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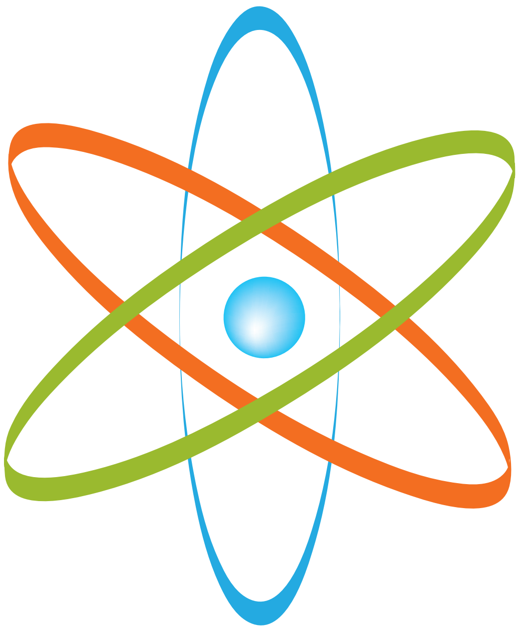
Implications of Risk Perceptions for Long Term Future of Nuclear Energy in India

A Sensitivity Analysis around Nuclear Energy Cost within an Integrated Assessment Modelling Framework

VAIBHAV CHATURVEDI, PRIYADARSHI R. SHUKLA,AND KARTHIK GANESAN



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ABOUT THE AUTHORS

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His research is focused on Indian and global energy and climate change mitigation policy issues- carbon dioxide emission stabilization pathways, low carbon and sustainable energy policies, modelling energy demand, and water-energy nexus within the integrated assessment modelling framework of the Global Change Assessment Model (GCAM). Vaibhav's recent work includes analyzing nuclear energy scenarios for India, Indian HFC emission scenarios, climate policy-agriculture water interactions, transportation energy scenarios, model evaluation, investment implications for the global electricity sector, and modelling the building sector energy demand scenarios for India. Vaibhav has been actively involved in global model comparison exercises like Asian Modelling Exercise (AME) and Energy Modelling Forum (EMF).

At CEEW, Vaibhav's research focuses on India within the domain of energy and climate policy, mid-range and long-range energy scenarios, HFC emission scenarios, urban energy demand pathways, and energy-water inter relationship. He has been actively publishing in leading international energy and climate policy journals.

Prof Priyadarshi R Shukla

Prof. Priyadarshi R. Shukla is a Professor in the Public Systems group at the Indian Institute of Management Ahmedabad, India. Prof. Shukla's scholarship covers diverse areas such as climate change and energy, resource management, environmental sustainability, development, and hierarchical mathematical modelling.

He is the Lead Author of IPCC Second Assessment Report and Technical Papers 1 and 4. He has published extensively on energy and environmental policies, with around 50 articles in top class peer- reviewed international journals, and has co-authored 12 books and over 20 international research reports. He has been a frequent presenter at international conferences and is a highly acclaimed and cited scholar. He has supervised 35 doctoral students at IIM Ahmedabad and 10 doctoral students at other international Universities.

He is a regular contributor to international research networks on energy and climate policy modelling like Energy Modelling Forum and Asian Modelling Exercise. Prof. Shukla was felicitated by the Prime Minister of India for his outstanding academic contributions and was a core member of the Intergovernmental Panel on Climate Change (IPCC) that was awarded the Nobel Peace prize in 2007.

Karthik Ganesan

Karthik Ganesan is a Senior Research Associate at CEEW, India. He leads the research efforts in the area of energy access and the future energy consumption pathways of rural India, and the opportunities for industrial energy efficiency gains. Most recently, he carried out an extensive analysis of the Indian government's policy support for RE industry and the cost implications of the exchequer. His focus has been to bring quantitative techniques from other domains, such as consumer choice models and system dynamics modelling to provide a holistic understanding of the various factors that influence energy policy and their impact in turn, on development and sustainability.

Prior to his association with CEEW he has worked on an array of projects in collaboration with various international institutions, with a focus on technology and environmental valuation. His published (and under review) works include the *Power Sector Expansion Plans in the Greater Mekong Sub-region: Regional governance challenges* (ADB), *Carbon Capture and Storage Potential for SE Asia* (ADB), *Valuation of Health Impact of Air pollution from Thermal Power Plants* (ADB), and *India's Energy Conundrum – What the future holds* (World Scientific).

Karthik graduated with a Masters in Public Policy from the Lee Kuan Yew School of Public Policy at the National University of Singapore. He has an M.Tech in Infrastructure Engineering and a B.Tech in Civil Engineering from the Indian Institute of Technology, Madras in Chennai.

ABSTRACT

Nuclear energy for power generation is expected to be a vital pillar of India's energy policy as well as emission mitigation strategy. However, there are divergent views from various quarters about the risk and liability associated with nuclear power plants. Risk mitigation through alternative measures increases the capital and operational costs of nuclear power. We undertake a cost sensitivity analysis within an integrated assessment modelling framework, for nuclear power generation and present its implications for India's energy and climate policy in the long run. We find that nuclear energy is competitive when risk induced costs are low under non-climate intervention (i.e. BAU) scenarios. However, even in BAU, nuclear energy deployment is seriously curtailed under higher risk induced costs. Consequently, fossil energy takes higher share, thus increasing the emissions substantially. Interestingly, nuclear liability off sets climate liability under climate policy scenarios. We find that nuclear energy is competitive, in the long-run, even under high risk induced costs if global climate stabilization policies corresponding to global 2 degree C stabilization target are pursued. Reaching emission mitigation targets however becomes much more expensive as a result of higher nuclear energy costs. Our results suggest need for credible risk assessment and more effective communication to reduce the risk perception gap between supporters and skeptics of nuclear energy to delineate an optimal role for nuclear technology in the Indian energy system.

1. INTRODUCTION

India's energy demand has witnessed a significant growth in the recent past. Commercial primary energy demand, excluding biomass and waste energy, has increased from 184mtoe in 1990 to 565 mtoe in 2011 (IEA, 2013), reflecting an average increase of 5.48% per annum. This rate was even higher at 6.88% between 2005 and 2011 (IEA, 2007; 2013), corresponding to an average yearly increase of 8.03%in per capita income during this period (WB, 2013). With 2011 electricity consumption in India at 684 kWh/capita(WB, 2013) being less than 15% of that of the developed economies (US, Germany, Japan, etc.), significant growth in India's' electricity generation capacity is required in the near and medium term to meet the growing demand.

Importance of nuclear energy for meeting India's energy challenges in the near as well as long term has been highlighted earlier in a number of studies (e.g. see Mallah and Bansal, 2010; Mohapatra and Mohanakrishnan, 2010; GoI, 2011; Remme et al., 2011; IAEA, 2012; Shukla and Chaturvedi, 2012; Kour and Dar, 2013; Shukla and Chaturvedi, 2013). Intermodel comparison studies have shown that nuclear energy plays a significant role in India's long term electricity production mix across energy models especially under climate policy scenarios (Clarke et al., 2012). The official government policy also has emphasized the importance of this energy source. This has been reflected in hectic efforts made by the Indian government to legislate the nuclear energy deal as well as in the increased pace of related negotiations with governments and businesses around the world for ensuring supply of nuclear technology and fuel.

While the government and numerous experts are optimistic about the future of nuclear energy in India, strong concerns remain in India and globally about the costs and risks of nuclear energy (Ramana, 2009; Sokolski, 2010; Abraham I, 2011; Chang et al., 2011; Hibbs, 2012). Ramana (2012) in his recent book reflects these concerns and argues against making nuclear energy an important pillar of India's energy supply policy. The argument is largely based on the history of nuclear disasters even in the most technologically advanced nations of the world, and thus on concerns about Indian government and managers' abilities to avoid and manage such a crisis, if it happens. Vehement demonstrations by the local populace against nuclear energy plants in various locations in India have only increased with time. The Fukushima nuclear disaster has only aggravated the concerns of those against nuclear power plants. Kundankulam and Jetapur are two recent examples. Indian judiciary has decided in favor of the Kundankulam plant that has achieved criticality recently, much to the disappointment of the protestors. Chang et al. (2011) analyze two modern day nuclear power plants, one in Florida and one in Georgia, in the USA and find that there are major risks and cost escalations associated with construction of the two plants which could lead to much higher costs to ratepayers.

Opposition to nuclear plants and significantly negative risk perceptions are not something confined only to India. Some are of the opinion that nuclear power is arguably the riskiest amongst all energy supply technologies (Mills, 2012). Germany has decided to phase out nuclear energy completely by 2022. Japan recently shut down its last nuclear reactor. Interestingly, even in the US the revived enthusiasm for nuclear power has dampened after Fukushima. However, all these are high income countries and don't face the huge energy supply-demand imbalance as faced in India. Each technology, be it renewable or nuclear, is important for bridging the energy gap in India. The challenge in India is to manage the negative risk perceptions around nuclear energy and prioritise investment in the appropriate technology.

There are alternative potential ways of managing opposition to nuclear power plant risks. One possible way is compensating and relocating people residing in the vicinity of proposed sites, something that is challenging to implement given India's prior experience with relocation and rehabilitation in the case of hydro power plants. Another way is increasing safeguards and risk mitigation measures through deploying most sophisticated nuclear plants with advance safety features. Another possibility is managing the negative risk through insuring the local population against any nuclear disaster. This implies that the nuclear operator, or the government as a guarantor, is to provide a risk cover to all the people who are potentially at risk. This doesn't mitigate the risk, if any, but it does help in assuaging concerns of local residents and dulls opposition.

Irrespective of the risk mitigation choice, one outcome is certain. Any risk mitigation measure is bound to increase the capital and operation cost of any given nuclear power plant. Our paper's objective is to find the implications of increase in cost of operating nuclear power plants, as a result of negative perceptions about this technology, for the Indian power sector in the short and long term. In other words, we undertake a sensitivity analysis of nuclear energy cost, including scenarios that internalize nuclear accident risk in the technology cost, and highlight its implications for India's energy future. Shukla and Chaturvedi (2012), in an earlier effort, analyse the implications of a targeted approach towards nuclear and solar energy in India. This paper contributes to the nuclear energy discussion in India from another dimension. Recent remark by the Russian government that if liability of any potential nuclear accident is shifted to Russia it would double the cost of nuclear technology being sold to India (The Indian Express, 2012),is testimony of the validity and importance of our argument and approach.

This paper takes a century long view of the nuclear energy in India. We follow the scenarios approach for the assessment. The scenarios are constructed based on two key factors which would drive the share of nuclear power in the future energy mix.

First is the total cost of nuclear power plant which includes: I) construction costs, ii) operating costs including fuel cost, iii) liabilities from externalities and risks during the period of a plant's operating life, iv) costs of storage of spent fuel and v) decommissioning costs. The estimates of the total costs vary widely across the literature. A sizable variability appears vis-à-vis the liabilities from externalities and risks. The divergence in cost assessment in this case varies widely across the stakeholders, the experts typically viewing the risks as small and public perceiving the risks as high. This perceptions gap often narrows during the periods with no major nuclear incidents. However, the gap widens following the major incidents such as at the Fukushima Daiichi Nuclear power plant in March 2011. The divergent views on the external cost of nuclear are also shaped by signals from policymakers. For instance, immediately after the Fukushima incident, the decision to close four nuclear power plants in Germany and phase out the remaining nine nuclear plants by 2022 was viewed as a signal for high risk. A similar interpretation can be made of the Japanese government's decision to shut down all 54 nuclear units in country within a year of the Fukushima incident. Currently, only two reactors are operational with many awaiting clearances after the string of stress tests to determine disaster readiness on these facilities. France and Russia were undeterred and continued with their nuclear plans which is interpreted as low nuclear risk perception.

Second is the level of global response to the climate change. Policymakers around the globe have committed to the 2 degree C stabilization target. However, in practice, a gap persists between the emissions pathway to achieve the long-term climate stabilization target and the emissions that the current mitigation policies would deliver (UNEP, 2013). The climate responses thus would range between the business-as-usual actions and the policies and measures to 2 degree C stabilization.

The paper considers 12 scenarios for India corresponding to the six (6) levels of risk represented by a per cent (%) increase in overnight construction cost of the project and two (2) climate scenarios representing 'no climate target' and '2 degree C stabilization target'. The paper assesses the change in India's energy mix for these scenarios and examines the sensitivity of nuclear power in the energy mix.

Our cost sensitivity analysis, though grounded in the discussion on risk, is critical for other reasons as well. The US experience with nuclear power plants has delivered little confidence in the cost and economics of nuclear power plants (Bradshaw and Gruber, 2007), and actual overnight capital cost have always overshot analysts' expectations by a wide margin (Cooper, 2012) suggesting that growth of nuclear power has been a non-market phenomena. The issues that have affected uncertainty in costs range from design issues to evolving regulatory requirement to long construction periods. Moreover, there are fundamental uncertainties in the cost of key components of fuel cycle (MIT, 2011). As highlighted by Kessides (2010), even with equal levelised cost and commercially proven technologies, different risk profiles of different technologies can influence the choice of power generation mix.

In the next section we discuss our scenario analysis framework, our assumptions related to the cost of nuclear energy under various scenarios, and the integrated assessment modelling framework. This is followed by results and discussions, after which we conclude with the main insights from our research.

2. SCENARIO DESCRIPTION, COST ASSUMPTIONS AND MODELLING FRAMEWORK

Differences in risk valuations across countries

There are significant differences in the valuation of risk across countries, which are reflected in their valuation of liability due to nuclear accidents. The liability amounts are 10 Bn US$ for USA, 1500 Mn Euros for France, 250 Mn US$ for India, and unlimited liability in case of Japan. Moreover, researchers have argued that there is an inherent subsidy over the specified liability amounts. The Price-Anderson Act of 1957 of the United states, and Heyes' (2002) subsequent analysis of the implicit subsidy given to nuclear energy operators provides a good basis for one such risk valuation. Another basis for valuation is the French nuclear liability law.

The Price Anderson Act (amended) of the United States provides for different levels of protection. The operator carries the primary liability of US$ 300 million (2005 prices) per reactor as the first level. Any damage above this mark is assessed equally against all operators up to about US$ 96 Mn per reactor. The combined insurance coverage is over 10 Bn USD (American Nuclear Society, 2005). This arrangement hence provides the coverage of 10 Bn USD by distributing the liability cost across operators, with the liability per reactor per accident being equal to 396 Mn USD.

The French Nuclear Liability Law, which derives from the Paris and Brussels conventions (1966, amended) like many other nations, allows for three layers of financial liability (Faure and Fiore, 2009). As per the revised values, the first tier the operator's liability is capped at 700 Mn Euros, the second layer is a liability of 500 Mn Euros borne by the state, and the third layer 300 Mn Euros liability borne by the contracted parties of the French and Brussels convention. These amounts, revised in the Modification Protocols of the Paris and Brussels convention have not been brought in force yet. The total insurance coverage is hence 1500 Mn Euros per reactor depending on the extent of actual damage. Interestingly, though the overall insurance coverage in the US is significantly higher than the coverage under the French laws, liability per reactor in the US is lower than that of a French nuclear reactor.

Moreover, as any nuclear disaster costs billion of dollars which is not necessarily matched by the liability coverage, there is an implicit subsidy involved here. Heyesand Liston-Heyes (1998) estimate this subsidy for USA to be equal to 2.32 Million USD per reactor per year (1998 prices[1]) of operation. Assuming 45 years of reactor life, total subsidy comes around to 125 Mn USD (in 2005 prices). Faure and Fiore (2009) analyse subsidy for French nuclear reactors for different scenarios of accident costs and probabilities. Their values range from .14 Million Euros to 3.3 Million Euros per reactor year. Thus for the case with highest

[1] The price year in this case is to the best of author's understanding as this is not clear from the document.

expected damages from an accident, the subsidy is almost 150 Million Euros per reactor, assuming 45 years lifetime.

Comparing the above estimates, it is clear that insurance coverage for a nuclear accident varies from 1500 Mn Euros in France to over 10 Bn US$ in the US. The insurance financing structure adopted by the US is interesting as it provides a high level of coverage at the same time not providing a huge financial burden per reactor. The objective of this last statement is not to say that one arrangement is better over the other, but is to highlight the variation in valuation of potential damages due to a nuclear accident, the associated liability coverage, and liability financing structures.

Liability as per Indian act: Implication of recourse to suppliers' clause

In case of India, recent developments indicate that for a high growth trajectory fuelled by nuclear power, India has to continue importing nuclear reactors as indigenous fuel and reactors might not be able to keep up with the pace of nuclear energy demand. The Kundankulam nuclear power plant has reactors based on the light water technology imported from Russia. Similarly, India is engaged in high level negotiations with the US as well as France, which are potential exporters of nuclear technology for India. The bone of contention is the nuclear liability law, which holds the supplier accountable (in part) for any nuclear accident in India.

The 2010 Civil Liability for Nuclear Accident Act (GoI, 2010) of India places the responsibility with the operator. Total liability is 2700 Crore INR (450 Mn USD), and operator's liability is limited to 1500 Crore INR (250 Mn USD), beyond which central government will bear the cost. However, the act also gives an opportunity to the operator to have a legal recourse to the supplier if the accident is a consequence of any act of supplier or its employee. As post accident it is really difficult to prove that the accident occurred due to either equipment fault or due to management negligence, suppliers are resisting as this shifts the financial liability to them even though they are not managing the operations. Russian authorities had earlier stated that a shift of accident liability to Russia will force it to double the price of the light water nuclear reactor exported to India for Kundankulam reactors 3 and 4 (The Indian Express, 2012)[2]. Interestingly, the amount of liability is only around 10% of the cost of a nuclear power plant. Still this clause has sparked a high decibel debate. This could be due to a variety of reasons- a concern that this clause will start a precedent for other countries to follow suit, or a future government might simply ignore the liability cap in case of any future accident and impose a higher liability on operators/suppliers (Ramana and Raju, 2013). Also, it has been argued that this recourse to supplier is India's radical departure from international practice and will find difficulty in acceptance worldwide (Jones, 2013).

[2] Interestingly, as per news reports, the deal for Kundankulam reactors 3 and 4 with Russia is close to finalization as on 11th March 2014. It is unclear from publicly available information if Russia has accepted India's nuclear liability clause as it is.

Scenario framing and cost assumptions

The developments discussed above have significant implications for the long term energy scenarios for India, which need to be analysed. Given the discussion on liability clauses as well as uncertainties associated with cost of different components and stages involved in the nuclear power plant cycle, it is important that we seek to understand the implications of future nuclear cost evolution pathways. In this context, we present and analyze combination of six nuclear energy technology scenarios and two climate policy scenarios. The technology scenarios range from reference costs, to cost increases of 10%, 25%, 50% and 100% by 2020 relative to the reference scenario, and ultimately to a scenario where nuclear energy is perceived to be prohibitively risky by the society, leading to no new builds of nuclear energy plants implying that the risk induced costs are too high. These cost assumptions exclude the fuel cost of nuclear energy which depends on the market demand and supply situation and is determined endogenously in the model. Two policy scenarios included here are reference policy scenario with no greenhouse gas mitigation target, and a climate policy scenario that envisages limiting radiative forcing level to 2.6 W/m^2(proxy for negotiated 2 degree C temperature stabilization target) in 2100. Table 1 details the scenario description and cost assumptions.

Table 1: Scenario Description and Cost Assumptions

Scenario Name	Scenario Description	Nuclear power plant non energy costs (in 2004 US$ Cents per KWh)		
		2020	2050	2095
Ref	Scenario with no climate policy targets and reference nuclear energy cost	5.09	4.93	4.72
Ref_10%	Scenario with no climate policy targets and non-energy nuclear cost 10% higher compared to Ref scenario	5.60	5.42	5.19
Ref_25%	Scenario with no climate policy targets and non-energy nuclear cost 25% higher compared to Ref scenario	6.36	6.16	5.90
Ref_50%	Scenario with no climate policy targets and non-energy nuclear cost 50% higher compared to Ref scenario	7.64	7.40	7.08
Ref_100%	Scenario with no climate policy targets and non-energy nuclear cost 100% higher compared to Ref scenario	10.18	9.86	9.44
Ref_Retire	Scenario with no climate policy targets and no new builds of nuclear energy plants	No new nuclear power plants built.		

2.6	Scenario with climate policy target of 2.6 W/m^2 radiative forcing by 2100 and reference nuclear energy cost	5.09	4.93	4.72
2.6_10%	Scenario with climate policy target of 2.6 W/m^2 radiative forcing by 2100 and non-energy nuclear cost 10% higher compared to Ref scenario	5.60	5.42	5.19
2.6_25%	Scenario with climate policy target of 2.6 W/m^2 radiative forcing by 2100 and non-energy nuclear cost 25% higher compared to Ref scenario	6.36	6.16	5.90
2.6_50%	Scenario with climate policy target of 2.6 W/m^2 radiative forcing by 2100 and non-energy nuclear cost 50% higher compared to Ref scenario	7.64	7.40	7.08
2.6_100%	Scenario with climate policy target of 2.6 W/m^2 radiative forcing by 2100 and non-energy nuclear cost 100% higher compared to Ref scenario	10.18	9.86	9.44
2.6_Retire	Scenario with climate policy target of 2.6 W/m^2 radiative forcing by 2100 and no new builds of nuclear energy plants	No new nuclear power plants built.		

Modelling framework: Global Change Assessment Model (GCAM)

We use GCAM ,Indian Institute of Ahmedabad (IIMA) version, for understanding the short, medium and long term implications of incorporating risk valuations in nuclear energy generation costs for India. GCAM is an energy sector focused integrated assessment model with an energy module, land use module and a climate module within the same framework. GCAM has been widely used for global and regional energy and climate policy scenario exercises (referClarke et al., 2008; Calvin et al., 2009; Wise et al., 2009; Kyle and Kim, 2011; Eom et al., 2012; Shukla and Chaturvedi, 2012; Chaturvedi et al., 2013; Edmonds et al., 2013). The world within GCAM is divided into 14 regions, with India as a separate region. The strength of GCAM is the detailed representation of the energy sector, both on the supply and demand side. GCAM models energy demand for three end use sectors- Building sector, Industry sector, and Transportation sector. On the supply side, electricity production is modeled in detail with nine fuels competing for electricity production, with more than one technology within each fuel. Nuclear energy, being a zero carbon source, is a key technology for electricity generation in GCAM.

The IIM Ahmedabad version of GCAM is different from core GCAM in its demographic and economic growth assumptions and representation of the building sector. GCAM-IIM has higher per capita income growth assumptions, and the building sector in GCAM- IIM is further disaggregated into urban residential, rural residential and commercial building sector. Also, we revise the cost for central PV power plants and assume that PV costs decline by 60% between 2005 and 2020, something that is closer to what is being observed[3]. For earlier studies using GCAM-IIM, please refer Shukla and Chaturvedi (2012), Shukla and Chaturvedi (2013), Chaturvedi and Shukla (2013), Chaturvedi et al. (2014). Table 2 presents gross domestic product (GDP) and population assumptions for our study.

Table 2: GCAM-IIM Economic and Demographic Assumptions

	GDP	Population		CAGR (%)	
	2005 Bn US$ (MER)	Billion		GDP	Population
2005	748	1.13			
2020	2230	1.31	2005-20	7.55	0.98
2035	6343	1.45	2020-35	7.22	0.68
2050	16008	1.53	2035-50	6.37	0.37
2095	75021	1.48	2050-95	3.49	-0.08

[3]PV costs reduced by almost 40% between 2008 and 2010. Non energy cost for central PV plants as assumed in GCAM-IIM are 13.74 US Cents/ KWh in 2020, 6.18 US Cents/ KWh in 2050 and 4.06 US Cents/ KWh in 2095.

3. RESULTS FROM MODELLING ASSESSMENT

3.1 Reference cost scenario (Ref sc and 2.6 sc)

India's electricity generation is bound to witness a high rate of growth given the energy starved situation today. This growth will be particularly high post 2020, when Indian average per capita incomes will drive rapid move towards electricity based technologies for meeting building energy service requirements, mainly cooling and appliances. Some move will also be towards electricity based private and public transportation modes and more efficient energy use processes in Indian industry. In our reference scenario, electricity generation increases by 2.6 times between 2005 and 2020, at a high rate of 4.7 times between 2020 and 2050, and then further by over two times by the end of century(Fig 1a).

Climate policy scenario with reference nuclear costs (2.6 Sc) witnesses a decrease in electricity generation in the short run, 13% by 2025 relative to Ref sc due to a sudden increase in carbon intensive energy prices. However, for meeting stringent climate targets, more and more end use services move towards electricity, and by the century end electricity generation is almost 35% higher relative to the Ref scenario (Fig 1a and 1b).

Fossil energy dominates the electricity generation portfolio under the Ref sc. More than 59% electricity is generated using fossil sources in 2095, and most of that is coal based. Importantly, nuclear energy emerges as the second most important electricity generation source with 11% share in 2050, which increases to 24% in 2095 (Fig. 1a and 1c).

Renewable energy, including biomass, provides 16% of electricity generated in 2095. The immense potential of solar energy in India is only marginally harnessed (7% share) under the reference scenario given the comparative lower cost of fossil as well as nuclear energy (Fig. 1a and 1c).

The criticality of nuclear energy based electricity for India becomes obvious under the stringent climate policy scenario, when this energy source powers on to take 40% share in 2050 and 70% share in 2095 in India's generation portfolio (Fig. 1d). Solar energy takes a share of 19% while carbon capture and storage (CCS) including biomass with CCS takes 8% share in 2095. Historically the largest nuclear power plant installation has been of 8.2 GW capacity in the Kashiwazaki-Kariwa nuclear power plant in Japan. An average installed capacity of 8 GW/ plant in the future for India implies 54 plants in 2050 and 285 nuclear power plants spread across India in 2095. Thus, given that economics will drive the penetration of nuclear globally, and assuming that there are no institutional and other issues limiting deployment of this form of energy in India, nuclear energy will become the focal point of India's response to climate change mitigation challenges.

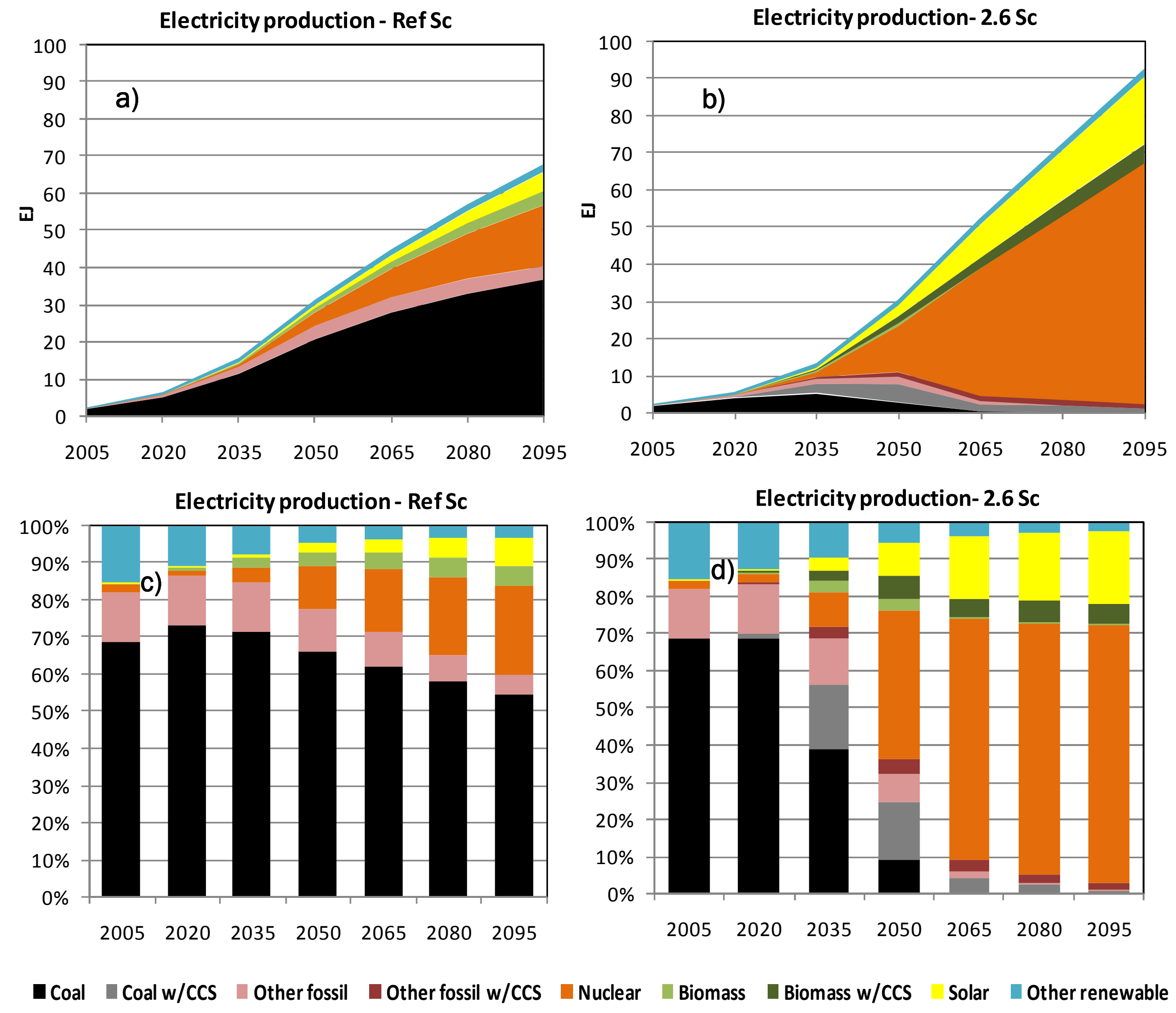

Figure 1: Electricity generation by technology and generation mix under the reference nuclear technology cost scenarios

3.2 Implications of risk induced increase in generation cost (Ref_10%, Ref_25%, Ref_50%, Ref_100%, 2.6_10%, 2.6_25%, 2.6_50% and 2.6_100% sc)

This section explores the implications of risk induced cost increase across the range of 10% to 100% (relative to Ref sc) in the non-energy cost of nuclear based electricity. Operator's liability in India is capped at INR 15 Billion (approximately .25 Bn US$). This is approximately 10% of the capital cost of a 1 GW installed capacity nuclear power plant. The 10% cost increase scenario is hence tied closely to the current liability limit set by the Government of India.

Generally speaking, a 10% increase in nuclear energy does not lead to any significant change in the electricity generation mix for India's future compared to the Ref scenario (Fig. 1a and

2a). Though installed capacity of nuclear energy declines by 10% in the next 10-15 years, and within a range of 15-20% in the medium to long term, the overall character of India's electricity mix is similar with nuclear energy still providing 9% of electricity generation in 2050 and 20% in 2095. We see a similar effect of a 10% cost increase under the climate policy scenario (2.6_10% sc) and nuclear energy still takes 35% share in 2050 and 67% share in 2095 (Fig. 2b and 3b). We can hence say that a 10% increase in electricity generation cost by nuclear energy relative to the reference scenario costs will not have any significant impact on India's electricity generation scenarios. This technology will still remain the focal point for India's response to emission mitigation challenges. It should be highlighted here that the reference scenario assumes a decline in costs of all technologies in the future.

A higher increase of 25-50% of nuclear technology's non-energy cost will have significant implications for the next 15-25 years irrespective of the policy scenario. Installed nuclear energy generation capacity declines by 40-60% due to increased costs (Ref_25%, Ref_50%, 2.6_25%, 2.6_50% sc) in the near term relative to the reference cost scenarios under respective policies (Ref sc and 2.6 sc). In the longer run however, it is the climate policy regime which critically determines the penetration of this technology. Under the Ref sc without any mitigation targets, nuclear energy penetration declines to 5-7% in 2050 and 11-16% in 2095 (Fig. 2c, 2e, 3c, 3e). However, a carbon price ensures that nuclear energy plays a critical role post 2050, with 51-61% electricity still produced by this technology in 2095, up from 18-28% in 2050 (Fig. 2d, 2f, 3d, 3f).

A 100% increase in nuclear energy cost is an extreme scenario, and reflects a huge risk premium put by the society on nuclear energy. This might imply much higher liability cap, enhanced safety features, or increase in costs like that for decommissioning. This extent of increase in risk induced cost of nuclear energy will have serious implications for the share of this technology under a reference scenario world and its share declines to 4% in 2050 and 7% in 2095 (Fig. 2g and 3g). Post 2030, installed capacity declines by 75-80% for all future years.

Similar effect is observed under the climate policy scenario as well (Fig. 2h and 3h). First, nuclear energy does decrease significantly due to increase in costs. In 2050, the decline in its share is from 40% in 2.6 sc (Fig. 1d) to 9% under 2.6_100% sc (Fig. 3h). For 2095, the decline is from 70% (under 2.6 Sc) to 34% when non-energy cost increases by 100%. Second, in the long run, even a doubling of non-energy cost of nuclear energy does not take away from its critical role in India's emission mitigation strategy. With over a third of India's electricity generation still coming from nuclear energy, this source plays an important role in meeting the twin goals of meeting energy demands as well as climate policy targets. Third, two key technologies gain in share as a result of decrease in the share of nuclear energy. Solar energy increases its share from 19% under Ref sc to almost a third of total power generation in 2095with a doubling of nuclear energy cost. Biomass with CCS is the other technology that witnesses an increase from 9% under Ref sc to 17% under 2.6_100% sc in 2095,

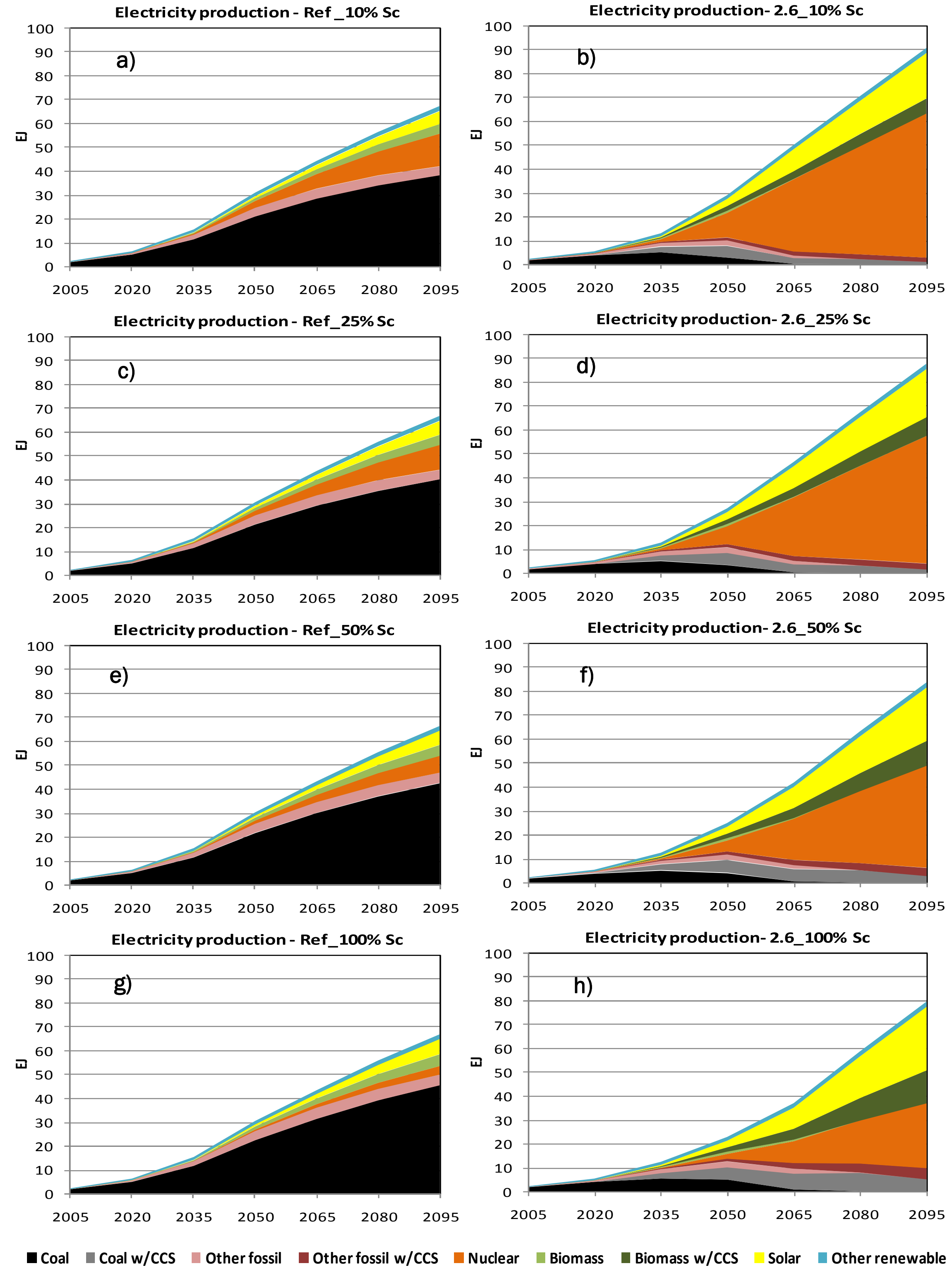

Figure 2: Electricity generation by technology across increased nuclear technology cost scenarios

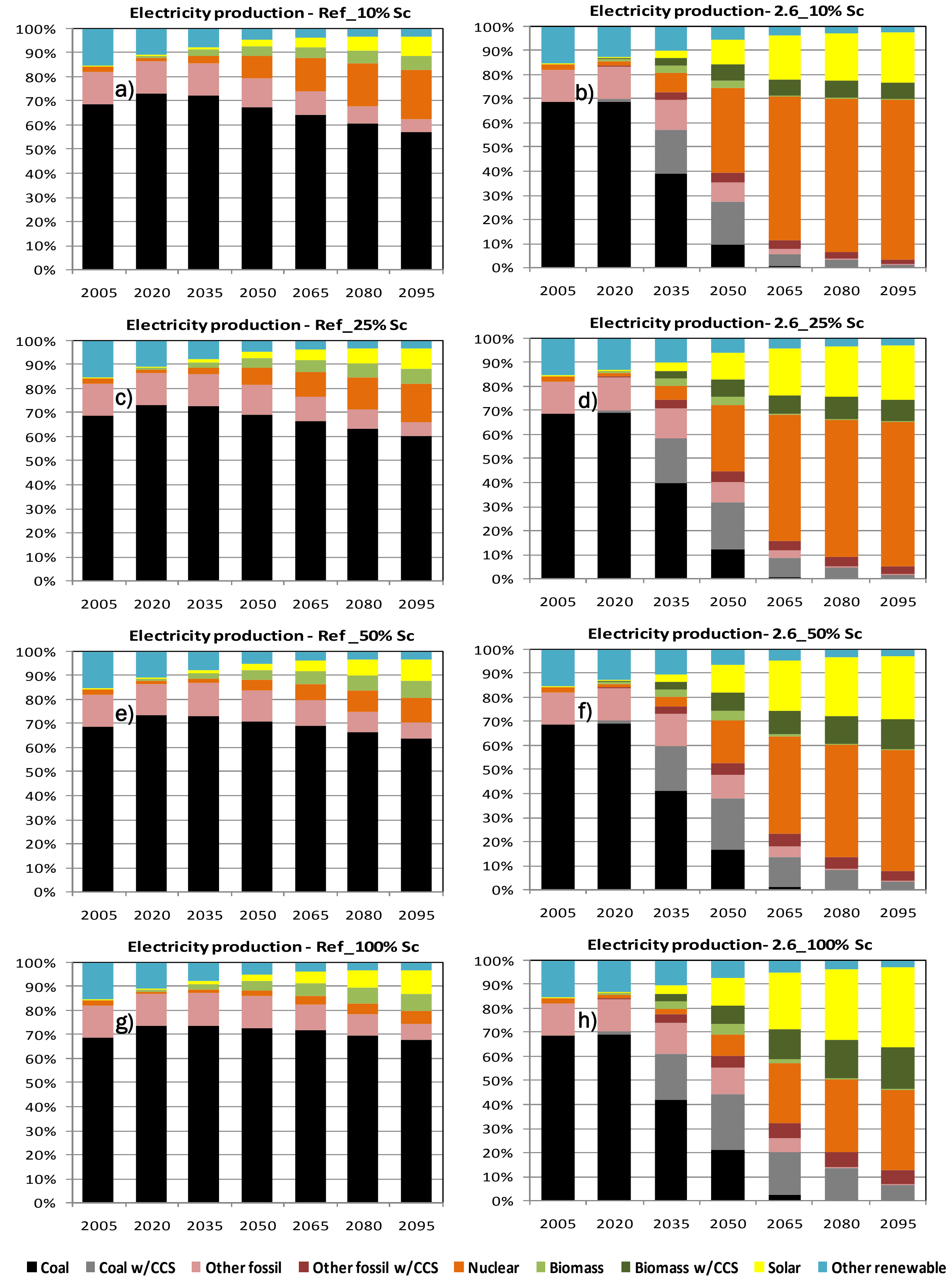

Figure 3: Electricity generation mix across increased nuclear technology cost scenarios

and fossil with CCS takes another 13% share in 2095. Solar energy is a zero carbon technology, while biomass_CCS is considered a negative emission technology as biomass is a also a zero carbon source across its lifecycle, and the CCS technology helps in capturing emissions during the electricity generation phase of biomass.

3.3 Can India think about becoming a no nuclear energy country?- Carbon dioxide emissions and mitigation cost Implications of phasing out nuclear energy from Indian energy supply portfolio (Ref_Retire and 2.6_Retire sc)

Under a reference scenario, with no obligations towards emission mitigation and adaptation, India can aim towards a no nuclear future. Achieving this objective is definitely possible from a technology perspective. Without any climate constraints, India can move towards either fossil energy or renewable sources of energy. However, cost dynamics ensure that even in the long run, nuclear is replaced by fossil sources, mainly coal rather than renewable energy (Fig. 4a and 4c). Unless a renewable energy push policy is pursued aggressively, fossil energy will dominate Indian energy systems.

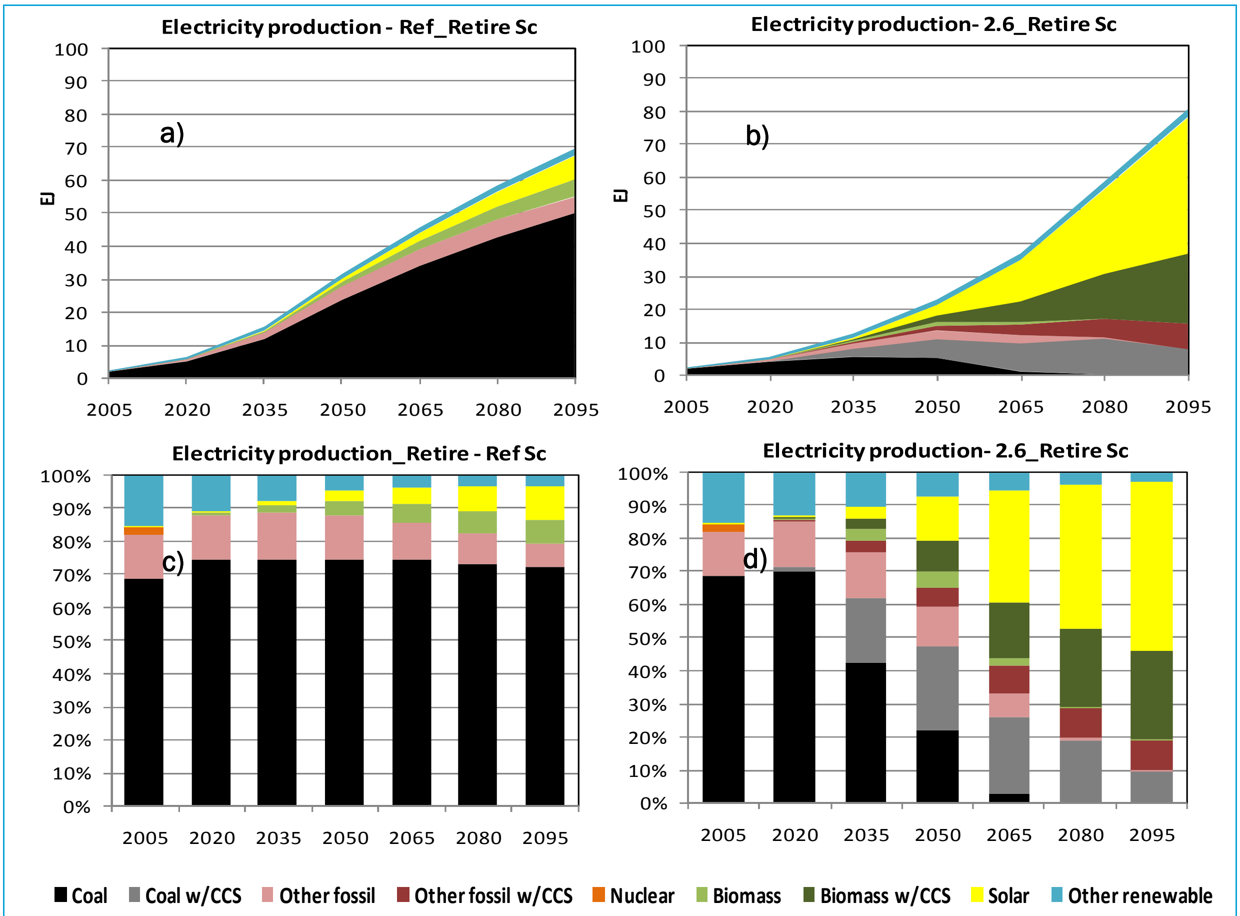

Figure 4: Electricity generation by technology and generation mix under the nuclear retire scenarios

This move towards even greater reliance of India's electricity production on fossil energy have implications for carbon dioxide emissions from the country. A no nuclear scenario will result in a substantial increase in emissions from the power generation sector. Emissions under the Ref_Retiresc are higher compared to the Ref sc by only 1% in 2020, but are significantly higher in the long term by 14% in 2050 and a huge 36% in 2095 (Fig. 5a). This directly implies that India will further move away from the goal of emission mitigation. In other words, reaching emission mitigation targets in the future will be more challenging and costly to achieve.

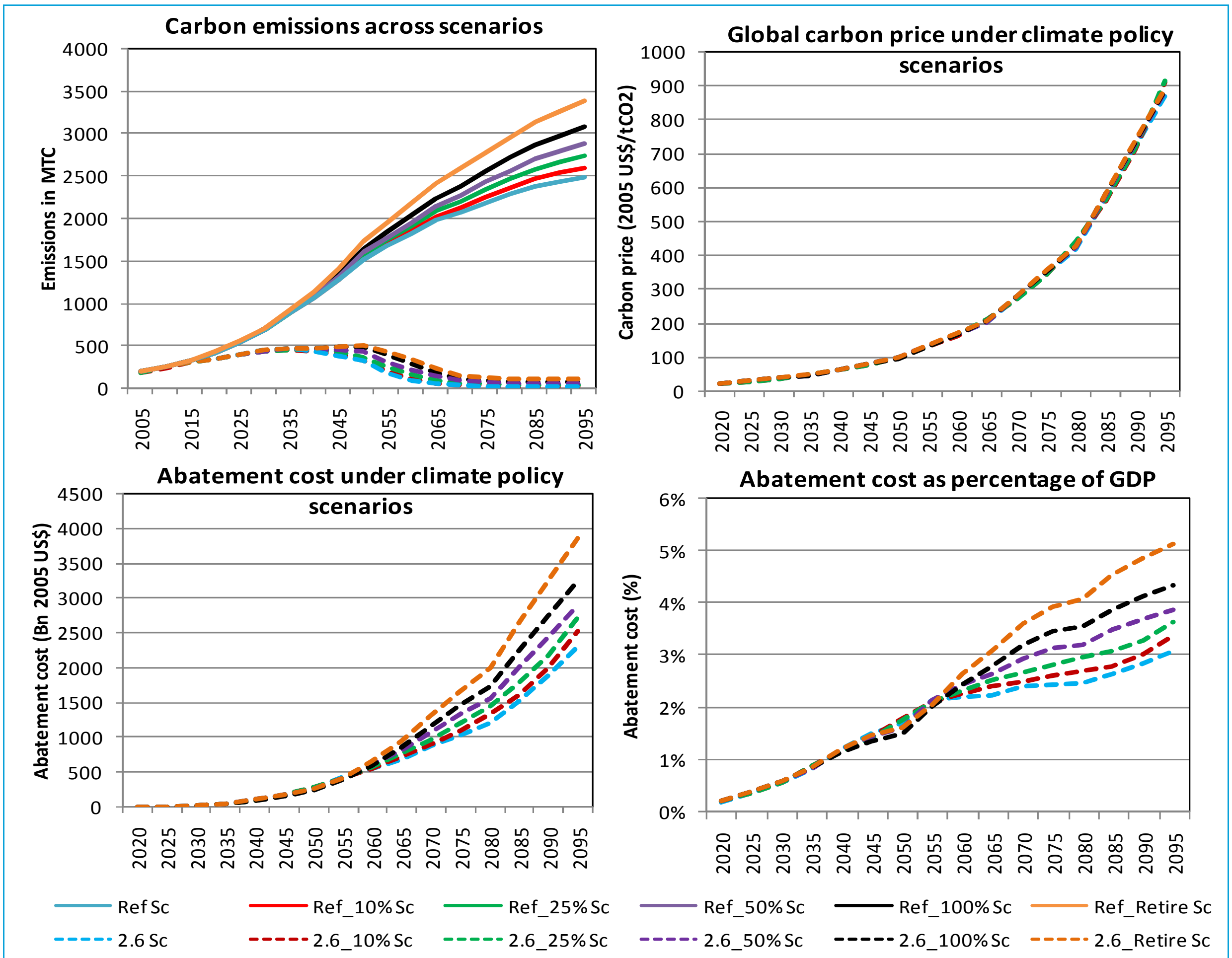

Figure5: Carbon dioxide emissions,global carbon price and abatement cost

Increase in emissions under the Ref_Retiresc can be directly attributed to the change in electricity generation mix (Fig 4a, 4b, 4c, 4d). As in the case of high nuclear scenarios discussed in the earlier section, when nuclear energy is completely phased out, electricity generation moves towards fossil energy sources, mainly coal. There is negligible increase in the absolute penetration of either renewable or biomass (Fig. 1a and 4a). This move towards more carbon intensive electricity generation has important implications for emission mitigation policies and costs.

In the 2.6 W/m^2 stabilization policy scenarios as well, there is an increase in Indian emissions due to a move away from nuclear energy (Fig. 5a). The important point to be noted here is that the stabilization scenario is a global stabilization regime, and as emission mitigation in India is now more costly (one key zero carbon technology is absent from the mitigation portfolio), mitigation is shifted to some other region where it is cheaper. This leads to higher Indian emissions under the climate policy scenario, but global emissions remain unchanged.

An important outcome is a shift in the peak year of emissions for India due to higher cost or phase out of nuclear technology. As a key technology is now more expensive (or missing) from the mitigation portfolio, it becomes difficult for the economy to reduce emissions in the short run as that would prove to be very costly. As a result, emission mitigation effort is shifted to future (Fig. 5a). With reference cost of nuclear energy, Indian emissions start declining from 2035. The peak year for emissions when the nuclear cost is doubled as well as when this technology is not available is 2050, which is a shift of 15 years.

A key outcome of increased cost of or phasing out of nuclear technology for India is steep increase in the cost of meeting climate policy emission mitigation objectives. There is almost no change in the short and medium term mitigation costs, however long term costs change significantly (Fig. 5c and 5d). From 2060 onwards, we see a steep increase in additional mitigation cost due to removal of nuclear technology. This increase is 19% in 2060 for the 2.6_Retire sc relative to the 2.6 sc, and 67% in 2095. The increase in 2095 for the 2.6_50% sc and 2.6_100% scenario relative to 2.6 sc is 26% and 41% respectively. It is thus clear that even a 25 and 50% increase in the cost of nuclear energy relative to reference cost means a lot in terms of long run mitigation cost for achieving a stringent climate target. A complete phase out will make it even costlier unless there is significant decline in the long run cost of alternative low carbon technologies.

4. DISCUSSIONS AND CONCLUSION

From the perspective of Indian energy policy, nuclear energy is a vital option for meeting the growing demands for electricity across Indian end use sectors. The importance has been highlighted by the signing of civil nuclear cooperation agreements with a host of countries including USA, Russia and France on the issue of fuel and technology supply, and development of a nuclear liability framework. At the same time, there are divergent views on India's nuclear energy ambitions given the potential risks associated with nuclear power production. Liability arrangements being proposed by India for mitigating risks associated with nuclear power production are central to the responses to bridge these opposing views.

Clarity on the extent of liability and other risk mitigation measures, based on scientific, technical, economic, social and environmental assessment, is essential for assessing the cost of building nuclear energy power plants in India. Ultimately, the increase in full cost of nuclear energy due to a variety of risk induced measures and the residual liability costs impacts competition between energy choices and hence India's future energy mix and emissions. This research paper is an attempt in this direction of understanding the implications of variability in estimation of full cost of nuclear energy for India's long term energy and climate change mitigation policy.

To this end, we analyze a suite of climate policy and nuclear energy technology cost scenarios within the integrated assessment modelling framework of GCAM. In this paper our scenarios are constructed on two parameters that may deeply affect the future energy system in India: I) the price of nuclear technology, including its external costs and risks, and II) the future climate change regime. We consider six nuclear technology costs regimes (ranging from reference cost to a complete nuclear shutdown scenario) and two climate regimes (no climate policy and 2 Deg. C stabilization policy which is the target under current climate negotiations). The analysis provides sensitivity of the future economic responses (e.g. energy mix) to the alternate scenario assumptions. There are some important insights from our research related to the role of nuclear energy in India's energy scenarios as well as the implications of risk induced cost increases for this energy source.

We find that nuclear energy is competitive when risk induced costs are low under business-as-usual scenarios; i.e. even in the absence of global climate stabilization policies. The current operator's liability cap proposed by the Government of India does not impede the penetration of nuclear energy in India's electricity mix. However, if the risk induced costs are high, then the increase in nuclear energy deployment will be seriously curtailed in the short as well as long run. Economics then favours increased deployment of fossil fuels, leading to significant increase in carbon dioxide emissions. Lower nuclear energy penetration hence shall increase the amount of emissions required to be mitigated for meeting potential emission targets in the future.

We highlight here that as per our analysis, nuclear liability off-sets climate liability. The trend discussed earlier also holds under a climate policy world, wherein also the nuclear energy penetration declines visibly under high risk induced costs scenarios. However, our results show that nuclear energy is competitive, in the long-run, even with high risk induced costs if global climate stabilization policies corresponding to global 2 degree C stabilization target are pursued. Nuclear energy can make important contribution to India's energy security, through the century, under all climate stabilization scenarios. This clearly highlights the criticality of nuclear technology in India's long term emission mitigation strategy. In a way, nuclear power is an important option globally for mitigating climate change risks. In that context, nuclear liability off-sets climate liability. Given the fact that Government of India is actively engaged in global climate negotiations and the 2 degree C stabilization target is an accepted target by the Government of India (GoI, 2008), our suggestion is to keep concurrent focus on nuclear and climate change while presenting the risks.

In the overall, the scenarios assessment shows that the fraction of nuclear energy in India's future optimal energy mix is sensitive to the risk induced cost increases (i.e. Indian society's perceptions of extent of risk associated with nuclear energy) and strictness of climate stabilization target and related global policies.

As the deployment of nuclear energy is decreased under higher cost increase scenarios, technologies that take on greater role in India's mitigation strategy are solar technology and biomass with CCS. Immense technical potential of solar energy in India becomes even more economically viable under the influence of a carbon price and higher cost (or absence) of nuclear. Biomass with CCS becomes important as it is a source of negative emissions for two reasons: first, the electricity generation is higher under the climate policy; and second, with less nuclear, the reference scenario emissions are higher due to a higher deployment of fossil energy. Interestingly, the peak year for Indian emissions under the climate policy scenarios shifts to 2050, a shift of 15 years towards the future, when the nuclear technology costs double or it is absent.

Increased costs of nuclear energy have serious implications for costs of meeting emission mitigation targets in the long run. In the medium run, till 2050, other low carbon technologies come in place of nuclear and the effect on mitigation cost is minimal. However further in time, in the second half the century, as the initial low cost potential of solar energy and CCS gets exhausted, mitigating emissions becomes more and more expensive in the wake of higher cost or absence of nuclear technology. Abatement cost for India in 2095 as a percentage of GDP is 3.1% with reference nuclear energy cost and penetration, which increases to 5.1% when nuclear energy technology is completely phased out.

Since the liability caps vary significantly across countries and since the penetration of nuclear is sensitive to risk induced costs, we conclude that credible risks assessment and its communication to stakeholders will be vital to ensure the due role nuclear would have in India's optimal long-run energy mix through the century. The diverse risk perceptions of stakeholders are rooted in varying causes. The suppliers risk 'perceptions arise primarily from ambiguities and frequent evolutionary changes in the Indian liability laws and regulations. The rational assessment of the liability amount as well as pinpointing of the responsibility can help suppliers to optimally internalize their risks in the cost structure. The local population's risk perceptions arise from different causes such as: the inadequate scientific information about technological risks, lack of operational information about the safety administration and their ability and commitment to implement routine safety protocols as well as their preparedness to respond to nuclear accidents.

The debates and arguments remains on what position India should take for future deployment of nuclear energy power plants. The stakeholders having higher risk perception who argue for stopping all nuclear power plants can in fact show that sacrificing 2% of GDP in 2095 is a little cost for doing away with the potentially disastrous nuclear incidents. On the other extreme, the stakeholders having lower risk perception of nuclear energy will argue that with improved safeguards and inherently safer new generation of nuclear power plants, the exclusion of nuclear power option will add significantly to the energy cost in India in all scenarios and more so in the stringent climate stabilization scenario. To them, lower cost of electricity would enhance welfare of millions who currently lack electricity access, and bear the cost of energy poverty.

The analysis in the paper shows that the asymmetric information about the nuclear risks among the stakeholders, unless corrected, would lead to misallocation of resources in India's future energy system. Our analysis shows that the added cost from this information asymmetry to the India's energy system will be substantial and shall keep rising through the century. The added cost of deviating from the optimal energy mix under the symmetric information would be even greater, nearly 2% of GDP in 2095, in case of stringent global climate change stabilization agreement.

Our paper highlights the implications of increased nuclear energy costs on India's energy mix as well as for India's emission mitigation strategy. At this juncture when India's energy system is expected to remain on the rising trajectory going into several decades, it is vital that the scientists and policy researchers assess the costs of nuclear risks and the Indian policy makers incorporate the best assessment of liability within The Civil Liability for Nuclear Damage Act, 2010, and other risk mitigation safeguards and measures for cost of nuclear power plants in India. Finally, bridging the information chasm about the risks from nuclear power plants among stakeholders will help to find best-fit for nuclear power in India's long-term optimal energy mix.

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REFERENCES

American Nuclear Society. 2005. Price-Anderson Act. Background for Position Statement 54

Abraham I. 2011. The risks of nuclear power. Economic and Political Weekly XLVI (16), EPW commentary

Bradshaw GB, Gruber CO. 2007.New nuclear power plants- Learning from history to understand costs and mitigate risks. 2007 AACE International Transactions

Calvin K, Edmonds J, Bond-Lamberty B, Clarke L, Kim SH, Kyle P, Smith SJ, Thomson A, Wise M. 2009. 2.6: Limiting climate change to 450 ppm CO2 equivalent in the 21st century. Energy Economics 31, ppS107-S120

Chang M, White D, Hausman E, Hughes N, Biewald B. 2011. Big Risks, Better Alternatives: An Examination of Two Nuclear Energy Projects in the US. Synapse Energy Economics, Inc.

Chaturvedi V, Shukla PR. 2013. Role of energy efficiency in climate change mitigation policy for India: Assessment of co-benefits and opportunities within an integrated assessment modelling framework. Climatic Change, In press

Chaturvedi V, Kim S, Smith SJ, Clarke L, Yuyu Z, Kyle P, Patel P. 2013. Model evaluation and hindcasting: An experiment with an integrated assessment model. Energy 61, pp 479-490

Chaturvedi V, Eom J, Clarke L and Shukla PR. 2014. Long term building energy demand for India: Disaggregating end use energy services in an integrated assessment modelling framework. Energy Policy 64, pp 226-242

Clarke, L., Wise, M. Edmonds, J., Placet, M., Kyle, P., Calvin, K., Kim, S., Smith, S. 2008. CO2 Emissions Mitigation and Technological Advance: An Updated Analysis of Advanced Technology Scenarios. Pacific Northwest National Laboratory Technical Report PNNL-18075; U.S. Department of Energy: Richland, WA, USA.

Clarke L, Krey V, Weyant J and Chaturvedi V. 2012. Regional energy system variation in global models: Results from the Asian modelling exercise scenarios. Energy Economics 34, ppS293-S305

Cooper M. 2012. Nuclear safety and affordable reactors: Can we have both? Bulletin of the Atomic Scientists 68 (4), pp 61-72

Edmonds JA, Calvin K, Clarke L, Kyle P, Wise M. 2012. Energy and technology lessons since Rio. Energy Economics 34, pp S7-S14

Eom J, Clarke L, Kim S, Kyle P, Patel P. 2012. China's building energy demand: Long term implications from a detailed assessment. Energy 46, pp 405-419

Faure M and Fiore K. 2009.An economic analysis of nuclear law subsidy. PACE Environmental Law review, Vol. 26, No. 2

GoI (Government of India). 2008. National Action Plan on Climate Change. Prime Minster'sCouncil on Climate Change, Government of India

GoI (Government of India). 2010. The Civil Liability for Nuclear Damage Act 2010. Act of Indian Parliament

GoI (Government of India). 2011. Low carbon strategies for inclusive growth: An interim report. Planning Commission, Government of India

Heyes AG and Liston-Heyes K. 1998. Subsidy to nuclear power through Price-Anderson liability limit: Comment. Contemporary Economic Policy XVI, pp 122-124

Heyes A. 2002. Determining the price of Price-Anderson. Regulation, Winter 2002-03

Hibbs M. 2012. Nuclear energy 2011: A watershed year. Bulletin of the Atomic Scientists 68 (1), pp 10-19

IAEA (International Atomic Energy Agency). 2012. Nuclear Technology Review 2012. International Atomic Energy Agency, Vienna

IEA (International Energy Agency). 2007. World Energy Outlook 2007. OECD/IEA, Paris, France

IEA (International Energy Agency). 2013. World Energy Outlook 2013. OECD/IEA, Paris, France

Jones T. 2013. Why India's Nuclear Liability Law is Harming Indian Interests. NEI Nuclear Notes, October 18, 2013. Accessed at http://neinuclearnotes.blogspot.in/2013/10/why-indias-nuclear-liability-law-is.html on January 10, 2014

Kessides IN. 2010. Nuclear power: Understanding the economic risks and uncertainties. Energy Policy 38, pp 3849-3864

Kour V, Dar SS. 2013. Significance of energy security in 21st century with reference to nuclear energy scenario of India. IOSR Journal of Humanities and Social Science 10 (5), pp 43-50

Kyle, P and Kim, SH. 2011. Long term implications of alternative light duty vehicle technologiesfor global greenhouse gas emissions and primary energy demands. Energy Policy 39, pp 3012-3024

Mallah S, Bansal NK. 2010. Allocation of energy resources for power generation in India: Business as usual and energy efficiency. Energy Policy 38 (2), pp 1059-1066

Mills E. 2012. Weighing the risks of climate change mitigation strategies. Bulletin of the Atomic Scientists 68 (6), pp 67-78

Mohapatra DK, Mohanakrishnan P. 2010. A methodology for the assessment of nuclear power development scenario. Energy Policy 38 (8), pp 4330-4338

MIT (Massachusetts Institute of Technology). 2011. The future of the nuclear fuel cycle. An interdisciplinary MIT study

Ramana MV. 2009. The Indian Nuclear Industry: Status and Prospects. Nuclear Energy Futures Papers, The Centre for International Governance Innovation

Ramana MV. 2012. The Power of Promise: Examining Nuclear Energy in India. Viking publication

Ramana MV and Raju S. 2013. The Impasse Over Liability Clause in Indo-U.S. Nuclear Deal. The New York Times, October 15, 2013. accessed at http://india.blogs.nytimes.com/2013/10/15/the-impasse-over-liability-clause-in-indo-u-s-nuclear-deal/?_php=true&_type=blogs&_r=2 on January 10, 2014

Remme U, Trudeau N, Graczyk D, Taylor P. 2011. Technology development prospects for the Indian power sector. IEA Information Paper, OECD/IEA, Paris, France

Shukla PR and Chaturvedi V. 2012. Low carbon and clean energy scenarios for India: Analysis of targets approach. Energy Economics 34, ppS487-S495

Shukla PR, Chaturvedi V. 2013. Sustainable energy transformations in India under climate policy. Sustainable Development 21, pp 48-59

Sokolski H. 2010. The high and hidden costs of nuclear power.Policy Review

The Indian Express. 2012. Reactors to cost double: Russia. In print on December 20, 2012, New Delhi Edition, accessed at http://archive.indianexpress.com/news/reactors-to-cost-double-russia/1047796/on September 25, 2013

UNEP (United Nations Environment Program). 2013. The Emissions Gap Report 2013. A UNEP Synthesis Report

Wise MA, Calvin KV, Thomson AM, Clarke LE, Bond-Lamberty B, Sands RD, Smith SJ, Janetos AJ and Edmonds JA. 2009. The implications of limiting CO2 concentrations for land use and energy. Science 324, pp 1183-1186

WB (The World Bank). 2013. World Development Indicators. Accessed at http://databank.worldbank.org/data/views/reports/tableview.aspx# on January 24, 2014

CEEW Publications

Books/Reports

Vaibhav Gupta, Karthik Ganesan, Sanyukta Raje, Faraz Ahmed, and Arunabha Ghosh (2013) Strategic Industries and Emerging Technologies for a Future Ready India, Report submitted to India's National Security Advisory Board, Prime Minister's Office, December

Rishabh Jain, Poulami Choudhury, Rajeev Palakshappa, and Arunabha Ghosh (2013) RE+: Renewables Beyond Electricity, CEEW-WWF Report, December

Rudresh Sugam and Arunabha Ghosh (2013) Urban Water and Sanitation in India: Multi-stakeholder Dialogues for Systemic Solutions, CEEW-Veolia Report, November, pp. i-147

Rajeev Palakshappa, Arunabha Ghosh, Poulami Choudhury, and Rishabh Jain (2013) Developing Effective Networks for Energy Access- An Analysis, CEEW-USAID Report, October

Nirmalya, Choudhury, Rudresh Sugam and Arunabha Ghosh (2013) 2030 Water Resources Group National Water Platform: Preliminary Investigation of the Possible Roles, Functions and Potential Governance, New Delhi Council on Energy Environment and Water-Water Resources Group Report, September, pp. i-25

Arunabha Ghosh et al. (2012) Concentrated Solar Power: Heating Up India's Solar Thermal Market under the National Solar Mission, Report (Addendum to Laying the Foundation for a Bright Future: Assessing Progress under Phase I of India's National Solar Mission), September, New Delhi, Council on Energy, Environment and Water; and Natural Resources Defense Council

Arunabha Ghosh, with Himani Gangania (2012) Governing Clean Energy Subsidies: What, Why and How Legal?, August, Geneva: International Centre for Trade and Sustainable Development

Rudresh K. Sugam, and Arunabha Ghosh (2012) Institutional Reform for Improved Service Delivery in Bihar: Economic Growth, Agricultural Productivity, and a Plan for Reorganising the Minor Water Resources Department, Research Report submitted to the Government of Bihar, July, New Delhi: Council on Energy, Environment and Water, and International Growth Centre, Patna

Council on Energy, Environment and Water; and Natural Resources Defense Council (2012) Laying the Foundation for a Bright Future: Assessing Progress Under Phase 1 of India's National Solar Mission, Interim Report, April, pp. i-37

Arunabha Ghosh, Arundhati Ghose, Suman Bery, C. Uday Bhaskar, Tarun Das, Nitin Desai, Anwarul Hoda, Kiran Karnik, Srinivasapuram Krishnaswamy, Radha Kumar, Shyam Saran (2011) Understanding Complexity, Anticipating Change: From Interests to Strategy on Global Governance, Report of the Working Group on India and Global Governance, December, pp. i-70

Martin A. Burton, Rahul Sen, Simon Gordon-Walker, and Arunabha Ghosh (2011) National Water Resources Framework Study: Roadmaps for Reforms, October, New Delhi: Council on Energy, Environment and Water, and 2030 Water Resources Group, pp i-68

Martin A. Burton, Rahul Sen, Simon Gordon-Walker, Anand Jalakam, and Arunabha Ghosh (2011) National Water Resources Framework Study: Research Report Submitted to the Planning Commission for the 12th Five Year Plan, September, New Delhi: Council on Energy, Environment and Water, and 2030 Water Resources Group, pp. i-584

Arunabha Ghosh (2010) Harnessing the Power Shift: Governance Options for International Climate Financing, Oxfam Research Report, October, pp. 1-90

Papers/Book Chapters

Arunabha Ghosh (2014)' Environmental Institutions, International Research Programmes, and Lessons for Geoengineering Research', Geoengineering Our Climate Working Paper, February 2014

Nirmalya Choudhury and Arunabha Ghosh (2013) 'Responsible Hydropower Development in India: Challenges for future', CEEW Working Paper 2013/5, December 2013

Rishabh Jain, Karthik Ganesan, Rajeev Palakshappa and Arunabha Ghosh (2013) 'Energy Storage for Off-Grid Renewables in India: Understanding Options and Challenges for Entrepreneurs', CEEW Report, July

Arunabha Ghosh, and David Steven (2013) 'India's Energy, Food, and Water Security: International Cooperation for Domestic Capacity', in Shaping the Emerging World: India and the Multilateral Order, edited by Waheguru Pal Singh Sidhu, Pratap Bhanu Mehta, and Bruce Jones, Washington, D.C.: Brookings Press

Rajeev Palakshappa et al. (2013) 'Cooling India with Less Warming: The Business Case for Phasing-Down HFC's in Room and Vehicle Air Conditioners,' Council on Energy, Environment and Water; Natural Resources Defense Council; The Energy and Resources Institute; and The Institute for Governance and Sustainable Development, November

Arunabha Ghosh (2013) 'Energy-Food-Water-Climate Nexus: Implications for India's National Security,' Paper submitted to India's National Security Advisory Board, Prime Minister's Office, March

Vyoma Jha and Rishabh Jain (2012) 'Results-Based Financing for Off-grid Energy Access in India,' Case-study on the Economics of Results-Based Financing in Study by Vivideconomics for Energy Sector Management Assistance Program (ESMAP), World Bank, Washington DC, October

Arunabha Ghosh (2012) 'Industrial demand and energy supply management: A delicate balance,' Empowering growth - Perspectives on India's energy future, A report from the Economist Intelligence Unit: 26-32, October

Arunabha Ghosh, Benito Müller, William Pizer, and Gernot Wagner (2012) 'Mobilizing the Private Sector: Quantity-Performance Instruments for Public Climate Funds,' Oxford Energy and Environment Brief, The Oxford Institute for Energy Studies, August, pp. 1-15

Sachin Shah (2012) 'Institutional Reform for Water Use Efficiency in Agriculture: International Best Practices and Policy Lessons for India,' CEEW Working Paper 2012/3, April

Arunabha Ghosh (2011) 'Seeking Coherence In Complexity: The Governance Of Energy By Trade And Investment Institutions,' Global Policy 2 (Special Issue): 106-119

Arunabha Ghosh (2011) 'Strengthening WTO Surveillance: Making Transparency Work for Developing Countries,' in Making Global Trade Governance Work for Development, edited by Carolyn Deere-Birkbeck. Cambridge: Cambridge University Press

Jason Blackstock, and Arunabha Ghosh (2011) 'Does geoengineering need a global response - and of what kind?,' Background Paper, Solar Radiation Management Governance Initiative, Royal Society UK, Chicheley, March

Policy Briefs & Legislative/ Government Briefings

Arunabha Ghosh (2013) 'Strategic Industries and Emerging Technologies for a Future Ready India,' Briefing to India's National Security Adviser, Prime Minister's Office, New Delhi, 18 October; to National Security Advisory Board, Mumbai, 3 December; and to India's Planning Commission, New Delhi, 10 December

Arunabha Ghosh (2013) 'Business Case for HFC Phase Down in India,' Briefing to Prime Minister's Office. New Delhi. 22 November

Arunabha Ghosh, Rudresh Sugam, Nirmalya Choudhury (2013) 'Integrated Energy, Environment and Water Plan for Jharkhand: Preliminary Investigations and Propositions,' Briefing to the Government of Jharkhand, Ranchi, 18 September

Nirmalya Choudhury (2013) 'Knowledge Hub under National Water Mission – Governance Issues', Briefing to the Ministry of Water Resources, Government of India, on the proceedings of the Working Group on Governance of the Knowledge Hub under the National Water Mission (a flagship mission of the Government of India under the National Action Plan on Climate Change), New Delhi, 26 August

Nirmalya Choudhury (2013) 'Governance Issues towards Creating a Knowledge Hub under the National Water Mission,' Briefing for a multi-stakeholder roundtable discussion on creating a Knowledge Hub under the National Water Mission (a flagship mission of the Government of India under the National Action Plan on Climate Change), New Delhi, 14 August

CEEW Publications

Arunabha Ghosh (2013) 'National Water Platform: Some Thoughts for Brainstorming Meeting,' Briefing to the Ministry of Water Resources, Government of India, on creating a Knowledge Hub under the National Water Mission (a flagship mission of the Government of India under the National Action Plan on Climate Change), New Delhi, 5 August

Rudresh Sugam and Urvashi Sharma (2013) "Capacity building in the urban water sector," Issue brief for the Fifth CEEW-Veolia Water Roundtable on Urban Water Management, 5 July

Arunabha Ghosh, Stephen O. Andersen, Bhaskar Deol, and David Doniger (2013) 'The Business Case for Avoiding & Replacing High-Global Warming Potential HFC Refrigerants While Phasing Out HCFC Refrigerants,' Briefing at the Montreal Protocol Open-Ended Working Group. Bangkok. 26 June

Rudresh Sugam and Urvashi Sharma (2013) "Water data and measurement," Issue brief for the Fourth CEEW-Veolia Water Roundtable on Urban Water Management, 27 May

Rudresh Sugam and Urvashi Sharma (2013) "Regulatory framework for urban water management in India," Issue brief for the Third CEEW-Veolia Water Roundtable on Urban Water Management, 9 April

Rudresh Sugam and Urvashi Sharma (2013) "Private sector participation in water management and water for all," Issue brief for the Second CEEW-Veolia Water Round table on Urban Water Management, 11 February

Arunabha Ghosh (2013) 'Renewable Energies and Trade: Addressing tensions and challenges,' Briefing to a high-level policy dialogue at the World Trade Organization meeting of Ambassadors. Geneva. 21 January

Rudresh Sugam (2012) "Water Utility Management in the Urban Water Sector," Issue brief for the First CEEW-Veolia Water Roundtable on Urban Water Management, New Delhi, 20 December

Karthik Ganesan (2012) "Climate Change and Business Leadership: Pathways to GHG Emissions Reduction and Sustainability in the Indian Cement Industry," Paper presented at the Third National ICRN Conference on Climate Change, Indian Institute of Science, Bangalore, 4 November

Vyoma Jha (2012) "Trends in Investor Claims over Feed-in Tariffs for Renewable Energy," Investment Treaty News, July

Arunabha Ghosh (2012) "Water governance priorities in India, South and East Asia, the case for integrated energy, environment and water plans, and Rio+20 goals," Briefing to the Brazilian Federal Senate, Environment, Consumer Rights and Oversight Committee & Agriculture and Land Reform Committee, Rio de Janeiro, 20 June

Arunabha Ghosh (2011) "Briefing on global governance to Ambassador Shivshankar Menon, National Security Adviser, Government of India," Prime Minister's Office, 20 December

Arunabha Ghosh (2011) "Governing clean energy subsidies: Why legal and policy clarity is needed," Bridges Trade BioRes, November

Vyoma Jha (2011) "Cutting Both Ways?: Climate, Trade and the Consistency of India's Domestic Policies," CEEW Policy Brief, August

Arunabha Ghosh (2010) "Negotiating around Tradeoffs: Alternative Institutional Designs for Climate Finance," European Climate Platform Report No. 10, Centre for European Policy Studies, Brussels, 9 December

Op-eds/Conference Papers/Other publications

Suresh P. Prabhu (2014) 'India's Green Growth needs Policy Push' Energy Next, 8 February. Available at http://ceew.in/pdf/Indias_Green_Growth_Needs_Policy_Push_Suresh_Prabhu.pdf

Suresh P. Prabhu (2013) 'Strengthening the regulatory network' The Hindu, 3 December. Available at http://www.thehindu.com/opinion/op-ed/strengthening-the-regulatory-network/article5415035.ece

Jake Schmidt, Stephen O. Andersen, Arunabha Ghosh, et al (2013) 'Cooling India with Less Warming: The Business Case for Phasing Down HFCS,' Fact Sheet, November.

Arunabha Ghosh (2013) 'More Lethal Greenhouse Gas' The Times of India, 25 October. Available at http://timesofindia.indiatimes.com/home/opinion/edit-page/More-lethal-greenhouse-gas/articleshow/24675848.cms

Arunabha Ghosh (2013) 'Himalayan Ecosystems and Himalayan Cooperation: A Himalayan Effort Needed?' Arctic Circle Forum. Reykjavik. 13 October.

Suresh P. Prabhu (2013) 'Sharing the burden of going green' The Hindu, 17 May. Available at http://ceew.in/pdf/SPP-Sharing_the_burden_of_going_green-The-Hindu-17May2013.pdf

Jamshyd N Godrej (2013) 'Bring in smart policies, clear the air on clean energy' The Economic Times, 17 April. Available at http://economictimes.indiatimes.com/opinion/comments-analysis/bring-in-smart-policies-clear-the-air-on-clean-energy/articleshow/19587149.cms

Arunabha Ghosh and Ricardo Meléndez-Ortiz (2013) 'Want clean energy? Avoid trade disputes'Business Standard, 15 April. Available at http://www.business-standard.com/article/opinion/want-clean-energy-avoid-trade-disputes-113041500023_1.html.

Arunabha Ghosh (2013) 'India's resource nexus: priorities for action' Mint, 10 April. Available athttp://www.livemint.com/Opinion/zAOvm6gwBKa6Bzr9DfSyxN/Indias-resource-nexus-priorities-for-action.html.

Arunabha Ghosh (2013) 'Private Sustainability Finance: Need for cash, role of institutions' NYU – UAE MOFA Workshop on Climate Finance and Institutions. Abu Dhabi. 22 April.

Sanyukta Raje and Vaibhav Gupta (2013) 'India-US Track II Dialogue on Climate Change and Energy: Enhancing Bilateral Cooperation between India and the US', Proceedings Report, 18-20 April.

Arunabha Ghosh and Anjali Jaiswal (2012) 'What's eclipsing India's solar sector' Business Standard,11 August. Available at http://ceew.in/pdf/AG%20&%20AJ-Business_Standard_11Oct12.pdf

Arunabha Ghosh (2012) ' Make it profitable to save resources' India Today, 26 March. Available athttp://ceew.in/pdf/AG-Make_it_profitable_to_save_resources-India_Today-26Mar12.pdf

Arunabha Ghosh (2012) ' Leave polemics out of the water policy ' The Hindu, 19 March. Available at http://ceew.in/pdf/AG-Leave_polemics_out_of_the_water_policy-The_Hindu-19Mar12.pdf

Arunabha Ghosh (2012) ' Innovation needs an ecosystem' Business Standard, 26 February. Available at http://ceew.in/pdf/AG-Innovation_Needs_an_Ecosystem-Business_Standard_26Feb12.pdf

Jamshyd N Godrej (2011) 'ET Awards' Agenda for Renewal 2011: Energy, the new poverty, says Jamshyd Godrej, Chairman & MD, Godrej & Boyce' The Economic Times, 24 November. Available at http://articles.economictimes.indiatimes.com/2011-11-24/news/30437448_1_clean-energy-energy-security-comprehensive-energy-plan

Jamshyd N Godrej (2011) 'Deregulation: Solving diesel conundrum' The Times of India, 28 January. Available at http://timesofindia.indiatimes.com/business/india-business/Deregulation-Solving-diesel-conundrum/articleshow/7375419.cms?referral=PM

Arunabha Ghosh (2009) 'Climate for a win-win dialogue' The Financial Express, 22 December. Available at http://www.financialexpress.com/news/column-climate-for-a-winwin-dialogue/557335/0

Arunabha Ghosh (2009) 'Street lessons in climate governance' The Financial Express, 18 December. Available at http://www.financialexpress.com/news/column-street-lessons-in-climate-governance/555484/0

Arunabha Ghosh (2009) 'Red herrings in debates over climate finance' Opinio Juris, 15 December. Available at http://opiniojuris.org/2009/12/15/red-herrings-in-debates-over-climate-finance/

Arunabha Ghosh (2009) 'Even climate is about the money' The Financial Express, 7 December

Arunabha Ghosh (2009) 'Making Copenhagen count' the GEG blog, 7 December.

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