (1) cooling water for heat exchanger and (2) cooling water for auxiliary equipment.

b) DM makeup – DM water makeup represents the water that is lost due to blow down. The water rejects from DM plant can be used for applications such as dust suppression.

c) Evaporation from reservoir – Reservoir is created to store water for use in power plant. Evaporation rate from reservoir depends upon the ambient conditions and the surface area.

d) Effluent discharge

e) Ash handling in case of coal based power plants – The burning of coal results in bottom ash and fly ash generated by coal based power plants. Fly ash and bottom ash are transported to ash pond by using wet slurry system where water is required.

f) Coal dust suppression in case of coal based power plants – Water is used for coal dust suppression at crushing areas and belt conveyers.

The schematic (Figure 3-7) of water consumption by a typical 2 x 500 MW coal based thermal power plant is provided in figure below. The water intake for power plants can be broadly divided into two categories - cooling requirement and power cycle requirement.

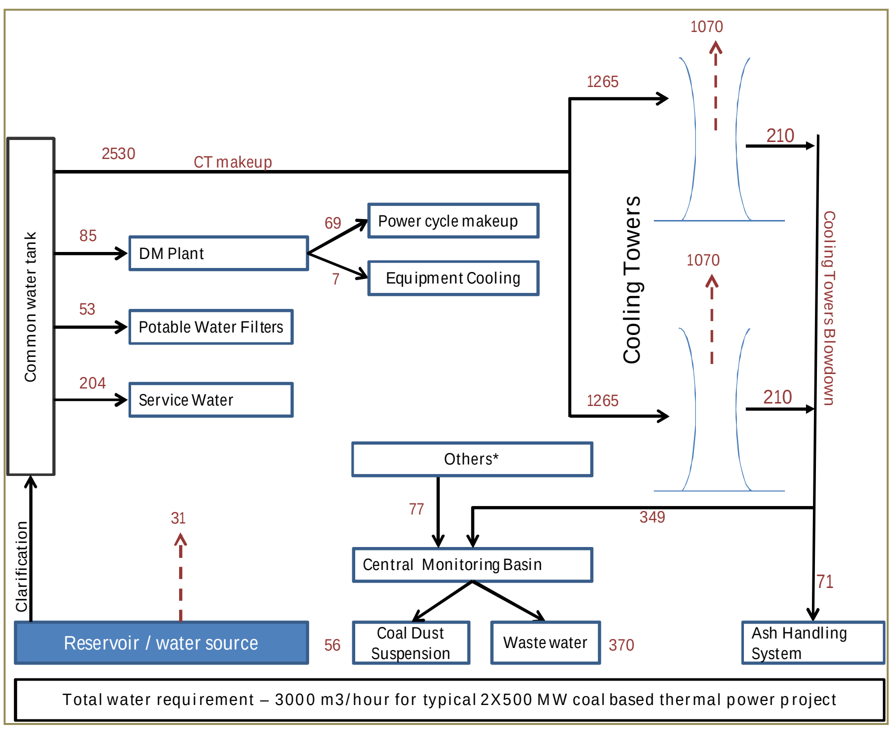

Figure 3.7: Water requirement in a typical 2 x 500 MW coal based thermal power plant

3.5 Impact of water constraint on long term energy supply

Eighty per cent of geographical area in India currently faces varying degree of water stress or scarcity according to a commonly used water stress indicator developed by Falkenmark[5]. Rapid urbanisation, agriculture growth and industrial development will put further stress on the water resources. Irrigation has an 85% share in the total water consumption in India. While water requirement for thermal power generation currently constitutes 1% - 2% of the total water requirement, thermal power generation is critically dependent on water for operations. Water is a key resource for thermal power generation and instances of thermal power plant shut down caused by lack of availability of cooling water are being reported6.

With the growth in thermal power generation, its share in water requirement is expected to rapidly increase. Thermal power capacity has increased by more than 75% in the last decade and is expected to grow by a further 90% in the coming decade. Current planning and approval process of thermal power plants do not appear to take into account long-term water availability and competing water uses of its water source. This poses a potential risk to power plant operations in the medium to long term, especially if they are located in the river basins that face water stress or water scarcity. Further, the draft National Water Policy 2012 prioritizes7 water allocation to domestic and irrigation sector over industrial / power generation. If a situation of water conflict arises, thermal power plant operations may be at risk if the water resources are diverted to higher priority sectors.

In order to ensure that the country's electricity needs do not come into conflict with the irrigation and domestic water needs, an assessment of the water availability related risk to future thermal power plants needs to be made at the river basin level. The statistics on national level water availability and requirements mask the regional differences that in turn are critical to understand in the effect of water stress on thermal power plants.

The technical life of thermal power plants is 15 years (for gas based power plants) to 25 years (for coal power plants)[8]. With renovation and modernization, the technical life can be further extended by another 15 to 20 years. Generation planning decisions taken today will lock in the fuel, technology and location of the thermal power plants for the next 30 – 40 years. Therefore, it is important to understand and analyze the policy implications of such decisions in the context of water stress. For this chapter, the reference year of 2050 has been chosen considering the 30 – 40 year time horizon so that policy decisions relating to setting up of new thermal power plants taken

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[5] Falkenmark water stress indicator views the water issue from a per capita availability perspective (Falkenmark 1989)

[6] http://www.unepfi.org/fileadmin/publications/water/chief_liquidity2-3India.pdf

[7] http://www.ndtv.com/article/india/maharashtra-parli-power-plant-shuts-down-after-severe-water-crisis-331952

[8] Maharashtra state water policy prioritizes industrial water requirement higher than irrigation water requirement.

today can mitigate water related risks by the year 2050. This chapter estimates thermal power capacity additions up to reference year (2050). It assesses water scarcity at the river basin level up to 2050 and evaluates the thermal power capacity that can be at risk based on forecasted geographical distribution of thermal power plants. It examines some of the key business drivers of cooling technologies and concludes with recommendations for de-risking thermal power plants from water stress.

3.5.1 Data sources

This chapter primarily relies on the national planning documents and research studies supplemented with limited primary data collection and modeling. Thermal power capacity (MW) estimates for a period up to 2050 are developed based on projections contained in national planning documents and extrapolated where there are gaps. In order to assess if the thermal power capacity exposed to water stress in 2050 can be significantly different in the event that there is a shortfall in planned capacity additions, an alternate scenario of lower thermal power capacity by 2050 has also been evaluated. Coastal plants have been excluded from this chapter as they do not impact freshwater sources.

Research studies on river basin water availability and requirements and climate change impacts have been reviewed and adapted to the requirements of this chapter. In examining the water stress, Falkenmark water stress indicator (Falkenmark 1989) and IWMI water stress indicator[9] have been used. The Falkenmark water stress indicator views the water issue from a per capita availability perspective while IWMI views the water issue from a water balance perspective.

The location of thermal power plants in 2050 is a key determinant for assessing thermal power capacity exposed to water stress. National planning documents do not contain information on the location of future capacity additions. A methodology has been developed to forecast the future power plant location that is based on the current pattern of development but subject to fuel reserve availability in the river basin. The methodology does not consider other parameters relevant to siting like transmission availability, local environment and forest issues, mine locations, fuel transportation, load centers, market arrangements, etc. Information has been collated from state and central environment approval process to develop another scenario of distribution of thermal power plants. The location analysis is superimposed on the water stress / water scarcity of river basins to examine the percentage of thermal power capacity that may be exposed to water stress.

As cooling technologies are expected to play a key role in mitigating water risks to thermal power plants, the key business drivers of cooling technologies have been examined. Limited primary

[9] *Smakhtin et al.* 2004

data collection on current performance of cooling technologies and financial modelling of coal and gas based power plants to assess the impact of cooling technologies have been carried out.

3.5.2 Overview of power sector in India

The total installed capacity at the end of the XIth Plan (2012) is 211,766 MW including 141,714 MW of thermal power plants (coal, lignite, gas, diesel, oil and naphtha), 39,416 MW hydro power plants, 4,780 MW nuclear and 25,856 MW of renewable energy plants. Table 3-3 below shows the installed capacity break-up by fuel/technology.

Table 3-3: Installed capacity by the end of 11th Plan

Fuel / technology	Installed Capacity (MW)
Coal and lignite / subcritical	114,871
Coal / supercritical	6,740
Natural gas / CCGT	18,903
Diesel and fuel oil	1,200
Hydro	39,416
Nuclear	4,780
Renewable Energy Sources	25,856

Source: CEA, MNRE, MOP

In addition, captive power capacity of 32,900 MW was operational by 31 March 2011 according to National Electricity Plan 2012. The fuel / technology break-up of captive power capacity is not available and therefore this has not been examined further.

3.5.3 Thermal power capacity expansion plan up to 2050

In the National Electricity Plan, CEA projects the thermal power capacity additions under three scenarios during the XIIth Plan (2012 to 2017) from 64,486 to 67,686 MW while thermal capacity additions during the XIIIth Plan (2017 to 2022) is expected to be 47,000 to 49,200 MW. This chapter considers the low renewable low gas scenario among the three scenarios developed by CEA, as it is the base case scenario of the National Electricity Plan and it is more likely given the current uncertainties surrounding availability of gas and prioritization of gas for fertilizer sector.

The Working Group on Power for XIIth Plan considers capacity additions from coastal power plants and accordingly, the coastal power plants have been considered as a percentage of the thermal capacity additions for the period 2017 to 2050. Coastal power plants are not expected to impact the freshwater resources. For the period up to 2032, CEA has made year-wise projections electricity demand in the draft 18th Electric Power Survey. On the assumption that the technology mix remains constant from 2022 onwards, CEA's demand forecast is expected to translate into a total installed capacity (including thermal and other power generation sources) of 718,456 MW by the year 2032. As there are no estimates available in the national planning documents beyond the period 2032, simple extrapolation of total electricity demand and consideration of maintaining same technology mix (as in 2022) are used to arrive at the installed capacity by 2050. The projected installed capacity under business-as-usual scenario is presented in Table 3-4 below.

Table 3-4: Projected installed capacity in MW (2017 – 2050) under business-as-usual scenario

Generation technology	2017	2022	2032	2050
Coal – coastal	28,232	35,612	61,142	99,660
Coal – inland	159,979	201,799	346,474	564,739
Gas	19,989	19,989	34,320	55,940
Hydro	48,620	60,620	104,080	169,646
Nuclear	7,580	25,580	43,919	71,586
Renewable Energy Sources	44,356	74,856	128,522	209,486
Total	308,756	418,456	718,456	1,171,056

Source: Central Electricity Authority , 2011

3.5.4 Underachievement of capacity expansion target

It is important to understand whether the thermal power capacity exposed to water stress is significantly different in the event of lower than expected power capacity additions. Actual power plant capacity additions on an average have been at the 65% level compared to the plan targets . The lower capacity scenario therefore assumes that the projected installed capacity up to 2050 will be 65% of the capacity projected in a business-as-usual scenario.

The operation of the power plant must assess the water risk in terms of water quality, quantity and the timing of the water availability. Many parts of India face high water stress and scarcity largely due to uneven availability and distribution of water resources, both geographically and seasonally. Therefore, it is important to analyze water availability at the river basin level. This has been done in the next section.

3.6 Water stress at river basin level

This chapter analyses the water availability and sectoral water demand at the national level. It assesses the water availability and requirement at the river basin level, analyses some of the issues related to climate change and examines the water stress at river basin level.

3.6.1 National water availability and sectoral water requirements

The total annual water resource potential in India is estimated to be in the range of 1870 to 1950 bcm, considering both surface and ground sources. Groundwater recharge is estimated to be 22 to 23% (CWC 2010; CGWB 2011, Amarasinghe, Shah and Anand 2008). However, all available natural freshwater, surface water or ground water resources are not accessible for use. Utilisable water resources have been assessed in the range of 1030 to 1160 bcm of which 60 to 65% is from surface water sources and the remaining is from groundwater sources (CWC 2010; ADB 2011). The utilisable water resource at the national level is expected to be 1141 bcm (CWC 2010; NCIWRDP 1999; ADB 2011) by 2050.

The current annual water requirement is estimated to be in the range of 635 to 815 bcm out of which the irrigation sector accounts for 85% of the total requirement, followed by the industrial and domestic sectors, which together account for the remaining 10 to 15% of the total water use (NCIWRDP 1999; ADB 2011; CWC 2010; Planning Commission 2009; Amarasinghe, Shah and Anand 2008). By 2050, water requirement is projected to be in the range of 895 to 1110 bcm out of which the irrigation sector is expected to account for 70 to 75% of the total requirement, followed by the industrial and domestic sectors (NCIWRDP 1999; ADB 2011; CWC 2010; Planning Commission 2009; Amarasinghe, Shah and Anand 2008).

The water requirement of the industrial sector including power is estimated to range between 145 to 160 bcm by year 2050 (NCIWRDP 1999, ADB 2011, Amarasinghe, Shah and Anand 2008). The share of power sector requirement for water is estimated to be 45% of the total industrial sector water demand (ICID 2005; CWC 2010; ADB 2011). Further, water requirement of thermal power generation is expected to be close to half of the total water demand of power sector and the remaining half is for other power generation technologies including hydro. Figure 3-8 below provides summary of the overall water requirement and sectoral distribution (high case) in detail.

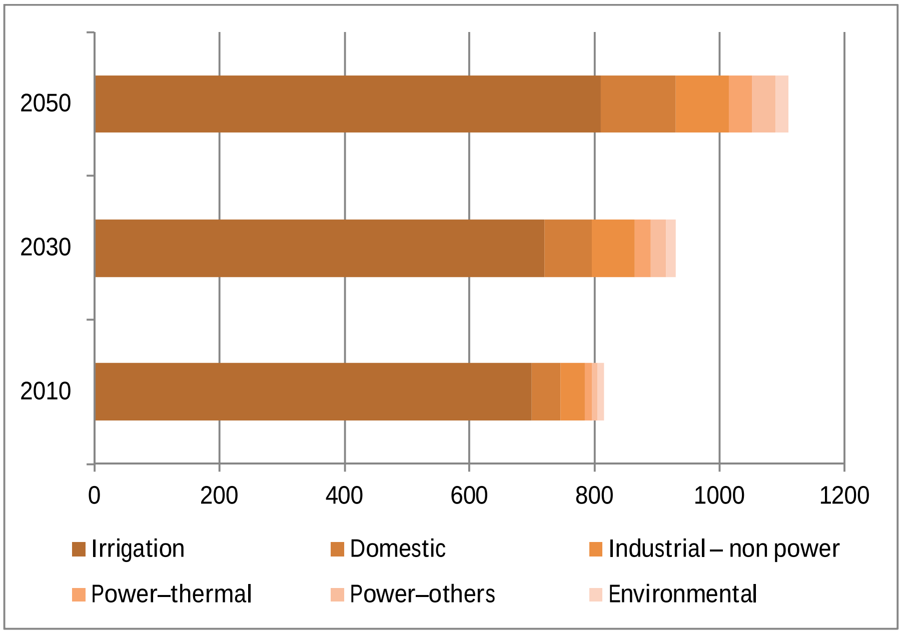

Figure 3.8: Water requirement for different sectors in BCM

Source: NCIWRDP 1999; Planning Commission 2009; Amarasinghe, Shah and Anand 2008; Own estimates

3.6.2 Water availability and requirement at river basin level

Studies have estimated the utilisable water resources and total water requirements up to 2050. These have been synthesized and adapted to develop the water resource and requirement forecast for the year 2050 which is set out in the Table 3-5 below.

Table 3-5: Water availability and requirement at river basin level in 2050

River basins	Per capita water available [2010]	Per capita water available [2050]	Utilisable water resources [BCM]			Total water requirement in 2050[2] [BCM]			Water gap[10] in 2050
			Surface water	Ground water	Total (1)	Surface water	Ground water	Total (2)	Net (1) - (2)
Indus	1242	915	46	26.5	72.5	47.24	29.88	77.12	-4.62
Ganga	1039	621	250	171.57	421.57	311.96	182.11	494.07	-72.50
Brahmaputra and Barak	11782	885	24	26.55	59.07	28.46	27.37	55.83	3.24
Subernarekha	935	484	6.81	1.8	8.61	7.43	2.62	10.05	-1.44
Brahmani-Baitarni	2063	1,206	18.3	4.05	22.35	17.53	3.59	21.12	1.23
Mahanadi	1786	1,322	49.99	16.5	66.49	36.5	24.46	60.96	5.53
Godavari	1454	1,145	76.3	40.6	116.9	56.45	42.33	98.78	18.12
Krishna	912	734	58	26.4	84.4	60.88	30.64	91.52	-7.12
Pennar	462	642	6.86	4.93	11.79	9.93	3.92	13.85	-2.06
Cauvery	518	576	19	12.93	31.93	20.08	15.1	35.18	-3.25
Tapi	714	813	14.5	8.27	22.77	13.31	4.88	18.19	4.58
Narmada	2205	1,629	34.5	10.8	45.3	23.81	6.9	30.71	14.59
Mahi	746	358	3.1	4	7.1	7.18	3	10.18	-3.08
Sabarmati	257	258	1.93	3.2	5.13	5.77	2.89	8.66	-3.53
West flowing rivers[11]	4879	962	36.21	17.7	53.91	40.73	10.35	51.08	2.83
East flowing rivers[12]	937	1125	29.84	37	66.84	40.27	17.58	57.85	8.99
Luni	486	627	14.98	11.23	26.21	16.98	11.75	28.73	-2.52
Minor rivers draining into Myanmar (Burma)	14,679	6,633		18.8	18.8	2.54	1.21	3.75	15.05
Total						1141.6		1167.6	

Source: CWC 2010; NCIWRDP 1999; ADB 2011

3.6.3 Impact of climate change on water availability at river basin level

Changes in rainfall due to global warming will influence the hydrological cycle and the pattern of stream-flows and demand. Studies on impacts of climate change on the river runoff in various river basins of India indicate that the quantity of surface runoff due to climate change will increasingly vary across river basins as well as sub-basins in the future. Climate change is expected to result in increase in average temperature that may affect the water availability in terms of high evaporation rates, melting of glaciers and changes in precipitation factors. Melting of glaciers due to increase in temperature may result in change in water flow of glacier fed river basins. Ganga, Indus,

[10] Water gap is calculated as a difference between utilizable water resources and water requirement. Positive values indicate water utilizable water resources exceeds water requirement. Negative values indicate water water requirement exceeds utilizable water resources.

[11] (Tapi to Tadri and Tadri to Kanyakumari)

[12] (between Mahanadi and Pennar and between Pennar and Kanyakumari)

Brahamaputra and Barak are likely to be impacted by climate change due to recession of the Himalayan glaciers. Changes in precipitation will result in changes in flow of water in the river basins. Under the climate change mid-century (MC) scenario (2021-2050) using the IPCC SRES A1B scenario, the majority of river systems will witness increased variability in precipitation levels at the basin level (Gosain et al. 2011). In another chapter by Jain and Kumar (2012), 25% of the river basins were expected to have variable but an increasing trend in annual rainfall 70% of the river basins were expected to have a decreasing trend, with the Ganga basin showing no trend. The Mahanadi and Krishna river basins might experience decreasing trend in annual rainfall and increasing trend in rainy days, which implies that droughts may become more recurrent in Krishna (an already water stressed basin). Similarly, in the monsoon season, Barak, an east flowing river might experience increasing rainfall and decreasing rainy days, which implies that floods may become more intense (Jain and Kumar 2012). The changes in precipitation from various studies are synthesized in Table 3-6 below. The impact of changes in precipitation on the water availability is outside the scope of this chapter.

Table 3-6: Change in precipitation (basin-wise)

Basin	Annual precipitation average (mm)[b]	Change in precipitation (MC scenario)		
		Mean	Low	High
Baitarni	1417.3*	-2.5	-15.7	4
Brahmani		-8.1	-12	0
Brahmaputra	2589.2	2.3	-30	12
Cauvery	1031.7	1.7	-8.5	5
Ganga	1051.2	-2.5	-2	2
Godavari	1106.8	-16.1	-34	24.6
Indus	1097.1	-16.6	-26	16
Krishna	838.1	-1.5	-15	12
Luni	397	-13.8	-31	15
Mahanadi	1344.4	-13.3	-18	21.6
Mahi	1002.6	-11.5	-15	21.8
Meghna	2171.8	-25	-50	5
Narmada	1108.7	-17.4	-26	21.7
Pennar	719.8	3.5	-17.5	7
Sabarmati	654.5	-13.7	-21	15.1
Subernrekha		-1.1	-5	6
Tapi	764.6	-17.5	-30	18.1

Source: Gosain et al 2011; Jain and Kumar 2012; MOEF 2010

3.6.4 Water stress at river basin level

There are two commonly used approaches for assessing water scarcity at the river basin level – Falkenmark water stress indicator (Falkenmark 1989) and IWMI water stress indicator[13]. Falkenmark water stress indicator is based on the per capita availability of utilisable water resources. It categorizes river basins according to no stress, stress, scarcity and absolute scarcity. Experts opine that the levels of scarcity and absolute scarcity indicate significant risk to water availability and water conflicts. IWMI water stress indicator is based on the ratio between total withdrawals to utilisable water. According to IWMI water stress indicator, the river basins can be classified as slightly exploited, moderately exploited, heavily exploited and over exploited. IWMI indicates that heavily exploited indicates environmentally water stressed basins and overexploited indicates environmentally water scarce basins. The thresholds for the two indicators are set out in Table 3-7 and Table 3-8 below:

Table 3-7: Falkenmark stress indicator

Category/Condition	Water Availability (m^3 per capita)
No Stress	>1,700
Stress	1,000-1,700
Scarcity	500-1,000
Absolute Scarcity	<500

Table 3-8: IWMI water stress indicator

Category/Condition	WSI = Withdrawals / (Total water availability – Environmental needs)
Slightly exploited	WSI<0.3
Moderately exploited	0.3<WSI<0.6
Heavily exploited	0.6<WSI<1
Over exploited	WSI>1

Applying the Falkenmark water stress indicator and IWMI water stress indicator to the river basins we find that most of the river basins in India are likely to face some degree of water stress. Table 3-9 provides the results of the analysis:

[13] *Smakhtin et al.* 2004

Table 3-9: Classification of river basins on water stress

Sl. No.	River basin	Falkenmark water stress indicator in year 2050	IWMI water stress indicator in year 2050
1	Brahmaputra and Barak	No stress	Heavily exploited
2	Western flowing rivers	No stress	Heavily exploited
3	Brahmani-Batarni	Stress	Heavily exploited
4	Mahanadi	Stress	Heavily exploited
5	Godavari	Stress	Heavily exploited
6	Narmada	Stress	Heavily exploited
7	Indus	Scarcity	Over exploited
8	Ganga	Scarcity	Over exploited
9	Subernarekha	Scarcity	Over exploited
10	Tapi	Scarcity	Heavily exploited
11	Mahi	Scarcity	Over exploited
12	Krishna	Scarcity	Over exploited
13	Pennar	Absolutely Scarcity	Over exploited
14	Cauvery	Absolutely Scarcity	Over exploited
15	Sabarmati	Absolutely Scarcity	Over exploited
16	Eastern flowing rivers	Absolutely Scarcity	Heavily exploited
17	Luni	Absolutely Scarcity	Over exploited

3.7 Thermal power capacity exposed to water stress

There are no studies or planning documents that provide guidance on location of the thermal power plants by 2050. A methodology has been developed to project the geographical distribution of thermal power plants at a river basin level.

3.7.1 Mapping future power plants to river basins

The current installed capacity and location has been mapped using GIS application on a river basin level. Further, the coal / lignite reserves have been mapped on the river basin level. The map showing the power plants and coal / lignite reserves on the water scarcity map is shown in Figure 3.9.

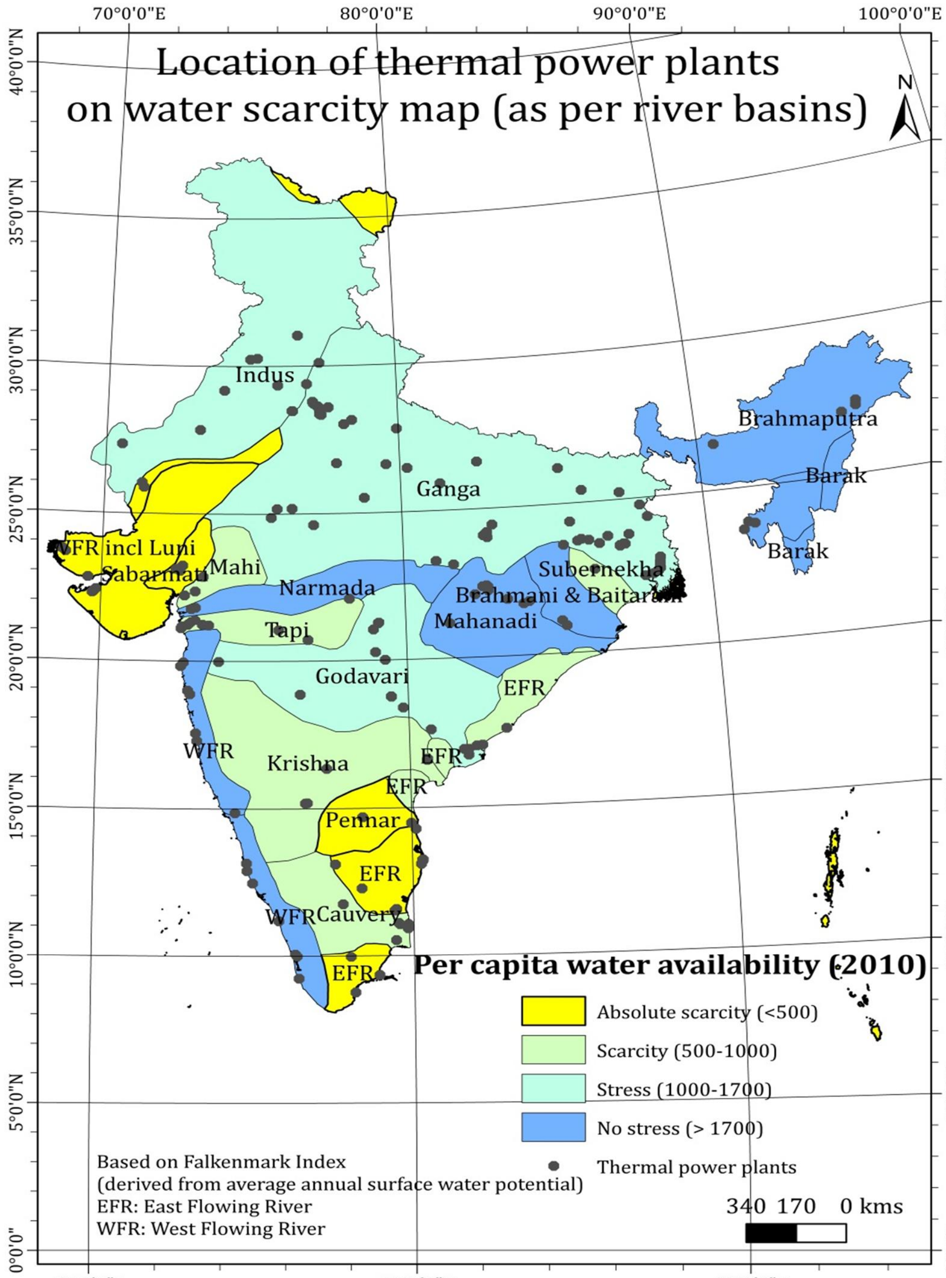

Figure 3.9: Coal deposits and plant locations on water scarcity map (2012)

Source: 1) Water scarcity map developed by Water and Resources Institute using Central Water Commission (2010) and IDFC (2011) data; 2) Power plant location plotting done by IGES using Global Energy Observatory database.

Following Table 3.10 shows the distribution ratio of thermal power installed capacity across the country along the major river basins.

Table 3-10: Installed thermal power capacity distribution (2012)

River basin	Thermal power capacity distribution (MW)
Ganga	34.9%
Indus	6.6%
Luni	6.2%
Sabarmati	1.0%
Mahi	1.5%
Narmada	1.0%
Mahanadi	8.6%
Brahmani and Batarni	3.2%
Subernrekha	0.3%
Godavri	10.5%
Tapi	5.6%
Krishna	4.6%
Pennar	0.8%
Cauvery	1.2%
EFRs	7.1%
WFRs	6.1%
Brahmaputra	0.4%
Barak	0.2%
Total	100%

The location of the future thermal power plants will be influenced by multiple factors including fuel reserves and mine location, fuel transport infrastructure, transportation costs, water availability, transmission and evacuation infrastructure, policy and regulatory framework, market and institutional arrangements, local environment and social considerations, etc. The case of inland coal / lignite capacity, coastal power plants and gas based power plants has been separately examined. For the inland coal/lignite power plant, the current pattern of development is expected to continue, i.e., inland coal power plants will continue to be located in river basins based on historical trends. There is subject to sufficient fuel (coal / lignite) reserves being present in the river basin such that it is able to support coal / lignite power plant for 25 years after 2050, i.e., any thermal power plant that is installed in 2050 should have access to sufficient reserve for 25 years of power plant operations. Some of the river basins like Ganga, Indus, Luni, Tapi, Krishna, Pennar and western flowing river basins are expected to reach the limits of fuel reserve during the forecast period and the balance capacity is assumed to be located in river basins that have surplus fuel reserves.Coastal power plants have been excluded from this chapter as these are not expected to impact the freshwater availability. Once-through cooling system has been prevalent for coastal located power plants. However, once-through cooling systems contribute to thermal pollution due to difference in inlet and outlet temperature and it is possible that future regulations may prevent the use of one-through cooling system for coastal power plants. Coastal thermal power plants may be mandated to use desalination technology or closed loop wet cooling system or dry cooling technology.

Future gas-based capacity addition has been assumed at inland locations in the same ratio as current gas-based capacity at each of the river basins as the availability of gas transportation infrastructure and not location of upstream gas wells is expected to be driver for location of gas based power plants. The chapter does not consider the development of gas infrastructure network on a river basin level or other considerations like locating gas plants close to load centers that may influence gas plant locations. Table 3-11 shows the inland thermal power capacity by river basin in 2050 based on the business-as-usual scenario. A similar geographical distribution of thermal power capacity for the lower capacity scenario has been done.

Table 3-11: Inland thermal power capacity in MW by 2050

River basins	Inland coal power plants [2050]	Gas-based power plants [2050]	Total thermal power plants [2050]
Ganga	150,000	12,500	162,500
Indus	17,000	344	17,344
Luni	17,000	0	17,000
Sabarmati	731	1,905	2,636
Mahi	686	3,970	4,656
Narmada	8,934	2,034	10,967
Mahanadi	157,056	0	157,056
Brahmani and Batarni	59,177	0	59,177
Subernrekha	428	0	428
Godavri	55,449	8,177	63,625
Tapi	26,049	6,496	32,545
Krishna	27,000	0	27,000
Pennar	1,050	0	1,050
Cauvery	840	2,090	2,930
Eastern flowing rivers	39,085	4,772	43,857
Western flowing rivers	4,255	11,213	15,469
Brahmaputra and Barak	0	2,440	2,440
Total	564,739	55,940	620,679

Source; Authors' estimate

The central and state environment approval process contains information on thermal power plants that are in various stages of environment approval. This information has been collated and analysed. The total thermal power capacity that is under various stages of environment approval process is in excess of 700,000 MW, which is comparable to the projected thermal power capacity in 2050. The thermal power capacity distribution based on the environment approval process information has been developed as the environment scenario and analysed together with the business-as-usual scenario and lower capacity scenario.

3.8 Water demand for thermal power generation in India

For thermal power generation in India, water is a crucial input factor. Water is even more critical for the coal fired power plants where India is using mostly domestic low grade coal with high ash content. Starting from coal handling plant till fly ash disposal along cooling tower water required in every important stages of power plant operation. Water is used in almost all areas/ facilities of thermal power stations in one way or other. A typical list of plant systems/ applications requiring consumptive water is indicated as below:

- Cooling water system for condenser & plant auxiliaries
- Ash handling system
- Power cycle make up
- Equipment cooling system & CPU regeneration, if applicable
- Air conditioning and ventilation system
- Coal dust suppression system
- Service water system and potable water system
- Evaporation from raw water reservoir

In the case of Indian thermal power generation, around 80% of the consumed water used by the plants' cooling system followed by the ash handling activities. In the context of total water withdrawal or intake for the power plant, cooling system takes around 65% of the total water withdrawal. Following Figure 3.10 shows the percentage distribution of total water use in a typical thermal power plant in India. In general, ash handling water comes from the cooling water blow down and thus is not part of the consumptive water for the power plant.

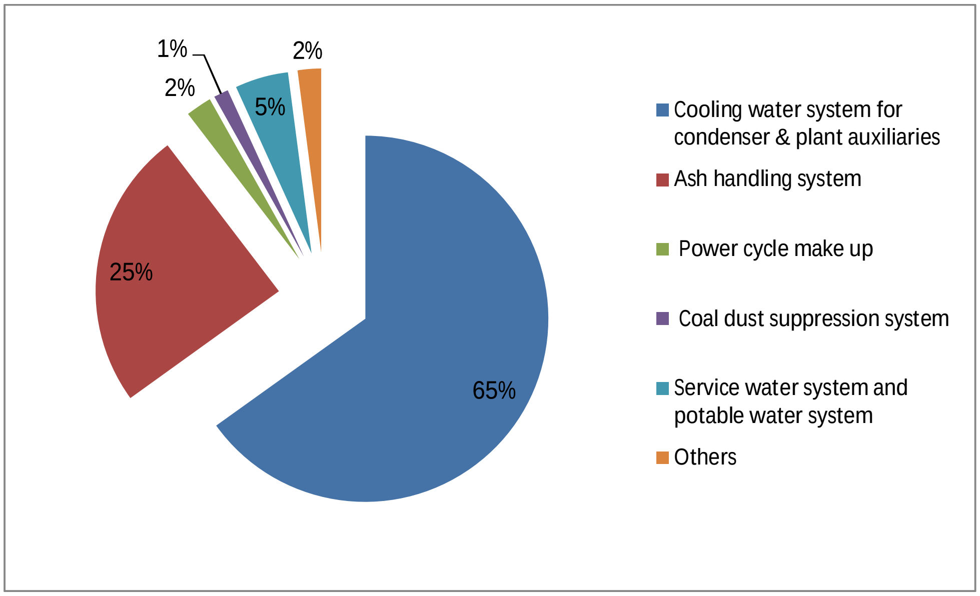

Figure 3.10: % distribution of water use by different activities in thermal power plant in India

Source: Data obtained from Central Electricity Authority report, 2012

3.8.1 Different cooling technologies used in India

Cooling technologies can be broadly classified as open and closed loop cooling systems and further to dry, wet and hybrid cooling systems. The sub sets of wet cooling systems are induced draft or natural draft cooling systems. Further there are cooling technologies that employ both wet and dry cooling at the same time and are better known as hybrid systems.

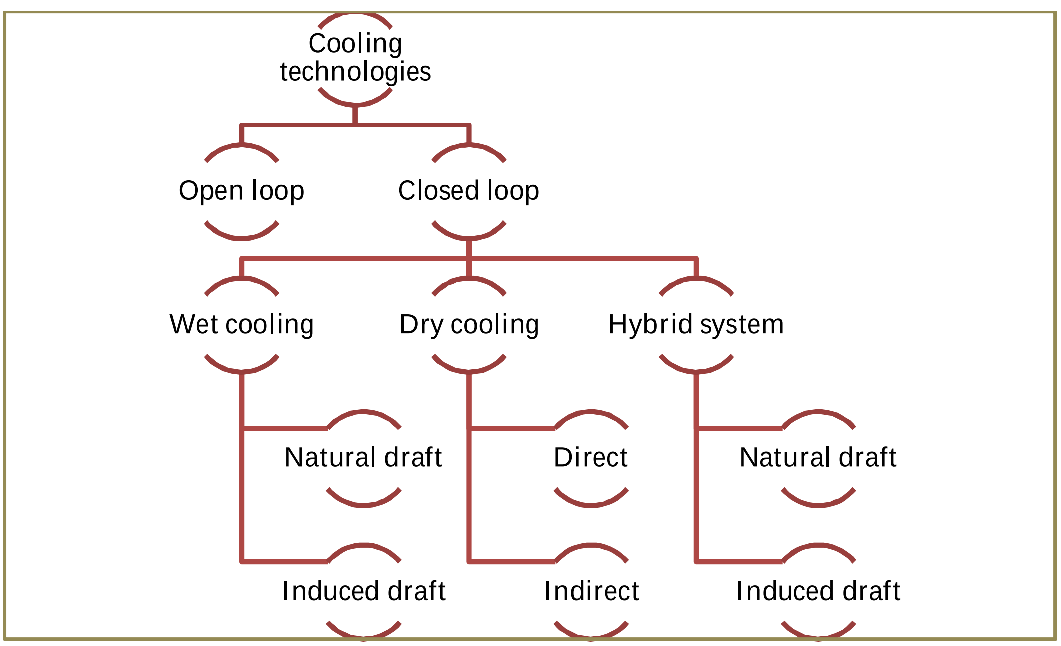

Figure 3.11: Classification of Cooling Technologies

Open loop cooling system (once through) are where the water is circulated through the condenser for condensing steam and returned back to the water body from where the water was drawn. Open loop cooling system is also known as once through cooling system. This type of cooling system creates thermal pollution as the temperature of water discharged is more than the temperature of water intake. The open loop cooling systems were disallowed by MOEF by its stipulation[14] dated January 02, 1999 for the power plants that are expected to be commissioned after June 01, 1999. This was done to prevent thermal pollution (source: report on minimisation of water requirement in coal based thermal power station15, CEA). Closed loop cooling system can be classified into three categories including dry cooling system, wet cooling system and hybrid cooling system. Wet cooling system employs the cooling tower technologies for condenser cooling. Wet cooling system can be classified as: a) Natural draft and b) Induced draft.

Water in a wet cooling system is circulated in the cooling tower where part of it is evaporated resulting in cooling of the water circulated. Makeup water for cooling tower includes loss due to evaporative cooling, drift and blow down.

Dry cooling system can be classified as direct cooling system and indirect cooling system. In the direct dry cooling system water is directly cooled by a system of finned tubes by pushing ambient air using mechanical draft fans or natural draft towers. In case of indirect dry cooling system the heat from low pressure turbine is condensed in the condenser by circulating water which in turn is cooled by pushing ambient air using mechanical draft fans or natural draft.

3.8.2 Estimates of water use coefficients in thermal power generation in India

The power plants with different generation and cooling technologies were selected to collect the primary data. The primary data collected from 14 units covers different power generation technologies and employ different cooling technologies (open loop, wet cooling and dry cooling system). The primary data has not been independently audited or verified (See Table 3.12).

[14] http://www.cpcb.nic.in/divisionsofheadoffice/pci2/ThermalpowerPlants.pdf
[15] http://www.cea.nic.in/reports/articles/thermal/min_of%20water_coal_power.pdf

Table 3-12: Primary data collection matrix

Fuel	Technology	Open through	Wet cooling	Dry cooling
Coal	Subcritical	√ (2)	√ (5)	Data not available
Coal	Supercritical	Data not available	√ (1)	Data not available
Natural gas	CCGT	√ (1)	√ (2)	√ (1)
Diesel	DG Set	√ (1)	Data not available	Data not available
Oil	Subcritical	√ (1)	Data not available	Data not available

The primary data collected for coal based thermal power plants indicated water consumption intensity for subcritical and supercritical plants based on wet cooling technology is in range of 2.96 m^3/MWh to 3.57 m^3/MWh. Water consumption in once through cooling system is in range of 0.16 m^3/MWh to 0.18 m^3/MWh . A once through cooling system is allowed only if sea water is used for condenser cooling. Sea water is not counted towards water consumption by the power plant (Fig 3-12).

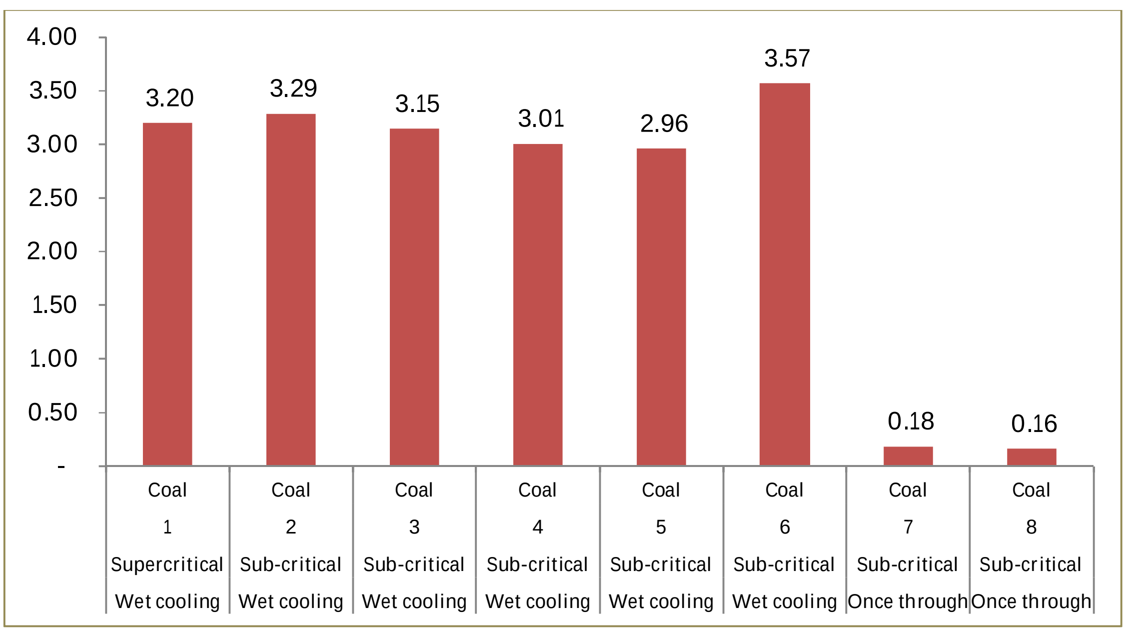

Figure 3.12: Water requirement by coal fired generating stations

Source: power plant survey

The primary data collected for gas fired thermal power plants indicated water consumption intensity for wet cooling technology is in range of 1.24 - 1.48 m^3/MWh and for dry cooling technology is 0.06 m^3/MWh and for once through cooling system is 0.10 m^3/MWh (Fig.3-13).

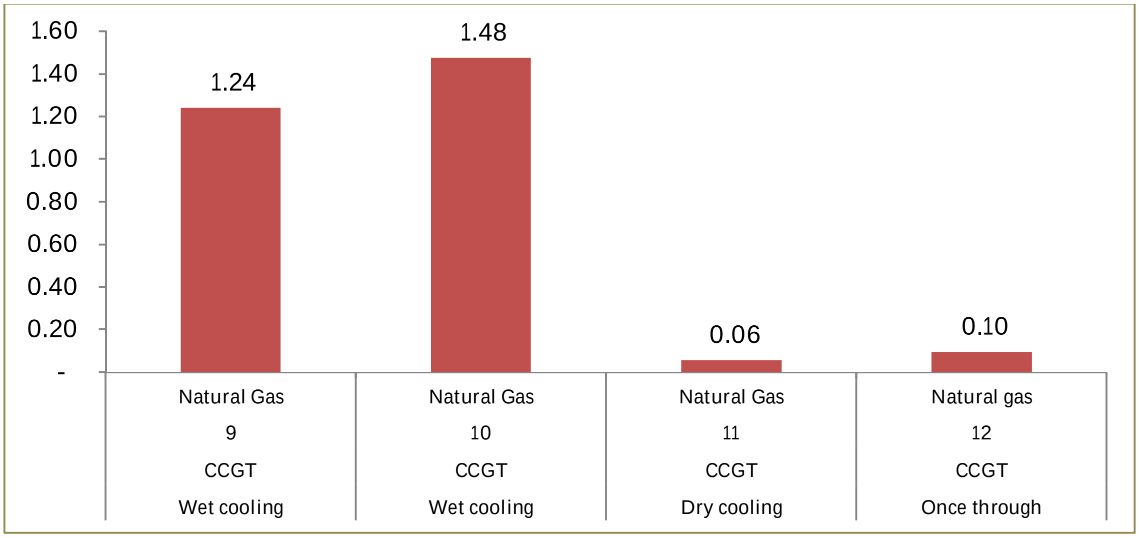

Figure 3.13: Water requirement by combined cycle generating stations

Source: Primary data collected

The primary data collected for diesel and oil fired thermal power plants indicates that water consumption intensity for once through cooling system is 0.82 m^3/Mwh and 0.21 m^3/Mwh respectively. The average water consumption for different technologies where primary data is available is shown in Fig.3-14.

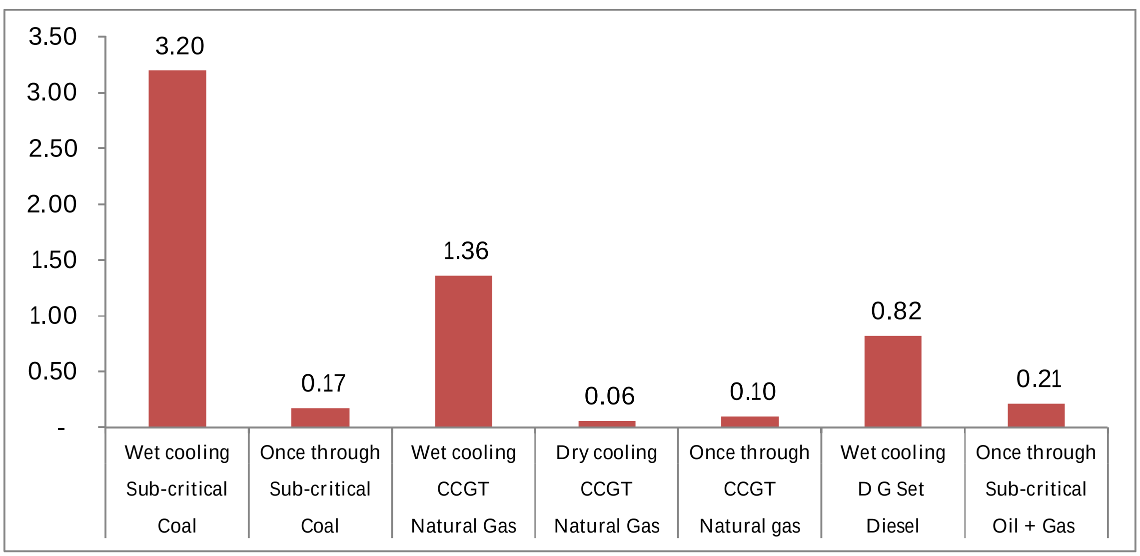

Figure 3.14: Average water requirement for different cooling technologies in m3/MWh

The data collected above corroborated with data sourced from CEA report[16] on minimisation of water requirement in coal based thermal power plants. The data available in the report published by CEA includes data on water requirement by the coal based thermal power plants employing wet and dry cooling and is shown in Table 3-13 below.

Table 3-13 : Water requirement by coal fired generating stations (supercritical/Subcritical)

Particular	Water requirement with wet cooling system (m^3/ MWh)	Water requirement with dry cooling system (m^3/ MWh)
Water requirement for the first year	3.6[17]	0.75[18]
Water requirement for the subsequent years	3.0	0.55[19]

Data source: CEA, 2012

Finally Figure 3.15 below shows the range of water coefficients in m^3/Mwh from different water cooling technologies used in the power plants.

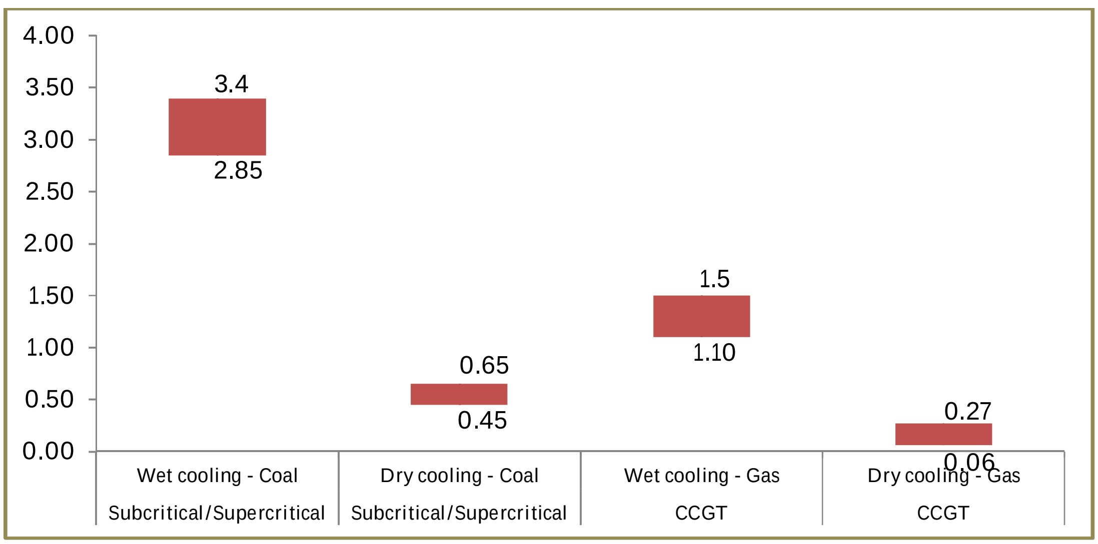

Figure 3.15: Range of water requirement by coal and gas fired power plants

Source: power plant survey and experts' opinion

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[16] http://www.cea.nic.in/reports/articles/thermal/min_of%20water_coal_power.pdf

[17] In case fly ash disposal system using high concentration slurry disposal is employed from the first year – the water requirement will be 3.0 m^3/MWh from the first year of operation.

[18] In case HSCD system is used against the dry fly ash disposal –there will be additional raw water requirement of 0.15 m^3/ MWh.

[19] In case HSCD system is used against the fly ash disposal –there will be additional raw water requirement of 0.15 m^3/hour/MW.

Based on above mentioned data and information collected during primary data survey and interview in various power plants in India, we derive the following critical information which are used in the model simulation:-

a) The water consumption is highest for coal fired power generation employing wet cooling technology. Water consumption for coal fired power generation employing wet cooling system is expected to be in range of 2.85 to 3.40 m^3/MWh.

b) Water consumption for coal fired power generation technology employing dry cooling system is expected to be in range of 0.45 to 0.65 m^3/MWh.

c) Water consumption for gas fired power generation employing wet cooling system is expected to be in range of 1.10 to 1.50 m^3/MWh

d) Water consumption for gas fired power generation employing dry cooling system is expected to be in range of 0.06 to 0.27 m^3/MWh.

e) Once through cooling system have low water intensity but can be employed only in case of coastal power plants. Once through cooling system are not allowed in thermal power plants by MOEF via stipulation dated January 02, 1999 except for coastal power plants using sea water. The water intensity for coal fired power generation using once through system is 0.17 m^3/MWh (as sea water used for condenser cooling is not counted towards water consumption) and for CCGT is 0.10 m^3/MWh.

3.8.3 Regulatory issues of cooling technologies in thermal power plants in India

Open loop cooling systems were disallowed by the MOEF for inland thermal power plants by its stipulation 20 dated 2 January 1999 for power plants commissioned after 1 June 1999. This was done to prevent thermal pollution (source: Report on Minimisation of Water Requirement in Coal Based Thermal Power Station21, CEA). Currently, a number of inland thermal power projects use wet cooling system. Dry cooling technologies reduce the water requirements by up to 80% for both coal power plants and gas based power plants. CEA in its report on minimisation of water requirement in coal power plants concluded that: Dry cooling systems, as such, are costly technologies and are not comparable to wet cooling system on techno-economic considerations. However, for sites where adequate quantity of water is just not available, dry cooling system offers possible solution for power plant installation with much reduced water requirement.

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20 http://www.cpcb.nic.in/divisionsofheadoffice/pci2/ThermalpowerPlants.pdf
21 http://www.cea.nic.in/reports/articles/thermal/min_of%20water_coal_power.pdf

Current dry cooling technologies are reported to be more expensive than wet cooling. In case of pit head coal power plant, the levelised cost of generation under a set of assumptions is estimated at INR/kWh 2.79 for dry cooling compared to INR/kWh 2.60 for wet cooling system. The levelised cost of generation is approximately 7.3% higher for dry cooling system. In case the coal power plant is located away from mines (distance from mine assumed as 2000 kms), the levelised cost of generation is estimated at INR/kWh 4.16 for dry cooling system compared INR/kWh 3.88 for wet cooling system. The levelised cost of generation is again 7.3% higher for dry cooling system.

In a situation where there is a flexibility of locating a power plant close to the mine mouth where water is scarce or close to water source which would involve coal transportation, dry cooling technology offers an interesting option to power plant developers. The decrease in cost of transporting coal versus increase in cost due to dry cooling provides an equilibrium point at approximately 300 kms under a set of assumptions. In other words, if the abundant water source is available at a site more than 300 kms away from the mine mouth, it is economical to set up a mine mouth based power plant with dry cooling provided that sufficient water is available for dry cooling at the mine mouth. In case of inland gas based power plant, levelised cost of generation under a set of assumptions is estimated at INR/kWh 3.40 for dry cooling compared to INR/kWh 3.30 for wet cooling. The difference in levelised cost of generation is sensitive to the price of water that is charged to power plant and is inversely proportion, i.e., the difference in levelised cost reduces if water tariff increases. At water tariff of 61.0 INR/m3, the levelised cost of generation based on dry cooling is estimated to be equal to wet cooling. It is expected that a number of policy measures will be required to address the water risk for thermal power plants.

3.8.4 Projected water demand for electricity generation

Though we have plan to conduct a national scale hydrological assessment of surface water availability which can supply required amount of water for energy production and generation, but in this chapter we used relatively simple method of proportional allocation to determine the long term water availability for energy sector in the country (See Figure 3-17).

Data on water withdrawal for electricity generation is not systematically available in India. Therefore, data has been compiled from various sources to project India's total water requirement for electricity generation until 2050 (Table 3-1). If the current technologies for coal based thermal power plants are continued (i.e open loop once through cooling system), the projected electricity generation in 2050 will require approximately 227 BCM of freshwater which is about 20% of the total annual utilizable water in the country (1122 BCM).

The National Commission on Integrated Water Resources Development (NCIWRD) projected that water requirement for electricity generation of the same period will be around 70 BCM using the government estimate of water intensity and demonstrated that the total water demand will be less than that of the total utilizable water resources in 2050. Based on our model estimate, the total water demand exclusively for electricity generation will be around 227 BCM by 2050, which will create deficit of around 100 BCM (exceeding by 10% of the total annual utilizable water) in terms of annual water supply and demand gap. Such significant difference in water use could be further attributed to heavily dependent on coal based power plants, operating with low quality coal, and with high water intense cooling tower technologies.

Although the regulation of cooling systems set out in 1999 was primarily to control thermal pollution, it inherently also acted as a check point for the volume of water use by thermal power plants in the country. It has been estimated that around 50% of existing operational thermal power plants in India were set up before 1999 and half of those are using open loop wet cooling systems. Therefore, around 20-25% of the total thermal power installed capacity in India, is still using open loop wet cooling (there is no exact number available but this figure was obtained from experts' interview). This means that more than 30 GW of installed capacity is still use fresh water at a rate of 80 -160 m3/MWh and around 100 GW of remaining capacity is using fresh or sea water in the closed loop wet cooling system at a rate of 2.8 to 3.4 m3/MWh. However, the open loop plants are very old and are expected to be retired within the next decade or so. It also appears that retrofitting of closed loop cooling system in these old plants is not economical. We have therefore estimated two different water demands based on both the pre-1999 and post-1999 regulatory situation. It indicates that if India were to continue pre-1999 open loop wet cooling system, the country would require a maximum of 227 billion cubic meters (BCM) of water per year just for thermal power generation by 2050 which would be 20% of the total utilisable water in the country by that time. However, with policy intervention that huge water demand could be reduced to around 85 BCM per year for electricity generation by 2050. This estimate considers gradual retirement of the old power plants (set up before 1999) and no new thermal plants to be set up with open loop wet cooling systems. This also indicates that India's electricity sector will also remain extremely water-intensive for the next couple of decades, if not beyond. Retrofitting of old power plants are not considered in this estimate as there is no existing regulation to mandate R&R activities to change open loop cooling system.

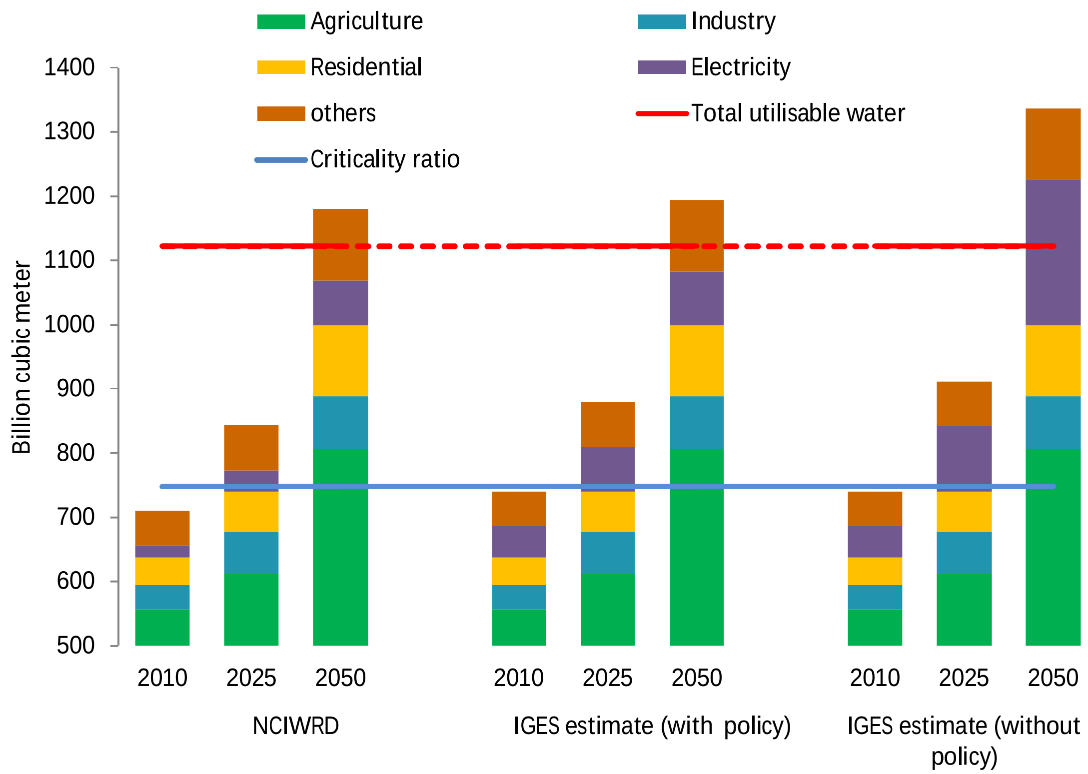

Figure 3.16 : Projected water demand compared to total utilisable water

[1]Criticality ratio is defined as extraction of 40% of total renewable water resources for human use

Note: 1) Base year of IGES model chapter was set at 2005 and water demand projection for electricity generation was estimated for 2010, 2025 and 2050 to compare with NCIWRD projection; 2) IGES estimates water demand for electricity sector only based on water use intensity of power plants. Electricity sector's water demand with policy intervention is basically considering the closed loop wet cooling system installed after 1 June 1999 and without policy water demand is a reference estimate of continuation of use of open loop wet cooling system in the thermal power stations. All other sectoral water demand projection follows NCIWRD projections.

Current water allocation for new thermal power plants setting up in India is fixed at 3 m3/Mwh, with provision of a four-year maturity time period. Furthermore, no permission is given unless the developers ensure and satisfy the authorities about the availability of the required amount of water. Such stricter regulations and restrictions aim to bring water efficiency into power plant operations. Water efficiency can thus be achieved in coal handling, fly ash handling, boiler operation and cooling systems. Figure 3.16 demonstrates the comparison of different estimates of total water demand for electricity generation in India and their corresponding impact on utilisable water resource. Our scenario projection (considering medium-level economic and technological development with no stringent climate target) shows that by 2050, Indian electricity generation together with other sectors will exceed the total utilisable annual water availability in the country, even with proper enforcement of MoEF regulation, i.e. achieving around 3 m3/Mwh standard.

3.8.5 Impacts on total utilisable water and deriving water availability constraint for energy sector in India

While it is suspected that by 2030 India as a whole will become more or less water scare due to various hydrological, demographic, climatic and environmental reasons, 135 m^3 of per capita utilizable water (664 m^3) will be needed additionally for electricity generation by 2050. This is the expected water foot print per capita for electricity generation in India by 2050 which is by an large approximately 20% of per capita total utilizable water. This instigates trade off and conflict among other water users in the country especially among agricultural use and residential use. Figure 3-17 shows the increasing water demand in residential and industrial sector due to increasing level of electrification. It is estimate that India will have more than 6% per annum electrification ratio which will substitute use of other primary energy resources like coal, kerosene, oil etc. As a matter of fact, electricity generation will not only increase the water intake for its own use but also increase the embedded water use for other sectors using electricity as source of energy (See Figure 3-18). By 2050 the incremental water demand in domestic, industry, and agriculture sector corresponding to electricity used in the sectors will be 41 BCM, 63 BCM and 40 BCM, respectively. It is estimated that direct and indirect incremental water demand related to electricity use by the sectors will create water scarcity for 7.25 million ha of irrigated cropland and about one third of projected total population (650 million) will face difficulties to access water for domestic use by 2050. However, the relative severity will be varied region wise depending on local renewable water availability, kind of dominant water users, population density, and trend of land use change and political power of the water user groups indeed.

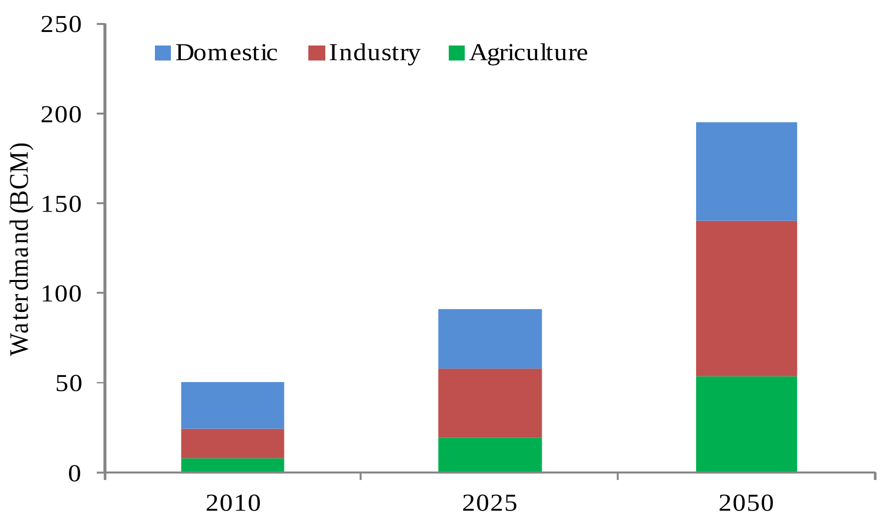

Figure 3.17: India's sectoral water demand corresponding to electricity demand

It has also been estimated that if India continues to consume water at the rate of 80 m^3/Mwh for its electricity generation then by 2050 per capita water demand will exceed per capita water availability. However, situation slightly gets better when India introduces stricter standard of water utilization in energy sector especially in power generation (3m^3/Mwh). Following Table 3-14 shows the comparison of long term per capita water availability situation in India under two different water use standards in Indian power sector.

Table 3-14: Impact of water for energy on per capita water availability

Year	Population (Billion)	Per capita available water (m3)/year	Per capita Utilizable water (m3)/Year	Per capita water consumption (m3)/year			
				NCIWRD	IGES Estimates		DOE
					@ 80 m3/mwh	@3 m3/mwh	
2025	1.46	1280	768	529	576	560	510
2050	1.69	1106	664	633	725	643	597

Source: National Commission for Integrated Water Resource Development, 1999; Department of Energy, US Govt., 2006

Note: The estimated per capita water consumption includes the embedded water consumption for electricity use

This estimate indicates that India's long term per capita water availability is in marginal condition even with high efficiency of water use technologies in its power sector. It has been further estimated that around 15% or more thermal power plants currently operating in India are having once through wet cooling system which are using water within the range of 80-160 m^3/Mwh and they are expected to continue operation until 2050. As a matter of fact, per capital water consumption in India by 2050 is expected to be more than 650 m^3/year while the per capital water availability remains at 664 m3/year. Finally it has been estimated that in India maximum amount of water that could be available for energy sector until 2050 is around 90 BCM per annum.

3.9 Model estimates

In this chapter we used the MESSAGE_Water as the key modeling tool for assessing the energy water nexus in energy systems of the country as a whole. The main purpose of this model is to assess the interlink between water resource availability and electricity generation in the region and how energy supply mix could be affected due to water scarcity in the long run. As we have described earlier that a water demand estimate module has been created for the standard MESSAGE model and thus it becomes capable of estimating endogenous water demand for the entire energy systems of the region, we therefore, used two scenarios to observe the impacts of water availability constraint on energy systems22. In the following section we briefly describe these scenarios.

3.9.1 Reference scenario without water constraint

In this scenario we considered all possible advance technologies to pitch in the system to reduce emissions as much as possible. Main reason for selecting such scenario is to provide maximum possible leverage to the energy system to reduce water load by selecting more renewable energy like solar PV and wind which are less water intensive. It is assumed that this scenario can achieve around 70% of the maximum feasible emissions reduction in the system.

Electricity Generation

Our reference scenario shows an optimistic future of renewable energy deployment which is inherently less water intensive indeed. However, coal, natural gas, oil and hydro remain the major sources of electricity generation until 2050 (Fig.3-18). This further corroborates the need of significant amount of water to produce required amount of power from thermal sources even with high renewable energy penetration and low carbon technology development. Thus the target of emissions reduction does not guarantee reduction of water dependence in power sector indeed.

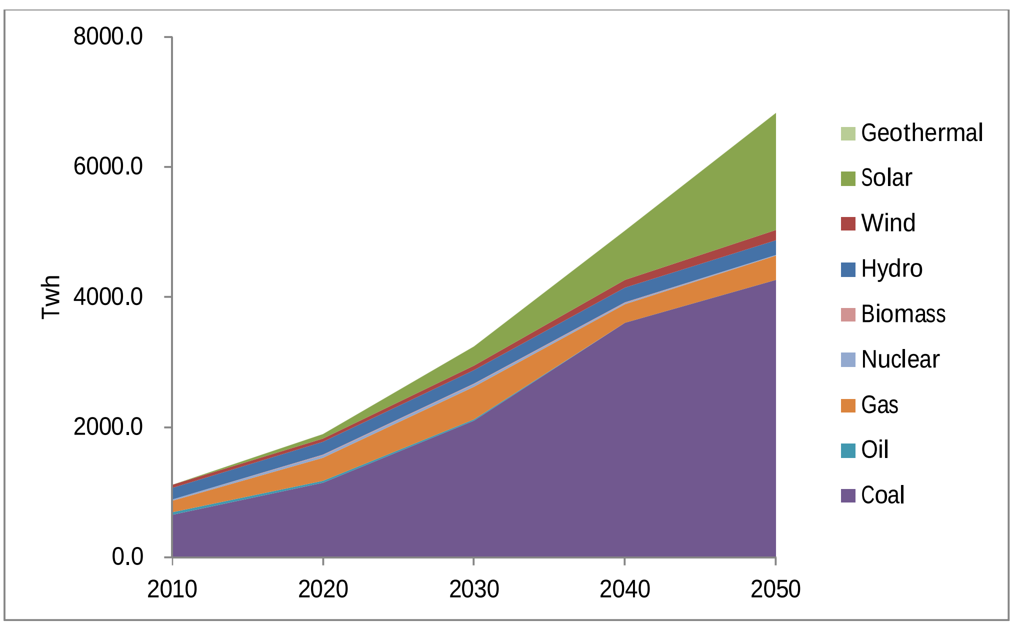

Figure 3.18: Electricity supply scenario trend of India

[22] Here we use the South Asia region of MESSAGE Model as proxy for India as India consists of 90% of the total electricity supply of the entire region and also have intra-regional power trading between Bhutan, Nepal. In 2010 out of 1100 Twh of regional generation India produces around 1000 Twh of electricity.

Primary Energy Consumption

In the context of primary energy consumption, the long term energy mix also depends on major water consuming fuels like coal, natural gas and oil. Figure 3.19 shows the long term primary energy consumption trend under no water availability constraint. It assumes that given all other conditions unchanged, the energy system doesn't face any water shortage in the future to fulfill the target of heavy renewable energy penetration.

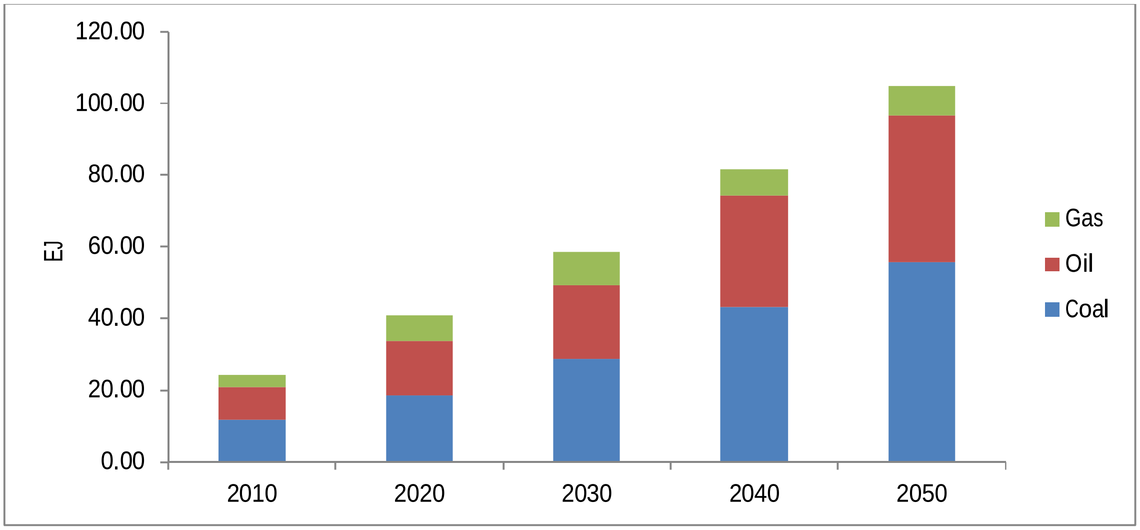

Figure 3.19: Primary energy consumption trend of India

3.9.2 Water constrained scenario

In this scenario we introduced the maximum water availability (up to 90 BCM per year) constraint for energy sector along with other conditions same as before. However, we also introduced several alternative technologies to mitigate the impact of water constraint like dry cooling and sea water cooling. Though these technologies are more expensive than conventional wet cooling system, they are adopted by the system in case of water constraint. This further indicates that if meeting energy demand is essential, deployment of alternative cooling technology is a must. Additional cost of these cooling technologies are however, adjusted in the standard O&M cost of corresponding power generating technologies. It is therefore, assumed that system under the global optimal condition will pick up certain alternative cooling technologies to mitigate the water shortage and to maintain the optimal energy supply amount.

Impact on electricity generation

Under the water constraint condition, the energy system behaves conservatively and deploys technologies which need less or no fresh water. As a matter of fact, sea water cooling in gas technology becomes predominant in this case. It has been observed that unless there is alternative technologies available to mitigate the impact of water scarcity for electricity generation, system fails to meet the required energy demand as well. Figure 3-20 shows the new electricity supply mix for the region under the water constrained condition.

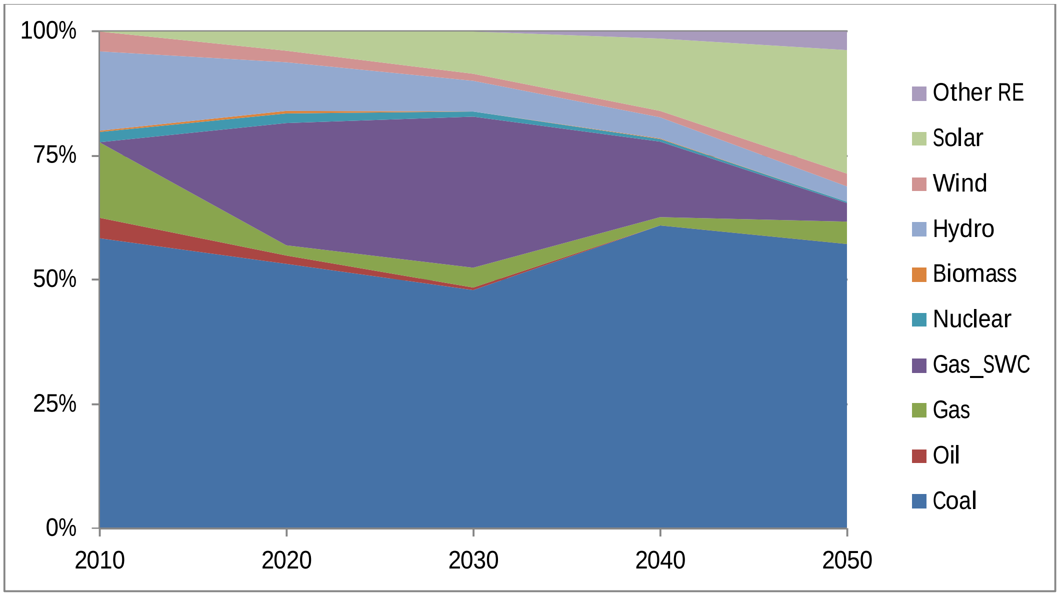

Figure 3.20: Electricity supply scenario trend of India under water availability constraint

Impact of primary energy consumption

It has been observed that water availability issue also affects countries' primary energy consumption. We find that coal and oil consumption decreases along with hydro power due to water scarcity and gas consumption increases to compensate the decrease in other fuel consumption (Fig.3-21).

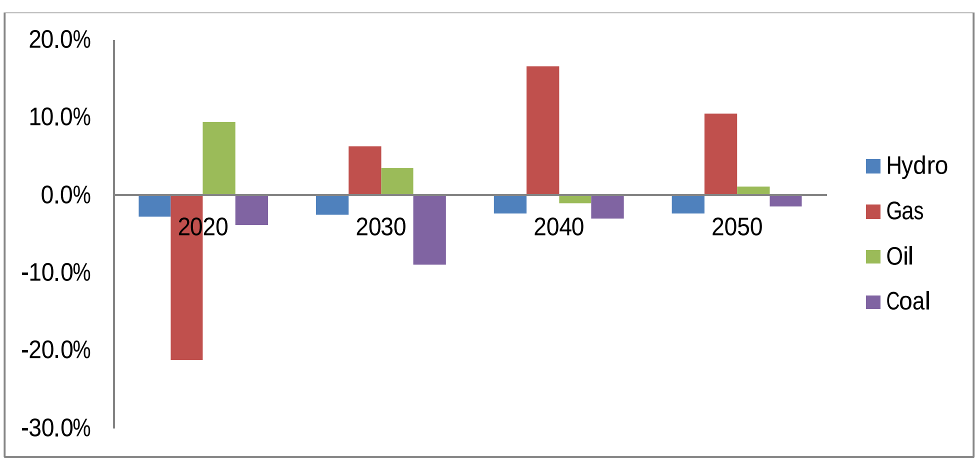

Figure 3.21: % Change in primary energy consumption due to water constraint

Impact on GHG emissions

It has been observed that water scarcity and its limited use in fact brings some extra benefits to the society in terms of reduction in CO_2 emissions from the energy sector. Due to increasing use of relatively less polluting fuels in energy generation (viz. natural gas) which are less water consuming as well, net CO_2 emissions reduces by around 6% until 2050 (Fig.3-22).

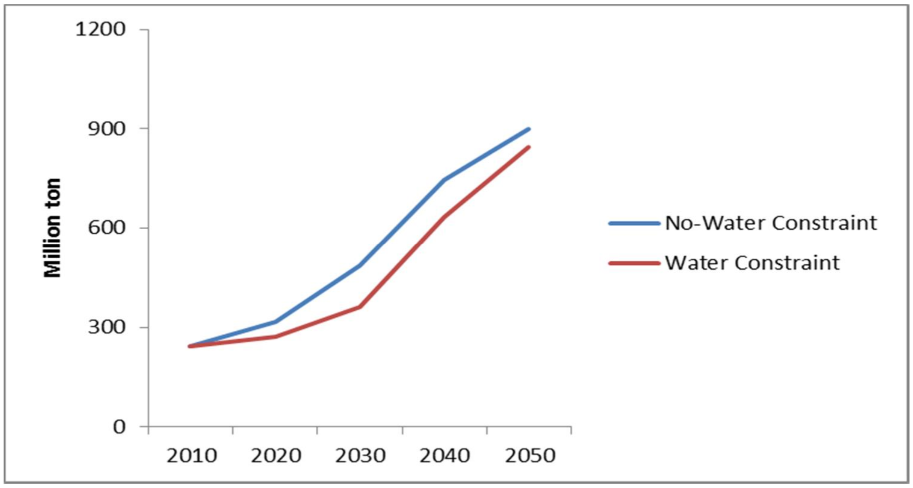

Figure 3.22: Impact of water constraint on CO_2 emission from power sector

Impact on energy sector investment

It has been observed that long term energy sector investment is also getting affected due to water constraint. Technologies with high water use coefficients like non conventional oil and gas exploration (shale gas, tar oil etc) are suspected to get affected in terms of reduced investment in the region (Fig. 3-23). These technologies need more than average water compared to the conventional fossil fuel extraction.

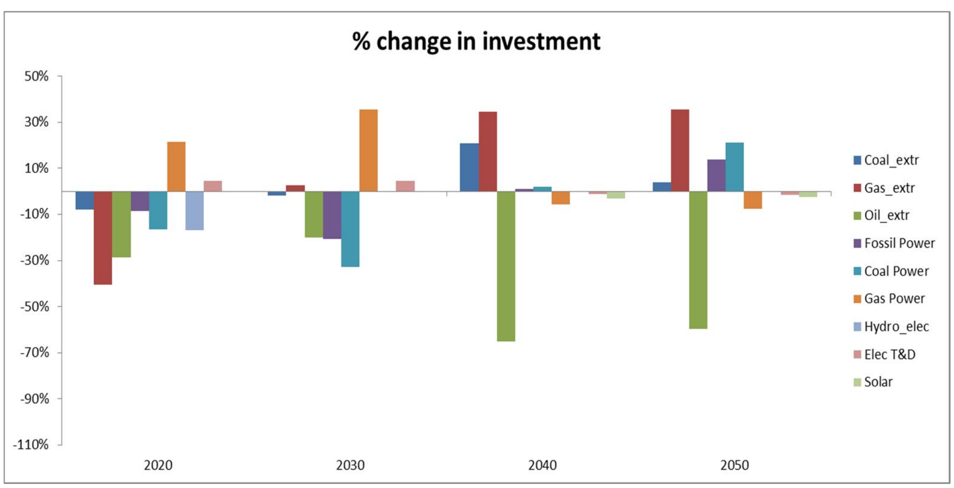

Figure 3.23: Impact of water constraint on energy sector investment

Impact on cross border energy trade

Another important parameter of judgment in the regional energy market is energy trade. The south Asia region especially India is having various long term energy trade projects either by grid interconnection or by building hydro power projects in the neighboring countries like Bhutan, Nepal and Afghanistan. It has been observed that such energy trading is suspected to be affected adversely due to water constraint. As we see in the figure below that among all other energy commodities, electricity trade gets affected most; the main reason is reduced hydro power generation. Such reduction in electricity trade in the region is going to be around 30% by 2030 (Fig. 3-24). Coal is another energy commodity which is going to get affected in the near future due to water scarcity mainly due to lack of water for coal washing. Dirty coal has lower international price than washed coal and thus the trade volume decreases.

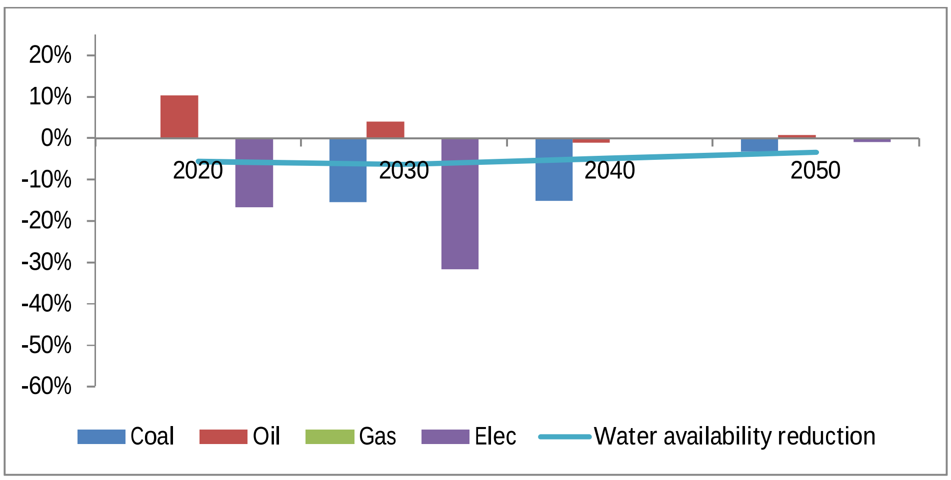

Figure 3.24: Impact of water constraint on cross boarder energy trade

3.10 Summary of findings

This section provides recommendations for addressing water risk to thermal power plants including amendments in the planning criteria, plant site related measures, demand side management and measures to improve water availability. These measures should not be seen in isolation or be seen to override other equally important economic, environmental and social considerations. These measures should be integrated in the long term water availability and competing water use planning, approval and implementation process of thermal power plants. Use of appropriate cooling technologies is expected to play an important role in terms of mitigating risk of power plant operation even in the scenario where all the measures to address water stress, water variability and water conflict issues have been undertaken.

3.10.1 Planning criteria for inland thermal power plants

The planning criteria for geographical distribution of inland thermal power plants should include long term water availability and competing water use, in addition to load centers, fuel availability, transportation, evacuation, local environment considerations, etc. The planning process should encourage locating thermal power plants in river basins that are expected to be at relatively lower water stress in 2050 – for example, locating power plants in no stress or water stressed according to Falkenmark water stress indicator. Narmada, Mahanadi, Godavari, Brahmaputra and Barak and Brahmani-Batarni have per capita water availability of more than 1000 m3/capita and hold coal reserves that are likely to be sufficient to meet the projected growth in inland thermal power capacity by 2050. Based on the model and other analytical assessment, it has been estimated that by 2050 India will be in severe necessity for water to meet the overall demand including power sector (See Figure 3.25). Situation will be further serious if we consider only surface water availability. Indian thermal power plants are mostly surface water fed and thus reduction in surface water availability will seriously affect the energy generation (See Figure 3.26). Following figures demonstrate the water supply and demand conflict mainly in the Indian subcontinent due to increasing demand in various sectors.

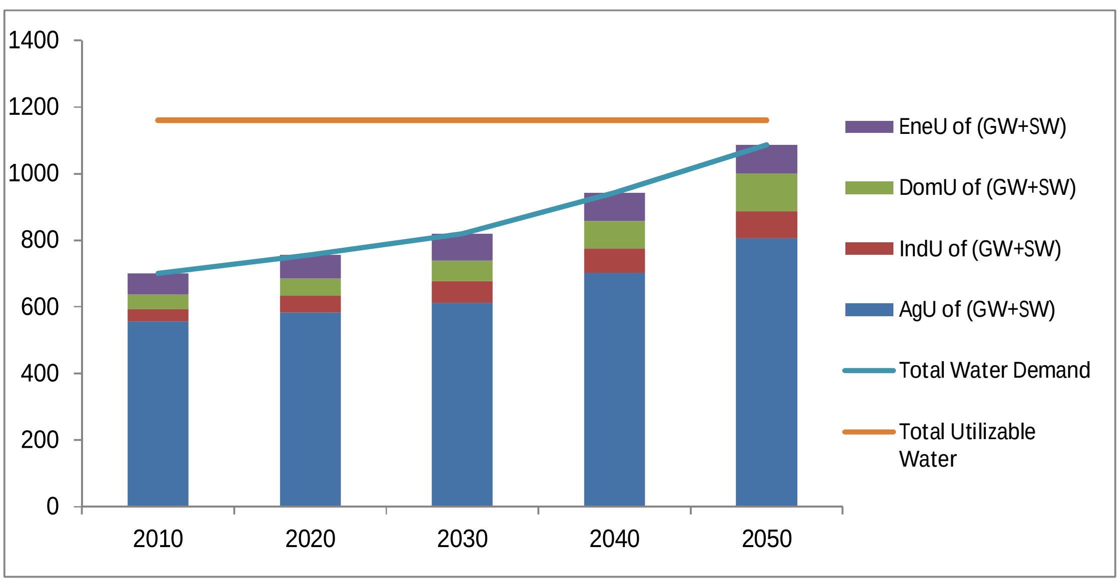

Figure 3.25: Water supply and demand conflict considering total water availability

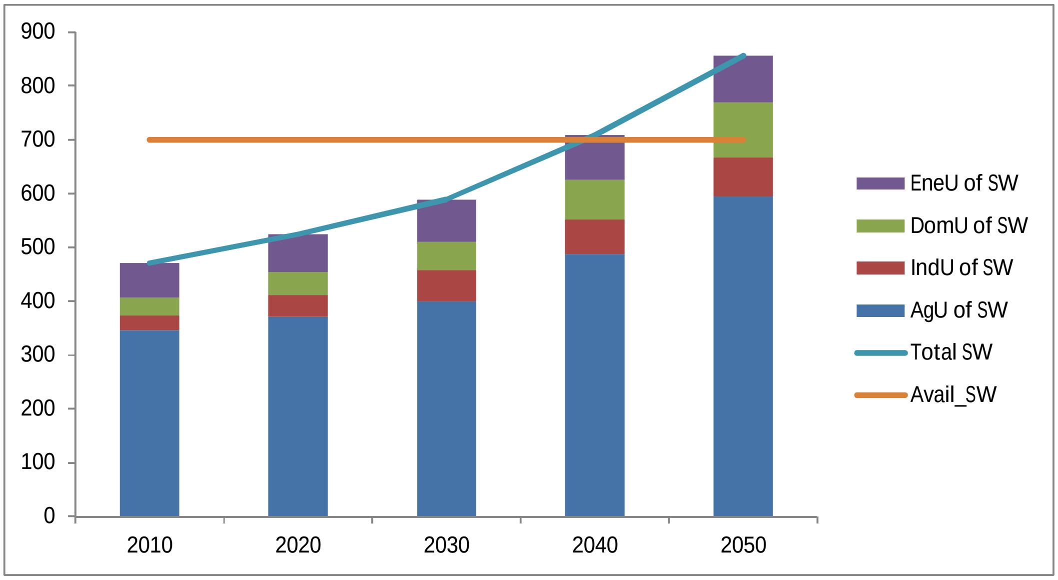

Figure 3.26: Water supply and demand conflict considering surface water availability only

3.10.2 Plant site related measures

The risk arising out of water variability is expected to increase, particularly in the context of climate change. Assessing the requirement of additional water storage at plant site and acquiring sufficient land for storage at the time of plant siting may reduce water variability risks. As per capita water availability decreases, the possibility of water conflicts with local communities is likely to increase. Engaging with the local communities and government in local watershed management to replenish watersheds will reduce the possibility of water conflicts. Such measures should be made part of the plant approval process by the Ministry of Environment and Forests and by the appropriate state government / central government that approves the investment.

Depending on the long term availability at the plant site and the competing water use, the appropriate government authorities should require the power plant developers to assess the appropriateness of cooling technology that is proposed to be employed while approving the project. Equally, the appropriate authorities should require an assessment that the power plant location has been optimized considering long term water availability and competing water use, among other things. 42% of the current thermal power capacity is owned by state power generators followed by central sector (36%) and private (22%) sector. The state power generators may face institutional barriers in implementing thermal power plants outside their home state. If the state power generators are expected to continue to play a significant role in thermal power generation in the year 2050, the state power generators should be incentivized to implement thermal power plants outside the home state in case the home state does not have sufficient water resources on a long term basis. Equally, the states that have sufficient water resources should encourage joint development of thermal power plants.

3.10.3 Demand side management

The end-use efficiency improvement in water consumption is targeted at 20% under National Water Mission through incentive mechanisms for water efficient technologies, engaging NGOs in activities related to water resources management (planning, capacity building and mass awareness), promote water conservation measures and expediting renovation and restoration of water bodies23. An increase of 20% water efficiency in irrigation sector has the potential to release 125 to 160 bcm of water at the national level. The IWMI water stress indicator is expected to change from 'overly exploited' to 'heavily exploited' for Indus, Krishna, Cauvery and Luna river basins if there is a 20% increase in water efficiency in irrigation sector.

Agriculture sector is a good representation of the water-energy nexus of a different kind. Subsidised / free power to agriculture sector has been stated to cause over exploitation and inefficient use of utilisable water resources. On the other hand, inefficient agriculture pump-sets are said to cause significant energy losses – both in the pump-sets as well as in the rural electricity distribution. Strengthening the agriculture sector through good agriculture practices, efficient irrigation techniques, efficient agriculture pump-sets and strengthening the rural electricity distribution will not only reduce local water requirements but bring down the electricity generation requirements also. Power plant developers should be encouraged to take a proactive role in promoting good agriculture practices in their nearby communities as part of their corporate responsibility activities.

3.10.4 Improving water availability

The river interlinking project envisages linking the water surplus river basins in India to the water deficit river basins. The project aims to provide a long-term solution to maintain equilibrium in availability and demand. The river linking projects is capital intensive and therefore it is important that the project is viewed as a win-win situation by the concerned states (ADB 2011). The river linking projects are expected to provide multiple benefits such as flood control, water for irrigation and electricity generation (ADB 2011). The dynamics for per capita water availability for thermal power plants may significantly change as a result of implementation of the river inter-linking project. The per capita water storage (225 m3/capita) is the lowest in India relative to comparable countries and world average (e.g. 1960 m3/capita for the United States and 1100 m3/capita for China; and

[23] http://moef.nic.in/downloads/others/Mission-SAPCC-NWM.pdf

world average of 900 m3/capita) (CWC 2010; Narula and Lall 2010; ADB 2011). Building water storage facilities is critical in addressing water availability and variability.

3.11 Conclusion

This chapter tries to identify the initial issues of water energy nexus by determining the demand for water by the energy sector to meet the needs of the economy. It has been observed that there is no such systematic approach taken by the regional governments to assess the long term water availability exclusively for energy sector. Water for human and commercial consumptions are more or less monitored and reported but there is a big gap in such estimation for energy sector. However, the energy sector in the Developing Asia region (mainly South Asia region) is heavily water dependent and more precisely water inefficient in the context of specific water consumption for energy. As a matter of fact, Asian developing economies especially the countries like India are very vulnerable to the long term water availability for energy production. Such countries are heavily dependent on thermal technologies especially coal and natural gas for their cheaper and reliable power generation and thus more dependent on water compared to other countries having alternative technologies. In Asia, until 2050 thermal technologies for energy generation and subsequently dependence on fossil fuels like coal and natural gas will be predominant. Our assessment shows that even under the most optimistic scenario of emissions reduction by deploying renewable technologies, thermal technology dependence will continue to such an extent where water scarcity may disrupt the long term energy planning of the countries. India being one of the fastest growing economies in the world, reliable energy supply is the most important issue for it. However, the chapter found that currently available long term energy planning (mainly under the 12th Five Year Plan) has hardly considered the issues of water resources constraint in the planning. Though, the Central Electricity Authority and Federal Regulators are concerned about it, but efforts are yet to be pushed up to sensitized the policy makers. The chapter demonstrated that within the range of 2040 to 2050, there is will be serious conflict among various water users' which can dampen the economic and social development significantly for the country. Increasing water demand for electricity generation will intensify inter-sectoral conflicts for freshwater. Thus, to mitigate such conflicts for freshwater appropriate policies should be taken in a timely manner. Such policies could be the introduction of water efficient technologies in power plants, promoting low water consumptive renewable energy (wind, solar photovoltaic) and the implementation of water demand management approaches for major water users. Moreover, India and the developing nations of Asia being in the stage of economic growth and prosperity, they are rather in an advantageous position to avoid long term technology and investment lock in by taking prudent decision of sustainable investment in the energy sector. Considering water energy nexus while building long term planning for energy could be considered as a risk hedging measure for investment indeed,

Though this chapter tries to measure quantitatively as accurate as possible to determine the specific water consumption of different energy technologies used in this region, but still plenty of assumptions are taken to cover the data gap. It has been observed that in most of the cases government and the energy companies do not estimate such water coefficient. Therefore, it is an important task ahead to build a reliable regional database for specific water consumption for energy technologies to further improve this assessment with more accuracy. It is also important to consider inter sectoral conflict of water use among various other demand categories in a long term manner to have precise estimation of sectoral allocation of water. Finally, it is also important to consider the reuse and recycling of waste water for energy sector to mitigate the impact of water shortage indeed.

3.12 Improvement suggestion for SE4ALL tracking on resource constraint

Improved energy access and improved cooking fuel use are the two major objectives of SE4ALL program. In this chapter we demonstrated that water resource is a key factor for sustainable electricity generation and supply in the Developing Asia region. And unless the region gets sufficient and uninterrupted power supply meeting these targets will be difficult. Therefore, based on this finding we have suggested certain additional indicators to enhance the potentiality of achieving the target of energy access set under the SE4ALL program. Table 3-15 shows the additional indicators proposed to enhance the potentiality of success of the target of universal access to modern energy under SE4ALL.

Table 3-15: Indicators for energy access tackling water resource constraint

SE4ALL Objective	Existing Tracking Indicators	Proposed Indicators
Universal Access to Modern Energy Services	% of population with electricity access % of population with primary reliance on non-solid fuels	• Annual water availability for power generation (Unit: Million Cubic Meter/year) • Specific Water Consumption of Power Plant (Unit: M^3 / Gwh)

Annual water availability for energy generation indicator is required to control and monitor water availability for power generation in a long term manner and under the influence of climate change, increasing other sectoral demand and various natural calamities. Existing water availability and supply data do not disaggregate energy sector demand from industrial demand. Therefore, it is important to create the energy sector water demand as a separate indicator for monitoring. Similarly, there is no systematic recording of water use for each unit of power generation in this region. Under the water stressed condition to continue with same level of power generation, it is important to improve the water use coefficient of each power plant. If the water coefficient is high for a power plant in water stressed region, it is a matter of concern. Therefore, appropriate measure should be taken to reduce the coefficient value (specific water consumption) either by improving water use efficiency within the power plant or by changing the water use technologies including cooling system and boilers etc.

Chapter 4
Regional Energy Cooperation[24]

4. Introduction

Over the last couple of decades, the East Asian Summit (EAS) region consisting of 16 member countries including China and India attained the highest level of economic growth in the world.25 As a consequence, energy demands in this region have also grown at the fastest rate in the world. International Energy Agency (IEA) estimated that by 2030 the cumulative energy demand of the whole EAS region will be around 7-8 Billion ton of oil equivalent (Btoe) to maintain the same rate of economic growth (IEA,2008). At the same time, the EAS region has huge untapped potential energy sources with relatively cheaper production cost.

Currently, except for a few bilateral and multilateral initiatives, the EAS member countries are independently trying to secure their respective energy supply chains. Under increasing threat of resource and environmental constraints along with the ongoing market structural change, depending heavily on domestic actions becomes risky, expensive and unreliable. Moreover, energy resources are geographically widely spread out with varied potentials of extraction in this region and so the technical and financial capacities of the governments to use them. This is further hindering rational extraction of those resources, processing and utilization in an efficient and effective way. The region's energy demand pattern and future prospects are also varied in nature from country to country. There is extreme variability in energy market condition which is a stumbling block for narrowing down the current development gap of this region. Table 4-1 shows the widely varied ratios of energy production to supply (energy self-sufficiency) of the major countries in this region.

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[24] Source of this chapter:

1. Bhattacharya, A. and S. Kojima (2010), 'Technical Report: *Economic Impact Analysis of East Asia Energy Market Integration'*, in Shi, X. and F. Kimura (eds.), Energy Market Integration in the East Asia Summit Region: Review of Initiatives and Estimation of Benefits. ERIA Research Project Report 2009-13, pp.40-100.
2. Bhattacharya, Anindya and Kojima, Satoshi. 2011. *Energy Market Integration In East Asia: What an Economic Analysis Tell Us*? Policy Brief 2011/10. Institute for Global Environmental Strategies (IGES). Vol.15. Hayama.

[25] EAS member countries are; Australia, Brunei Darussalam, Cambodia, China, India, Indonesia, Japan, Korea, Malaysia, Myanmar, New Zealand, Philippines, Singapore, Thailand, and Viet Nam.

Table 4-1: Ratios of domestic energy production to supply (descending order in 2008)

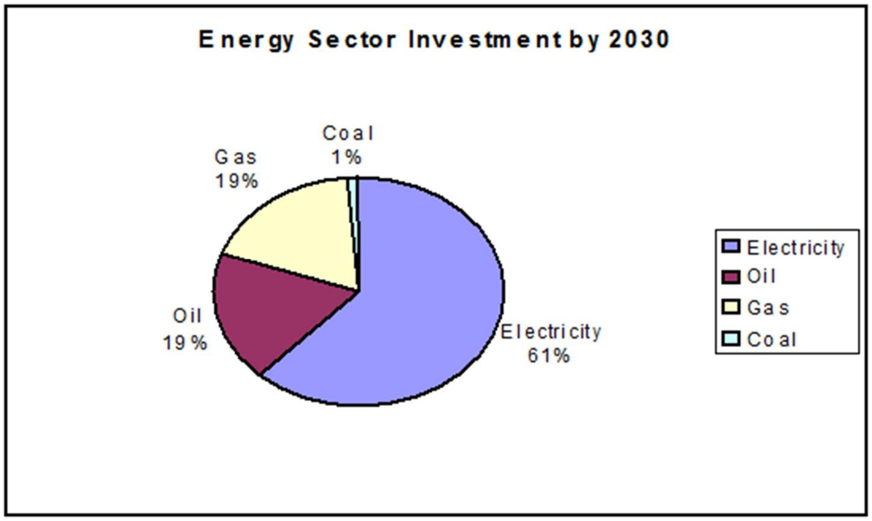
Country	2000	2008
Australia	2.16	2.30
Indonesia	1.55	1.75
Myanmar	1.23	1.47
Malaysia	1.61	1.28
Vietnam	1.30	1.20
China	0.97	0.94
New Zealand	0.85	0.87
India	0.80	0.75
Cambodia	0.81	0.70
Thailand	0.61	0.60
Philippines	0.49	0.57
Korea	0.17	0.19
Japan	0.20	0.17

Source: IEA, 2010. Nuclear energy is counted as domestic energy production.

Except some countries like Australia, Indonesia, Malaysia, Vietnam and Myanmar, most EAS member countries are below 1, which means their external dependency on energy supply. Apparently, the countries like Japan, Korea, India, Philippines need robust energy supply chain for the future to secure their growth prospect and thus rationale for regional cooperation arises.

4.1 Cross border energy infrastructure development and cooperation

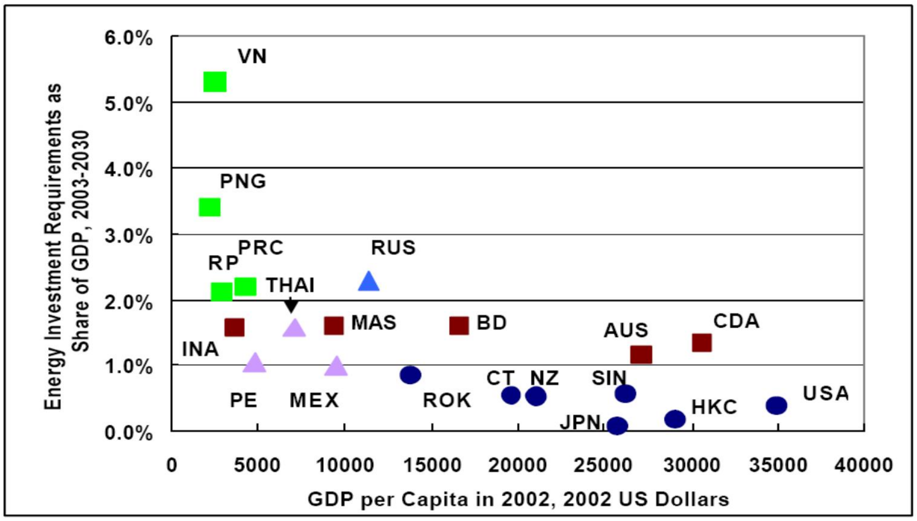
Energy sector investment is one of the most critical sectoral investments in the modern world which are directly linked with the economic and social development of the countries. This is even more important for the developing countries, especially in Asia, who are economically growing at a very fast rate compared to the rest of the world. It has been estimated (IEA ,2003) that cumulative total global investment, required only for energy sector, is around 16 trillion US Dollars between 2003 and 2030 to meet the energy demand by that time out of which Asian developing countries require around 4 to 5 trillion US Dollars to fuel their economic growth. Figure 4-1 shows the percentage distribution of the investments in various categories within the energy sector which shows that the electricity sector is the single largest category for investment followed by oil and gas sectors.



Source: IEA Energy Investment Outlook 2003

Figure 4.1: Energy sector investment pattern

Nearly about 70% of the world's total primary energy demand increase will occur in the developing and the transitional economies and its majority will occur in Asia, especially in China, India and Indonesia. However, there is no dearth of primary energy resources so far to meet the projected demand in the world but the most challenging part now is how to mobilize the required finance and investments to convert those resources into usable energy in the given time frame of the requirement. Compared to the developed countries in the OECD region, energy sector investment for the developing countries like China, India, Indonesia are quite significant in terms of percentage of total GDP of those countries. It has been estimated that the developing countries necessitate bigger share of their GDPs to meet the energy sector investment need compared to the developed countries and a coordinated approach to meet the target of energy investment is thus crucial for them. For India and China, the scale of investment will be around 2.5% of their GDPs by the year of 2030 which are quite significant in an absolute term indeed (IEA 2007). Nevertheless, to fuel the economic growth for these countries, reliable and affordable supply of energy is also very important in terms of achieving required level of energy security. The Fig 4-2 shows the country-wise energy sector investment burden in terms of GDP share. This figure below shows that lower the economic development of the country higher the needs of the energy sector investment. For example, Vietnam needs around 5.2% of its GDP to meet the energy sector investment while the United States needs only 0.3% of its GDP.



Source: IEA Energy Outlook 2007

Figure 4.2: Energy Investment Burden and Development

Considering the vulnerability of the energy situation and massive investment requirement associated with various political, social, financial and engineering uncertainties, ASEAN and other major developing country cooperation in Asia like SAARC and GMS have been involved in developing certain coordinated regional cross border energy infrastructure development initiatives since last two decades to minimize the investment costs and reduce the risks of investments and engineering difficulty and overall to achieve a certain level of energy security in the long run. The major rationale for such cross border energy projects could be further listed out as follows which are basically motivating the region to go forward with such coordinated initiatives:

- Locational difference between energy demand points and primary energy resource supply points. There are several cases where the smaller and less developed countries are endowed with higher amount of primary energy resources compared to the bigger and richer countries needing more energy. Thus, cross border energy projects can balance the demand and supply.
- Achieving energy security through energy trade. Cross border projects provide energy security by diversifying energy forms and resources and by lowering the cost of supply.
- Substantial benefits of the smaller exporting countries. Cross border projects can open a new channel for significant amount of national income for the small exporting countries. For an example, Bhutan can earn up to 25% of its GDP by selling power to India through the cross border power grid interconnection.

4.2 Objective of this study

It is envisaged that in the process of energy market integration in the EAS region, cooperating countries will liberalize their energy commodity trade through respective tariff and export subsidy/tax removal. This is to achieve unification of border taxes to the energy traded commodities. This is a step forward towards the formation of regional market of energy commodities. The objective of this charter is therefore, to evaluate the impact of energy commodity trade barriers removal on economy, society and environment as a whole. This is envisaged to demonstrate that regional trade cooperation will enhance the regional economic activities and will help increasing the GDP as well. Similarly it is also been evaluated how the cross border energy infrastructure projects including power grid interconnection can enhance the situation of power supply in the market and can improve the macroeconomic condition of the participating countries followed by the assessment of environmental impacts. Finally this chapter is to investigate the impacts of energy commodity trade liberalization followed by cross border energy infrastructure development on sufficient energy supply in the network which can help the SE4ALL to achieve the objective of energy access.

4.3 Detailed model description

We employed the Regional Environmental Policy Assessment (REPA) model for assessing the potential impacts of policy scenarios of energy market integration in the region . The REPA model is a multi-regional computable general equilibrium (CGE) model developed based on the GTAP-E model (Burniaux and Truong 2002) for conducting integrated policy impact assessment encompassing environmental, economic and poverty impacts in East Asia (Kojima 2008). The current version of the REPA model employs 22-region 32-sector aggregation of the GTAP database Version 7 (see Table 4-2) in which all the 16 EAS (East Asia Summit region) members are treated as a single region.[26] The sectoral aggregation maintains the most detailed energy sector (commodity) classification of the GTAP database where six energy sectors (coa, oil, gas, p_c, ely, and gdt) are classified.

[26] GTAP Version 7 data set aggregates Brunei Darussalam and Timor-Leste as one region (labelled as other South-east Asia), but we assume that this region represents the economy of Brunei Darussalam as its GDP share based on 2008 World Bank GDP ranking reaches 95.8%.

Table 4-2: Sectoral mapping and clarification

No.	Code	Sector classification	No.	Code	Sector classification
1	pdr	Paddy rice	17	lum	Wood products
2	ogr	Other grains	18	ppp	Paper products, publishing
3	v_f	Vegetables, fruit, nuts	19	p_c	Petroleum, coal products
4	osd	Oil seeds	20	crp	Chemical, rubber, plastic products
5	c_b	Sugar cane, sugar beet	21	i_s	Ferrous metals
6	lvd	Livestock and daily	22	nfm	Metals nec
7	oag	Other agriculture	23	mvh	Motor vehicles and parts
8	frs	Forestry	24	ele	Electronic equipment
9	fsh	Fishing	25	mfn	Manufactures nec
10	coa	Coal	26	ely	Electricity
11	oil	Crude oil	27	gdt	Gas manufacture, distribution
12	gas	Gas	28	cns	Construction
13	omn	Minerals nec	29	tpn	Transport nec
14	pcr	Processed rice	30	atp	Air transport
15	fdp	Food products	31	dwe	Dwellings
16	twl	Textiles, wearing apparel and leather	32	osv	Other services

4.3.1 Recursive dynamic setting

The REPA model incorporates dynamics towards 2020 by solving for a series of static equilibria connected by exogenous evolution of macroeconomic drivers. For each time step, the following macroeconomic drivers were exogenously shocked to update the data sets:

- Population
- Capital stock
- Skilled and unskilled labour
- Economy-wide total factor productivity (TFP)

Except for economy-wide TFP, growth rates of exogenous drivers and GDP were estimated based on the unpublished macroeconomic projections of the Center for Global Trade Analysis at Purdue University. Then, growth rates of economy-wide TFP were obtained by calibration against the projected GDP growth and other macroeconomic drivers.

It might be worth noting that the employed methodology does not use equation of motion of physical capital to update the stock of physical capital. The employed methodology assumes that the evolution of the economy during each time step is represented as the shift of steady-state equilibrium caused by exogenous shocks. This method is consistent with the steady-state equilibrium assumption underpinning static general equilibrium theory. The current study employed single time step for the entire simulation period (2004-2020).

4.4 Policy scenario for simulations

Here we have described two policy scenarios that have been tested on a regional market of East Asia Summit. Policy scenarios are developed based on the ideas of promoting the electricity supply in the market with affordable price and with required reliability of services. In the context of achieving the target of achieving 100% increase in access to electricity followed by reduction of solid fuel use in cooking, we have created two major scenarios of energy commodity trade barrier removal and enhancing cross border energy infrastructure development and cooperation.

4.4.1 Removal of energy commodity trade barriers

This policy scenario represents complete trade liberalisation of energy commodities. This scenario is simulated by removing all the import tariffs and the export subsidies (or taxes) of energy commodities among 16 EAS members reflected in the base data. Please note that these figures are estimated based on the two bilateral imports values evaluated at the world price and the market price, recorded by the GTAP database. Some positive tariff rates may be resulted from very small import values, which are often generated during the process of balancing social accounting matrix. For example, the database records the following values corresponding to coal imports from Singapore to India: 0.00106 million USD at the market price and 0.00092 million USD at the world price. Because these tariff rates do not affect our trade liberalisation simulation, we did not scrutinise whether these small trade values reflect actual trade flows or merely fictional values for balancing social accounting matrix.

4.4.2 Physical linkage of energy infrastructure

Originally it was planned to assess the impacts of physical linkage of energy infrastructure by removing international margin transport costs of energy commodities among the EAS members, but it was found that no significant margin transport costs are recorded in the base data in 2004. Instead, we refer to a previous study on potential impacts of cross-border energy infrastructure development in order to provide policy implications of physical linkages of energy infrastructure (Bhattacharya and Kojima 2008).

Bhattacharya and Kojima (2008) assumed that the cross border electricity infrastructure (CBEI) projects substitute a part of electricity development and that a half of the public investment directly contributes to capital accumulation of the electricity sector and the remaining portion is spent for government purchase of the outputs of the other services sector that include public administration etc. Bhattacharya and Kojima (2008) used a previous version of REPA model with the GTAP database version 6 (corresponding to the year 2001), and conducted simulations with giving the following four types of exogenous shocks to the database updated from the year 2001 to the year 2020:

- Total baseline public investment by 2020 for electricity sector without CBEI projects
- Incremental power generation between 2001 and 2020 due to the above baseline investment without CBEI project
- Total public investment by 2020 for electricity sector with CBEI projects
- Value of power traded between two countries due to CBEI projects

Then, the corresponding changes in capital stock in the electricity sector, in government purchase of outputs of the other services sector, and in outputs of the electricity sector due to electricity trade were endogenously solved.

4.5 Policy impact analysis

In this section we have analysed the impacts of policy measures to remove energy commodity trade barriers in terms of removing export and import duties and non-tariff barriers and also simulated a situation where a cross border energy infrastructure project is developed. The impacts are measured keeping in view the objectives of increasing energy supply in the market so that it access to energy can be increased and also more people get access to non-solid cooking fuels like gas, electricity and kerosene. Here we have analysed the impacts under two major categories: a) impact of national economy and b) impact on energy commodity production.

4.5.1 Impact of energy trade liberalization

Under this policy scenario energy commodities are expected to be traded freely within the region. Free trade arrangement of energy commodities will have mixed economic impact on the regional economy of the EAS. Heavily export driven countries are expected to be relatively big loser while the energy importers could be at better off condition.

Impact on national economy

In terms of real GDP, some countries in the region gain but some countries lose under this trade liberalisation scenario. However, such loss is relatively small and in some cases negligible (e.g. Australia). Table 4-3 shows the percentage changes in GDP (in year 2020) under this trade liberalisation scenario.

Table 4-3: Impacts of energy trade liberalisation on real GDP (Year 2020)

Region	% change from 2020 Baseline scenario
China	0.000
Japan	0.003
Korea	0.052
Cambodia	0.128
Indonesia	-0.065
Lao PDR	-0.130
Myanmar	-0.044
Malaysia	-0.078
Philippines	0.011
Singapore	-0.070
Thailand	0.011
Vietnam	0.263
Brunei Darussalam	-0.147
India	0.368
Australia	-0.002
New Zealand	-0.003
Rest of the World	-0.010
World Total	0.000
EAS Total	0.024

In the general equilibrium world reflected in the CGE models, economic impacts of trade liberalisation occur through complicated inter-sectoral and international linkages. For example, such energy trade liberalisation negatively impacts Australian national real outputs. The largest negative impacts are observed in non-ferrous metal and in other manufacturing sectors. This real output reduction accounts for Australian real GDP loss to a certain extent. On the other hand, the real GDP loss of Singapore is mainly due to the reduction in trade balance, as trade liberalisation will undermine comparative advantage of the current free trade policy of Singapore. Our simulation results are consistent with our expectation that trade liberalisation will improve economic performance as a whole even though some members or sectors will win and the others will lose.

Impact on sectoral output

Table 4-4 shows sectoral output change due to energy trade liberalisation from base line values in 2020. All the major coal producing countries gain in their production except India. Indian coal sector will reduce its output by around 1.2% in 2020. Similarly, the petroleum product output in Vietnam reduces by around 13% but that in Cambodia increases by around 11%. On the other hand, countries like Australia will increase its coal production by around 0.3%. Indonesia, China and Vietnam will also increase their coal outputs.

Table 4-4: Impact of trade liberalisation on sectoral real output: difference from baseline (%)

Region	Coal	Crude Oil	Gas	Petroleum products	Electricity generation & distribution
Cambodia	0.11	0.22	-0.04	10.85	0.22
China	0.00	0.02	-0.03	-0.33	-0.02
India	-1.21	-0.03	0.01	1.00	1.46
Indonesia	0.20	0.18	0.02	-1.08	-0.21
Lao PDR	-0.09	-0.02	0.00	-2.35	0.33
Malaysia	0.13	0.14	0.31	-0.18	-0.31
Myanmar	0.12	-0.08	0.29	-0.08	-0.63
Philippines	-0.13	1.41	-0.01	5.06	0.06
Singapore	0.00	0.14	-0.36	5.02	0.16
Thailand	0.03	0.06	-0.01	1.08	0.00
Vietnam	0.13	-0.15	-0.48	-13.39	0.06
EAS Total	0.01	0.08	0.08	0.63	0.11

Source: Model estimated

Further investigation revealed that the domestic coal price in India will drastically reduce by around 28% compared to the 2020 baseline price. This price change can be attributed to the reduction of domestic coal demand due to the cheaper imported coal as a result of trade liberalisation. In fact, due to high ash content, domestically produced coals in India are not attractive to the coal users like power plants, steel and cement manufacturing companies. Power producing companies can replace their supply of domestic high ash content coal by the better quality imported coal if the coal trade is liberalised. Thus under the trade liberalisation scenario, Indian coal import is expected to increase by 78% from the 2020 baseline level as shown in Table 4-5.

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Table 4-5: Percentage change in energy import values compared to the baseline 2020

Region	Coal	Crude Oil	Gas	Petroleum products	Electricity generation & distribution
China	3.421	-0.446	-2.427	10.048	-0.714
Cambodia	16.726	26.923	15.315	63.946	-0.671
Indonesia	41.033	3.846	110.274	6.306	1.709
Lao PDR	-7.358	-5.729	-0.905	23.383	-1.481
Myanmar	62.136	-4.911	86.141	1.042	3.140
Malaysia	-1.705	10.000	88.387	4.000	1.481
Philippines	4.146	11.912	1.708	4.258	-1.733
Singapore	-1.754	9.231	1.351	2.963	0.741
Thailand	-3.873	2.157	1.047	12.472	0.000
Vietnam	18.807	-6.494	-23.419	22.727	0.420
India	78.100	3.455	6.506	14.570	-17.508
Rest of the World	-2.159	-0.943	0.000	0.000	0.000

Source: Model estimated

4.5.2 Impact of cross border energy infrastructure development

We have (Bhattacharya and Kojima, 2008) have assessed the potential impacts of the following two major cross border infrastructure projects:

- *China – Thailand Power Trading: Jinghong and Nuozhadu HPP Project*
- *Malaysia-Indonesia Power Grid Interconnection (Peninsular Malaysia- Sumatra, Indonesia 600 MW PTL and Malaysia - West Kalimantan 300 MW PTL)*

We first estimated the benefits of baseline scenario of national energy investment plan without any cross border projects. Then, the impacts of the above cross border projects were assessed as the difference from the results under the baseline scenario. As only a couple of projects were selected, the impact on GDP was very small, as shown in Table 4-6. However, positive economic impacts in terms of GDP were observed in all the participating countries.

Table 4-6: Impact of energy infrastructure linkage on GDP

Country/region	BAU (2020) (Million USD)	Baseline (Million USD)	China-Thailand + Malaysia-Indonesia Project (Million USD)
China	3,322,748	3,361,013	3,361,089 (0.002) [1.15]
Indonesia	291,015	293,943	293,952 (0.003) [1.009]
Malaysia	183,687	183,889	183,843 (-0.024) [0.08]
Philippines	120,246	120,206	-
Singapore	160,161	160,048	-
Thailand	213,538	220,868	220,914 (0.02) [3.45]
Viet Nam	53,432	53,473	-
Other ASEAN	111,701	111,529	-
Rest of the world	7,570,850	7,560,629	-

(xx) : shows the % change of GDP to the baseline 2020 energy investment scenario

[xx]: shows the % change of GDP to the BAU scenario without any national energy investment

Results indicates that having cross border energy infrastructure development projects are beneficial to all the participating countries in terms of having overall macroeconomic benefits.

4.6 Conclusions

Model result demonstrates that due to energy commodity trade liberalization, participating member countries are getting benefits in various energy sectors within their economies which have direct or indirect impacts on the targets of SE4ALL. Based on the impact assessment conducted here using top down multi regional CGE model, it has been observed that both energy commodity trade liberalization at a regional scale and regional cooperation in energy infrastructure development are both having positive impacts on regional economy as a whole if not with all member countries. It has been further observed that sectoral output also increases in many cases in the region. For example, due to trade barrier removal Indian electricity sector output grows additionally by 1.46% compared to the business as usual situation. Given the volume of power generation in India (around 1100 TWh in 2012) and its expected growth rate, 1.5% additional generation is significant for the country. It can be in the range of 30-35 Billion Units of electricity. India at present is having more than 400 million people out of electricity connection. As a matter of fact, energy trade liberalization can therefore, supply around 7.5 Kwh of electricity per capita to each of these people who are having no electricity connection. Further investigating the reasons behind the increase electricity supply, it has been observed that due to trade liberalization, Indian power sector gets easier access to fuel supply (mainly coal) and can enhance its declining plant load factor (PLF) which around 65-70% on average now. Lower PLF indicates lower utilization of assets and loss of revenue to the power companies and the government as well. Trade liberalization can therefore, address the issue of lower PLF of Indian power sector and can improve the generation without new capacity addition. This is further confirmed by noting the positive impact on GDP for India under the trade liberalization condition. Similarly in the Developing Asia region as a whole, electricity supply may increase compared to a situation where trade barriers exist. In this case we have observed around 0.11% additional power flow in the network just due to trade liberalization in the region by 2020. Trade liberalization heavily affects the export and import of energy by the countries and the region as a whole. All major resource rich countries become heavily import driven. Indonesia observes more than double gas import compared to BAU scenario by 2020 with 40% increase in coal import as well. Indian coal import increased by around 78% compared to BAU scenario by 2020. These findings indicate that trade liberalization opens the pathway of easy flow of energy resources in the countries where the demand increases rapidly. Therefore, trade liberalization has positive effect on having sufficient supply of energy in the system which can support SE4ALL to achieve the target of better energy access.

4.7 Improvement for SE4ALL tracking on regional energy cooperation

It has been assessed that, to provide better access to modern energy to more number of population and also to provide access to non-solid fuel for cooking, having sufficient amount of electricity supply is essential. Supply of electricity in the national and regional power grid can either be achieved domestic production or by import. Given the non-uniform distribution of energy resources across the Developing Asia region, it is beneficial to have a seamless trading system of energy commodity and electricity as well among the countries. Such system can not only reduce the cost of energy supply but also can conserve energy resources which reserve to production ratio. In the Developing Asia region cost of energy supply is an important factor for its access to more number of people. If the cost of supply increases it will be unaffordable to poor people who are more in number and are the key target beneficiaries for SE4ALL. Based on our analysis we have identified three additional indicators (see Table 4-7) to be monitored so that the potentiality of achieving the overall target of access to modern energy can be increased under the SE4ALL program.

Table 4-7: Indicators for energy access with regional energy cooperation

SE4ALL Objective	Existing Tracking Indicators	Proposed Indicators
Universal Access to Modern Energy Services	% of population with electricity access % of population with primary reliance on non-solid fuels	• Trade and non trade barriers (TBs & NTBs) for coal/oil/NG (export & import duties) (Unit: % of duties levied) • Percentage (%) of installed power generation capacities from cross border projects. • Percentage (%) of power flows in the grid coming from cross border projects

Energy commodity trade indicators (export and import duties) will allow the policy makers to monitor how the regional energy market is growing. Ideally it should go down to zero where free trade will prevail and market will get rid of all sorts of distortion. Price rationalization of energy commodity will take place under non tariff regime only. Number of cross border projects and corresponding contribution to the national and regional power grid will further assist the policy makers to monitor how cost effectively and resource efficiently energy sector development is happening which can be sustained for longer period of time and can provide affordable energy to the beneficiaries. So more number of cross border energy projects and higher the % of electricity trading is happening through cross border projects will support SE4ALL's access to modern energy objective positively.

Chapter 5

Energy Pricing and Reform[27]

5. Introduction

Asia's rapid economic growth has put it on track to eradicate "extreme" poverty, defined by the World Bank as daily consumption of less than $1.25 per person, by 2030. However, the Asian Development Bank debated this as too low given that nowadays, things like mobile phones are seen as necessities. ADB has calculated a more suitable daily minimum of $1.51. This lifts Asia's 2010 poverty rate to nearly one-third of the population, adding 343m people more to the ranks of the poor. The ADB believes food insecurity, energy insecurity and the risks of natural disasters, global economic shocks and the like, should also be taken into account when measuring poverty. This would further raise Asia's 2010 poverty rate, to nearly 50%.

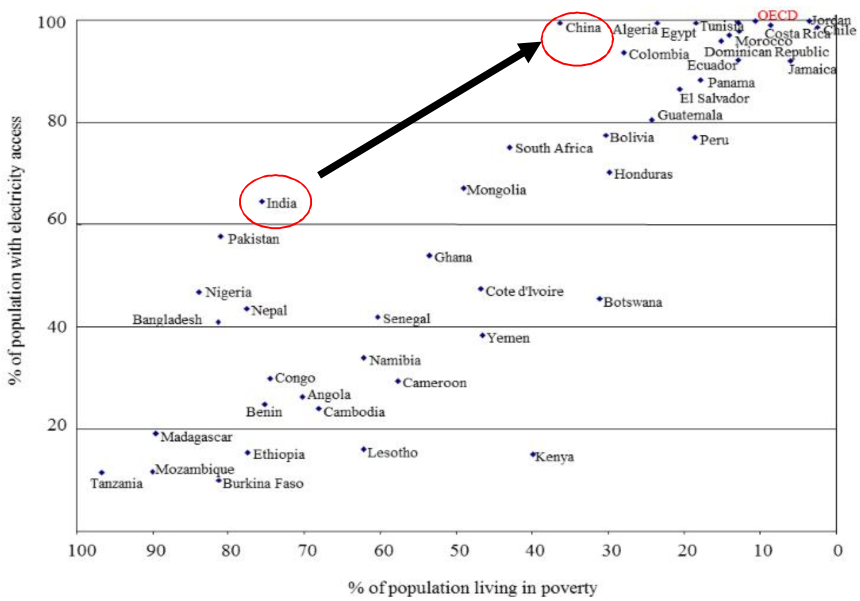
Source: ADB 2010

Figure 5.1: Poverty in Asia

It has been estimated that (see Fig 5-1) that more than 1 billion population in Developing Asia region is living under the $1.51 per day at 2005 PPP term who are living in marginal condition without access to modern sources of energy and electricity (ADB, 2010). As a matter of fact, the

[27] Source of this chapter: Bhattacharya, Anindya and Kojima, Satoshi. 2014. *Price Reform and Enhanced Investment in the Energy Sector.* In Wu, Yanrui, Kimura. Fukunari, and Shi, X. (eds.), Energy Market Integration in East Asia: deepening understanding and moving forward. Routledge. New York. (page:130-143). http://www.ewidgetsonline.net/dxreader/Reader.aspx?token=c402a7cb79b3456ba75beb3a2cd9cc88&rand=968615295&buyNowLink=&page=&chapter=

Developing Asia region is the poorest region in the world in terms of energy poverty covering the issues of lack of electricity supply and access to modern cooking fuels (non-solid fuels). It has been further estimated by the International Institute for Applied Systems Analysis (IIASA) in the Global energy Assessment report in 2012 that the Asian Developing region itself needs around 150-160 Billion USD of investment by 2030 to provide modern non-solid cooking fuels to the poor and around 80-90 billion USD of investment by 2030 to provide electricity supply to them (GEA, 2012). Figure 5-2 below shows the relationship between accesses to electricity versus poverty level across the world region.



Source: Global Energy Assessment Report, Chapter 2 (p.165)

Figure 5.2: Energy access versus poverty

For the country like India having more than 70% people living in poverty having just above 60% population having access to electricity, is a mammoth task to move towards position of China or other OECD countries. This is a situation of vulnerability of the majority of the Indian population to have sustainable development and growth. Moving from high poverty low electrification situation to low poverty high electrification regime, affordability of energy is a crucial factor. In this region due to very high level of poverty, affordability of energy is crucial for its wider acceptability. Just to keep the energy prices low the regional governments are actively using the energy subsidy fiscal measure to provide affordable energy to this huge number of people in this region. Bhattacharya and Kojima (2012) estimated that around 80-90 billion USD (at 2008 USD value) of subsidy amount is spent in energy sector in Developing Asia region on every year to provide cheaper fuels. Globally it has been estimated that around 550 billion USD is spent on energy subsidy which 5 times higher that the money spent in renewable energy sector (IEA, 2012). Major effects of such continued subsidy in the energy sector are not only crippling the governments to spend on other developmental sectors but also continuously weakening countries' economic strength. It has become a vicious energy financing cycle in the region which is continuously pulling it down. As mentioned before that the region needs around 250 billion USD to provide access to energy including electricity supply and modern cooking fuel, removal of existing level of subsidy (around 80 billion USD) can therefore, substantially support the program.

5.1 Objectives of this study

The common notions about energy subsidy removal evolve around the ideas of negative impact on people's disposable income and social welfare followed by national economic loss. However, decomposition of subsidy beneficiaries demonstrates that majority amount of subsidy goes to the affluent section of the society due to their better access to fuel supply. Subsidies are given on modern energy fuels like petrol, diesel, LPG , kerosene etc. Given the access situation in the region it is estimated that more than 60% of subsidized fuels are used by the non-poor in the region. Thus energy subsidy is neither helping poor people nor helping the nation as a whole.

The main objectives of this chapter is therefore, to demonstrate that

a) Energy subsidy removal can enhance the output of electricity sector significantly which can subsequently increase the supply of electricity in the network by improving efficiency and

b) Energy subsidy removal is not adversely affecting the national and regional economy and social welfare

The goal of this chapter is therefore, to link energy subsidy removal program, its progress and achievement to the objective of SE4ALL of energy efficiency improvement.

5.2 Energy price reform

In the context of market maturity, regulation on the energy commodity pricing is considered very essential. More matured the market is, less regulated and controlled the energy prices are. Based on this basic principle we found that countries' overall economic growth highly correlated to the energy commodity pricing regulation and control. As a matter of fact these price controls often happen through restricted price pass-through to the consumers which are in other way price subsidy. With the objective of protecting the poorer section of the consumers being negatively affected by the international oil price fluctuation, subsidies are provided. However, often these subsidies are perverse in nature and distort the market in a bigger way while producing negative incentive for misuse and overuse of cheaper energy sources (UNEP, 2003). It has been further observed that in the

East Asia region energy subsidies are deep rooted in their social and political structures starting from the ages of colonization by the Western forces when providing cheaper energy to the local people was a strategy for over extraction of natural resources without much protest. Nevertheless, energy subsidy is a stumbling block for the East Asian economic development via the route of its energy market harmonization. In this study we therefore, would like to investigate the impacts of energy price reform in the form of reduction and removal of subsidies going towards energy commodities mainly coal, oil, and natural gas, electricity and gas distribution in the market on national and regional economy and environment as well.

5.3 Model used for this study

We employed the Regional Environmental Policy Assessment (REPA) model for assessing the potential impacts of energy pricing reform in the EAS region. The REPA model is a multi-regional computable general equilibrium (CGE) model developed based on the GTAP-E model (Burniaux and Truong 2002) for conducting integrated policy impact assessment encompassing environmental, economic and poverty impacts in East Asia (Kojima 2008). The version of the REPA model applied to this subsidy analysis employs 22-region 32-sector aggregation of the GTAP database Version 7 (see Annex-I and II), in which all the 16 EAS members are treated as a single region.[28] The sectoral aggregation maintains the most detailed energy sector (commodity) classification of the GTAP database where six energy sectors (coa, oil, gas, p_c, ely, and gdt) are classified.

5.3.1 Recursive dynamic setting

The REPA model incorporates dynamics towards 2020 by solving for a series of static equilibria connected by exogenous evolution of macroeconomic drivers. For each time step, the following macroeconomic drivers were exogenously shocked to update the data sets:

- Population
- Capital stock
- Skilled and unskilled labour
- Economy-wide total factor productivity (TFP)

Except for economy-wide TFP, growth rates of exogenous drivers and GDP were estimated based on the unpublished macroeconomic projections of the Center for Global Trade Analysis at

[28] GTAP Version 7 data set aggregates Brunei Darussalam and Timor-Leste as one region (labelled as other South-east Asia), but we assume that this region represents the economy of Brunei Darussalam as its GDP share based on 2008 World Bank GDP ranking reaches 95.8%.

Purdue University. Then, growth rates of economy-wide TFP were obtained by calibration against the projected GDP growth and other macroeconomic drivers. It might be worth noting that the employed methodology does not use equation of motion of physical capital to update the stock of physical capital. The employed methodology assumes that the evolution of the economy during each time step is represented as the shift of steady-state equilibrium caused by exogenous shocks. This method is consistent with the steady-state equilibrium assumption underpinning static general equilibrium theory. The current study employed single time step for the entire simulation period (2004-2020).

5.4 Database construction

Identification of actual subsidized energy commodity is a real challenge due to very complex pricing mechanism. Starting from well head to retail pump there are several taxes and duties levied on the energy commodity in various stages of its supply chain. Moreover, across the region there are different types of price protections given by the national Governments which affect the final pricing of the commodities in the markets. Majority of them are coming in the form of reduced taxes and duties in the occasion of higher international crude oil price (above certain threshold limit). Energy price pass-through is an overall indicator of such price protectionism based on the price-gap concept which is used to identify the subsidized commodities in the retail market.

Using the price gap analysis followed by the price pass-through test it has been identified that in the East Asia Summit region (comprising 16 member countries) there are mainly three types of refined fuels in the markets whose retail market prices are less than the actual market determined prices. The fuels are: Domestic LPG, Kerosene and Transport Diesel. All these fuels' market prices are not fully pass-through in the case of international crude oil price changes during 2004 and 2005. As a matter of fact, these are the subsidized fuels which are in general prevailing across the region in all the 16 member countries. Rest of the fuel types more or less follows full market price pass-through except certain exception like gasoline in Indonesia and Malaysia.

In the GTAP database and model there are mainly three types of prices: producers' price, market price and consumers' price. From the zero profit condition we obtain the producers' price. From supply and demand equilibrium otherwise known as market clearing condition, we obtain market determined prices. Finally from the household welfare maximization we obtain the consumers' price. Though the prices are determined separately and endogenously but they are linked to each other via the government intervention as taxes or subsidies. The final prices of the fuels in the market comprises of both producers' tax/subsidy and consumers' tax/subsidy. If PH, PD and PY are the consumer price, market price and producers' prices of some domestic fuels say kerosene then they are linked as follows in the GTAP model:

$P_H = P_Y\,(1+\alpha)\,(1+\beta)$

$P_D = P_Y\,(1+\alpha)$ and $P_H = P_D\,(1+\beta)$

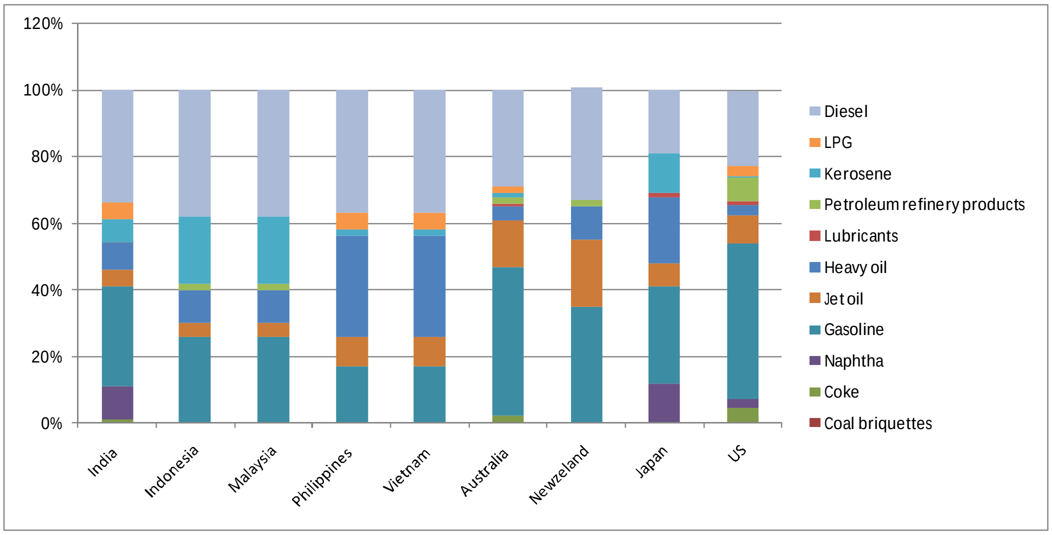
Where, α is the producer' tax/ subsidy and β is the consumers' tax/subsidy (sign is positive when it is tax)

It has been observed that for the domestic subsidized fuels (kerosene, LPG and diesel) the subsidies are provided at the consumer price end rather than producers' price end.

In the GTAP 7 database, we have p_c as a combined sector which includes all the major refined petroleum products including gasoline, diesel, aircraft fuel, kerosene, LPG, lubricants, naphtha and other petroleum products like coke and bitumen. GTAP records all these items together as net taxed mainly due to heavy taxation on gasoline, aviation fuel, naphtha and fuel oils. Across the region all these petroleum refined products are taxed domestically at different stages of their production chain. In the context of energy subsidy removal for full scale price pass-through in the region, it is necessary to differentiate the taxed and subsidized items from the common heading of p_c in the GTAP database. Based on the above discussion, we have further created two different sectors after separating the p_c combined sector as follows:

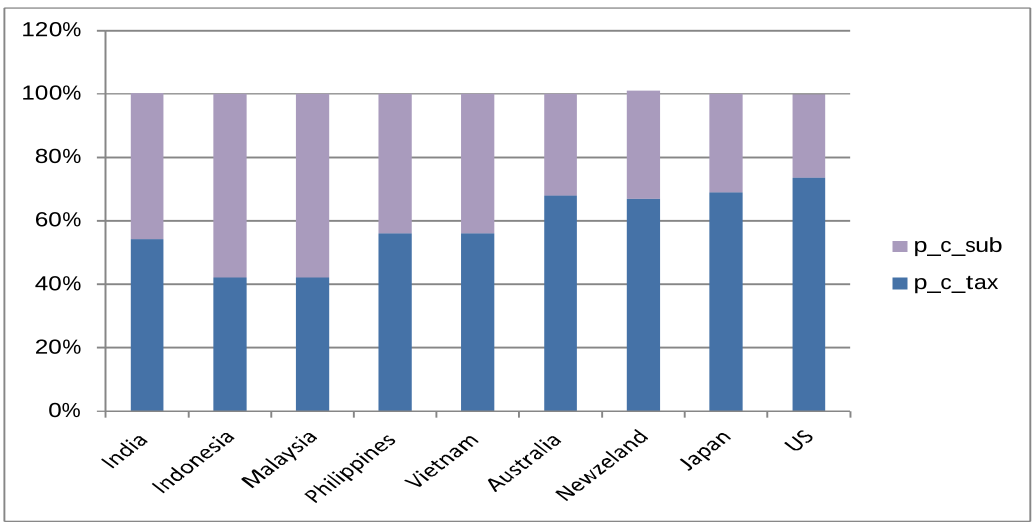
- p_c_tax: This includes all the commercial fuels which are primarily taxed in all the countries in the EAS region. This sector includes gasoline, naphtha, fuel oil, heavy oil, lubricants, petroleum coke and bitumen and other refinery products.
- p_c_sub: This includes all the domestically used fuels plus the fuel affects the household disposable income i.e. transport diesel. It is assumed that transport diesel price is highly elastic to the consumer price index and cost push inflation in the market. So in most of the countries the transport diesel prices are not fully pass-through to the market. Remaining fuels are domestic LPG and kerosene which are often subsidized as a welfare measure of the Government.

The following figures (Figure 5.3 & Figure 5.4) show the major country wise percentage distribution between commercial and domestic use fuels as per our given definitions above. This indicates that in the region developing countries have more price supported fuels for domestic users than developed countries and across the region diesel fuel comprises majority of the petroleum refined products apart from Gasoline. Therefore, due to continued price support for such a major fuel definitely have significant economic impact as a whole.



Source: Authors' estimated

Figure 5.3: Country wise composition of supply of petroleum products



Source: Authors' estimated

Figure 5.4: Country wise ratio of taxed and subsidized fuels

In the process of conducting GTAP 7 database splitting, we need detailed information on production, consumption, export and import values of commercial and domestic fuels which are at present aggregated under p_c sector. Though data availability is very poor especially for domestic fuels like kerosene and LPGs in the developing countries, we used the following assumptions to simplify the splitting process.

– For splitting production inputs such as capital, labour and intermediate inputs, we assume that the input shares for the domestic and commercial fuels are the same as those of crude oil intermediate input. Crude oil is the single largest intermediate input for all these fuel commodities.

- We obtained the export and import data of the domestic and commercial fuels from the national statistics and obtained the ratios which are used to split the p_c sector export and import values.
- We use the same ratio of consumption of domestic and commercial fuels in the market for splitting the value of household purchase of domestic and commercial fuels. These ratios are obtained from the refined fuels consumption data for each country. The same ratios have been used to split the household import and intermediate purchase and imports, too.

We have used the Splitcom Software developed by the Monash University in Australia to split the GTAP 7 database with our desired sectoral disaggregation of p_c_tax and p_c_sub. The software can use varieties on information on different parameters of the splitting variable to split it into desired sub categories. In general the standard splitting occurs under the assumption of equal ratio of 50-50 of all the factor inputs, intermediate purchase, imports and exports and also among the household, government and intermediate firms' consumption. However, that simple level splitting was not useful for this study as it was dealing with the tax and subsidies related to the energy commodities. The Splitcom also provides an option to disaggregate the sector using their market price and taxes (all together the agent's price) also.

During the process of subsidy data collection it has been identified that the majority of the subsidies are going to the consumers rather than the energy producers. As a matter of fact, the GTAP recorded Producers' Tax (i.e. PTAX) where not subject to our modification. We only focused on the consumer level taxes and subsidies (i.e. DPTAX) which are determined in the GTAP as the difference between the VDPA (value of domestic purchase at agent's price) and VDPM (Value of domestic purchase at market price). In general if the difference is positive then consumers are paying tax for that commodity to buy and if it is negative then it is subsidy for the consumers. Therefore, in the Splitcom software we used the output, supply and price level splitting for the consumers which are denoted by the row weights in the split matrix. Colum weights represent the splitting weights of the producers of the commodities using different factor inputs and intermediate commodities including labour and capital. As PTAX is not the target of our analysis, we therefore, used the standard ratio of 50-50 split of the base price and taxes of all the inputs for the production. The Table 5-1 below shows the final splitting ratios those have been used for the consumption and production side splitting of the p_c sector of the GTAP 7 database.

Table 5-1 : Final splitting shares used for Splitcom splitting user weights preparation

	p_c consumption share		p_c import share		p_c export share		p_c output share	
	p_c_tax	p_c_sub	p_c_tax	p_c_sub	p_c_tax	p_c_sub	p_c_tax	p_c_sub
China	0.46	0.54	0.60	0.40	0.60	0.40	0.54	0.46
Japan	0.70	0.30	0.69	0.31	0.69	0.31	0.69	0.31
Korea	0.70	0.30	0.69	0.31	0.69	0.31	0.69	0.31
Cambodia	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Indonesia	0.11	0.89	0.10	0.90	0.16	0.84	0.16	0.84
Laos	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Myanmar	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Malaysia	0.11	0.89	0.10	0.90	0.16	0.84	0.16	0.84
Philippines	0.56	0.44	0.56	0.44	0.56	0.44	0.56	0.44
Singapore	0.70	0.30	0.74	0.26	0.74	0.26	0.74	0.26
Thailand	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vietnam	0.56	0.44	0.56	0.44	0.56	0.44	0.56	0.44
Brunei	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
India	0.46	0.54	0.60	0.40	0.60	0.40	0.54	0.46
Australia	0.62	0.38	0.69	0.31	0.41	0.59	0.68	0.32
New Zealand	0.59	0.41	0.67	0.33	0.67	0.33	0.67	0.33
Brazil	0.46	0.54	0.60	0.40	0.60	0.40	0.54	0.46
EU	0.70	0.30	0.74	0.26	0.74	0.26	0.74	0.26
USA	0.70	0.30	0.74	0.26	0.74	0.26	0.74	0.26
Russia	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
MENA and Venezuela	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Rest of the world	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

Source: Authors' estimated

The major problem that we faced in the database preparation was data inconsistency between the GTAP record and the subsidy data recorded from other external sources. GTAP doesn't record subsidy separately in the database. So we had to collect from third party sources which were often very large compared to the total output values. As a result, it was impossible to use the collected information as subsidy amount for p_c_sub commodity as it was creating negative agent's price for that particular energy commodity which means that the consumers are getting additionally paid for buying the commodity from the seller. In reality this situation doesn't exist. In the process of investigating the trouble we identified that to make use of GTAP database we have to make the subsidy data consistent with the GTAP recorded data on VDPA and VDPM for each commodity. Finally we made some data adjustment using the following assumptions to make the final split database consistent to the GTAP base data. The assumptions are as follows:

- If the country's VDPM of p_c sector is higher than the total subsidy amount recorded from the external sources, then we will take the whole amount (100%) as consumer subsidy for the p_c sector for that particular country.
- If the VDPM of p_c sector is lower that the total subsidy amount recorded from the external sources then for the East Asian developing countries we use the ratios between 30-40% as the consumer level subsidies depending upon the country's energy sector profile, total amount of subsidy paid and historical trends of subsidy etc. As a result, Indonesia and Malaysia falls under the highest level i.e. 40% of total subsidy goes to the consumers and 30% is for the transitional economies like China and India. However, due to data inconsistency, our adjustments are envisaged to undermine the total impacts of subsidy in the analysis. It is partial in nature and therefore, the impacts are also indicative and partial.

Table 5-2 below shows the adjustments in the total subsidy amount which are used for the analysis.

Table 5-2: Subsidy amount adjustment for GTAP base data consistency

Region	Actual subsidy amount recorded (M$)	GTAP derived VDPM for p_c_sub (M$)	Subsidy removal for the simulation (M$)	Adjusted subsidy as % of total recorded subsidy
China	27,800	8,657.7	8,340	30
Japan	465	4,366.3	465	100
Korea	400	1,895.1	400	100
Cambodia	300	13.8	0	0
Indonesia	11,400	4,616.5	4,570	40
Laos	N/A	7.4	0	0
Myanmar	N/A	87.8	0	0
Malaysia	3,500	1,803.1	1,400	40
Philippines	200	275.7	200	100
Singapore	0	58.3	0	0

Thailand	3,100	2,006.0	1,240	40
Vietnam	1,400	74.0	0	0
Brunei	2,000	33.9	0	0
India	18,300	7,199.7	5,759	31
Australia	8,000	1,230.9	615	8
New Zealand	N/A	250.3	0	0
Brazil	1,000	4,209.5	1,000	100
EU	3,900	14,155.2	3,900	100
USA	184	24,185.0	184	100
Russia	38,700	3,726.8	1,863	5
MENA and Venezuela	9,000	8,740.4	8,653	96
Rest of the world	270,000	19,356.3	9,678	4

With this subsidy data we further developed the splitting ratio of the subsidized energy commodity prices for their base value and the tax/subsidy amount. In addition to that for the output and supply ratio of the taxed and subsidized petroleum commodities we used the ratios mentioned in the Table 5-1 under the column heading of consumption, export and import. Finally, using all these ratios we created the final weights for splitting the p_c sector for the consumer side in the database. For the producer side splitting where p_c is used as intermediates for production of other goods and services, we used the output ratios mentioned in the Table 5-1 determined from the national refinery through-put. For intermediate supply we used the 50-50 ratio between domestic and import supply and for the base and tax, we also used 50-50 share. After aggregating all these ratios we finally derived the column weights for splitting the p_c sector from the producers' point of view. Splitcom finally use the row and column weights all together to split the original GTAP 7 database p_c sector into p_c_tax and p_c_sub sectors. Moreover, after splitting the database it is appeared that a very few countries are actually net subsidized. In our estimation, Indonesia, Cambodia and Brunei are net subsidized. In the policy simulation we could only reduce subsidies from these countries in the East Asia Summit region. The total amount of subsidy reduction simulated in this model is around USD 450 million in year 2000 base year. Therefore, the obtained results in this study reflect a partial view of the subsidy removal impact of this region as we recorded much higher subsidy flowing in the market. This is mainly due to the limitation in the GTAP database structure and the corresponding GTAP model structure.

5.5 Simulation results

After adjusting the subsidies that can be reduced or removed without creating the negativity of the VDPA (which is otherwise making the energy commodity free of charge) as the policy measures to curb energy subsidy in the market, we shocked the model with the 100% subsidy removal policy. It is to clarify here that this 100% subsidy removal is not the 100% actual amount of subsidy removal that is existing in the market. The simulation results are analysed for three main indicators of the economy and environment: GDP as macroeconomic performance indicator, Equivalent Variation for the social welfare measure and CO2 as the environmental indicator.

5.5.1 Economic impact

In this study we measured the economic impacts of energy subsidy removal from the market in terms of changes in real GDP of the countries. Though we could reduce subsidies for couple of countries only in the EAS region, but the impacts are measured across the regions. Figure 5.5 below shows the percentage change in real GDP for various regions in the world.

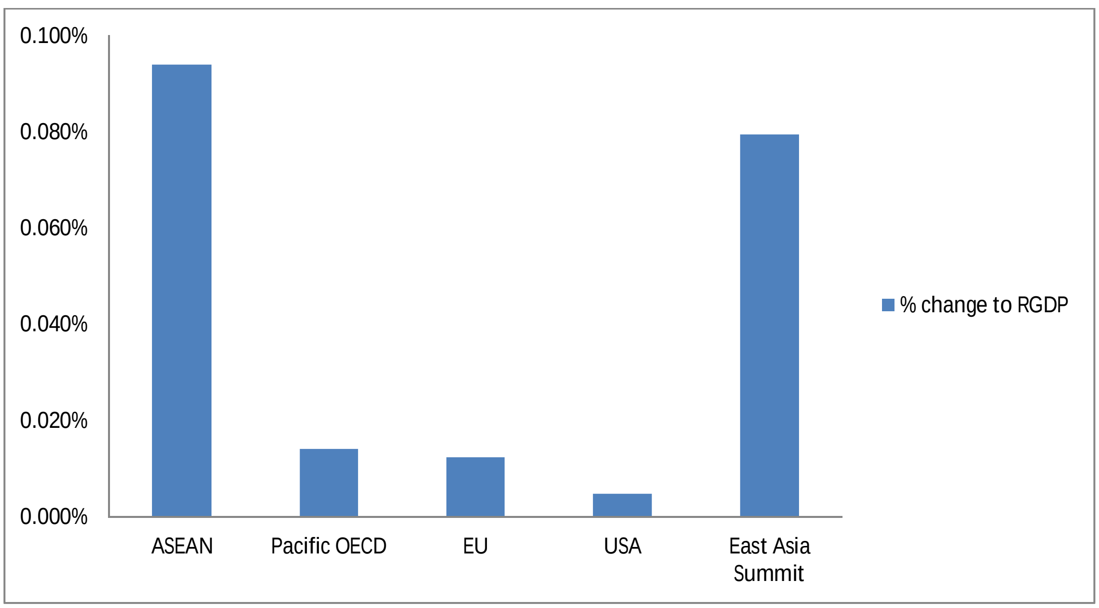


Figure 5.5: Percentage change to BAU real GDP by 2020

The EAS region as a whole would be benefited by around 0.08% by 2020 in terms of regional real GDP while ASEAN region will be benefited by around 0.09%. Though the impacts are small in nature due to the magnitude of subsidy reduction compared to the GDP is negligible, but the result indicates that energy subsidy removal at the consumers' end can bring overall economic benefits to the country. However, a proper benefit sharing mechanism needs to be in place which can compensate the initial real income loss to the consumers due to price increase as a consequence of subsidy reduction.

5.5.2 Impact of electricity generation

It has been estimated that energy subsidy removal has overall positive impact on electricity generation and supply in the market. As the common notion of energy subsidy removal goes that it will adversely affect the economy and welfare of the people and will also hurt the business in power sector, the current simulation demonstrates that in reality it happen other way round. The Figure 5-6 shows the impact of energy subsidy removal by 2020 in the Developing Asia region compared to other regions in the world which clearly indicates an increase of around 0.1% additional power in the network for supply. Further investigation reveals that energy subsidy removal in the region can release around 200 Mwh of additional power in the network by 2020 which can be supplied to enhance the accessibility as per the target of SE4ALL.

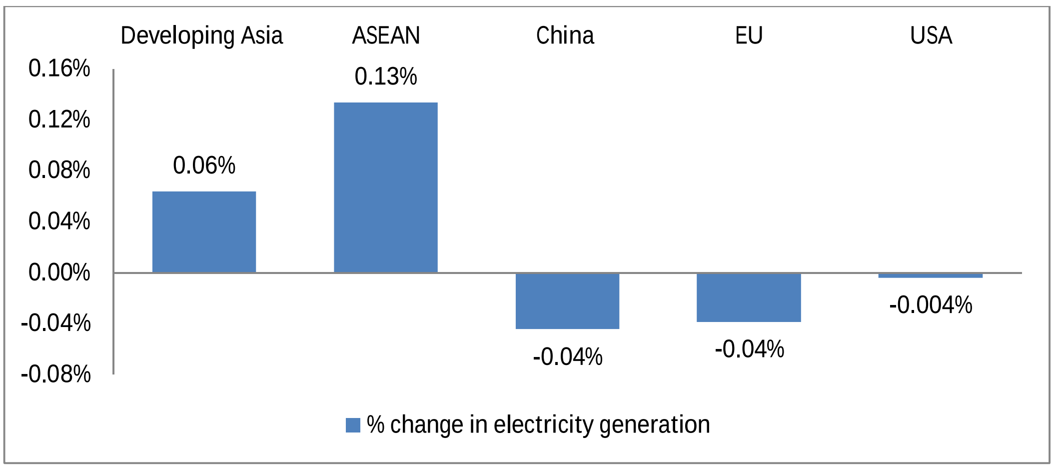


Figure 5.6: Impact on electricity generation due to subsidy removal

5.5.3 Environmental impacts

As expected, energy subsidy removal demonstrates its positive impacts on GHG emissions reduction from energy sector. Due to reflection of actual cost of energy in the market, demand for energy gets further adjusted in the perfect completion condition and clears the market at lower demand for energy. As a matter of fact, this reduces the energy wastages and improves energy efficiency in use. Finally, this impact gets reflected in terms of reduced CO_2 emissions from the energy sector in the region.

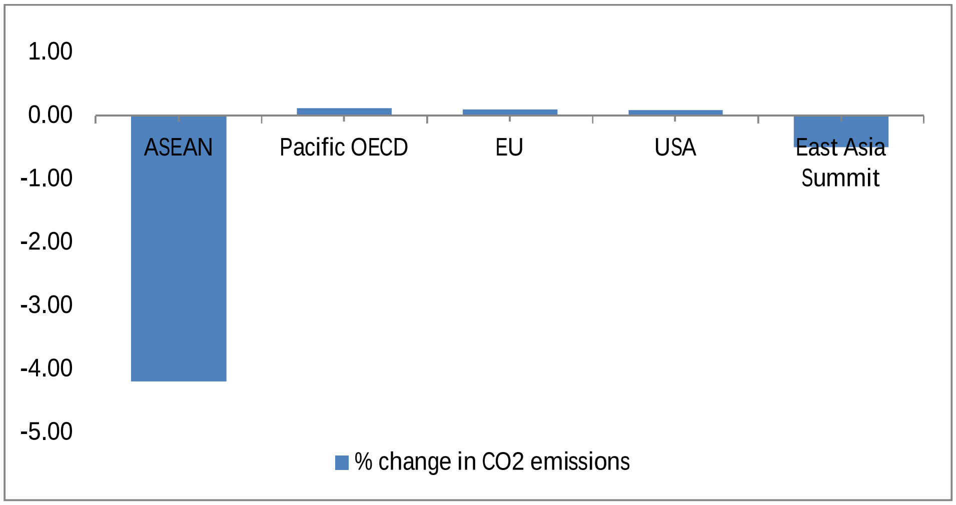


Figure 5.7: Percentage change to BAU of CO_2 emissions by 2020

ASEAN region is expected to get the maximum benefits of CO2 emissions as Indonesia is the major country of this country conglomeration. EAS region as a whole is also going to get the benefits of reduced CO_2 emissions. However, rest of the regions including EU and USA are expected to get higher CO_2 emissions indeed. This further corroborates that domestic action on efficient energy utilization including price reform has rather domestic impacts than cross regional impacts. It is therefore, important for the countries to have their own domestic policies to have better utilization of energy including full cost pricing of energy in the market.

5.5.4 Social welfare impacts

In the context of energy pricing reform it is often discussed among the policy makers that it would be affecting the welfare of ordinary consumers in the market. This is perhaps the hardest point against the energy price reform activities. In this study we further demonstrated that energy subsidy reduction and subsequent reduction in market distortion could actually bring over all welfare benefits to the society in terms of additional job creation and poverty headcount reduction. Figure 5-8 below shows the social welfare benefits of energy subsidy removal from the selected countries in the EAS region.

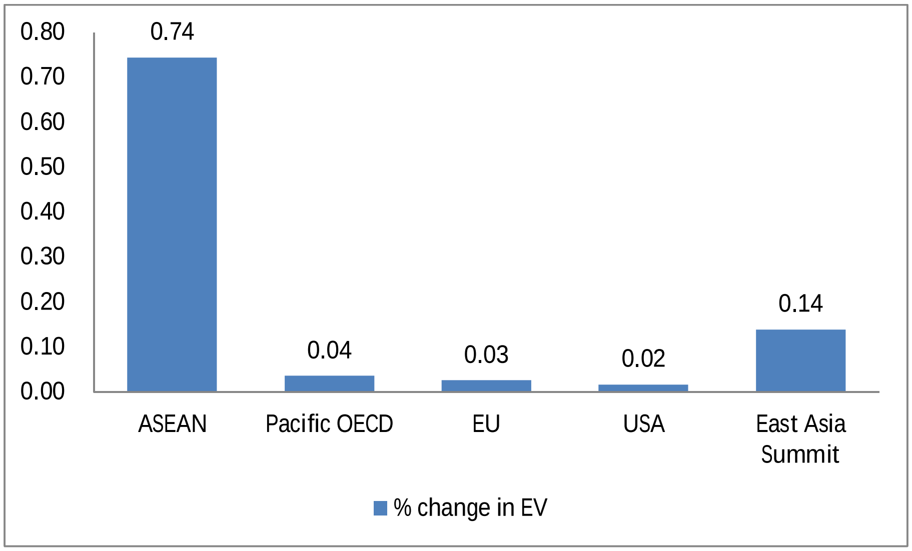


Figure 5.8: Percentage change to BAU of EV by 2020

The simulation result shows that energy subsidy removal has all the positive impacts on the economy and the environment as desired. Subsidy removal works as productivity efficiency improvement booster and agent for reduction of market distortion which resulted in higher economic output. This has been reflected in the regional as well as domestic macroeconomic performance. As we have mentioned earlier that due to subsidy data adjustment we could only found Indonesia, Brunei and Cambodia as net subsidized country, due to subsidy removal they are the highest gainer of the macro economic benefits and social welfare including emissions reduction. Indonesia's economic gain is the highest among all other countries in all aspect. As a matter of fact, even for a few countries to take measures on energy subsidy removal, the whole region is getting benefits of that.

5.6 Policy implications

The major policy implication of this study is demonstration of the benefits of energy price reform on macro economy, social welfare and environment as a whole. For example, 475 Million USD[29] equivalent subsidy removal from the Indonesian domestic energy retail market (mainly the consumers' subsidy) resulted in decrease in the total amount of demand for domestic subsidised

[29] Due to data inconsistency between GTAP 7 database and the externally collected energy subsidy data for Indonesia, it appears in the modified GTAP 7 database that Indonesia is having 457 Million USD net subsidy in the economy on 2004. In this study we simulated the scenario of removal of entire 457 Million USD as a policy measure to reduce energy subsidy in Indonesia. Works need to be done to remove these discrepancies to match the subsidy amount with the reality. However, this simulation indicates the impacts of energy subsidy removal on the economy and environment not exactly by values but more on direction of changes which can help the policy makers to further think on how to deal with the energy subsidy issues in the market.

energy commodities i.e. kerosene, LPG and diesel by around 10% compared to the baseline scenario. The policy makers in general perceive energy subsidy as a tool to provide social welfare to the poorer section of the nation. But amidst increasingly volatile energy market especially due to extreme uncertainties in the international prices, the East Asian Summit region countries who are the major energy net importer in the world now, seemingly facing difficulties to continue with the huge burden of subsidies. This study shows an indication that even small removal or reform of the energy pricing could fetch the most desired results for the policy makers. It is demonstrated that the common perception of subsidy removal that it will affect the welfare and national GDP due to inflationary effect of energy price increase, may not be correct for this region. There is ample evidence that energy price reform can bring larger benefits to the countries.

Finally we extract the main policy implications of this study as follows:

- Electricity sector is not getting affected by subsidy removal. Its overall output is increasing especially in the developing Asia region. As a result, it can support SE4ALL program in terms of providing more power t distribute and also by improving efficiency of energy market and reducing the losses.
- It is important for the countries to define their energy subsidy definitions so that countries can statistically estimate its energy pricing status of net taxed or net subsidised. If the countries are net taxed on their energy commodities then reduction of subsidies in one particular energy commodity may not bring the overall economic benefits.
- It is important to have systematic energy subsidy accounting system at the national level to use the information for analytical purposes.
- Subsidised energy commodity market is expected be affected by reduced demand and sales due to removal of subsidies in certain cases only. It may affect the outputs of these sectors by reduced jobs and corporate earnings. However, as the money may flow to other sectors for government or private sector spending, outputs may grow in those sectors which will overall compensate the economic losses. In this context, it has been estimated that national GDP will be benefited out of such reallocation of resources.
- As a measure to curb GHG emissions, energy subsidy removal will work very effectively in lieu of carbon tax. Additional tax on emissions may adversely affect the economic efficiency due to its distortional behaviour. But removal of subsides will do dual job in the market. One, it will reduce the market distortion which will help to improve the economic efficiency and two it will force the end users to improve efficiency of use and conserve energy which

will ultimately reduce CO_2 emissions. Policy makers can therefore consider this tool as an effective mean to combat global warming and climate change related issues in the region.

An integrated energy market can expedite both the process of pricing reform where the benefits and costs can be shared among the countries and the private sector investments in the forms of FDI to energy sector. The combination of energy pricing reform and energy sector investment liberalisation is thus expected to enhance the economic development of the region and also to encourage people to use more efficient and cleaner fuels.

5.7 Conclusions

Energy price reform as the measures of improving energy efficiency in the system and increasing power supply in the market, do have significant impact on Developing Asia region. As a result, price reform can function as a policy tool to achieve the targets of SE4ALL i.e. doubling energy efficiency and providing 100% access to modern energy including electricity supply and non-solid cooking fuels. Energy price reform removes the market distortion and increases the economic efficiency and productivity which positively affect the overall macroeconomic growth and the environmental effects by reducing GHG emissions. This is especially beneficial for the developing economies where still majority of the consumers are using low cost, inefficient and dirtier energies for livelihood.It has been observed that energy price reform can serve the dual purposes here by improving energy efficiency and supply in the market and by improving the macroeconomic condition of the region which can subsequently financially support the energy access program.

Developing Asia region can consider its energy market to be integrated under the framework of gradual and systematic energy price reform which will reduce the financial burden of the respective governments and will also help them to reduce the market distortion with improvement in energy efficiency. This study tries to demonstrate such potential benefits of energy pricing reform in quantitative manner using computable general equilibrium models. The challenge associated with quantitative assessment of energy pricing reform is essentially data issues in which further disaggregation of fossil fuel commodities are required to identify net subsidised commodities. Our original CGE model partially overcomes the challenge, and it helps in revealing the necessity of further improvement, such as introduction of economic and social costs of insufficient energy supply, and further distinction of conventional technologies and cleaner technologies.

5.8 Improvement for SE4ALL tracking on energy pricing

It has been so far discussed the importance of energy pricing in the market to provide better access to modern energy and also to improve energy efficiency and reduce losses. As we have been developing an advanced and improved version of SE4ALL tracking and monitoring framework based on the backward linkages of the existing targets to various issues in line with economy, technology and political issues, we therefore, would like to propose an additional set of tracking indicators for SE4ALL's Energy Efficiency and Access to Modern Energy based on our assessment in this current chapter.

Here we have proposed additional three new indicators to be monitored to enhance the potentiality of the success of achieving the targets of access to modern energy and doubling the rate of energy efficiency improvement. These new indicators are envisaged to track both the two target under the SE4ALL (see Table 5-3).

Table 5-3: Indicators for energy access and energy efficiency with price reform

SE4ALL Objective	Existing Tracking Indicators	Proposed Indicators
Universal Access to Modern Energy Services	a) % of population with electricity access	• Percentage (%) of price support on each category of fuel • Total annual energy subsidy budget • Number of energy commodities in the subsidy list
Doubling global rate of improvement of energy efficiency	b) Rate of improvement in energy efficiency	

It has been observed that in the Developing Asia region though energy subsidy is very commonly used, but the monitoring and reporting systems of such subsidies are very poor. Hardly there is any record exclusive prepared for energy subsidy. Understanding these drawbacks, we have proposed these new indicators under the SE4ALL existing tracking indicators to improve the monitoring systems. List of energy commodities under subsidy scheme is an important tracker in this regard to understand the direct beneficiaries of this program. % of price support on each category of energy commodity will reveal the amount of consumers' subsidy goes to the market from government budget. Total annual budget for subsidy with fuel category will provide a comprehensive idea about the total outlay of money in this regard. Finally, indicator of subsidy removal targets will capture the political will of the government to address this crucial and politically sensitive issue.

Chapter 6

Renewable Energy Equipment Trade and RE Promotion[30]

6. Introduction

Rapid economic growth over the last five decades has made Asia the most dynamic and flourishing region of the world. Sustained growth led the region toward improved standard of living, reduced poverty, and a more prominent role in the global economy. This impressive growth, nevertheless, has caused huge increase in energy demand for the region as a whole. Catering to the needs of the "factory Asia", energy consumption in this region since 1980 has persistently been much higher than the consumption in other regions of the world. The cumulative energy demand of the region is likely to reach between 7 and 8 billion tonnes of oil equivalent (Btoe) by 2030 (IEA 2008). To ensure sustained growth, these are some of the priority issues that the region must address. Scholars and policymakers alike suggest that an integrated renewable energy (RE) market may resolve many of the region's energy-related problems. SE4ALL is also having its third objective as improving renewable energy percentage in the global energy supply mix. Benefits of renewable energy in the supply mix are not new to anyone anymore. However, renewable energy supply is not coming at its expected level. In the last chapter we have discussed that how the fossil fuel subsidies are hampering the growth of an efficient energy market in the region and along with the difference in funding between subsidy and renewable energy investment. Globally fossil fuel related subsidies crosses around 500 billion USD compared to around 120 billion USD of investment in renewable energy only. It is also observed that globally the renewable energy sector investment follows the boom-bust cycle which is linked to international crude oil price. As a matter fact, renewable energy is yet to get into main stream investment line in energy sector across the world. Given the objective of SE4ALL to double the RE supply mix, it is important to make the investment mainstream. the current and the following chapters are dedicated to develop certain new mechanism to improve the renewable energy sector investment, development and growth.

This chapter uses an empirical model to examine the bilateral RE equipment trade within the Developing Asia regional countries and its determinants. It attempts to examine RE production through analyzing the RE equipment trade within this region. Section 2 of the chapter explains why

[30] Source of this chapter: Moinuddin, M. and A. Bhattacharya (2013), 'Towards an Integrated Renewable Energy Market in the EAS Region: Renewable Energy Equipment Trade, Market Barriers and Drivers' in Kimura, S., H. Phoumin and B. Jacobs (eds.), Energy Market Integration in East Asia: Renewable Energy and its Deployment into the Power System, ERIA Research Project Report 2012-26, Jakarta: ERIA. pp.131-162.

the Developing Asia should promote RE and why RE is important for the region's energy market integration. It also discusses the problems and difficulties in promoting RE in the region. Section 3 puts forward the rationale and objective of the study, while section 4 describes the methodology as well as the specification and the structure of the econometric model used in the empirical analysis of the study. Section 5 explains the variables used in the model and related descriptive statistics. Section 6 provides the estimation results with associated discussion. Section 7 concludes the paper with a discussion on regional policy implications based on the results of the study.

6.1 Significance of RE for the EAS Region

The rationale behind promoting the use of RE in this region is manifold. The EAS countries in 2011 accounted for more than 21 billion metric tons of CO_2 emissions, which is about 65% of total global carbon emissions (EIA 2013). Increasing the share of RE in the supply mix will enhance these countries' emission mitigation efforts. Also, energy self-sufficiency is quite low among most of the EAS countries (Table 6-1) and the region as a whole is net energy importer. But the EAS countries have huge potential for RE, which has largely remained untapped. Increased use of RE in the region will help reduce the import of primary energy on one hand, and diffuse the pressure on domestically available conventional energy resources on the other.

Table 6-1: Energy production, import, export, supply and consumption

Country	Production (Ktoe)	Import (Ktoe)	Export (Ktoe)	TPES (Ktoe)	TFC (Ktoe)	Energy self-sufficiency ratio	RE potential (GWh)
Australia	310,620	42,990	228,620	124,730	75,280	2.5	100,000,000
Brunei	18,559	157	15,459	3,314	1,701	5.6	154
Cambodia	3,621	1,437	N/A	5,024	4,262	0.7	60,000
China	2,208,962	386,242	50,499	2,417,126	1,512,218	0.9	529,373
India	518,671	244,143	62,699	692,689	457,491	0.7	1,44,000
Indonesia	381,446	42,119	214,725	207,849	156,449	1.8	421,684
Japan	96,790	427,270	18,040	496,850	324,580	0.2	1,132,265
Republic of Korea	44,920	266,840	45,800	250,010	157,440	0.2	18,718
Lao PDR	N/A	N/A	N/A	N/A	N/A	N/A	24,960
Malaysia	85,878	39,468	50,580	72,645	43,329	1.2	58,094
Myanmar	22,530	239	8,879	13,997	12,887	1.6	52,000,000
New Zealand	16,860	7,140	4,280	18,200	12,770	0.9	80,000
Philippines	23,417	22,374	3,851	40,477	23,818	0.6	327,996
Russian Federation	1,293,049	22,887	601,986	701,523	445,764	1.8	7,602,000
Singapore	404	134,521	56,754	32,774	23,724	0.0	0
Thailand	70,559	64,432	12,982	117,429	84,582	0.6	34,312
United States	1,724,510	725,640	192,060	2,216,320	1,500,180	0.8	481,800,000
Vietnam	65,874	13,572	20,848	59,230	48,515	1.1	165,946

Notes: Ktoe = Thousand tonnes of oil equivalent; Lao PDR = Lao People's Democratic Republic; TPES = Total primary energy supply; TFC = Total final consumption; N/A = Not available; Energy self-sufficiency = Ratio of energy production to supply (Production/TPES). *Source: Romero, Bhattacharya and Elder 2010; IEA 2012a; IEA 2012b; Sargsyan et al. 2011.*

6.1.1 Importance of RE for EAS energy market integration

The EAS member countries are quite heterogeneous in terms of their levels of economic development and distribution of energy resources (both conventional and RE) availability. As such, it is unlikely that individual countries will be able to cater to the growing energy needs all by themselves. Indeed, the region needs a robust energy system which can ensure reliable, affordable and timely supply of energy for undeterred sustained growth and development. At present, with the exception of a few bilateral or multilateral schemes, there is hardly any collective initiative for ensuring energy security for the Asian region. This study argues that special arrangement for RE market integration can promote balanced utilization of abundant RE resources scattered among the member countries. Since the Asian region as a whole is the net importer of energy, therefore, efficient and effective utilization of indigenous resources are crucial for long term sustainability and economic integration.

6.1.2 Difficulties in promoting renewable energy in the region

Large scale deployment of renewable energy in the region faces plenty of problems as well, in spite of having huge potential. In this study we focused on certain particular issues which have potential to maneuver the decision making processes to promote renewable energy in the region.

- *Inconsistency in RE financing:* Like any other infrastructure projects, financing in RE schemes are often quite large with lengthy period of return on investments. There was a significant surge in RE investment on a global scale from 2004-2008, but as credit dried up along with the global financial crisis in 2008, investment dropped sharply in the aftermath (IEA 2010). On a global scale, about four-fifth of total RE investment comes from Europe and two EAS member countries—China and the United States. In 2011, the total capital investment in renewable energy sector in India exceeds total investment in the fossil fuel sector compared to the year 2010. However, it is envisaged that such change in investment portfolio has little relationship to the motivation for greening energy supply compared to on-going natural gas supply problem in the India energy market.
- *Asymmetric development status of RE technologies across the region:* Enhancing the use of RE in the EAS region requires that the member countries have access to the state-of-the-art RE generation technologies and equipment. Within this region, significant asymmetries exist in terms of the development status of RE technologies. For example, solar PV is very advance in China while India is very advance in wind technology, but Vietnam is still lagging far behind in development stage of its own solar and wind technology (Figure 6.1: Asymmetric development status of RE technologies in Asia). Collaboration among nations for increasing the trade in the RE equipment area is therefore necessary.

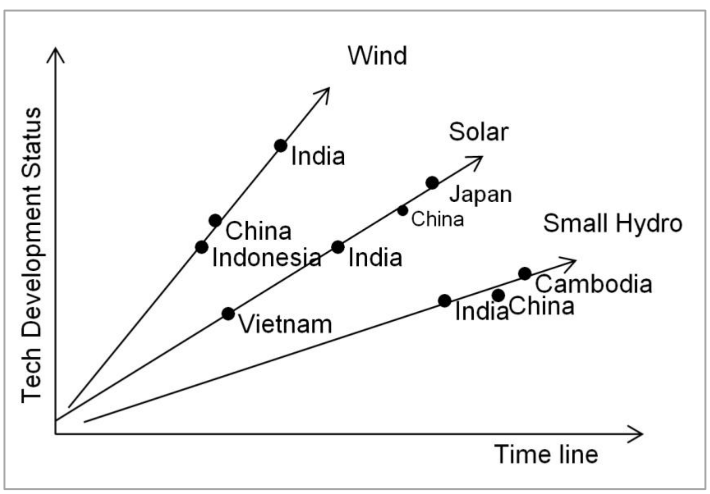


Figure 6.1: Asymmetric development status of RE technologies in Asia

Source: Authors.

- *Low trade in RE technologies/components/equipment:* As of 2005, most of the trade in renewable technologies/equipment takes place among the OECD countries (Steenblik 2005). Several factors are inhibiting the RE equipment trade in the EAS region. One such trade-retarding factor is the existence of various forms of tariff and non-tariff barriers. For example, in India, RE components face over 9% import tariff, while in China the figure is over 8% (Table 3). Meanwhile, the United States, a new member of the EAS, is likely to impose tariffs ranging from 24% to 36% on solar panels imported from China (Cardwell and Bradsher 2012). China may face similar anti-dumping duties from other developed countries, particularly the European Union. However, many developing countries cannot afford to maintain feed-in-tariffs and other subsidies. These countries often depend on import tariff to protect their own RE equipment industry. Consequently, they are likely to face unfair competition if they are required to lower their tariffs while developed countries continue to provide subsidies to their RE equipment producers (Jha 2009).

6.2 Rationale and objectives of this study

It appears that larger deployment of renewable energy in the region is not only barred due to its high initial investment cost but also for lack of uniform availability of technical knowledge and engineering support related to building renewable energy power plants. As a matter of fact, a gap has been noticed between good policy to promote renewable energy at a regional scale and on the ground implementation. In this study we therefore, would like to address the issues which can narrow such gaps and can increase the real deployment of renewable energy.

This study underscores that trade in technologies/equipment used in harnessing renewable energy is one of the most important aspects for integrating the renewable energy market in the EAS region. This study is essentially concerned with mitigating the asymmetric development status of RE technologies across the region by enhancing trade in RE equipment in the region. We assume that if the RE equipment trade increases across the border, it will also increase the use of RE in the national energy supply mix and subsequently in the regional mix as well.

6.3 Methodology

The study primarily employs an econometric analysis to investigate the interrelationship among selected indicators to prove the hypothesis of the study that in order to have more renewable energy equipment trade, countries need to have certain domestic market conditions fulfilled. Such enabling conditions can therefore, promote regional energy market integration. These conditions include the share of export/import tariff of RE equipment, existing renewable energy supply share in the total electricity supply mix, research and development budget spending, domestic share of renewable energy technology patent and other enabling policy environment in the domestic market. Based on the findings of the analysis, the study will outline the way forward for integrating the RE technology/equipment market in this region and general energy market integration.

6.3.1 Econometric model specification

While the renewable energy sector has received significant attention in recent years, only limited studies have so far addressed the dynamics of trade in renewable energy equipment/components (RETC). In particular, for the EAS region there is hardly any literature covering prospects and challenges of intra-regional RETC trade. A 2009 study by Veena Jha attempted to analyze the trade in major climate mitigation technologies and components for 34 selected countries/regions. The study provides important insights about the factors that affect RETC trade, particularly how trade is affected by tariff, subsidies, share of renewables in the energy grid, and share of patents. The study stresses the challenges relating to identification of single-use RETC goods, and highlights that producers in the developing countries are likely to be in disadvantageous position as these countries in general do not enjoy the right incentives such as high feed-in-tariff in the same way as the producers in the developed countries do. This study, however, does not take into consideration all the EAS member countries. Additionally, as most of RETC trade is highly concentrated among the developed countries, particularly in the EU, it is difficult to grab a clear idea about the RETC trade and the special situations among the EAS countries. The empirical analysis of the study also does not consider some important factors such as RETC research and development budget, the potential of the individual countries for RE, or RE promo-ting regulatory frameworks.

Algieri, Aquino and Succurro (2011) used the Balassa index to investigate the international specialization patterns of the world's major solar photovoltaic (PV) industry. They identified the role of several market and trade drivers such as subsidies. However, the study did not cover any other RETC. Similarly, a recent study by Cao and Groba (2013) developed a gravity model for 43 countries to analyze the development of solar PV and wind energy technologies export from China to demonstrate the country's competitive position against the world. However, none of these studies covered any other RETC such as those relating to bioenergy, hydro or geothermal (the next subsection of this paper discusses the major RETC's included in the current study).

The current study has been conducted more in line with the work of Jha (2009) as discussed above. The multivariate regression under the current study has been further enhanced by including other important determinants of trade flows among the EAS countries. In order to isolate the trade effects and market integration potential of the selected determinants without being biased with the major RETC traders such as the European Union countries, the geographical coverage of this study has been kept limited to the 18 EAS countries only. The next subsections of the paper discuss the RETC taken into consideration in this analysis, and the selection of variables as well as the logic of their inclusion. The basic premise of this study is that an economy is likely to export renewable energy equipment/components (hereinafter RETC) with supporting policies such as feed-in-tariff and other subsidies, and an enabling regulatory framework. This study develops an econometric model to analyze the effects of various relevant trade barriers, market drivers, and policies such as price support mechanisms (e.g. feed-in-tariff and other subsidies) and regulatory frameworks that can affect the trade in RE technology, equipment and associated goods and eventually the RE market integration in the EAS region. A multivariate cross-country regression has been used for assessing how the export of RETC is affected by the chosen independent variables. The geographical scope of the study is the 18 EAS countries.

6.3.2 Model structure

In this study, we will use cross-section data for year 2011 to estimate the effects of the factors and determinants of RETC export in the EAS region. The model has been specified with the following regression equation:

$$EXP\_RETC_{ijt} = \beta_0 + \beta_1 SGDP_{jt} + \beta_2 TAR_{ijt} + \beta_3 RGD_{it} + \beta_4 PAT_{it} + \beta_5 RND_{it} + \beta_6 CWP_{it} + \beta_7 FIT_{it} + \beta_8 SUB_{it} + \beta_9 POL_{it} + u_{ijt}$$

where,

EXP_RETC_{ijt}	=	Export of renewable energy technology and components from exporting country *i* to importing country *j* at time *t;*
$SGDP_{jt}$	=	Country *j*'s share in the whole region's GDP at time *t*;
TAR_{ijt}	=	Import tariff on RETC by both importing country *j* and the exporting country *i* at time *t*;
RGD_{it}	=	% of renewables in the energy grid in the exporting country *i* at time *t*;
PAT_{it}	=	% of inventions (represented by the share of a country in global registered patents) of the exporting country *i* at time *t*;
RND_{it}	=	Research and development budget of the exporting country *i* at time *t*;
CWP_{it}	=	Country-wide potential for renewable energy generation in the exporting country *i* at time *t*;
FIT_{it}	=	Dummy on feed-in-tariff provided to renewables in the exporting country *i* at time *t*;
SUB_{it}	=	Dummy on other subsidies (capital subsidy, gran, or rebate)
POL_{it}	=	Other renewable energy promoting policies focusing on regulatory framework in the exporting country *i* at time *t*;
u_{ijt}	=	Error term.

The study conducted a coefficient diagnostics test for checking the presence of collinearity among the independent variables. The issue will be discussed in the later part of this paper.

6.4 Description of the variables

In the following section we describe the variables that we have selected to conduct this analysis.

6.4.1 Identification of RE technologies/components/equipment

A major issue for this study is to identify which commodities should be categorized as RETC. As some of these commodities can have multiple uses, isolating them as RE-related is often not a straight-forward task. Underscoring the role of RE sources in providing energy services in a sustainable manner particularly in addressing climate change, the Special Report on Renewable Energy Sources and Climate Change Mitigation of the Intergovernmental Panel on Climate Change (IPCC) has identified six types of RE technologies: bioenergy; direct solar energy; geothermal energy; hydropower; ocean energy; and wind energy (IPCC 2011). This study has attempted to cover the RETCs that are related to all these six broad categories.

A study conducted by Paul Lako (2008) focused on RETCs within the energy supply sector. Instituted by the International Centre for Trade and Sustainable Development (ICTSD), this mapping study identified the key RETCs. Izaak Wind, the former Deputy Director (Harmonized System) of the World Customs Organisation later continued this mapping study, which classified the major RETC under 85 different 6-digit Harmonized System (HS) codes, divided in 42 headings (Wind 2009). Yet another study by Veena Jha further refined the RETC listing to better reflect the predominantly single-use commodities that are assumed to be directly RE supply, exports and imports (Jha 2009). The current study and its econometric analysis will be based on these 69 identified 6-digit HS codes.[31]

6.4.2 Bilateral export flows of RETC among the EAS countries

The dependent variable of the multivariate regression is cross-border export flows of RETC among the EAS countries. Data for each of the 69 6-digit HS lines with base year of 2011 have been collected for each country. The United Nations (UN) COMTRADE Database (2013) is the main source of this data. China and Japan are by far the largest exporters of RETC in the EAS region, followed by the Republic of Korea and the United States (See Table 6-2). Smaller economies of the region such as Cambodia, Myanmar and Brunei Darussalam export negligible amount of RETC in the region.

[31] Complete list of these RETC is available in Annex 1 of this document.

Table 6-2: Individual country's total export of RETC in the EAS region, 2011 (US$ million)

Country	RETC Export	Country	RETC Export
Australia	434.5	Malaysia	3099.5
Brunei Darussalam	6.5	Myanmar	0.7
Cambodia	0.3	New Zealand	177.3
China	26032.2	Philippines	1190.7
India	945.7	Russian Federation	315.3
Indonesia	1065.7	Singapore	4735.0
Japan	20079.6	Thailand	2142.6
Republic of Korea	8236.2	United States	8087.1

Source: UN COMTRADE Database 2013.

6.4.3 Importing country's share in regional gross domestic product (GDP)

The size of the total economy measured in terms of its GDP, plays an important role in international trade. Empirical analyses of trade show that bilateral trade between two countries is positively related to their economic sizes in terms of GDP. While the current study does not apply a gravity model, it underscores the importance of the EAS countries' relative economic size as an important factor for import of RETC. Data on the importing countries' GDP relative to the total GDP of the whole region has been collected from the World Bank's World Development Indicators 2013 (Myanmar data has been taken from The World Fact book 2013–14 of the Central Intelligence Agency (CIA)). As we can see from Table 6-3, that the United States accounts for an overwhelming share (41%) of the total EAS region GDP, followed by China (20%) and Japan (16%). Among the ASEAN countries, Indonesia (2.3%), Thailand (1%), and Malaysia (0.8%) comprise the highest shares, whereas Brunei Darussalam, Cambodia and Lao PDR account for negligible share.

Table 6-3: Individual country's share in total GDP of the EAS region

Country	Share in regional GDP (%)	Country	Share in regional GDP (%)
Australia	3.76	Malaysia	0.78
Brunei Darussalam	0.04	Myanmar	0.15
Cambodia	0.03	New Zealand	0.44
China	19.94	Philippines	0.61
India	5.04	Russian Federation	5.06
Indonesia	2.31	Singapore	0.65
Japan	15.99	Thailand	0.94
Republic of Korea	3.04	United States	40.85
Lao PDR	0.02	Vietnam	0.34

Source: World Development Indicators 2013; and CIA World Factbook 2013 -2014.

6.4.4 Import tariff on RE technology/components/equipment in the importing country

Export of RETC adversely gets affected by the presence of tariff barriers in the importing country. Data on the EAS countries' import tariffs (69 6-digit HS line RETC products) have been collected from the World Trade Organization's Integrated Trade Database. Table 6-4 presents individual country's simple average ad valorem tariff on RETC products. As can be seen from the table, tariff rates vary from country to country. Those maintaining high tariffs include Cambodia, Brunei, the Russian Federation, India and China, whereas Singapore, Japan and Australia maintain 0% - 1% tariff (Table 4). The coefficient on this variable is expected to bear a negative sign, indicating that lowering or removal of tariffs is likely to lead to higher levels of RETC trade and eventually greater integration of the energy market in this region.

Table 6-4: Import tariff rates on RETC in the EAS Countries

Country	Simple Average AV Tariff (%)	Country	Simple Average AV Tariff (%)
Australia	0.8	Malaysia	4.8
Brunei Darussalam	11.7	Myanmar	1.8
Cambodia	12.5	New Zealand	1.4
China	8.5	Philippines	4.5
India	9.4	Russian Federation	11.4
Indonesia	2.6	Singapore	0.0
Japan	0.7	Thailand	6.2
Republic of Korea	6.8	United States	2.1
Lao PDR	6.7	Vietnam	6.2

Source: WTO Integrated Trade Database 2013.

6.4.5 Share of RE in the electricity grid of the exporting country

Percentage of renewable energy in the exporting country's total electricity generation mix is an important factor in terms of demonstrating the technological advancement and know-how of the country. Consequently, higher share of RE in the electricity grid implies that the exporting country has more potential to transfer RE technologies to other countries. The regression analysis of this study has included this factor as an explanatory variable in the model, and the coefficient is expected to bear a positive sign. Table 6-5 below shows the difference among the EAS countries in terms of electricity generated from renewable sources. Larger economies such as China, United States, Russian Federation, India, and Japan generate higher volume of electricity in absolute terms. However, as electricity consumption in these economies is very high, they also depend heavily on fossil fuels. Consequently, the percentage of electricity generated from renewables may not be very high in all the cases. Nonetheless, the percentage for these economies is more than 10%, indicating their strong technological capacity in RE. It is important to note that some smaller countries such as Lao PDR and Myanmar have very high share of electricity produced from renewables mainly due to use of massive amount of biomass , although the absolute amount is much lower compared to more advanced economies. The model of this study uses the percentages as an independent variable and the expected sign is positive.

Table 6-5: Share of RE in electricity generation in the EAS countries 2011 (in Billion Unit)

Country	Amount and % of electricity generated from RE	Country	Volume and Share of RE in electricity generation
Australia	24.86 (11.0%)	Malaysia	7.69 (6.5%)
Brunei Darussalam	0.00 (0.0%)	Myanmar	5.05 (68.8%)
Cambodia	0.05 (5.2%)	New Zealand	33.50 (76.9%)
China	770.92 (19.7%)	Philippines	17.72 (27.4%)
India	162.00 (16.4%)	Russian Federation	166.59 (16.7%)
Indonesia	26.95 (16.7%)	Singapore	1.17 (2.7%)
Japan	116.44 (11.1%)	Thailand	8.68 (6.0%)
Republic of Korea	7.55 (1.6%)	United States	520.07 (12.7%)
Lao PDR	3.23 (89.0%)	Vietnam	27.38 (30.2%)

Source: EIA 2013.

6.4.6 Research and development (R&D) budget in the RE sector of the exporting country

Technology is undoubtedly at the core of this discussion as mentioned earlier that asymmetric development of technology among the EAS countries is one of the major deterring issues for regional renewable energy development. Although the interest in RE spurred significant research and development activities, technologies and equipment for generating energy from renewable sources are still at their early stage in this region. Though, several such technologies are already commercially available, but many others are yet to be fully developed which can ensure reliable and affordable supply of electricity. Continued financial support for R&D activities is essential. However, RETC R&D is quite expensive and there are considerable asymmetries among the EAS countries in terms of their budget for such R&D. The hypothesis of this study assumes that higher R&D budget leads to improved technological achievement both quantitatively and qualitatively, which eventually provides greater scope for RETC exports. Based on this, an explanatory variable on RETC research budget has been added to the model, with the assumption that the coefficient will be positive. Bloomberg New Energy Finance and UNEP have been the primary sources, from which RETC R&D data for the world and the major EAS economies such as the United States, India and China has been collected. For the other countries, data has been calculated by weighing their gross domestic product (GDP) against the global RETC R&D budget and cross-checked with the Asia-Oceania region's R&D budget provided by Bloomberg. The United States spends the highest amount for RETC R&D followed by China and Japan (Table 6-6). On the other hand, the smaller countries such as Brunei Darussalam, Cambodia and Lao PDR spend negligible amount. The trend in RETC R&D expenditure corresponds to the export of RETC; countries with higher budget tend to export more RETC commodities.

Table 6-6: RETC R&D budget of the EAS countries, 2011

Country	RETC R&D Budget, US$ million	Country	RETC R&D Budget, US$ million
Australia	160.9	Malaysia	33.6
Brunei Darussalam	1.9	Myanmar	-
Cambodia	1.5	New Zealand	18.6
China	853.7	Philippines	26.2
India	215.6	Russian Federation	216.7
Indonesia	98.8	Singapore	28.0
Japan	684.4	Thailand	40.3
Republic of Korea	130.2	United States	1748.7
Lao PDR	1.0	Vietnam	14.4

Source: Compiled from UNEP/Bloomberg New Energy Finance 2012, and World Development Indicators 2013.

6.4.7 Share of RE technology inventions of the exporting country

Along with R&D budget, access to and diffusion of RETC is affected by the presence of various forms of intellectual property rights, particularly by patents.32 Jha (2009) observes that the "number of patents that have been registered in the renewable energy sector in different countries could provide an indication of the dissemination of renewables across borders." To avoid the difficulty of getting specific data on registered patents of the identified 69 RETC technologies we used the study conducted by Dechezleprêtre et al. (2008). Using data from EPO/OECD World Patent Statistical Database (PATSTAT), Dechezleprêtre considered 13 different classes of technologies which include seven RE technologies (wind, solar, geothermal, ocean energy, biomass, waste-to-energy, and hydropower), methane destruction, climate-friendly cement, energy conservation in buildings, motor vehicle fuel injection, energy-efficient lighting, and Carbon Capture & Storage. We assume that the data generated in this study can reasonably be used in the regression analysis of the current study. The EAS countries' innovation data (as percentage of global registered patents) is presented in Table 6-7. The geographical distribution of RETC inventions varies within the EAS region and a serious gap can be seen among the developed and developing country members of the EAS. Japan leads the world with an overwhelming 37%of RETC inventions followed by the United States (12%), China (8%) and the Republic of Korea (over 6%). All these countries are also the major exporters of RETC in the region. Most of the smaller developing countries do not hold any significant share in the RETC global innovation.

Table 6-7: Percentage of global RETC inventions of the EAS countries

Country	% of global RETC Inventions	Country	% of global RETC Inventions
Australia	2.5	Malaysia	0
Brunei Darussalam	0	Myanmar	0
Cambodia	0	New Zealand	0
China	8.1	Philippines	0
India	0.2	Russia	2.8
Indonesia	0	Singapore	0
Japan	37.1	Thailand	0
Republic of Korea	6.4	United States	11.8
Lao PDR	0	Vietnam	0

Source: Dechezleprêtre et al. 2008

32 However, other forms of intellectual property rights, such as trade secrets, may also protect technologies and innovations. This study only takes into consideration patent protection, assuming that patent counts likely to be positively correlated to the quantity of non-patented innovations and transfers (Dechezleprêtre et al. 2008).

Country-wide potential for RE generation in the exporting country: This study has added an explanatory variable on country-wide RE potential of the EAS countries in the regression analysis. RE potential is expected to boost a country's efforts in specializing in certain technologies related to RE-abundant resources, which will yield higher export of these RETC. On a general level, the region has huge untapped RE potential, albeit at different levels across the region (Table 6-8). In particular, the United States, Australia, Myanmar, and the Russian Federation possess tremendously high RE potential. Only Cambodia and Singapore have low potential. The hypothesis of the study is that the coefficient on this variable may take a positive or negative sign, but it will depend on the extent to huge the potential has been utilized. A negative sign may indicate underutilized potential and inverse correlation with the exports.

Table 6-8: Renewable energy potential in the EAS countries

Country	RE potential (GWh)	Country	RE potential (GWh)
Australia	100,000,000	Malaysia	58,094
Brunei Darussalam	154	Myanmar	52,000,000
Cambodia	60,000	New Zealand	80,000
China	529,373	Philippines	327,996
India	1,44,000	Russian Federation	7,602,000
Indonesia	421,684	Singapore	0
Japan	1,132,265	Thailand	34,312
Republic of Korea	18,718	United States	481,800,000
Lao PDR	24,960	Vietnam	165,946

Source: Romero, Bhattacharya and Elder, 2010; World Bank 2011.

6.4.8 Renewable energy promotion policies

Considering the importance of RE in ensuring energy security, many of the EAS countries have adopted policies that promote the use of RE. As these policies may guide the production of RE or deployment of RETC (Jha 2009), they drive the RE market in general and may also positively affect trade in RETC. These RE-promoting policies may fall under three broad categories: financial incentives, public financing, and regulatory policies (REN21, 2013). Financial incentives may include policies such as capital subsidy, grant or rebate, tax incentives and energy production payment.

Regulatory policies may vary widely and include feed-in-tariff, utility quota obligation, net metering, obligation and mandate, and tradable renewable energy certificate. Among them, feed-in-tariff is one of the most important drivers of RE in many countries of the world. In the EAS region, nearly half of the member countries maintain some form of feed-in-tariff.

The econometric analysis of this study considers three dummy variables reflecting RE-promoting policies in the exporting country. Although based on the policies identified by REN21, the categorization of these policies has been slightly modified to serve the purpose of this study. The variables included in the regression are: feed-in-tariff, other subsidies, and other regulatory policies. In the case of other regulatory policies, this study considers four subcategories (utility quota obligation, net metering, obligation and mandate, and tradable renewable energy certificate), and the dummy is unity when any of the four subcategories is present (zero otherwise). The absence or presence of these policies is presented in Table 6-9.

Table 6-9: Renewable energy policies in the EAS countries

Countries	Capital subsidy, grant, rebate	Feed-in tariff	Regulatory Policies			
			Utility quota obligation	Net metering	Obligation and mandate	Tradable RE Certificates
Australia	√	√	√	-	√	√
Brunei Darussalam	-	-	-	-	-	-
Cambodia	-	-	-	-	-	-
China	√	√	-	-	√	-
India	√	√	√	-	√	√
Indonesia	-	√	-	-	√	-
Japan	-	√	-	-	-	-
Republic of Korea	√	-	√	-	√	√
Lao PDR	-	-	-	-	-	-
Malaysia	-	√	√	-	√	-
Myanmar	-	-	-	-	-	-
New Zealand	√	-	-	-	-	-
Philippines	√	√	√	√	√	-
Russian Federation	√	-	-	-	-	-
Singapore	-	-	-	√	-	√
Thailand	-	√	-	-	√	-
United States	-	-	-	-	-	-
Vietnam	-	-	-	-	-	-

Source: Compiled from REN21 Renewables Interactive Map Country Profiles 2013

6.5 Model estimates and discussion

This study conducted a least square regression with all the variables including the three dummies. The results of the model estimates are presented in Table 6-10, followed by the analytical discussion on the effects of the factors on RETC export among the EAS countries.

Table 6-10: Regression results

Dependent Variable: Bilateral exports of RETC from country *i* to country *j* Method: Least Squares Included observations: 237		
Variable	Coefficient	t-Statistic
Importer's share in regional GDP	0.801535	11.30526**
Import tariff on RETC	-0.297445	-3.378478**
Share of RE in electricity generation	0.917617	8.790657**
Share of Inventions	0.636375	8.908713**
R&D budget in RETC	0.265317	3.756623**
Country-wide RE potential	-0.167356	-4.123828**
Feed-in-tariff	-0.222000	-0.493205
Other Subsidies	-3.145050	-8.796140**
RE promoting policies	4.174112	8.760244**
R-squared	0.691603	
Adjusted R-squared	0.679375	
F-statistic	56.56258	

Notes:
*1. * and ** denote significant at 5% and 1% levels respectively.*

Source: Authors' calculations based on the results of the model.

The importing country's share in the region's total GDP has been found to be highly correlated to the import of RETC from the exporting countries, suggesting that countries with higher share of regional GDP tend to import more RETC. As can be seen from Table 11, 1% increase in the importer's share in regional GDP is likely to increase the import from other EAS countries by 0.8%. We can therefore assume that as the economies of many of the EAS countries continue to grow, these countries will import more RETC. This further indicates that in terms of increasing renewable energy share in the total final energy consumption (SE4ALL target) bigger economies are in better position compared to smaller economies. Therefore, in the context of promoting RE supply, the smaller economies can either form a consortium of countries or can tie up with larger economies to promote the RE equipment trade flow in the country. In the South and South East Asia regions there are already numbers of country conglomerations who are in some cases nonfunctioning as well. In terms of promoting RE supply in the market, those country groups can play an important role.

On the other hand, import tariff has a negative correlation with RETC trade. The estimations show that the presence of tariff hinders the trade in RETC; a 1% increase in tariffs is expected to decrease RETC export to the importing country by about 0.30%. In other words, removal or reduction of tariffs by the importing countries will facilitate increased RETC exports from their trading partners, and will lead to higher RETC trade among the EAS countries.

The positive and nearly proportional coefficient for the share of RE in electricity generation indicate that countries which already possess advanced technologies for generating electricity from renewables are likely to export more RETC. Similarly, share of global RETC inventions and RETC R&D budget have high to moderate impact on RETC export, indicating that EAS renewable energy market integration will be increased once the countries invest more on RETC R&D, and once they start holding more registered patents for RETC commodities.

The negative sign on RE potential suggest that this variable is adversely affecting RETC trade. This study argues that given the current state of RETC trade in the region, the result is not so unexpected. The region's RE potential has so far been remained underutilized and consequently has not had any positive effect on RETC exports in the region. In terms of achieving the target of RE supply under SE4ALL, it is therefore, important for the countries to harness their domestic RE potential as much as possible. Policies should be aligned to promote RE potential tapping within country by various fiscal, economic and financial incentives. In such cases countries should take mid to long term planning supported by the international agencies (if required) to develop target oriented plan to harness RE potential.

It is further observed from this analysis that to promote the renewable energy use it is important to have a coordinated approach within the countries which can compensate the relative drawbacks of each individual country. Asymmetric development of renewable energy technologies in the region hampers the uniform and seedy development of a particular RE technology in the region. In the context of promoting RE use in the region under SE4ALL it is important to have seamless enabling environment of renewable energy promotion which includes but not limited to technology availability, affordable cost, locally available technical knowledge, hustle free financing option etc. Seamless trade of RE equipment in the region can thus support creating the enabling environment for RE promotion in the region.

6.6 Regional policy implication

The chapter analyses the prospects of an integrated renewable energy market in the region from the vantage point of RETC trade, associated market barriers and major drivers. The study finds that the region has huge potential for RETC trade which will eventually pave the way for enhanced RE use in the region. Despite this potential, certain factors such as high tariff rates, low level of inventions among the developing countries, and underutilized potential inhibit the growth of RETC trade in the region. Based on the findings of the analysis, this study makes the following policy recommendations which can further promote the use of renewable energy in this region and can enhance the potentiality of the success of targets set under SE4ALL:

- The Asian Developing countries should remove or reduce import tariffs on RETC to spur trade in these commodities. This will help address the problem of asymmetric technological development particularly in the smaller economies, and eventually lead to higher use of RE in the region. The overall RE market will also be more integrated.
- Investing in RETC R&D and fostering inventions will enable these economies to acquire more advanced RE technologies. Subsidies in RETC R&D can generate significant impact on the demand structure and markets for the RE industries.
- Untapped RE potential of the region may be addressed through efforts toward increased RETC trade so as to increase the access to advanced technologies for the countries which are in need. Once these countries have the appropriate technologies, they will be able to tap their respective RE potential.

6.7 Improvement for SE4ALL tracking on renewable energy

It has been so far discussed that renewable energy equipment trade and cooperation has positive impact on promoting renewable energy supply in the market and also it encourages the regional market integration which further creates the enabling environment to promote RE. Given the objective of doubling the RE mix in the total final energy consumption in the world of SE4ALL program, renewable energy equipment trade has an important role to play. Therefore, we have introduced a set of additional tracking indicators under SE4ALL to monitor the improvement in RE equipment trade scenario in the region and envisaged to increase the potentiality of achieving the target of renewable energy and energy efficiency improvement under the SE4ALL program.

Table 6-11: Indicator to increase potentiality of promoting renewable energy

SE4ALL Objective	Existing Tracking Indicators	Proposed Indicators
Doubling share of renewable energy in global mix	a) Share of renewable energy in Total Final Energy Consumption	• RE equipment trade volume in the region (unit: billion USD/year) • No. of RE technology patent • R&D budget for renewable energy (Unit: Billion USD/year)

As discussed earlier, RE equipment trade has positive impact on promoting renewable energy supply in the market and regional cooperation in this matter. As renewable energy resources and potential are scattered across the region heterogeneously, it is important to have regional coordination to maximize the use of such potential to achieve the target of RE supply under the SE4ALL program. RE equipment trade is an important indicator in this regard. Similarly, RE technology patent and R&D budget are also good indicators to follow the progress of RE utilization in the market. To achieve the target of doubling the RE supply mix in TFEC at a global scale, it is imperative to have a holistic approach to promote this sector.

Chapter 7

Energy Sector Investment[33]

7. Introduction

The well-being of modern-day society depends heavily on the stability of its energy supply. Unfortunately, in today's world the majority of countries, irrespective of their level of development, are increasingly facing challenges to such energy supply stability, especially in the electric power sector. The lack of investment in the power sector is a big bottleneck in the steady and continued flow of energy in the market and this poses a perceptible risk to the sustained growth and development of modern society (IEA, 2008). The core reason behind such lack of investment is the negative influence of high embedded investment risk in the electricity sector. Conventionally, energy planning was based on least-cost technologies, in which systems performed in environments of relative cost certainty, relatively slow technological progress (when compared to the current rapid level of progress), high availability of homogeneous electricity generating technologies and stable energy prices. But in today's world, the energy planners are facing tremendously complex environments full of uncertainties and risks. For example, the prices of metals that are typically used in power plants have significantly increased – by over 100% – during the last few years as compared to the year 2000 (International Energy Agency, 2008). Escalating energy and labor costs at the construction stage further aggravate the complexity of energy planning. Except for the capital borrowing costs, all other input cost factors related to power plant commissioning have increased significantly over the last seven or eight years, and more interestingly, all the cost factors are fluctuating more and more in nature (IEA, 2008). As an example, international crude oil prices fluctuated over 70% in a single year, 2008 ($145/barrel in July to $50/barrel in December), which jeopardized many energy planners' forecasts around the world. These huge fluctuations in costs add a high degree of uncertainty in the planning process and the corresponding costs related to risk mitigation. In addition to such price uncertainty, the cost of environmental damage, especially in terms of climate change, further complicates the situation.

Amid such uncertainty and complexity, in order to attain a stable and reliable energy supply chain, energy importing countries are increasingly paying huge risk insurance premiums, in addition to all the other costs, to generate electricity (IEA, or the producers in developing countries. Such

[33] Source of this chapter: Bhattacharya, Anindya., Kojima, S. 2012. Power Sector Investment Risk & Renewable Energy: A Japanese case study using portfolio risk optimization method. *Energy Policy Journal* (40). P69-80.

systematic risk coverage is becoming a huge burden on the government exchequer, and may well be engendering reductions in social welfare budgets and jeopardizing the social development of certain countries. As a matter of fact, continued government support for the protection of energy price risk not only weakens a country's financial strength but also weakens the consumers' capacity to pay in the long run, by reducing their level of disposable income. This situation varies country-by-country according to the level of maturity of the respective electricity markets. In the developed countries where most of the electricity markets are deregulated and vertically disintegrated, investors are taking on investment risks with the hope of payback from the consumers through upward tariff adjustments. Conversely, in developing countries like India where the electricity markets are mostly regulated and immature in terms of structure, state owned power companies are receiving a high degree of price support from the government based on them agreeing not to increase consumer tariffs. The prices of coal and oil destined for power companies are fixed by the government well below the market price and buffered from any short term external fluctuations through huge subsidies. For example, in the United States, power companies are paying an additional 0.4–1.7 cents/kWh (Bolinger and Wiser, 2008) to gas suppliers as a price premium in order to secure long-term price contracts and avoid any price spikes caused by spot prices in futures markets. In India, one state government provides around $260 million per annum to the power distribution companies just to protect the retail price from external influences.

While the global electricity market is reeling under the uncertainties and high risk of various input factors, renewable energies can still maintain a lower risk profile mainly due to their lack of linkage with fossil fuel prices. Nevertheless, there are certain renewable energies, such as wind and solar, which can entail a bigger risk exposure due to increasing material, labor and operation and maintenance (O&M) cost fluctuations, which are based on the scale of operation. However, as the bulk of the electricity market risk stems from fossil fuel price and supply volatility, such risk is not a factor in renewable energy markets. But, renewable energy does have its own risks, which are significant, such risks being technological, financial and regulatory in nature. A major drawback for renewable energies in a competitive electricity market is their high price tag, which reduces their competitiveness. Despite the above, renewable energy is still advantageous in terms of cost if the monetary costs of embedded risks related to conventional power are factored into the price of conventional power.

The purpose of this paper is to demonstrate the importance of fully clarifying the financial risk as a part of the decision-making process in power sector investment. Following this course of action would also lead to promotion of the supply of renewable energy. Using the method of mean variance portfolio risk analysis, a tool typically used in the field of financial sector investment, we demonstrate that having a diversified power sector investment portfolio that includes low risk renewable energy can actually reduce the overall investment risk of the portfolio. This can subsequently reduce the cost of risk hedging in terms of achieving a certain level of energy supply security. By creating an experimental electricity supply portfolio with high diversity (more fuel choices), we first estimated the most prudent form of cost-risk-return behavior for each technology; second, forecasted the possible range of percentage of renewable energy supply in the system and finally, conducted simulation optimization to minimize the supply portfolio risk with certain constraints and requirements. It is to be noted here that for the sake of experimental simplicity we only focused on the positive aspects of renewable energy, and ignored the negative issues, such as the potential investment risk of intermittency of power generation. Hence, this is a simple attempt to demonstrate the benefits of adding renewable energy to the electricity supply portfolio, while maintaining all other conditions unchanged. In this context, the first objective of this paper is to reveal the importance of considering risk explicitly in the electricity sector planning process, and the second objective is to demonstrate the implication of such risk-based planning on better utilization of the potential of renewable energies in the country. This paper is structured as follows. Section 2 introduces the concept of investment risk and its importance in the overall context of this paper. Section 3 deals with a specific case study on Japan under various scenarios along with corresponding results and discussions. Finally the Sections 4 and 5 deal with the conclusion and the policy recommendations, respectively.

7.1 Importance of investment risk analysis for energy planning

With regards the risks embedded in the electricity sector, the perception of the risk actually varies across the different structures of the electricity market. The government-run electricity market sees risk coverage as a social welfare bypassing much financial prudence, while the private sector-run market sees it as an additional financial burden. Over the last couple of decades, the electricity market has globally shifted more towards private sector participation; consequently, the embedded risk of this sector has become the main factor affecting the world today. During the period of 1990–1997 total private sector investment in the world electricity market, especially in the developing and the transitional economies, increased from $1 billion to $52 billion (in 2002 dollar value). It then dropped below $17 billion during 2002 partly because of high uncertainties in the market in areas of regulation, pricing and fuel supply costs (IEA, 2003). Foreign direct investment (FDI), in the form of international private sector investment, also plays a major role in the development of the world's power sector. FDI for the energy sector increased steadily during the nineties but then dipped down in the early 2000s. However, as a matter of fact, there are two clear trends in the contemporary electricity sector market; one is the overall increase in the importance of private sector participation and the other is the lack of continued interest in power sector investment by the private participants. It has been estimated that by 2030, a total of $16 trillion equivalent in investment will be required in order to meet the global energy demand (IEA, 2003). This figure could not possibly be met by the public sector alone, and therefore public-private-partnership is very much the need of the hour (ADB/ADBI, 2009).

In the context of creating the enabling environment for the private sector investment to the tune of trillions of dollars, it is imperative to have mature and risk-proof market conditions at the outset. In this context – and specifically in terms of developing Asia's energy sector – the Asian Development Bank Institute (in its latest publication on ''Infrastructure for a Seamless Asia'') emphasizes the role of increased private sector participation, as well as improvements to the institutional structure thereof. However, according to the institute, the one major obstacle for private sector participation in the energy sector is the lack of a proper market risk management mechanism (ADBI, 2009). Further, energy, especially the electricity sector itself, is very capital-intensive and needs more than the average capital investment for the same amount of return on investment in other sectors (IEA, 2003). Moreover, the capital recovery period is also very long and in some cases can be more than 20 years. The risks associated with capital investment in this sector are therefore very high and varied, as classified below (International Energy Agency/Nuclear Energy Agency, 2005):

- Financial risk arising from risks involved in project management
- Economy-wide risks due to fluctuations in electricity demand and availability of labor and capital
- Regulatory and political risks due to sudden changes in the financing conditions, adverse regulations and imposition of carbon tax
- Internal risk of companies due to sudden changes in company policy on diversity of generation technologies
- Price and volume risk in the electricity market

Among the above list of five perceived risks for power sector investment, the first one, financial risk, is considered the most important for the private sector players in the market. However, the market price and the volume of production of electricity are also crucial for investors in terms of generating revenue and sustainability of the business. A regulated market, where power off-take is ensured either by regulation or by law, is a much safer place for investments than any competitive free market. As a matter of fact, in most developing countries, electricity markets are mainly government regulated, therefore the electricity production volume may not be of much risk for the investors, but the price of electricity could be; hence the cost of generation is the factor of greatest importance. In the rapidly changing energy market, the cost of power supply is becoming more and more unpredictable in nature. Upwards of 60% of the total cost of fossil fuel-based electricity generation is due to the cost of production of the fuel supply, while around 20% is due to the rapidly changing construction costs associated with power plants. This highlights the level of vulnerability and exposure of the generation costs to the external factors influencing the fuel supply, and other input actors. Therefore, the key challenge to opening up the bottleneck of power sector investment is to be able to manage and have control over the investment risk. In this context, renewable energies could play a much bigger role, as the characteristics of the fuel make it relatively risk-free. The concept of fuel supply diversity is very appealing in this context, which basically means to increase the number of fuels used in the electricity generation basket (Awerbuch and Berger, 2003). A diversified supply portfolio can actually address two issues. In the short run, it provides a country with more hedging power against sudden shocks associated with conventional fuel supplies, and in the long run it can give more macro-economic stability to the countries that rely heavily on energy imports, like Japan. It should also be noted that increases in the price, as well as volatility of oil can actually dampen the macro-economic growth of oil importing countries by increasing inflation and unemployment, and further by depreciating the value of financial and other assets. However, attaining more system diversity alone cannot significantly eliminate uncertainty unless the process is followed by a risk assessment of all the portfolio components, which are then regrouped in a systematic manner.

7.2 Assessment of Japanese energy market

This section deals with a case study experiment of investment risk mitigation in the Japanese electricity market using the concept of portfolio risk optimization, a tool used in the financial market.

7.2.1 Electricity market risk in Japan

Japan is a country with one of the highest amounts of energy imports of the world's industrialized OECD countries. In FY2006, Japan imported around 82% of its total primary energy supply, which further demonstrates its very high exposure to the external influences and risks related to energy supply. In Japan's electricity market, around 8% of the supply comes from hydro, 65% from thermal and 26% from nuclear power. Therefore, with thermal power representing 65% of supply, and with up to 100% of fossil fuels imported, Japan already embraces a huge risk burden in order to have a stable, affordable and reliable fuel supply chain over the long term. Table 7-1 shows the FY2006 status of various primary energy supplies and their respective domestic production and import status in Japan, which further corroborates the high risk predicament of Japan's electricity market, a risk primarily borne by the investors.

Table 7-1: Primary Energy Supply Status in Japan (FY2006)

Item Unit: Petajoules	Total	Coal	Oil	Natural Gas	Nuclear
Total Primary Energy Supply	23,770	4806	9115	3601	2656
Domestic Production	4300	0	33	148	2656
Import	19,470	4806	9082	3452	0
% of Import	82	100	99.6	95.8	0

Source : Japan Statistical Year Book 2009, Chapter 10, Excel Sheet 10-17

With the above described condition of risk exposure, we have identified four major sources of risk investors can face during the development and operation of power projects in Japan. The sources of risk are capital costs, fuel costs, operation and maintenance costs and the environmental costs, which equate to the price CO_2 is traded at in the world market. Since the carbon-tax is yet to be implemented in Japan, the world CO_2 trade price is considered as representing the environmental risk for power companies. Figure 7-1 shows a breakdown of the total costs into input cost components of various power generating technologies in Japan.

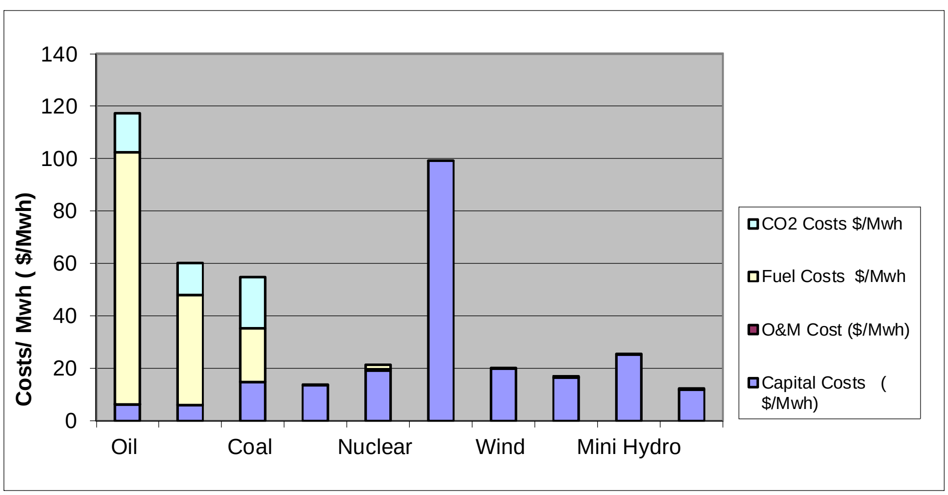


Figure 7.1: Decomposition of power generation cost

It is very apparent from the above figure that the electricity generation portfolio of Japan is inherently highly exposed to fuel cost risks, as more than 62% of its electricity is generated from fossil fuels such as coal, oil and natural gas. It is also very clear that renewable energy involves higher capital costs, but no actual fuel or CO_2 cost risks. Therefore, a trade-off already exists in the present energy portfolio of Japan—one that involves systematic hedging of the risks associated with fuel costs, one of the biggest costs in such portfolio. Figure 7-2 shows the pattern of risks involved in each technology due to various cost stream risks. This further emphasizes the fact that the major fossil fuel-based technologies are associated with very high risk in terms of their exposure to fluctuations in fuel cost and price of CO_2.

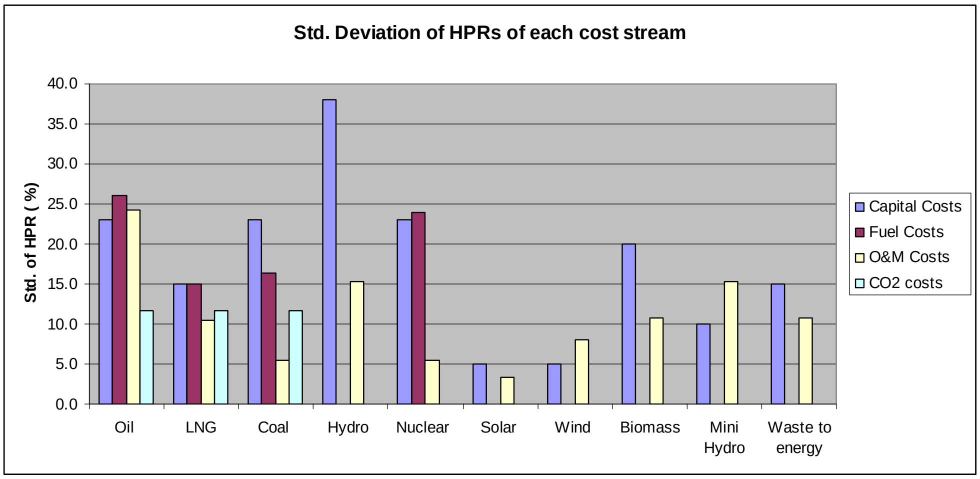


Figure 7.2: Standard deviation of holding period returns of each cost component

Holding Period Return (HPR) is an indicator of the return on assets of a portfolio, and in the above case is the percentage change of the cost stream on a year-to-year basis. Portfolio risk is always estimated as the standard deviation of the holding period returns (HPRs) of future generating costs of the input factors (streams). The HPR is defined as: HPR= (EV–BV)/BV, where EV is the ending value and BV the beginning value (see Brealey and Myers, 2004 for a discussion on HPRs). For fuel and other cost inputs (streams) with annual reported values, EV can be taken as the cost in year t+1 and BV as the cost in year t. Hence, HPRs measure the rate of change in the input costs (cost stream) from one year to the next (Box 1).

Box-1 : Basic concept of generating portfolio cost and portfolio risk

Electricity generating costs and returns: Generating cost ($/kWh) is the inverse of a return on investment (kWh/$), i.e., a return in terms of physical output per unit of monetary input.

Expected portfolio cost: With a two-asset generating portfolio, expected portfolio cost is the weighted average of the individual expected generating costs for the two technologies.

Expected portfolio cost = X_1 E(C_1) + X_2 E(C_2), where X_1 and X_2 are the fractional shares of the two technologies in the mix, and E(C1) and E(C2) are their expected levelised generating costs per kWh.

Expected portfolio risk: Expected portfolio risk, E(σp), is the expected year-to-year variation in generating cost. It is also a weighted average of the individual technology cost variances, as tempered by their covariances:

Expected portfolio risk = $E(\sigma p) = \sqrt{}(X_{12}\sigma_{12} + X_{22}\sigma_{22} + 2X_1 X_2 \rho_{12}\sigma_1\sigma_2)$,

where: X_1 and X_2 are the fractional shares of the two technologies in the mix; σ_1 and σ_2 are the standard deviations of the holding period returns of the annual costs of technologies 1 and 2 ; and ρ_{12} is their correlation coefficient.

Each individual technology actually consists of a portfolio of various input costs (cost streams) (capital, operating and maintenance, fuel, CO_2 costs, and so on). Total risk for an individual technology – that is, the portfolio risk for those cost streams – is σ_T. In this case, the weights, X_1, X_2, and so on, are the fractional share of total levelized cost represented by each individual cost stream. For example, total levelized generating costs for a coal plant might consist of ¼ capital, ¼ fuel, ¼ operating costs, and ¼ CO_2 costs, in which case each weight Xj = 0.25.

Further discussion is given in the next section, before the actual analysis of this study is presented. However, note that the standard deviation of year-to-year basis HPRs is the indicator of the portfolio risk for all cost streams under a single technology (Bazilian and Roques, 2008). For example, oil-fired power plants have the highest percentage of fuel cost risks (i.e., 26.1%), while renewable energy sources have no such risks. On the other hand, renewable energies entail high capital cost risks. Due to rapid advancements in solar and wind technologies in Japan, risks associated with capital cost increases are very low compared to other renewable technologies, including biomass, mini hydro and waste to energy. However, for other fossil fuel technologies such as oil, coal and natural gas, capital cost risks are high mainly due to increases in the costs of raising capital, and continuous technology upgrades. Large hydro power projects in Japan have the highest capital cost risk due to the high land value and very high costs of rehabilitation, as is the case for nuclear energy. Therefore, identifying and selecting the type of power generating technology based only on the average generation costs can actually underestimate the inherent risks of investments, which can reduce the return in the future.

In the next section we discuss the methodology of analyzing the risk return profile of various power generating portfolios and show how to create an efficient frontier-based portfolio. Portfolios on the efficient frontier are optimal in nature, and give the range of technological intervention for a particular country to maximize its renewable energy generation potential.

7.2.2 Methodology of optimization of portfolio risk

Portfolio theory is usually applied in the context of financial portfolios to estimate expected portfolio risk and return on a year to- year variation basis. As explained by Awerbuch and Berger (2003) in the case of an electricity generation portfolio, costs are measured as generating costs and the returns are measured as the inverse of the generating costs, i.e., physical output per unit of monetary input (kWh/$). In this analysis we used the same concept of portfolio costs and return and their contribution to the overall risks of the portfolio. Figure 7-3 shows a schematic diagram of the experiment in this paper.

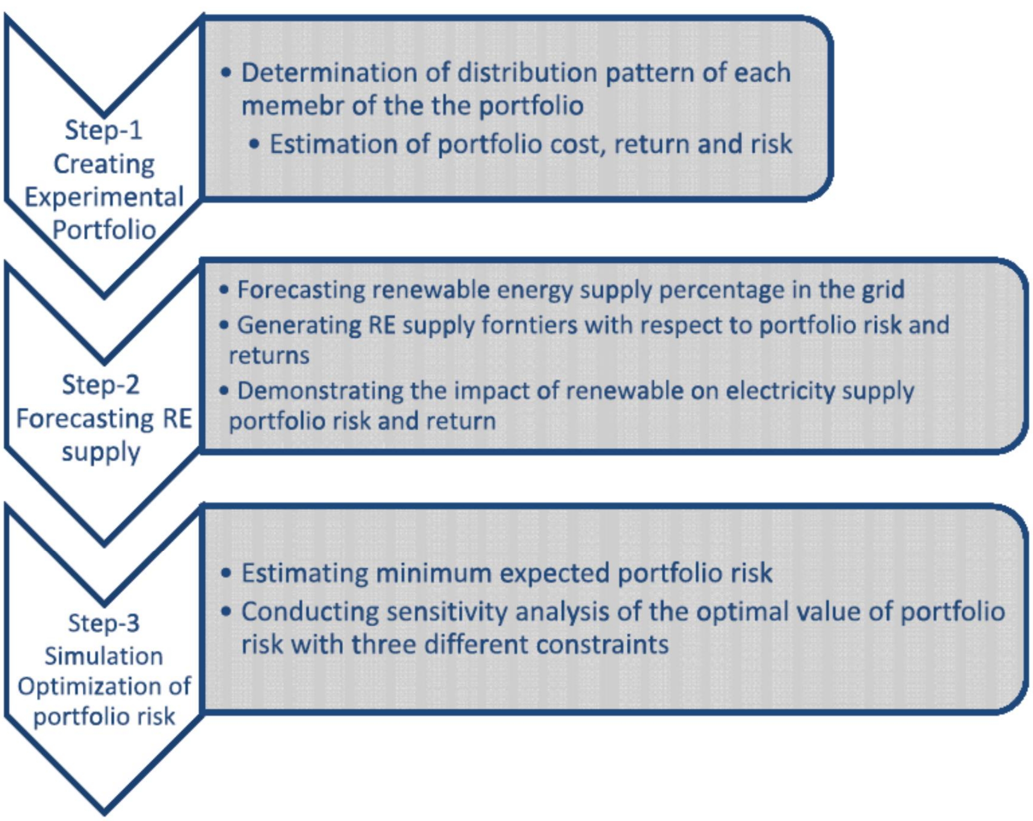


Figure 7.3: Process of simulation optimization of portfolio risk

Estimation formulas

The expected value of portfolio cost is expressed as the weighted average of the individual expected generating cost of each technology, as follows:

$E(c_j) = \sum w_i.E(c_i)$ where i= 1,2....n (1)

where w_i is the share of the i^{th} technology in the portfolio and $E(c_i)$ is the expected value of the weighted average generating costs of the i^{th} technology per Kwh (c_i).

The expected value of the portfolio return is expressed as the weighted average of the individual expected return of each generating technology in the portfolio:

$E(R_p)=\sum w_i E(R_i)$ where i= 1,2,....,n (2)

Here, $E(R_i)$ is the expected value of return from the i^{th} technology (R_i).

The expected value of portfolio risks ($E(\sigma_p)$, where σ_p is the portfolio standard deviation) has been estimated as the year-to-year variation in the generating costs. It is also a weighted average of the individual technology cost variances tempered by their covariance. The expression of the expected portfolio risks is as follows:

$E(\sigma_p) = [\ \sum_{(i=1 \text{ to } n)} w_i^2\ \sigma_i^2 + \sum_{(j=1 \text{ to } n)} (w_{i.}w_j\, cov_{ij})\ ]^{1/2}$ where $i \neq j$ (3)

Here, σ_i and σ_j are the standard deviations of the holding period returns (HPRs) of the annual costs of the i^{th} and j^{th} technologies, respectively[34], and ρ_{ij} is the correlation among them. HPR is defined as HPR= (EV-BV)/BV, where EV is the ending value and BV is the beginning value of the cost of supply of each technology in the portfolio. For fuel and other cost components, EV can be taken as the costs in the year of t+1 and BV as the costs in year t. Hence, HPR measures the rate of change of cost on a year-to-year basis. The correlation coefficient ρ_{ij} is the measure of the diversity in the portfolio. The lower the ρ_{ij} among the portfolio members, the greater the diversity, which finally reduces expected portfolio risks $E(\sigma_p)$. In other words, increasing the portfolio diversity by adding more technologies can bring down the portfolio risk, which can be observed by the absence of correlation among the portfolio components. This further corroborates the concept that adding more renewable energy to the portfolio (fuel/CO_2 emissions risk-free technology) can actually bring down the expected value of the risk of the electricity supply portfolio.

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[34] Here covariance of the HPRs of two different technologies (i & j) is expressed as follows: $Cov_{ij} = (\rho_{ij}\ \sigma_i\ \sigma_j)$.

Basic assumptions

Based on an understanding of the current makeup of power generation in Japan, an experimental portfolio (Portfolio EX) has been created using the level of contributions to the total electricity supply mix that has existed since 2004. Table 7-2 shows the base case scenario of the technologies in terms of their weighted average generating costs ($/MWh), standard deviation of the HPRs of the input cost stream (basically, the individual technological risk) and the expected return on investment from each technology (inverse of the generation costs). We further simplistically assumed that this cost structure would remain unchanged over the period of time even with an increasing level of investments in the sector. As a matter of fact, due to the very high levels of technical and managerial efficiency in Japan, even for renewable energy, there is very little room for any further cost reductions related to the installed capacity. Hence, in our experimental portfolio, we considered the costs taking year 2004 as the basis for all estimations.

Within the experimental portfolio, each fossil fuel technology component is set with the range of percentage contribution and distribution pattern based on its historic contribution in the total supply mix over the last 25 years. For the renewable energies, we obtained data for the five years from 2002–2007, and we used a uniform distribution, based on individual potential minimum and maximum supply limits. Finally, using the historical data, we estimated the best fitting distribution for each technology using the standard statistical computing mechanism of the Crystal Ball simulation software.[35]

In Japan, the contribution of renewable energies to the total electricity supply is around 1%. Of this 1%, the largest proportion comes from waste to energy technology, followed by solar, with the total contribution of other renewable energies being negligible. In our experimental portfolio, we apportioned equal importance to all technologies and assumed that all the renewable energy technologies contributed equally to supply, with the total at 1%. One of the major reasons for providing equal weight to all the available renewable energy technologies in Japan and finally including them in the portfolio as members is to create a highly diversified portfolio which theoretically has a lower level of risk. We also wished to provide better visualisation of the impacts of other renewable energy technologies on the risk profile of the electricity supply portfolio of Japan. Table 7-3 shows the distribution pattern for each technology used in the simulation.

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[35] During distribution fitting, Crystal Ball computes Maximum Likelihood Estimators (MLEs) to fit most of the probability distributions to a data set.

Table 7-2: Base case technology characteristics

Technology	Composition (% of mix)	$E(\sigma_p)$	E(Ci) ($/Mwh)	$E(R_p)$ (Mwh/$)
Oil	13	14.88	29.3	0.034
LNG (Gas)	31	9.84	15.0	0.067
Coal	21	10.37	13.7	0.073
Hydro	9	19.0	6.7	0.148
Nuclear	25	13.32	7.0	0.142
Solar PV	0.20	3.50	49.7	0.020
Wind	0.20	5.44	10.1	0.099
Biomass	0.20	12.98	8.4	0.118
Mini / Small Hydro	0.20	10.55	12.7	0.079
Waste to energy	0.20	29.70	6.2	0.162

Table 7-3: Distribution assumption for each technology

Technology	Best Fit	Basic Parameters
Oil	Beta	Minimum= 0.1092 Maximum= 0.4417 α= 1.11; β= 2.05
LNG (Gas)	Student's t	Midpoint= 0.27 Scale= 0.0114; DF= 1
Coal	Lognormal	Location= 0.086 Mean= 0.13; SD= 0.043
Hydro	Triangular	Minimum= 0.077 Likeliest= 0.078; Maximum= 0.177
Nuclear	Beta	Minimum= 0.91 Maximum= 0.31 α= 2.74; β= 1.23
Solar PV	Uniform	Minimum= 0.00 Maximum= 0.04
Wind	Uniform	Minimum= 0.00 Maximum= 0.05
Biomass	Uniform	Minimum= 0.00 Maximum= 0.02
Mini / Small Hydro	Uniform	Minimum= 0.00 Maximum= 0.03
Waste to energy	Uniform	Minimum= 0.00 Maximum= 0.04

Simulation optimization model

Simulation optimization can handle a much larger number of scenarios than the traditional optimization method and can also deal with the uncertainties embedded in the input factors, which is why we used it for our current analysis. Simulation optimization can approximate the reality value of the objective function while incorporating various sources of uncertainties and variability in the forecast, which can affect the performance of the optimization process (Better et al., 2008). As a matter of fact, there are two separate functions occurring in a logical sequence to provide a statistically significant output. The optimization procedure, based on a metaheuristic search algorithm, uses the outputs from the simulation model running in parallel. This simulation, which could be called a system evaluator, determines the merit of the input factors based on their predetermined probability distributions and generates the most suitable output for the optimizer. The optimizer then generates a new set of input values, which are then evaluated by the simulation model. This process iterates for around 10,000 times, each time with a unique random number generated by the simulation model, until the global optima is reached. Due to uncertainties embedded in the input values and the complexity of the objective functional form, it is very hard to judge the shape of the solution space of this kind of optimization problem using normal processes of optimization. Using normal optimization, the process it is very likely to halt in the local optima. Use of metaheuristic optimization, on the other hand, can overcome this problem by using adaptive memory and population sampling techniques. For this purpose we used the Crystal Ball OptQuest simulation software, as it offers all the required features to conduct simulation optimization described above.

The objective function of our model is to minimize the portfolio investment risk expressed as E(sp) under the given constraints of proportional allocation of different electricity generating technologies in the portfolio. Assuming there are *n* different technologies in the portfolio, the optimization problem can be described as

$$\text{Minimize } (E(\sigma_p)) = \text{Min } [\, \sum w_i^2\, \sigma_i^2 + \sum (w_i . w_j\, cov_{ij})\,]^{½} \qquad (4)$$

where $i \neq j$, $i = 1,2,3\ldots n$ and $j = 1,2,3,\ldots n$

subject to $\sum w_i = 1$ and $i= 1,2,3,.n$; $w_i^{min} \leq w_i \leq w_i^{max}$

$$\sum w_i^{RE} \geq 1.37$$

Where w_i is the share of the i^th^ technology in the portfolio. W_i^{min} and W_i^{max} are the lower and upper limits of the proportion of the i^th^ technology in the portfolio. Σw_i^{RE} is the total allocation of renewable energies in the portfolio. Σw_i^{RE} worked as a requirement[36] for this simulation optimization problem. Here, we bound this simulation with a requirement of renewable energy supply above the base line scenario of 1.37% (as of 2005, only 1.37% of the total electricity supply in Japan came from renewable energy) to ensure increased utilization of renewable energies in the supply portfolio[37]. Again the second set of constraints determines the limits of contributions of different technologies in the portfolio. The limits are set based on the information of their historical contribution to the supply portfolio and their potential future contribution, as per the national energy outlook of 2030. The main purpose of such stricter constraints is to limit the optimal value within the national plan of electricity supply mix in Japan.

Simulation technique

In this spread sheet-based risk analysis model, we used both spreadsheet calculation and a simulation technique to analyze the effects of varying inputs on the outputs of the system. Varying inputs were determined by their statistical distributions. Here, we used the Monte Carlo simulation technique with Latin Hypercube[38] sampling option. Monte Carlo simulation randomly and repeatedly generates values for uncertain variables to simulate a model. The values for the probability distribution for each assumption (various inputs) are random and totally independent. The random value selected for one trial has no effect on the next random value generated. Crystal Ball performs Monte Carlo simulation using spread sheet values with specific assumptions, and forecasts objectives in a three-step process. The three steps in this process are generating a random number for every assumption as per it's given probability distribution, recalculating the spreadsheet and finally generating a forecasted value in the designated cell. This process iterates unless the simulation reaches the stopping criterion. As a matter of fact, we used 1000 iterations for each spreadsheet calculation. Use of the Latin Hypercube sampling feature of the Crystal Ball software meant that we were able to use relatively little iteration. To avoid the use of a common random number, Crystal Ball uses a Multiplicative Congruential Generator which utilizes an iteration formula $[(r \leftarrow (62089911.r).mod(2^{31}\_1)]$ by which a random number repeats with a probability of 1 in several billion trials.

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[36] Requirements restrict forecast statistics. These differ from constraints, since constraints restrict decision variables (or relationships among decision variables).Requirements are sometimes called ''probabilistic constraints'', or "chance constraints''.

[37] Though, this stricter requirement has a potential threat to opt out the renewable energy free portfolio optima, but as an experiment to observe the impacts of renewable energies on overall portfolio risk, we followed this path.

[38] In Latin Hypercube sampling, Crystal Ball divides each assumption's probability distribution into several non-overlapping segments with equal probability. During a simulation run, the software selects a random assumption value from each segment according to the segment's probability distribution. The major benefit of LH sampling is the need for fewer trials before achieving the closest approximation of the objective function.

7.3 Results and discussions

At the beginning of our experiment, we plotted each technology of the experimental portfolio in separate risk-return and cost-risk reference frames mainly to clarify the relative position of each technology in the context of risk, cost and return characteristics. We conducted a simulation to forecast the ranges of renewable energy supply percentage (within the experimental portfolio of electricity supply) under the given conditions of portfolio cost and risk, respectively. Finally, we conducted simulation optimization for minimization of the portfolio risk.

7.3.1 Risk-return-cost behaviour of the experimental portfolio

As discussed earlier, the risk associated with each technology is the standard deviation of the year-to-year variation of the HPR of each input cost component. Return is measured as the inverse of the weighted average generation cost for each technology. This provides insight into how a combination of technologies in a portfolio can behave in terms of reducing risks and increasing returns.

Using Equations (2) and (3) we have estimated the return and risk for each technology based on the holding period returns behavior of the various input costs related thereto. The HPR of each technology was estimated using data from a paper published by Awerbuch and Spencer (2007) (mainly the capital and O&M costs HPR), The Institute of Energy Economics Japan (2007) (for fuel cost HPR) and European Climate Exchange (2008) (for CO_2 cost HPR). Figure 7-4 shows the relative position of each technology in terms of risk and return.

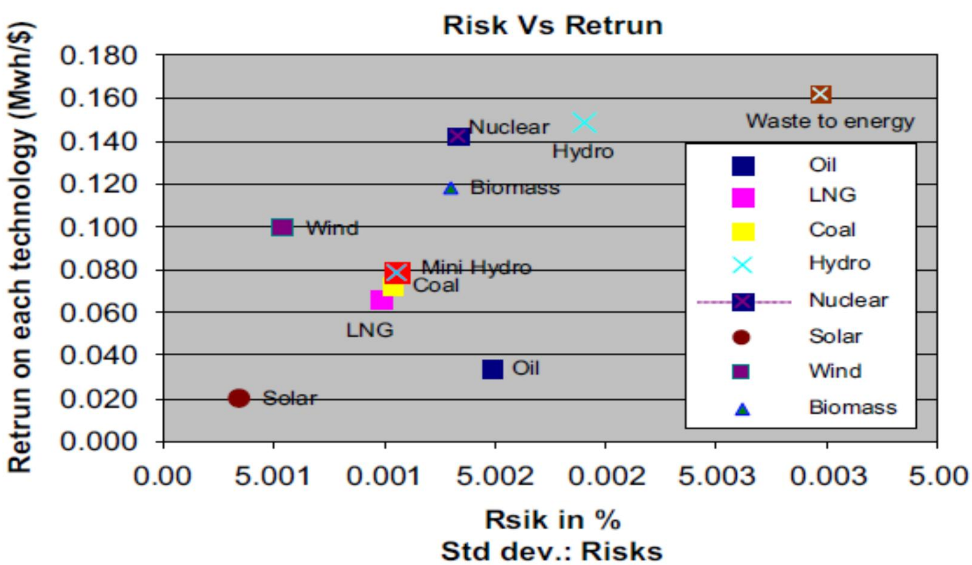

Figure 7.4: Risk-Return relationship of power generating technologies in Japan

From this result we can further infer that the current major electricity supply technologies of the Japanese national grid involve medium to high risks to investors in the power sector, whereas lower risk technologies like solar and wind are still under-utilized (around 0.2–0.5% of the total electrify supply). Therefore it is puzzling as to why electricity generation in Japan is heavily skewed towards higher-risk technologies (Elder et al., 2007). Our risk analysis shows that the waste to energy technology is the most risky renewable energy technology in the portfolio.

Figure 7-5 whose y-axis is the inverse of the y-axis of the Figure 7.4, (portfolio return is the inverse of portfolio cost) shows the relative positions of various power generating technologies in Japan in the reference frame of weighted average cost of generation[39] of each technology, and their respective risks. This further demonstrates that though solar photovoltaic (PV) are the most expensive electricity generation option for Japan, it is still a less risky option for the country. Ironically, the waste to energy technology option appears to be the most risky option of all the renewable energies in the country, despite Japan being the pioneer in waste to energy technology development. Wind energy appears to be a favored option for Japan as it involves very low risk and comparatively low cost of generation. In actual fact, other than solar PV, for Japan, all other renewable energies are less expensive but slightly more risky than fossil-fuel-based electricity generation technologies. Further, overall risks related to cost of technology are very low in Japan for renewable energies due to the availability of highly advanced technology within the country. But, due to the very high labour costs and scarcity of other resources, total generation costs are often very high. For example, waste to energy technology is very advanced in Japan, but due to the price of the waste collection system, which is very high, the overall generation cost of power from this renewable source has become highly expensive. Similarly, wind technology is not very expensive in Japan, but because of the high land cost, the resulting total generation cost becomes expensive.

[39] Weighted Average Cost of Generation (WACG) has been estimated using simple weighted average mean principle where every input factor's contributory percentage has been multiplied with its actual value contribution and finally added up over all the inputs (WACG= Σ (xi.Ci) where i= 1 to n and Σxi= 1.

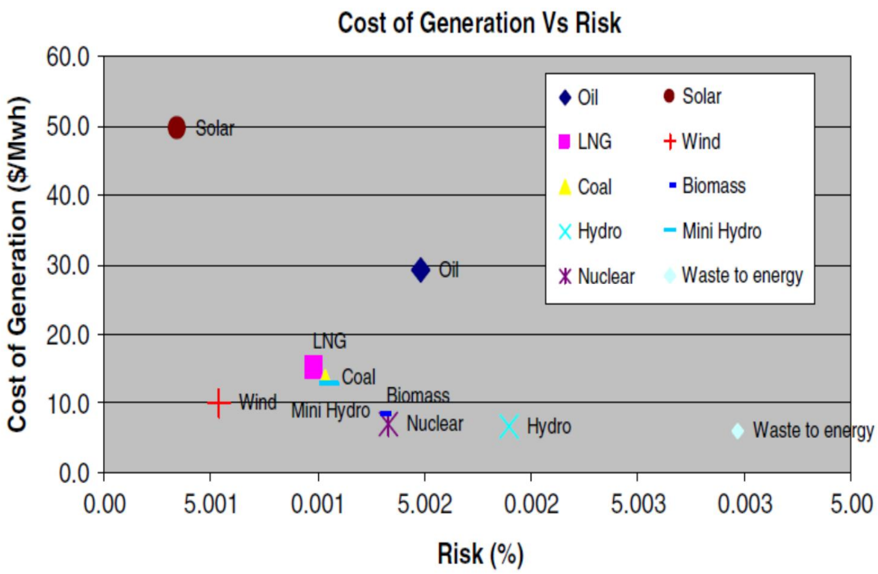

Figure 7.5: Generation cost and investment risk profile of each technology

It is, therefore, very important to analyze the electricity generating technologies from a risk-cost composite perspective rather than solely a cost perspective. This can help to avoid any low cost bias, which ignores the hidden investment risk.

7.3.2 Forecasting renewable energy supply

The first set of simulations has three objectives. First, it aims to forecast the renewable energy supply percentage in Japan without any technical, financial and environmental constraints. Second, it aims to generate two separate renewable energy supply frontiers corresponding to expected portfolio risk and return, respectively. Lastly, it aims at demonstrating the impact of renewable energy in the electricity supply portfolio in terms of the expected risk and cost in Japan. With the given supply distribution assumptions (see Table 7-2) of the input technologies in the experimental electricity supply portfolio, the simulation model forecasted that the renewable energy supply could provide up to 14–15% of the total electricity supply in Japan over the next decade until 2020, provided all other conditions to harness those energies remain the same. We use the simple lead forecasting technique which basically optimizes the forecasting parameter to minimize the error between the historical data and the fit value over a specified number of periods. Here we used total 10 year projection with one year interval period. Mathematically saying the simple lead forecasting, the fit value for period t is calculated as the (lead)-period-ahead forecast from period t=0. The fit value for t=1 calculated with simple lead forecasting is the same as the fit for the standard forecast, which is a 1-period-ahead forecast from period t=0. The residual at period t is calculated as the difference between the historical value at period t and the lead-period-fit obtained for period (t). The lead root mean square error (RMSE) is calculated as the root mean square of the residuals as calculated above. Extension of the line XY (see Fig. 5-5) represents the range of the possible RE supply in Japan. However, the expected generation cost of the experimental portfolio tends to increase due to the inclusion of expensive renewable energy technologies. In Figure 7-6, the curve AB represents the RE supply frontier drawn on two reference scales: expected portfolio risk and expected portfolio cost. In the expected portfolio risk scale, the point Q on the frontier is the lowest possible risk, which indicates around 10% of renewable energy contribution in the experimental electricity supply portfolio. Similarly, point P on the frontier of the expected portfolio cost is the lowest possible expected portfolio cost, which indicates around 9% renewable energy supply. Therefore, this clearly demonstrates that expected portfolio risk analysis allows a greater percentage of renewable energy supply in the portfolio than expected portfolio cost analysis. This result adds further weight to the importance of considering portfolio risk in investor decision-making processes, which could enable a higher level of investment for renewable energy supply.

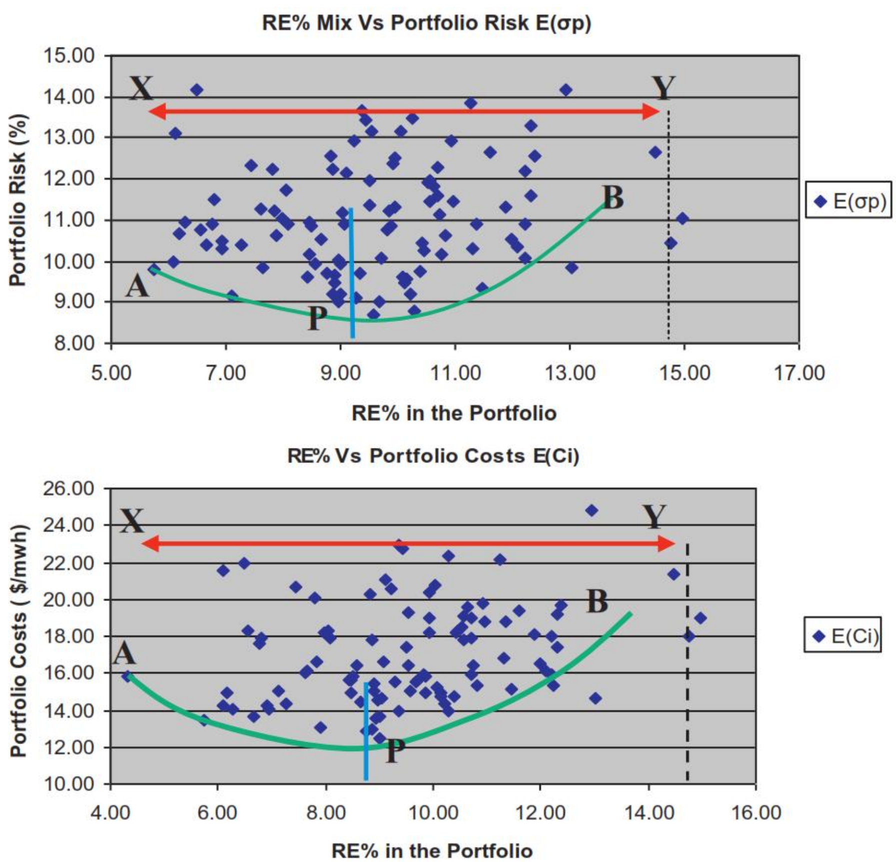

Figure 7.6: Range of renewable energy supply

Finally, to demonstrate the impacts of renewable energy inclusion in the experimental portfolio, we performed two simulations; i.e., one with and one without renewable energies in the portfolio. The important assumption we made here was the assumption of 100% supply from conventional sources (actually 99% as of year 2004) for the 'without' renewable energy portfolio. We then compared the expected portfolio risks and costs for these two experimental portfolios as well (see Table 7-4).

Table 7-4: Impact of renewable energy in the portfolio

Portfolio	**Portfolio Risk [E(σ_p)] (% change)**	**Portfolio Cost [E(C_i)] (% change)**
Portfolio without renewable energy contribution	10.30	13.87
Portfolio with renewable energy contribution	10.20 (-1%)	13.97 (+0.7%)

Source: model estimated.

From the above result we may further conclude that renewable energy may have a positive impact on expected portfolio risk reduction, but may not have a positive impact on expected portfolio cost reduction. In this experiment, we found that due to inclusion of just 1% of renewable energy supply in the 'without' renewable energy portfolio, expected portfolio risk also drops by 1%. As we explained earlier, risk is synonymous to the cost for investors; this 1% risk reduction would certainly reduce the cost, and such risk aversion through renewable energies could be of interest to power sector investors.

7.3.3 Simulation optimization of portfolio risk

So far we have discussed the importance of the energy supply portfolio risk and how it is affected by changes in the supply mix. We have also seen that a risk analysis-based portfolio allows more renewable energy in the portfolio than that of a cost-based portfolio. In the third set of simulations, we conducted a risk simulation optimization experiment with our experimental portfolio with the objective of estimating minimum expected portfolio risk. This experiment was further extended under three different constrained situations for the purpose of sensitivity analysis. We assume that there are three main input constraints which can affect the risk pattern of an energy supply portfolio with renewable energies in Japan. Based on a literature review we further identified that fossil fuel price (the border price after import tax adjustment) (IEEJ, 2007), capital costs of renewable energy generation (Iida, 2002, Ito et al. 2006) and international carbon price (measured in terms of USD/tCO_2) (Takase and Suzuki, 2010) can be considered as the three key factors affecting portfolio risk and cost in Japan; hence the need for a test of the sensitivity of the portfolio risk using these three main input factors.

We conducted our simulation optimization with the requirement of renewable energy supply greater than 1.37% to create the baseline scenario. This simulation was then followed by three more tests with three different scenarios to observe the impacts of these constraints on the objective function, i.e., expected portfolio risk and its corresponding decision variables such as expected portfolio cost. Finally, with these four simulations, we estimated four different optimal risk levels for the same experimental portfolio. Discussed below are the individual simulation results.

A. Baseline scenario with minimum RE supply requirement (Scenario-1)

Base-case scenario (S-1) deals with the optimization of the expected portfolio risk E(σp) under the set of basic decision parameters and the constraint of a minimum renewable energy supply obligation of 1.37% or above. This result shows that the achievable minimum portfolio risk is 8.9%, which is just below the RE supply frontier in the portfolio risk frame (see Table 7-5). The simulation also estimated that, for Japan, the corresponding renewable energy supply percentage within the 95% confidence interval could be between 8.5 to 9.1% of the total national supply. Table 5 shows the result of optimization.

Table 7-5: Optimal generation portfolio (Scenario-1)

Variables	Constraint Range	Optimal Value (all in %)
Objective function:		8.9
Expected Portfolio Risk $E(\sigma_p)$	Minimization	
Constraints:		95% Confidence Interval :
Minimum RE supply obligation	RE% >= 1.37	Upper 95% limit = 9.1%
		Lower 95% limit = 8.5%
Portfolio Cost:		95% Confidence Interval :
$E(C_i)$		Upper 95% limit = 16.84 $/Mwh
		Lower 95% limit = 16.01 $/Mwh

This result indicates under-performance of the renewable energy sector in the Japanese electricity market. Currently, Japan's electricity supply portfolio has a 10.2% risk and 1% renewable energy supply. Our simulation result shows that Japan can reduce the expected portfolio risk by up to 8.9% (11% less than the baseline situation) and can eventually increase the renewable energy supply up to 9% of the total national supply of electricity.

B. Scenario of high fossil fuel price (Scenario-2)

Scenario-2 simulation is essentially a sensitivity analysis which checks the impact of high fossil fuel price on expected portfolio risk and cost, and impact of such on the percentage of renewable energy supply. We simulated this scenario with a 10% fossil fuel price increase at the border, compared to the baseline scenario. Further, we ignored extreme cases of oil price volatility in our simulation, such as recent cases in which swings of over 70% were observed (on 2008 July, the international crude oil price reached an all time high of $147/barrel and then dropped below $40/barrel within 6 months). The result shows a significant increase in the expected portfolio risk compared to the baseline case (S-1), but little change in the corresponding renewable energy supply percentage. Portfolio risk increased by around 24% but there was negligible change in renewable energy supply and expected portfolio cost. This result indicates that an increase in fossil fuel price would definitely increase the investment risk, but more surprisingly, may not help to increase the supply of renewable energy, thus contradicting the conventional thinking—which states that there is a positive correlation between high fossil fuel prices and increased renewable energy supply. The primary reason for such behavior could be the short-term nature, as well as high unpredictability of such price surges, the presence of which is not sufficient cause for investors to switch over to renewable energy technologies. We also found that inter-fuel substitutions among the fossil fuels are quite prominent in the case of sudden increases in their prices, such as where oil-based power production is quickly replaced by natural gas or even coal, or vice-versa, based on the relative cost difference between them. As a matter of fact, historically it has been observed that during periods of high fossil fuel price, investment in renewable energy R&D activities rose significantly, but unfortunately not in the actual supply of energy. The reasons for this could be the comparatively longer gestation period required to set up renewable energy power plants than the duration of high fossil fuel price regimes, as well as the negligible impact on reducing the additional financial burden due to high fossil fuel prices. Another possible reason could be the simple fact that policy makers and investors are unaware of the overall benefits of renewable energy. At the policy level this could provide further incentive to governments and law makers to create durable policies for new and renewable energy development. Table 7-6 shows the simulation results.

Table 7-6: Optimal generation portfolio (Scenario-2)

Variables	Constraint Range	Optimal Value (all in %)
Objective function:		
Expected portfolio risk $E(\sigma_p)$	Minimization	11.03
Constraints:	RE% >= 1.37	**95% Confidence Interval of RE% mix in the portfolio :**
RE%	***Fuel Cost ($/Mwh)***	
Fuel Cost (Oil)	Oil > $96.2	
Fuel Cost (LNG)	LNG > $42	Upper 95% limit = 9 %
Fuel Cost (Coal)	Coal >$20.4	Lower 95% limit = 8.1 %
Fuel Cost (Nuclear)	Nuclear >$1.72	
Expected Portfolio Cost:		**95% Confidence Interval of portfolio cost :**
$E(C_i)$		Upper 95% limit = 17.2 $/Mwh
		Lower 95% limit = 16.14 $/Mwh

C. Scenario of high capital costs of renewable energy supply (Scenario-3)

Scenario-3 simulation shows the various impacts of increasing the capital cost of renewable energy generation on the expected portfolio risk and cost. According to the simulation result, inclusion of high capital-cost-intensive renewable energies in the supply portfolio would increase the expected portfolio risk as well as portfolio cost. In Japan, generation of solar power is still very expensive, although it is associated with very low risk. Similarly, due to the high cost and limited availability of land, Japan also needs to consider utilizing off-shore wind energy production, although this entails even higher costs than on-shore production. Therefore, in spite of having low risk advantages, solar and wind technologies require considerable capital investment, which may offset other benefits of the portfolio. In this scenario, we attempted to measure the impacts of a 10% increase in capital costs of renewable energy generation as regards the expected portfolio risk. Table 6 shows the optimal results of the key parameters.

The simulation result further indicates that the expected portfolio risk increases by 37% and the corresponding renewable energy supply drops by 5% compared to the baseline scenario. There is also a slight increase in expected portfolio cost of 2%, mainly due to an increase in capital cost. The major reason for such a high portfolio risk could be due to a heavier reliance, from the investor viewpoint, on fossil fuels than renewable energy in order to avoid the higher costs related to the latter. This greatly increases the portfolio risk. Table 7-7 shows the result of this simulation.

Table 7-7: Optimal generation portfolio (Scenario-3)

Variables	**Constraint Range**	**Optimal Value (all in %)**
Objective function:		
Expected Portfolio Risk $E(\sigma_p)$	Minimization	12.08
Constraints:	RE% >= 1.37	**95% Confidence Interval of RE% mix in the portfolio :**
RE%	***Capital Cost ($/Mwh)***	
Capital Cost (Solar)	Solar > $109.12	Upper 95% limit = 8.9 %
Capital Cost (Wind)	Wind > $21.8	Lower 95% limit = 8.1%
Capital Cost (Biomass)	Biomass>$17	
Capital Cost (Mini Hydro)	Mini hydro > $27.7	
Capital Cost (Waste to Energy)	Waste to energy > 12.9	
Portfolio Cost:		**95% Confidence Interval of portfolio cost**
$E(C_i)$		Upper 95% limit = 17.34 $/Mwh
		Lower 95% limit = 16.37 $/Mwh

D. Scenario of high international carbon price (Scenario-4)

Scenario-4 simulation, as a part of sensitivity analysis, aims at analyzing the impacts of a carbon price increase in the international market on the expected portfolio risk and subsequent renewable energies supply in Japan. Being an Annex-I country, Japan's GHG emissions reduction targets are set out by the Kyoto Protocol, which states its obligation to reduce emissions to the targeted level. Purchasing emission units from the international market through either Assigned Amount Units (AAU) or Certified Emissions Reductions (CERs) is therefore an important means by which Japan can achieve its Kyoto target. Unfortunately, the price of CERs is liable to wide fluctuations in the international market due to demand and supply instability. Accordingly, we used the standardized carbon price index developed by the European Climate Exchange (ECX) based on the EU Allowance Emissions Trading pricing for our analysis. It has been observed that the ECX C-price index increased by around 20% between 2005 and 2008 due to high demand. However, in the last quarter of 2008, the price began falling drastically due to the global economic crisis amidst falling demand for emission reduction certificates. Based on such circumstances, we conducted an additional sensitivity analysis to determine expected portfolio risk with a 10% increase in ECX price index, and simultaneously observed the corresponding impact on renewable energy supply.

Table 7-8 shows the results of the simulation with a 10% increase in the ECX price index for carbon. The prediction shows that the expected portfolio risk can be minimized by up to 12.08%, which is still 37% higher than the baseline scenario. Further, the percentage of renewable energy supply in the portfolio stays at around 8.9%, which is close to our baseline scenario. This result further indicates that the international CER price has a negative effect on the portfolio risk but has no impact on renewable energy supply and expected portfolio cost.

Table 7-8: Optimal generation portfolio (Scenario-4)

Variables	**Constraint Range**	**Optimal Value (all in %)**
Objective function:		
Expected Portfolio Risk $E(\sigma_p)$	Minimization	12.08
Constraints:		**95% Confidence Interval of RE% mix in the portfolio :**
RE%	RE% >= 1.37	
Carbon price index at ECX	C-price >= € 27/ton CO_2	Upper 95% limit = 9 % Lower 95% limit = 8.1%
Portfolio Cost:		**95% Confidence Interval of portfolio cost :**
$E(C_i)$		Upper 95% limit = 17.06 $/Mwh Lower 95% limit = 15.98 $/Mwh

7.4 Conclusion

It has been observed that incorporation of renewable energies in the supply portfolio can basically reduce the expected portfolio risk but can also increase the expected portfolio supply costs and expected portfolio return. Under the baseline situation of the experimental portfolio, where there are no significant changes in the external factors, expected portfolio risk can be optimized at a reduced level, compared to the current situation. This indicates the importance of two major policy decisions in the area of energy sector investment. Firstly, it emphasizes that it would be advantageous, from an electricity investor's viewpoint, to utilise portfolio risk reduction and secondly, it shows that using all available renewable energy resources to form a diverse supply portfolio would reduce the investment portfolio risk.

Due to the very high level of uncertainties in the market, power sector investment is becoming more and more risky in today's world. Environmental protection measures and the increasing severity of other policies further complicate this situation. To date, in the context of power sector planning, the prevailing paradigm places emphasis on minimizing the cost, with risk-minimisation only implied, when compiling estimates. The aims of this study were to demonstrate the importance of making the portfolio risk explicit, and also to show that such risk can be mitigated through including renewable energy in the portfolio. Results of our modeling also show that the risk in portfolios with a renewable energy component is sensitive to variations in input cost factors, and that consequently, portfolio risk increases concomitantly with any escalation in cost factors. Even if the price of CO_2 increases, this creates a negative pressure on the renewable energy contribution in the portfolio and also increases the contribution from the relatively cleaner conventional technologies like hydro and Liquefied Natural Gas (LNG). In essence, the key to determining the risk of a portfolio is the standard deviation of the price fluctuation; so the portfolio risk is neutral to the absolute value of the fossil fuel price, and is not affected in a steady price situation. An important conclusion to be drawn from this is that even during a low cost fossil fuel price regime, if there is high price volatility, the portfolio risk will still be high, which could incline investors towards renewable energies to reduce the portfolio risk. This is one of the best features of using portfolio risk–it makes investors neutral to the absolute value of input costs, but increases their awareness of cost fluctuations. This would add further credibility to policies intended to stabilize input cost fluctuations, and in that respect renewable energies could play a crucial role. This study demonstrates that even Japan, an energy efficient and technologically advanced country, is still using a traditional energy planning mechanism based on the least-cost supply principle, which suffers from high risk exposure to price and cost fluctuations of the input factors. In effect, the lack of explicit risk in Japan's electricity sector has meant that its power supply portfolio has remained in the high risk category unnoticed for a very long time. This case study corroborates this finding further, and predicts that while lowering the electricity supply portfolio risk, Japan could attain a level of renewable energy supply of around 9% with only a moderate increase in supply cost. Sensitivity analysis further shows that with a change in the input cost factors of 10%, the percentage of renewable energy supply is only marginally affected, but the corresponding portfolio risks and costs vary within the range of 18-20% compared to the baseline scenario. Table 7-9 shows a comparison of the various scenarios of renewable energy supply compared to the year 2004 base case scenario.

Table 7-9: Comparative analysis of different scenarios

Scenario	*Expected Portfolio Risk (%)*	*RE Supply (%)*	*Expected Portfolio Cost ($/Mwh)*
Baseline Scenario	*10.20*	*1.37*	*13.87*
S-1	*8.9 (-12.7)*	*8.8 (528.5)*	*16.5 (18.9)*
S-2	*11.03 (8.13)*	*8.5 (507)*	*16.7 (20.4)*
S-3	*12.08 (18.4)*	*8.5 (507)*	*16.9 (21.8)*
S-4	*12.08 (18.4)*	*8.4 (507)*	*16.5 (18.9)*

(Bracketed figures indicate percentage change to the baseline figures)

In conclusion, it is immediately apparent that selecting an electricity supply portfolio for Japan which can increase the renewable energy contribution is a challenge even with the portfolio risk optimization approach. Managing the three important issues of cost, risk and supply percentage, therefore, requires continued governmental policy support. To conclude, a summary of the findings appears below:

- Investment risk mitigation should be made one of the explicit objectives of power sector investors.
- Including renewable energies in the investment portfolio can increase the generation cost of the portfolio, but can also reduce the portfolio risk and corresponding risk hedging costs.
- Ironically, price fluctuations, not absolute price figures represent the root cause of high investment risk. Therefore, it is more important to control price fluctuations than to reduce the actual price. Policies should therefore be formulated to stabilize such fluctuations, hence the need for Government intervention.
- The international carbon price (tested with a 10% increase) has negligible impact on portfolio risk and corresponding renewable energy supply. Therefore, an increase in carbon price may not encourage investors to invest in renewable energy to reduce their portfolio risk.
- The conventional notion of a positive correlation between fossil fuel price increase and investment in renewable energy may not work in reality if the corresponding risk perspectives are considered. This finding invites further investigation into the behaviour of renewable energy investment during high fossil fuel prices.

7.5 Improvement for SE4ALL tracking on renewable energy investment

Drawing on the example of Japan, this study suggests that providing an explicit account of investment risk is beneficial for power sector investors in energy market, where the bulk of energy resources are imported. Risk already exists in the market but is often hidden behind obfuscated accounting, which prevents investors from making rational decisions about their investments. To maintain steady investments in the power sector and to supply reliable, efficient and affordable electricity to the consumers, we recommend two sets of policies.

The first set is oriented towards the government, who can play the key role in creating an enabling environment by providing continuous policy support to promote renewable energy in the market. Drawing on the results of reduced impact of fossil fuel prices on renewable energy generation, the government needs to consider setting out unconditional policy measures to promote new and renewable energy, irrespective of the other market conditions.

The second set of policy recommendations is aimed at investors, who should consider two key issues: first, making the investment risk explicit in their decision making process and second, mitigating this risk through investing more in renewable energy within the same investment portfolio. Further, at the national scale, the government can also enhance the risk sensitivity of investment within the country by introducing certain regulatory policies to control government price support for fossil fuel procurement, fuel price protection and subsidies, and so forth, which have a direct impact on the investment risk. This paper also recommends reforming the standard accounting system of tariff calculation by mandating internalization of the risk premium costs. Further, this study also indicates the need for the government to take a more proactive role in the development of renewable energy by reducing the costs related thereto. In this context, continued fiscal support for renewable energy, along with policies that make the risk analysis more explicit, are key factors.

As mentioned at the beginning of this paper, this study is an experiment to demonstrate the importance of renewable energy in the portfolio of electricity supply, hence priority has been given to those aspects which enhance the importance of renewable energy in the supply portfolio. As a matter of fact, a significant portion of investment risk is also related to the power off-take situation, especially the power purchase agreements (PPA). Quite often, poor PPAs result in huge investment losses to power producers. In this study, we did not address the inherent risks involved with renewable energy generation that can potentially undermine the purpose of promoting renewable energy; rather, we highlighted the more positive aspects, and invite policy makers as well as investors to ponder on the issue of promoting renewable energy in greater detail. A comprehensive risk analysis of renewable energy under the overarching principle of market would constitute an interesting topic for future research. Given the importance of renewable energy investment within a comprehensive power sector investment portfolio, we have identified certain important parameters to be monitored in terms of ensuring continued development of renewable energy sector. As SE4ALL targeted to achieve doubling of RE supply in the supply mix, continued investment in the RE sector is must. Therefore, we proposed a set a additional indicators along with existing SE4ALL RE indicator to enhance the potentiality of the success of achieving the target of doubling the share of renewable energy in the energy supply mix in the developing Asia region.

Table 7-10: Indicators to increase potentiality of achieving RE target under SE4ALL

SE4ALL Objective	Existing Tracking Indicators	Proposed Indicators
Doubling share of renewable energy in global mix	b) Share of renewable energy in Total Final Energy Consumption	• Cost of fuel price risk hedging (Unit: Billion USD/year) • Investment portfolio risk (in %) • Investment portfolio cost (in Billion USD/year)

It has been observed that the power companies incur huge cost on a regular basis to hedge the risk of international fossil fuel price fluctuation. Quite often these costs are passed on to the consumers and consumers are required to share the burden of the same. Conventionally, power sector investment decisions are made based on the least cost option basis but it has been demonstrated here that investment portfolio risk minimization based decision making process can reduce the portfolio cost by reducing the risk hedging expenditure. Per percentage of risk reduction can add certain economic benefits to the portfolio which compensates the additional cost of renewable energy sector development. Therefore, in the context of achieving target of doubling RE supply in the TFEC across the world, a paradigm shift in investment decision making process can be very beneficial indeed. In this new indicators we therefore, incorporated certain parameters which can directly or indirectly measure the benefits of renewable energy sector investment. The proposed indicators are however, more suitable for individual power companies who are investing in the market rather than the policy makers, but a statutory or voluntary reporting mechanism can be introduced by the authority to make this indicator wise reporting a regular phenomena if not mandatory at the beginning.

Chapter 8
Conclusions and recommendations

8. Need for improved analytical framework

In the process of conducting analysis and observing the intricacies of multifarious influences on national and regional energy sector, it has been understood that access to modern energy commodities with high energy efficiency and with cleaner production process, availability of energy resources alone cannot meet the objective. Given the increasing complexity in socio-economic condition followed by increasing dynamism in demographic condition and increasing level of political uncertainties including international terrorism, having sustainable energy supply chain is becoming a tough challenge to the countries. Having sufficient energy resources is not a big challenge now in front of the world rather having robust energy resources distribution system is a crucial issue. World has enough coal for another two hundred years, oil for another seventy years and with new discovery of shale gas, this particular fuel type is almost unlimited. As a matter of fact, energy resource scarcity is not big threat to the mankind. Nevertheless, energy poverty is grasping the world aggressively where the Developing Asia region is the most vulnerable one. Being poor in indigenous fossil fuel resources and backward in technology and financial resources, the region has become perennial net energy importer. Unfortunately, the region is also having the highest population growth rate and house one third of world population (more than 2 billion) having lowest level of par capita income in the world (less than 1.51 USD/day). As a result, people of Developing Asia are unable to pay for high cost imported energy to meet their energy demand adequately. Due to lack of technology and financial resources neither these countries able to develop their own energy market which can sufficiently supply energy to meet the increasing demand, nor they are able to afford to pay increasing price of imported energy in the international market.

Though in recent days there are certain emerging economics in the Developing Asia region who are using their indigenous resources, technologies and finance to promote their energy sector, but a pivotal factor of cost effectiveness still drives the majority of the decisions in this context. As a result, coal still remains the major source of energy in the region and it will continue for next couple of decades mainly because of its affordability. In the context of Sustainable Energy for All, while the objective is to provide access to modern energy, it is imperative to have modern affordable energy indeed at least in the Developing Asia region. Affordability of energy is ensured under certain conditions like low extraction, processing and distribution cost of energy, use of proven technology, mass scale of production and optimal sharing of resources. In the new framework of tracking of

SE4ALL we are fundamentally based on these principles of affordable energy supply in the region. In each chapter, we have tried to prove the justification of each of the corresponding principles of affordability of energy. Existing tracking framework of SE4ALL does not consider the issue of affordability of energy where the energy resources are globally scattered and so as ownership of resources. It is imperative to align the tracking indicators of SE4ALL with affordability commensurate with national or regional economic characteristics.

8.1 Water and energy resources nexus

This chapter aims to demonstrate that for sustainable thermal power generation in the Developing Asia region, which is the most affordable sources of electricity, water availability is must. Unless adequate water availability is ensured, long term supply of power from thermal sources will be jeopardized. This will not only hamper the economic and social development of the region but will also distract the achievement target of energy access under SE4ALL. Though water is very crucial for this region's energy supply, but there is no systematic measuring and monitoring facility to investigate the relationship of water and energy supply.

This chapter tries to identify the issues of water energy nexus by determining the demand for water by the energy sector to meet the needs of the economy. It also estimates for certain countries the total available water in the long term for energy sector. It has been observed that there is no such systematic approach taken by the regional governments to assess the long term water availability exclusively for energy sector. Water for human and commercial consumptions are more or less monitored and reported but there is a big gap in such estimation for energy sector. However, the energy sector in the south Asia region is heavily water dependent and more precisely water inefficient in the context of specific water consumption for energy. As a matter of fact, Asian developing economies especially the countries like India are very vulnerable to the long term water availability for energy production. These countries are heavily dependent on thermal technologies especially coal and natural gas for their cheaper and reliable power generation and thus more dependent on water compared to other countries having alternative technologies. In Asia, until 2050 thermal technologies for energy generation and subsequently dependence on fossil fuels like coal and natural gas will be predominant. Our assessment shows that even under the most optimistic scenario of emissions reduction by deploying renewable technologies, thermal technology dependence will continue to such an extent where water scarcity may disrupt the long term energy planning of the countries. India being one of the fastest growing economies in the world, reliable energy supply is the most important issue for it. However, the chapter found that currently available long term energy planning (mainly under the 12th Five Year Plan) has hardly considered the issues of water resources constraint in the planning. Though, the Central Electricity Authority and Federal Regulators are concerned about it, but efforts are yet to be pushed up to sensitized the policy makers. The chapter demonstrated that within the range of 2040 to 2050, there is will be serious conflict among various water users' which can dampen the economic and social development significantly for the country. Increasing water demand for electricity generation will intensify inter-sectoral conflicts for freshwater. Thus, to mitigate such conflicts for freshwater appropriate policies should be taken in a timely manner. These policies could include mandating water efficient technologies in power plants, promoting low water consumptive renewable energy (wind, solar photovoltaic) and implementation of water demand management approaches for major water users. Moreover, India and the developing nations of Asia being in the stage of economic growth and prosperity, they are rather in an advantageous position to avoid long term technology and investment lock in by taking prudent decision of sustainable investment in the energy sector. Considering water energy nexus while building long term planning for energy could be considered as a risk hedging measure for investment indeed,

8.2 Energy trade liberalization and regional cooperation

This chapter aims to demonstrate the advantages of regional cooperation of energy resource sharing via trade to achieve a level of affordability. Basic principle of cooperation is to achieve the lowest long run marginal cost of energy supply for the region by sharing the resources and technology in an optimal way. In the context of achieving the target of access to energy under the SE4ALL program, energy trade liberalization and regional energy infrastructure cooperation are important indicators to monitor. In this chapter we discussed about the issue of regional trade of energy and it implication on economic growth and development along with environmental impacts. It is assumed that given the Asian diversity of natural resources and economic condition it is beneficial for the region as a whole to move more towards an integrated energy market. Energy commodity trade liberalization is a step towards effective market harmonization and integration and thus empirically assessed in this chapter to understand how far this policy can be effective especially for regional welfare improvement, economic develop followed by environmental condition to fulfill the objectives of sustainable development.

Under this policy scenario energy commodities are expected to be traded freely within the region. The Asian region comprises of both energy exporter and importer countries including some countries like China and Indonesia who are the net importer of energy but also big exporters of energy in the region too. The chapter found that removing trade and non trade barriers for energy commodities (coal, oil, natural gas, LNG, electricity) within this region will help to improve the macroeconomic condition as a whole by 2020 with a tune of 0.025% of total regional GDP. However certain countries might lose in terms of GDP loss but given the fact of overall positive achievement, such trade liberalization can be further promoted. In terms of individual energy commodity sector output, region gains in total as well compared to BAU scenario by 2020. However, due to improve energy commodity flow , use of energy also increases in the region which increases overall GHG emissions in the region by 2020 compared to BAU situation. Asian region also gains in social welfare due to energy commodity trade liberalization which translates into more employment generation and job creation.

8.3 Energy price reform

In this chapter we aims to demonstrate that subsidizing energy in the market is not a long term solution to provide affordable and reliable energy to the consumers rather pricing energy at market clearing rate can bring more social and economic benefits to the country in the long run. Energy price reform removes the market distortion and increases the economic efficiency and productivity which positively affect the overall macroeconomic growth and the environment by improving process efficiency and by reducing CO_2 emissions. This is especially beneficial for the developing economies where the majority of the consumers continue to use low cost, inefficient and dirtier energies. In the context of achieving the target of energy efficiency improvement globally under the SE4ALL program, energy price reform plays a crucial role indeed and therefore, it is considered to be an important indicator to be monitored on a regular basis. The framework of gradual and systematic energy price reform will facilitate the Asian region to integrate its energy market. Such framework will reduce the financial burden of the respective governments and will also help them to reduce market distortions with improvement in energy efficiency. The regional governments can also develop the energy sectoral investment plans in their respective countries to bolster their economic growth and consumption of more efficient and cleaner fuels.

This chapter tries to demonstrate such potential benefits of energy pricing reform in a quantitative manner using CGE models. The challenge associated with quantitative assessment of energy pricing reform is essentially data issues in which further disaggregation of fossil fuel commodities are required to identify net subsidized commodities. Our original CGE model partially overcomes the challenge, and it helps in revealing the necessity of further improvement, such as introduction of economic and social costs of insufficient energy supply, and further distinction of conventional technologies and cleaner technologies.

We summarize the main policy implications under four different categories. Firstly, it is important for the countries to define their energy subsidy so that countries can statistically estimate its energy pricing status of net taxed or net subsidized. If the countries are net taxed on their energy commodities then reduction of subsidies in one particular energy commodity may not bring the overall economic benefits. Secondly, it is important to have a systematic energy subsidy accounting system at the national level to use the information for analytical purposes. Thirdly, the subsidized energy commodity market is expected to be affected by reduced demand and sales due to removal of subsidies. It may affect the outputs of these sectors by reduced jobs and corporate earnings. However, as the money may flow to other sectors for government or private sector spending, outputs may grow in those sectors which will overall compensate for the economic losses. In this context, it has been estimated that national GDP will benefit from this reallocation of resources. Finally, as a measure to curb CO2 emissions, energy subsidy removal will work very effectively in lieu of a carbon tax. Additional tax on emissions may adversely affect the economic efficiency due to its distorting impact. However, the removal of subsides will have two effects in the market. One, it will reduce market distortions which will help to improve economic efficiency and two, it will force the end users to improve efficiency of use and conserve energy which will ultimately reduce CO2 emissions. Policy-makers can therefore consider this tool as an effective means to combat global warming and climate change-related issues in the region. An integrated energy market can expedite the process of pricing reform where the benefits and costs can be shared among the countries and the private sector investments in the forms of foreign direct investment (FDI) in the energy sector. Energy pricing reform is thus expected to enhance the economic development of the region and also to encourage people to use more efficient and cleaner fuels.

8.4 Renewable energy equipment trade

In this chapter we aim to demonstrate that south-south collaboration in technology development and knowledge sharing can bring down the cost of energy generation from new and renewable energy sources. It has been observed that new and renewable energy technologies are asymmetrically developed in the region. For example, solar technology became super advance in China but not in Indonesia or Vietnam or India. However, wind technology has become world class in India compared to China and other countries in the region. Sharing these regional technologies and knowledge could be much more cost effective in terms of developing new and renewable energy market in the region. In the context of promoting new and renewable energy in the supply mix at a global scale, renewable energy equipment trade is an important indicator. Upward movement of this indicator ensures more collaboration and exchange of technology, knowledge and finance to develop renewable energy in the region. Instead of procuring high cost western world technologies with more strings attached to these technology transfers, procuring regional and local technologies are more cost effective and technically feasible. In the context of achieving the objective of rapid development and deployment of renewable energy in the global energy supply mix under the SE4ALL program, renewable energy equipment trade movement is an important indicator to be monitored.

8.5 Energy sector investment diversification to promote RE

In this chapter we aim to demonstrate that to entice power sector investors to invest in new and renewable energy sector it is important to demonstrate the cost effectiveness of such investment over conventional investments in fossil fuel sector. While SE4ALL aims to double the renewable energy supply in the global energy mix, it is therefore, important to make renewable energy sector as mainstream investment sector globally. It is projected that by 2030s world energy demand will grow up to 17000 Mtoe out of which more than 8000 Mtoe is expected to be supplied by the new and renewable energy sources under the SE4ALL goal plan. At present world is producing only around 250 Mtoe of energy from renewable sources. Therefore, a massive growth is required in RE supply which cannot be achieved unless it is mainstreamed and supported by all levels of stakeholders.

This chapter deals with an issue of investment in the renewable energy sector which is one of the most critical factors for this sector to become mainstreamed. This chapter deals this issue from a unique point of view which is related to investment portfolio risk. Assuming investors have more than one investment plan simultaneously and therefore, risk of entire investment portfolio is an important decision making criteria. The conventional pricing mechanism used for electricity systematically hides huge investment risks which are embedded in the overall cost of production. Although consumers are often unaware of these risks, they present a large financial burden on the economy. This chapter applies the portfolio optimization concepts from the field of finance to demonstrate the scope of greater utilization of renewable energies while reducing the embedded investment risk in the conventional electricity sector and its related financial burden. This chapter demonstrates that RE investment can compensate for the risks associated with the total input costs; such costs being external volatilities of fossil fuel prices, capital costs, operating and maintenance costs and the carbon costs. By means of example, this case chapter shows that Japan could in theory obtain up to 9% of its electricity supply from green sources, as compared to the present 1.37%, based on the utilisation of a portfolio risk-analysis evaluation. Explicit comparison of the monetary values of the investment risks of conventional and renewable energy sources shows that renewable energies have high market competitiveness. The chapter concludes with a recommendation that, as a business objective, investors would benefit by focusing on electricity supply portfolio risk minimization instead of cost

8.6 Proposed additional indicators for the framework of SE4ALL

To monitor the progress and to ensure the success of achieving the targets set under the SE4ALL program, a tracking framework has already been developed by the group of researchers and institutions across the world. The tracking framework is one way simple and easy to implement at a global scale but at the same time lacks in specificity. Fundamentally the existing framework works in a mutually exclusive environment, where all factors are independent and do not influence others. Based on our extensive research on various cross sectoral issues related to energy sector development, it has been envisaged that in the modern world, energy is no longer a mutually exclusive sector rather mutually dependent to other non energy resources, factors and economic agents. Understanding this, we have further proposed a set of additional indicators along with the existing framework for tracking of sustainable energy supply for all which is based on the principle of integrated assessment of all mutually dependable factors and resources required to achieve the supply and demand equilibrium in the market. The additional indicators are determined to increase the potentiality of achieving the targets set under the SE4ALL program especially for the developing Asia region. The schematic diagram (Figure 8.1) below shows the additional indicators along with the existing indicators of the tracking framework of SE4ALL which are more in numbers and in detail.

The list of indicators is exhaustive but not only limited to the list provided here. There could be several other factors which can influence and affect the success of achieving the target of SE4ALL. For example, human behavior, life style and more importantly political factors are not considered here in this study and to prepare this list which can have profound influence on the success of SE4ALL program. Moreover, the list of indicators mentioned in the Figure 8-1 below are also not all empirically studied in this thesis due to limitation of data, methodology and scope of work for this thesis. But all of them are conceptually linked to logical conclusion of providing an inclusive set of tracking framework for SE4ALL in the Developing Asia region. It is therefore, a scope of future research on remaining indicators mentioned in this inclusive tracking framework to investigate the causal relationship between the performance of the indicators and the rate of success of the corresponding target under the SE4ALL in the region.

We believe that Developing Asian countries will adopt this relatively complex monitoring framework and can enhance their energy supply and demand situation for sustainable development in the coming decades.

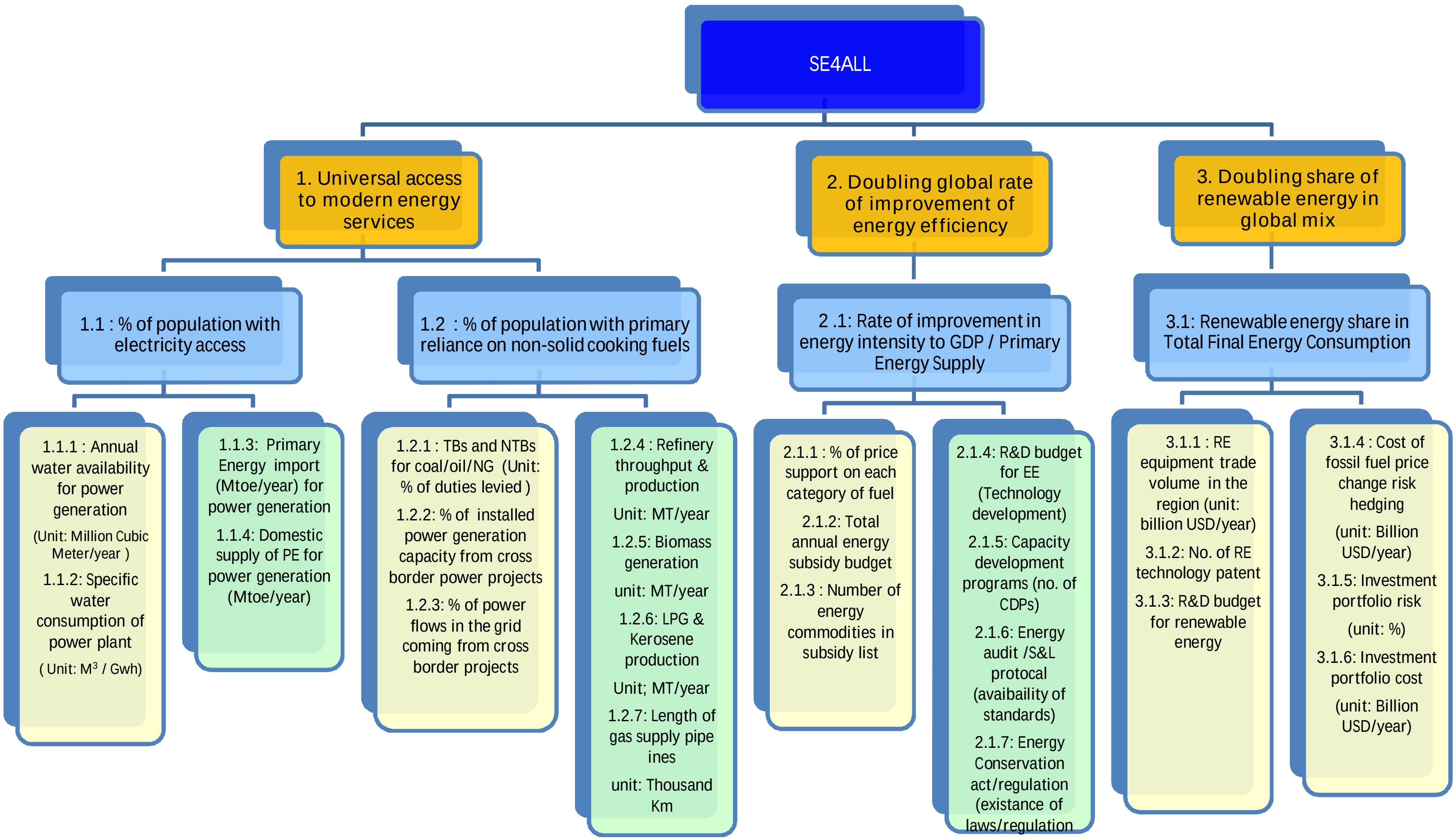

Figure 8.1 : Inclusive Tracking Framework for successful implementation of SE4ALL

Green box indicators are not studied in this thesis   Yellow box indicators ate studied in this thesis

8.7 Limitation and drawbacks of this thesis

Here we have tried to deep dive to the details of root cause analysis of each indicator set under the target of SE4ALL at a global scale mainly to identify the ancillary but most essential parameters which are undoubtedly need to be followed p. As mentioned in the beginning of the thesis that the main purpose and goal of this work is to enhance the potentiality of success of achieving the target set for SE4ALL and not to develop an alternative, it is therefore, imperative to understand here that this additional list of indicators mentioned in this thesis are not the full and exhaustive list. Rather the proposed indicators are the major ones which are essential but there might be several other important factors as well which are left out. For example, we have not considered the issues of human behavior in this analysis. But in the modern complex society, behavior of society is an important aspect to control environmental damages and also to achieve sustainable development target. Life style change is an utmost important issue now in terms of reducing GHG emissions and controlling the global warming. Since the target of SE4ALL is to ascertain the supply of basic modern energy to all in an environmentally benign manner, life style change is an essential action. However, in this thesis we have not considered that as an indicator. Similarly, we could not cover other factors like countries' economic, political and regulatory environment which are also important for successful achievement of the targets.

In terms of methodological issues we have developed couple new techniques to estimate the cross sectoral impacts of energy generation, supply and consumption. Water Energy systems model and macroeconomic CGE models are developed to evaluate the impacts of water on energy supply and importance of regional cooperation on energy supply respectively. In addition to these we have also used the special CGE model to investigate the impacts of price rationalization on energy supply situation followed by risk analysis model to promote investment in the market for RE. All these techniques are having their own uniqueness but also come with several limitations indeed. For water-energy model the major limitation is on its aggregated approach. We used the national scale water availability data and its forecasting to develop the constraint in the energy model. Given the characteristics of water availability it is ideally should be at river basin level. But we could not do that due to non-availability of data and required technical support. This is a scope of further improvement indeed for this analysis where sub-regional water supply analysis needs to be linked to sub-regional energy systems to perform this nexus analysis in a more precise way. Similarly, for the macro-economic CGE model, we have used the MRIO GTAP model which is having some inherent drawbacks indeed. The GTAP model uses only the percentage change in sectroal growth and cannot deal with the direct sectoral investment allocation which is the real life case. It means that using this model we could not conduct the impact assessment of direct investment in renewable energy sector. Though we tried to avoid this problem in the model used for the energy price rationalization chapter by upgrading to GAMS based GTAP model, but still the problem of dealing of sectoral investment in the form of FDI could not be dealt as wished. We by passed this problem by assuming a weighting factor which allocates some money to the sector from the kitty of total domestic savings. Thus there are certain methodological shortcomings already existing in the models used in this thesis which are required to be addressed in the future for betterment of the analysis and for more precise results.

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11. Bhattacharya, Anindya, Ghosh, J., Lata, C. 2015. *NAMA Decision Support Tool Ver.1.0*. UNDP Low Emissions Capacity Building (LECB) Report for Bhutan. 2015. (Forthcoming). UNDP Low Emissions Capacity Building (LECB) Report for Indonesia. 2015. (Forthcoming).
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