8th ANNUAL CONFERENCE ON CLIMATE CHANGE

4th & 5th August, 2017

Climate Action: Mitigation and Adaptation in a Post Paris World

Summary Report, Policy Briefs and Research Papers

भविष्य की पुनर्कल्पना RE-IMAGINING FUTURES
TISS

Organised by:
Centre for Climate Change
and Sustainability Studies
Tata Institute of Social Sciences,
Mumbai

Suported by: Rosa Luxemburg Stiftung

ROSA LUXEMBURG STIFTUNG
SOUTH ASIA

8th International Conference on Climate Change

Climate Action: Mitigation and Adaptation in a Post Paris World

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RE-IMAGINING FUTURES

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Tata Institute of Social Sciences

Centre for Climate Change and Sustainability studies,
Tata Institute of Social Sciences, Mumbai.

Rosa Luxemburg Stiftung,
South Asia

Centre for Climate Change and Sustainability Studies, Tata Institute of Social Sciences, Mumbai

The climate change group at TISS, started active inter-disciplinary research in the area of climate change and sustainable development in 2008. The group was formalized into a Centre for Climate Change and Sustainability Studies in the year 2012. A two year M.A./M.Sc. Programme in Climate Change and Sustainability Studies was also started, in the academic year 2012-2013. Drawing from the overall vision of the School of Habitat Studies, the Centre foregrounds the search for equitable and sustainable solutions to the issues and problems associated with climate change mitigation and adaptation. In the context of sustainability, including climate change, the Centre focuses on the search for paradigms that do not limit fundamental human capabilities and provide a future that is not limited by want, deprivation or scarcity. The Centre recognizes the intersection of the natural and the social in the study of climate change and sustainability and encourages the development of a unified view of a range of disciplines in research, teaching and pedagogy.

The Centre for Climate Change and Sustainability Studies is therefore envisioned as a platform to conduct inter-disciplinary research, teaching and advocacy in areas such as climate science, energy, water, resource economics and environmental governance. The teaching programme is designed to equip students to understand and address the intertwined challenges of environmental protection and development confronting the world today. It provides the students with an opportunity for theoretical and practical engagement with these challenges and issues in a critical framework based on values of equity and social justice, that recognizes the imperative for development in terms of material needs as well as other dimensions of human well-being.

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Rosa-Luxemburg-Stiftung (RLS) is a political foundation from Germany that works within the tradition of workers' and women's struggles. Bearing the name of Democratic Socialist Rosa Luxemburg (1871-1919), the foundation serves as a forum for debate and critical thinking about political alternatives, as well as a research centre for progressive social development. It is affiliated to the German left party DIE LINKE.

The RLS office in New Delhi has been established in 2010. It is responsible for the foundation's activities in the South Asian region, comprising India, Nepal, Bangladesh, Sri Lanka and Pakistan. The main areas of work are related Social Transformation, Labour and Agriculture. RLS primarily works in cooperation with local partners with whom projects are jointly developed and implemented.

Furthermore, RLS promotes the discourse among activists, scientists and intellectuals from South Asia and Germany as well as from other regions of the world. A special focus lies on creating networks among countries of the Global South. The foundation also provides space for critical discourse and publishes educational material.

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BACKGROUND NOTE

The Paris Agreement, drafted in December 2015 has been ratified by 149 of the 197 Parties to the UNFCCC as of June 22, 2017. The Agreement signals a commitment to keeping temperature rise to “well below 2°C” from pre-industrial levels and, in fact, “pursuing efforts to limit temperature rise to 1.5°C above pre-industrial levels”. This goal is to be achieved through the self-determination of mitigation efforts by each country, viz. Nationally Determined Contributions (NDC), which will be monitored and reviewed from time to time. However, the post-Paris negotiation process has been dealt a major setback with the US President deciding to withdraw the United States from the Agreement.

Even without this setback however, there is definitely a disjuncture between the two most important aspects of the Paris Agreement, viz. the global target for limiting temperature rise and the self-determined mitigation commitments by individual countries. A global target for restricting temperature rise to below 1.5 or 2 deg. C implies in scientific terms a cap on the total carbon that can be emitted into the atmosphere even though such a cap may not have found explicit mention in the Paris Agreement. On the other hand, the sum total of the mitigation commitments put forward by each country may be well beyond the emissions allowed to the world to restrict temperature rise to a specific level. This is in fact true at the present juncture as the emissions reductions proposed by countries in Paris are well short of what is required to restrict temperature rise to below 2 deg. C, let alone 1.5 deg. C. In addition to this, parties are under no obligation to increase the ambition of their proposed mitigation efforts and only under a non-binding moral obligation to meet even the proposed targets, inadequate as they may be. While acknowledging the inadequacy of the existing efforts, the outgoing Secretary of State for the US, John Kerry, had nevertheless argued that the Agreement would send a signal to businesses the world over that green investments were the road to the future. To leave the future of the planet to the whims of the market and the faith that global capital would recognize its self interest in investing in climate change mitigation would be a dubious strategy in itself, but the withdrawal of the US from the Agreement has exposed the insecurity of definitive action even on this front. Without one of the largest emitters of carbon dioxide (in both per capita and historical terms) making an effort to reduce emissions, the combined efforts of others are likely to be either woefully inadequate or put unreasonably high burdens on less-developed countries.

However, climate action on both the mitigation and adaptation front continues to remain important for countries such as India which find themselves in a uniquely challenging situation. It can be argued that green technologies can no longer be categorized as ‘necessary but expensive’ and are rapidly becoming competitive with conventional energy technologies. There is growing evidence to support this argument. On the other hand, it is not yet evident that the large amounts of infrastructure and industrial deficits in less developed countries can be overcome alongside this energy transition. This however needs to be concretely debated to address the question of whether it is in the interests of less developed countries to pursue an energy transition voluntarily and unilaterally.

It is also true that a large section of the global population, especially in less developed countries, is extremely vulnerable to the potential impacts of climate change. A weak effort in mitigation would imply a correspondingly higher effort required to adapt to the inevitable changes in climatic patterns. The inclusion of the 1.5 deg. C target in the Paris Agreement has muddied the waters considerably as regards to adaptation finance. There is no doubt that a 2 deg. C temperature rise would result in greater impacts and greater adaptation requirements than a 1.5 deg. C temperature rise. However, a global commitment to the 1.5 deg. C target may be used to imply the requirement of adaptation funding to address impacts of this reduced temperature target. The need to begin building a scientifically sound understanding of what climate change adaptation would entail is therefore urgent and irrefutable.

Many less developed economies are undergoing rapid structural transitions. Such transitions are technically, economically, and politically challenging in and of themselves. The addition of the growing requirements of climate change mitigation and adaptation within the confines of an unequal world order significantly increases the degree of difficulty in ensuring a decent life to a majority of the population living in these countries. It is this context that should inform discussions and deliberations on climate action, especially in less-developed countries. The conference on climate change at TISS will attempt to bring this perspective to the discussion even as it includes a broad range of topics – from the developments in climate science to sector specific interventions for climate change mitigation and adaptation.

The conference will host academicians, policy makers, experts and representatives of civil society from within and outside the country. The focus of the discussions will be on sector specific developments and new strategies to achieve equitable outcomes in the aftermath of the Paris Agreement.

Schedule for the International Conference on Climate Change

Climate Action: Mitigation and Adaptation in a Post-Paris World

Day 1

Session Category	Session Description/Topics	Speaker	
Registration and Tea			
Plenary	Opening Remarks	Tejal Kanitkar	TISS, Mumbai
	Welcome Address	Amita Bhide	Dean, School of Habitat Studies, TISS
Inaugural Session Session Chair: Prodipto Ghosh, TERI, New Delhi			
Plenary	Inaugural Panel - International Negotiations and Domestic Climate Action - Interconnections and Contestations within and outside the Paris Agreement	Navroz Dubash	CPR, New Delhi
		Jyoti Parikh	IRADe, New Delhi
		T. Jayaraman	TISS, Mumbai
	Discussion		
Tea			
Session I: Climate Action - Mitigation: Up to 2030 and Beyond Session Chair: Kirit Parikh, IRADe, New Delhi			
Plenary	Understanding the Mitigation Targets and their Implications- Equity vs. Voluntary targets	Tejal Kanitkar	TISS, Mumbai
	The Externality Effects of Renewables on India's Fossil Fuel Power Sector Investments	Prodipto Ghosh	TERI, New Delhi
	Fossil fuels to renewable energy - Politics of the transition	Ashim Roy	NTUI, New Delhi
	Low Carbon Road Map for Industries- Focusing on the Cement Sector	K.N. Rao	ACC, Mumbai
	Discussion		
Lunch			
Session II: Climate Action - Adapting to Climate Change: Finance, Politics and Regional Planning Session Chair: Anand Patwardhan, University of Maryland, USA			
Plenary	A Sustainable Development Framework for India's Climate Policy	Sujatha Byravan	CSTEP, Bengaluru
	Socio-Economic Implications of the 1.5 deg. C Target	Purnamita Dasgupta	IEG, Delhi
	Climate Impacts and Adaptation in India - what is required?	K.S. Kavi Kumar	Madras School of Economics, Chennai
	Perspectives on Evaluating Vulnerability and Adaptation Requirements	K. Narayanan	IITB, Mumbai
	Discussion		

Tea **3.50 -4.00 p.m.**			
Session IIIA: Climate Action: Climate Policy and Politics **Session Chair: Sudhir Chella Rajan, IIT-M, Chennai**			
Break-out	Business, Organized Labour and Climate Policy Forging a Role at the Negotiating Table	Peter J. Glynn	Bond University, Australia
	Decomposition analysis of factors influencing emissions and their impact on mitigation targets committed in Paris Agreement	Kashmira Pawaskar	Center for Climate Change and Sustainability Studies, TISS, Mumbai
	Climate Change in the High North Conflict or Cooperation?	Prantik Mitra and Aanchal Pruthi	Climate Sciences and Policy, TERI University
	Electricity-Water Nexus: SSP Based Assessment	Poonam Nagarkoti	CEEW, New Delhi
	Discussion		
Session IIIB: Climate Action - Vulnerability and Adaptation **Session Chair: B. Venkateshwaralu, V.N. Marathwada Agricultural University, Parbhani**			
Break-out	The Wet and the Dry: Development Planning in the Era of Climate Change	Sanjana Krishnan	TISS, Mumbai
	Climate change vulnerability at household level in urban and rural areas of Nepal	Madhav Giri	Tribhuvan University, Nepal
	Climate Change and Vulnerability Index for Four Selected Villages: A Case Study of Karnataka	M. Balasubramanian	ISEC, Bengaluru
	The Growth Effects of Natural Disasters: Does the Level of Development Matter?	Vikrant Panwar	IIT-Rourkee, Uttarakhand
	Discussion		
Plenary	**Special Lecture** - Low Carbon Options for India in the Context of Current Global Political Developments	Kirit Parikh	IRADe, New Delhi
Conference Dinner			

Day 2

Session Category	Session Description/Topics	Speaker	
Plenary	**Special Lecture** - Regional Earth System Prediction as a Decision-Making Tool for Adaptation and Mitigation	Raghu Murtugude	University of Maryland, USA
Session IV: Climate Science - Impacts, Risk analysis and attribution **Session Chair: Raghu Murtugude, University of Maryland, USA**			
Plenary	Global Warming and Monsoon Circulation	Subimal Ghosh	IITB, Mumbai
	Dynamics of Equatorial atmosphere and Oceans	Sridhar Balasubramanian	IIT Mumbai
	Discussion		
Tea			
Session V: Climate Change Adaptation - Sector Specific Strategies **Session Chair: K.S. Kavi Kumar, MSE, Chennai**			
Plenary	Climate variability and climate change impacts on Agriculture	B. Venkateswarlu	VN Marathwada Agricultural University, Parbhani
	Assessing Climate Induced Migration and Policy Responses in South Asia	Sanjay Vashist, Harjeet Singh	CANSA and ActionAid International, New Delhi
	Impacts of floods on State Finances - A Study of five States in India	Unmesh Patnaik, T. Jayaraman	TISS, Mumbai
	Impacts of climate variability on Crop Yields - An empirical study for Karnataka	Kamal Murari, Sandeep Mahato	TISS, Mumbai
	Discussion		
Lunch			
Session VIA: Climate Action - Sector Specific Strategies (Agriculture and Fisheries) **Session Chair: B. Venkateswarlu, VN Marathwada Agricultural University**			
Break-out	Economic and Non-Economic Loss and Damage from Droughts in Western India: Role of Crop-insurance and Irrigation	Chandra Sekhar Bahinipati	GIDR, Ahmedabad
	Simulated vs. Empirical Weather Responsiveness of Crop Yields: U.S. Evidence and Implications for the Agricultural Impacts of Climate Change	Malcolm N. Mistry, Ian Sue Wing, Enrica De Cian	Università Ca' Foscari, Venice, Italy
	What Determines Adaptation Responses in Marine Fishing Communities?	Krishna Malakara Trupti Mishra, Anand Patwardhan	IITB, Mumbai
	Application of Decision Support System for Agro technology Transfer (DSSAT – a crop simulation model) to assess the impacts of mean temperature rise on wheat yield	Himanshu Pathak	Kerala State Planning Board, TISS, Mumbai
	Discussion		

Session Category	Session Description/Topics	Speaker	
Session VIB: Climate Action - Climate Action: Energy and Mitigation **Session Chair: C.E. Karunakaran, TNSF, Chennai**			
Break-out	The study of causal relationship between road transport infrastructure, energy use, economic growth and CO2 emission in India	Namita Singh, Trupti Mishra, Rangan Banerjee	IITB, Mumbai
	Financing of Solar Technology: A Comparative Analysis of Policy Measures Across the Developing and Developed Worlds	Maria Chirayil	Centre for Climate Change and Sustainability Studies, TISS
	Techno-Economic Analysis of Rooftop Photovoltaic (RTPV) Systems for various Indian States	Jaymin Gajjar	CSTEP, Bengaluru
	Development of Framework to Estimate Crop-wise, Region-wise Electricity Usage for Irrigation	Akanksha Doval & Priya Jadhav	IITB, Mumbai
	Discussion		
Tea			
Session VII: Climate Change Mitigation & Adaptation - Strategies for the Future **Session Chair: Navroz Dubash, New Delhi**			
Plenary	Energy Policy in the Era of Climate Change - Way forward	Rangan Banerjee	IITB, Mumbai
	Transformative Climate Action - Possibilities and Potentials	Sudhir Chella Rajan	IITM, Chennai
	Discussion		
	Closing Remarks and Discussion	Tejal Kanitkar and T. Jayaraman	TISS, Mumbai

EXECUTIVE SUMMARY

The 8th Annual Climate Change Conference, organized by the Centre for Climate Change and Sustainability Studies (CCSS) of the Tata Institute of Social Sciences (TISS) and supported by the Rosa Luxemburg Stiftung, took place on the 4th and 5th of August, 2017 at the TISS campus in Mumbai. The theme of this year's conference was 'Climate Action: Mitigation and Adaptation in a Post Paris World'. Issues ranging from climate policy in the era of the Paris Agreement to adaptation strategies in agriculture in India, were discussed in various sessions, over two days of the conference. A summary of some of the important sub-themes discussed during the conference is presented below.

International negotiations and domestic climate action – Interconnections and contestations within and outside the Paris Agreement

The conference started off with a stimulating inaugural session under the chairmanship of Dr. Prodipto Ghosh, in which panellists Prof. Jyoti Parikh, Dr. Navroz Dubash, and Prof. T. Jayaraman discussed the implications of the Paris agreement for developing countries. In particular the discussion centred on whether the agreement addressed the issues of equity and climate finance adequately, while keeping in mind the necessities of climate science. The then recent announcement of the United States to withdraw from the Paris Agreement, played an important role in the discussion. While it was argued within the session, that such an action by the United States perhaps cleared the way for more meaningful and constructive dialogue at the negotiations, a counterview was also put forward that the United States was unlikely to stop playing a role in the negotiations. The panel also discussed various aspects of the Nationally Determined Contributions (NDC). This included, the form it should take for a developing country like India, the need for a balance between mitigation and adaptation targets and the implications of the NDC towards meeting temperature goals stated in the agreement. While there were sharply contested ideas about the importance and effectiveness of the NDCs within the Paris Agreement to meet temperature targets, there was a consensus among the panellists about the need for a serious rethink on linkages between adaptation and mitigation and the need for a new framework to do so.

Climate Action - Mitigation: Up to 2030 and Beyond

The discussion in this session revolved around the mitigation burden and the NDCs. The panellists discussed the proposal of whether developing countries like India should consider declaring a long term NDC (beyond 2030) in terms of the carbon budget. Such a proposal it was argued, allows future carbon space for economic development, acknowledges the results of climate science and gives India an opportunity to articulate equity in terms which can be operationalized. The conference saw a discussion on future scenarios and challenges for low carbon development. The panellists also pointed out that it will be difficult for India and other nations to bring down the emissions by themselves, sufficient pressure needs to be put on the US and China. It was also acknowledged that despite our very little historical responsibility, we still need to take ambitious and effective action and perhaps even go beyond NDCs. The session also included discussions on mitigation strategies adopted by some key industries and the action required to meet the targets set in the NDCs.

Climate Action – Adapting to Climate Change: Finance, Politics and Regional Planning

Panellists of this session stressed on the importance of adopting a sustainable development framework for India's future climate policy. The panellists pointed out that a very large section of our population lives without even the basic facilities, such as, access to clean and safe drinking water, clean air, and is highly vulnerable to impacts of climate change. Given this situation, there is a need to incorporate the framework of Sustainable Development Goals (SDG) in India's NDC. At the same time, efforts should be made to bring adaptation and SDGs in sync with each other. As a part of the adaptation strategy, the panellists also called for better models to assess the impact of weather shocks on economic outcomes. Another agenda discussed was the identification of livelihoods vulnerable to the impacts of climate change as well as to devise adaptation strategies suitable to local contexts.

The next issue discussed was that of urban adaptation and particularly the issues of rising urban population and risks from climate extremes to urban development, such as flood management and control. The conference also saw a discussion on impact of climate extremes such as floods and its implications for finance in the different flood prone States in India.

The conference witnessed an engaging discussion on the differential impacts of climate change based on caste, class and gender. Vulnerable communities and socially disadvantaged groups, such as those belonging to the scheduled castes and scheduled tribes have been highly affected by climate change but India and its neighbour Nepal have fallen behind in planning and implementation of adaptation measures for vulnerable communities. Moreover, any adaptation policy initiative will need to keep in mind that the capacity to adapt is context-specific and varies from country to country, from community to community, among social groups and individuals, and also over time.

Another topic of discussion was the role of climate change as one of the influencing factors for migration. It was highlighted that the international literature on climate change does not provide a clear definition on climate induced migration and displacement. Consequently, it is difficult to devise policy responses to such events. However, a counterview put forward was that migration and displacement within a region as well as at the international level were driven more by political and economic changes and that attributing ongoing displacement to climate change may be premature.

Sector specific impacts and adaptation strategies

The conference witnessed a number of interesting presentations on sector specific impacts of climate change, especially in the case of agriculture and fisheries. Crop insurance and irrigation schemes were discussed as two strategies for mitigating loss and damages from droughts especially in the Western Indian context. The discussion led to the recommendation that there is a need to properly account for non-economic loss and damage, which is currently unaddressed in policy literature. It was also suggested that the existing insurance mechanisms should be revised for better risk management. In terms of fisheries, a discussion on the multiple climate and non-climate related stresses, affecting the Indian marine fishing community was discussed. This included extreme weather events, declining fish stocks and pollution.

Energy Policy in the Era of Climate Change-Way forward

One of the focus areas of the conference was energy policy in the era of climate change. In the last three or decades there have been some advances in initiating energy transitions, particularly a transition away from the use of traditional fuels, although the pace of such transitions has been slower than desired. It was emphasised that much of this transition was driven by public sector investments. In the past few years however, the thrust of the transition as well as its nature has undergone a shift. The issue of climate change and now the recently concluded Paris agreement for which India has submitted an ambitious NDC including a commitment to install 100 GW of solar power by 2030, has had a significant role to play in this shift. Further, economic imperatives such as the reduction in prices of shale oil and natural gas, technological developments and significant drop in prices of Solar PV and wind were identified as some of the key drivers for the transition. Other issues discussed were the need for providing affordable electricity, improving forecasting, decentralised distribution, self-sufficiency in terms of technology as well as analysing the equity impact of the alternative strategy and the impact on growth.

Conclusion

In the concluding session, the discussion turned back to the central question of equity in the era of climate change. While equity remains important in the international negotiations, in terms of both mitigation and adaptation action, it is also equally important and challenging to address questions of equity domestically. The issue of a just transition, especially for those working in high risk sectors such as mining and thermal power, does not usually get the attention commensurate to the scale of its potential impacts. It was highlighted that not only was it necessary to articulate the concerns of equitable development in a clear manner, it was also important to ensure that when converting these conceptualizations to concrete action, the focus remained firmly on improving the living conditions and wellbeing of the poorest and most vulnerable sections of the country's population. The discussion in the concluding section underlined the need to foreground the concept of equity in all aspects of development and environmental protection – adaptation to and mitigation of climate change, policy making and development practice in the era of climate change.

CONTENTS

UNDERSTANDING THE PARIS AGREEMENT: EFFECTIVENESS, EQUITY AND EXIT

Navroz K. Dubash
Centre for Policy Research

The Paris Agreement is quite different from other international agreements, in that it is built around a predominantly bottom-up structure with some top-down elements. The bottom-up structure is a nationally-based structure, subject to national constraints. Every country is supposed to figure out its own national constraints, and then figure out its pledge. What does this kind of structure imply for developing countries?

To begin with, what are the potential downsides, and how likely are they? Is there a risk, for example, that developing countries like India could get 'squeezed' - even though [the Paris Agreement] is voluntary and subject to national determination – into taking on more than we are comfortable with? A longstanding fear and risk in the whole process of climate change negotiations is that developing countries will be required to take on more than they should, as compared to benchmarks of equity and by their own development imperatives. My own sense is that in the current political context, as well as legal context, that risk is relatively lower than it has been for many years. Legally, the Paris Agreement has a lot of safeguards to ensure the contributions are truly nationally-determined-that's how the framework is constructed. And politically you have much less pressure because you don't have industrialized countries, particularly with the US withdrawing. So, I don't see the 'squeeze' problem as being terribly great.

The other question, of course, is "Is the Paris Agreement meaningless?". Because it is voluntary, bottom-up, and so on, is the Agreement not really going to get us anywhere? There are two answers to this – one pessimistic and one optimistic. If you are a hardcore international relations realist, or a formalist lawyer, you would say that there are no penalties to non-compliance, that the only way anything will get done is if countries mutually agree to tie each other's hands, and this agreement doesn't do that, therefore it won't do very much. The other more optimistic point of view, which says that the Paris Agreement is not meaningless, comes from the more sociological or constructivist view in international relations (and also institutional economics) which says that what also drives countries is shifting ideas, norms, and expectations and resultant actions. What the Paris Agreement tries to do is create a virtuous cycle of those norms and expectations, where instead of change happening because countries being pushed, at some point enough countries put enough policies on the table that the fear of being pushed too hard gives way to a fear of being left behind. If you see the transition to a low-carbon future as increasingly the way in which things will happen in the future, then your policies are driven less by a fear of being taken advantage of, and more by the fear of being a laggard. So, for example, if you see that a renewable energy transition is accelerating, you'll want to make sure that you jump on that bandwagon. So, in a sense, whether we think Paris is meaningless or not depends on which of these two frameworks make the most sense.

We don't yet have a clear sense yet to judge definitively which interpretation will prevail -- whether countries will go slow because of an unsolved collective action problem (countries fail to take mitigation because of the lack of credible penalties for non-compliance) or whether expectations and economic patterns will change sufficiently fast to render compliance frameworks largely irrelevant. But I tend to think that the bottom-up nationally-determined contribution framework that emerged from Paris creates the potential for interesting conversations within countries about where their interests lie. And because other sustainable development objectives tend to align (often, but not always) with climate objectives, this provides interesting potential for development discussions within countries about what sustainable development really means. That creates some space for a virtuous rather than vicious cycle.

By focusing on these bottom up actions, does the Paris Agreement undermine equity in climate outcomes? The most unambiguous weakness of this approach, is that it also risks throwing responsibility for adaptation back to vulnerable countries instead of requiring true global cooperation to support populations. In terms of equity in mitigation, there are two possible answers. If we think about equity in terms of tons of carbon, then if the objective is that every country gets the ability to emit a certain number of tons of carbon or GHG according to some global calculation-whether based on some sort of carbon budget or other allocation scheme-then yes, it could risk being seen as inequitable. If the question is, "Does every country get to emit as many tons of carbon as it thinks it needs to achieve its development story?" then the Paris Agreement is meant to allow for that, because every country gets to make that choice. So, it depends on how you see the equity story playing out. If we find that the mixture of technology, shifting investments and shifting incentives is leading us to a transition where every ton of carbon is increasingly de-linked from development outcomes, in other words, as you move towards a low-carbon future, the importance of having access to more tons for a country decreases over time. If the optimistic version of the Paris Agreement prevails, then equity also becomes less of a concern, because a ton of carbon becomes less important to your development outcomes as countries are induced to move towards a low-carbon future.

If this optimistic version of the story does play out, it would suggest that we maybe globally moving in the right direction on addressing climate change, but it by no means guarantees we will do enough to avoid dangerous anthropogenic climate change. It continues to be a stiff challenge to adjust national economies fast enough and far enough to avoid 2 degrees warming, let alone 1.5 degrees. Notably, while this point about the urgency and speed of change is often used to critique bottom up approaches, it applies equally stringently to a top down approach based on allocation and compliance. Advocates of a top down approach often argue that we simply do not have the time or leisure to afford to wait for national economies to slowly turn around, and therefore argue for a top down approach. What they tend to forget, however, is that simply setting a target is also not a guarantee that it will be met nor that the change will occur any faster. If the history of the climate negotiations has shown anything, it is that an effort to drive national change by forging global agreement on quantitative targets and accompanying sticks has had little effect on national decision making.

Perhaps the most interesting aspect of the Paris Agreement, therefore, is that it places the emphasis on national level engagement, in the form of the "Nationally Determined Contributions" that form the bedrock of the Agreement. In essence, the Agreement recognizes that, ultimately, national politics will drive national outcomes. And it sets in place a series of top-down triggers and hurdles – such as review, a stock-take, and national expert appraisals to try and stimulate national debate and nudge countries toward more aggressive action. While there is no certainty that the aggregate effect of these national politics will produce a good climate outcome, it does shift the focus to where I believe it must primarily lie in order to advance action on this issue – the national arena. The Paris Agreement shifts the space for organizing, mobilizing and advocacy for those who care about climate outcomes firmly to the national level.

President Trump's recent declaration of intent to pull the US out of the Paris Agreement is an interesting test case of how national politics around climate change can be tumultuous, and have far reaching consequences. Trump's statement baldly summarizes the state of climate politics in the United States. And in so doing, it has had at least some salutary effects in spurring a mobilization of domestic actors in the US. While these are early days, there are signs that this mobilization could lead to some potentially progressive politics around climate change in the US, particularly if all of this comes to a head around November 4th 2020 (the next national election). I think there is enough indication that in the high-growth areas of the US (which tend to be the democratic states) mitigation and adaptation action continue quite unabated. And so, perhaps counter-intuitively, the US may not, in fact, move much slower in terms of achieving its target, limited as that target is. Among US analysts, some have argued that in areas like the electricity sector, market dynamics have taken over and drive cleaner electricity outcomes of whether or not Obama era policies persist and are implemented. Other areas like methane reduction are a little more of a question mark.A lot depends on whether Mr. Trump stays in power only until 2020 or persists until 2024. If he is in power until 2024, he has a longer time to wield a wrecking ball to US policies. If he leaves in 2020, the salutary effect of spurring a national debate enabling the mobilization of key constituencies (interestingly including many businesses), and spurring decentralized action might even be net positive for US climate politics. Globally, Mr. Trump's announcement has forced a closing of ranks, and even a scramble among emergent powers to step forward into a perceived global leadership vacuum. Moreover, the galvanizing effect nationally and globally, of a declaration of withdrawal is better than the alternative that Mr. Trump was reportedly considering: for the US to stay in the Agreement and simply lower its pledge. This second option would have sent a signal that important aspects of the Paris Agreement notably the ratchet mechanism which says you have to stick to your pledge and even move up, do not hold. The incentive for other countries would then have been to follow suit since the signal sent out would have been that national pledges can be lowered in a manner that is politically acceptable and does not require exiting the Agreement. Instead the US statement presents a starker, more binary choice – stay within the Agreement and honour your pledge, or bear the political costs of exit. While it is hard to be unambiguously positive about the prospect of the US pulling out of the Paris Agreement, it certainly does seem to have created fertile ground for new forms of engagement which may prove to be a silver lining.

In sum, the Paris Agreement is less an agreement in the conventional sense of international law – one that determines a negotiated outcome and establishes processes to enforce compliance with that outcome – and more of a guided process that seeks to steer national economies toward a low-carbon transition. It places national climate politics at the centre of the process, through regular production of Nationally Determined Contributions and establishes global procedures to try and keep national processes on track. Whether the pessimistic version of the Paris Agreement (that it is toothless), or the optimistic version (that it helps shape collective expectations of change and in so doing encourages a virtuous cycle across national economies), will depend in large part on national policy, engagement and mobilization in key countries around the globe in the coming few years.

THE PAST AS PROLOGUE – THE US WITHDRAWAL FROM THE PARIS AGREEMENT AND ITS SIGNIFICANCE

T. Jayaraman
Tata Institute of Social Sciences (TISS), Mumbai

Notes on climate policy tend to have a short shelf life and this one is no exception. While being drafted subsequent to the climate workshop for whose proceedings this was intended, the events that have taken place subsequent to this workshop have pushed this brief beyond the limits originally set for it. Hence without apology this note will deal with some key issues in global climate policy that go beyond its original mandate in terms of the time period covered. The newer elements were certainly emergent at the time of the workshop but have since gained in salience.

On June 1, 2017, the president of the United States Donald Trump announced the withdrawal of the United States from the Paris Agreement. However, when the State Department of the US communicated the intention formally to the United Nations it made clear that the United States would leave the door open to two possibilities even as it awaited withdrawal at the earliest opportunity afforded to it since it had already signed the agreement. One that it would be open to further negotiations to obtain terms that would be more favourable to it. The second, importantly, that it would participate in the proceedings of the UNFCCC and certainly COP 23 to be held at Bonn, noting particularly that it would participate in all proceedings related to the implementation of the Paris Agreement.

This is not the first time of course that the United States has thrown down the gauntlet to the entire world especially in matters of global environmental governance. But just as the danger of global warming has no parallel to refer back to, neither perhaps does the brazenness with which the United States has announced that it would turn its back on facing up to the world's most urgent environmental problem. Despite the fact that it was the United States that, in many ways, dominated the negotiations over the entire period from Copenhagen to Paris, it has now declared that it wants more out of the agreement than it has already obtained.

It is useful to note at the outset that the reading of the crisis that this move represents as the consequence of a purely domestic policy difference spilling over into the international arena is too simplistic. For one, the United States since its refusal to ratify the Kyoto Protocol, has consistently projected two faces on climate change. One is of continued engagement in the climate negotiation process, where it has strenuously intervened to shape the agenda. The second is the simultaneous widespread opposition to any serious climate action on the part of the United States, opposition centred especially in the political class in Washington, but also drawing in substantial sections of other parts of US society. The ascent of Donald Trump to office has of course exacerbated the situation, with the naysayers dominating the engagement aspect, altering the earlier balance. But the simultaneous presence of both has long characterised US climate policy. Indeed, the differences between these two faces has come to a head only recently. From the days of the non-ratification of the Kyoto Protocol to the rejection of the Waxman-Markey proposals for emissions reduction by the United States, floated early in the Obama presidency, the common character has been more evident than their differences. Thus, mere anti-Trumpism in US climate policy, can hardly be embraced wholeheartedly as a positive contribution. Nor for that matter have the Democrats in the US legislature ever been seen clamouring for any serious climate action (even if they were not deniers) and bar Obama little, or rather even less, would have been achieved.

There is good reason to emphasise this point since a new wave of activity on the climate front has announced itself as a substitute to official climate-policy making. It has in fact sought to equate its commitment to the goals of the US under the Paris Agreement with the official commitment made earlier by the United States government by the official signing of the agreement which was communicated by Obama during his presidency. This is a patently problematic stand since the UNFCCC as a treaty (ratified by the United States) between state Parties has no room for the formal recognition of responsibility towards the implementation of any agreement under its aegis. This announcement has been openly made now at COP23, notably by Jerry Brown, governor of California, who is to host a global climate summit in San Francisco next September. However even Parties well-disposed to his coalition of various stakeholders, that are keen to implement the US commitments in practice despite their government, have not greeted this announcement with any enthusiasm. If indeed non-State stakeholder commitments were to find place as an official commitment by the country where they choose to define their location, this could rapidly lead to an unravelling of the UNFCCC regime itself. Non-state actors cannot be held responsible in any legal fashion by any multilateral institution such as the UNFCCC whereas Parties can be held responsible under international law (however weakly that term may translate itself into in practice).

COP 23 convened under the shadow of this evolving scenario and has helped clarify the import of the US withdrawal from the Paris Agreement. The first, somewhat shocking, development was the eagerness of the Fijian presidency of COP 23 to accommodate the developed countries by keeping the question of pre-2020 mitigation commitments under the second period of the Kyoto Protocol entirely off the agenda. Despite thorough-going opposition which India and China led from the front, the item was not reinstated but hived off for consultations. The impact of this development is that: (a) a commitment made as part of the understanding that led to the Paris Agreement was starkly violated; (b) it was a move to further undermine the significance of the principle of common but differentiated responsibilities and respective capabilities, especially in relation to large developing countries; and (c) push the agenda of forcing further action on developing countries by bringing forward and collapsing the time-frame of different sequences of actions, where pre-2020 commitments ought to proceed the implementation of the Paris Agreement.

But even more significantly the united front put by the European Union with the United States, ranged against the developing, especially the large, countries was the real revelation of the opening skirmish over the agenda of COP23. As the conference has progressed the cementing of this relationship has been clear. The more contentious the divide with developing countries, the firmer has been the closeness. Individual European nations escape notice by the fact that their common position is articulated by the European Union. But others like Australia, Canada, New Zealand, Switzerland, Japan have all distinguished themselves by their lack of criticism of the US position. Indeed, the US in the negotiating rooms has been treated as an active partner in the effort to implement an agreement that they have announced they are withdrawing from.

Quite apart from the fact that the bold rhetoric immediately after the withdrawal of the US, has now been shown what it truly signifies, namely very little, it is important to track down the real essence of why this strong relationship between all developed countries continues despite their tactical differences or differences in nuance and emphasis. From the period prior to Copenhagen, intensifying over the years, the developed country agenda has focused on

(i) denying, undermining and eventually setting aside differentiation;

(ii) pushing the burden of climate mitigation on the large developing countries or developing regions, especially those that are in the ranks of the "emerging economies";

(iii) keeping their emission reduction commitments to a minimum, relying on future offsets under some global carbon market mechanism;

(iv) putting up a strong stand to limit the claims to climate finance by the developing countries and

(v) eventually relying on markets and the private sector to take care of climate action.

Whatever be the variations in the way this basic agenda is articulated, the developed countries are united in this.

The point is that this alliance includes Donald Trump and indeed other developed country leaders with a climate-denialist past. There is, to be sure, a difference of style, but not one of substance. There may also be differences over timing, over whether markets are ready to take the burden or not and so on. But essentially, these differences are nowhere near as important as the areas of fundamental agreement that unite these apparently discordant voices. COP 23 and the manner of its functioning has clearly brought this to the fore.

So, it is not the Trump withdrawal that one should speak about. It is the US withdrawal and whatever be the rhetoric of the foreign ministers of developed nations or the domestic political debate in the US, this is how we should characterise it. And in this is reflected a fundamental agreement on certain key issues (and not disagreement) among the developed nations. And it is from this perspective that the negotiations should be tackled, now and into the future.

THE MITIGATION BURDEN BEYOND 2030 – SHOULD DEVELOPING COUNTRIES BE THINKING OF NEW (I)NDCS?

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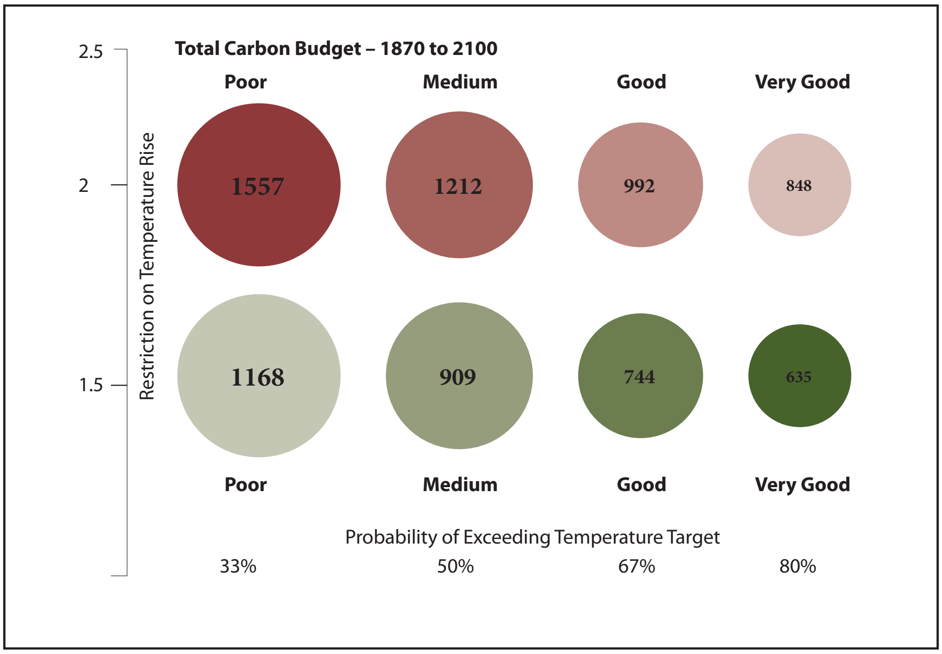
As of 7 November 2017, 169 of the 197 Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have ratified the Paris Agreement. At the outset, it is important to review some of the key targets that have been set in the Paris Agreement. Parties have agreed to commit, in principle, to climate action that will limit temperature rise to below 2 deg. C from pre-industrial levels. In fact, Parties to the UNFCCC have also agreed to pursue efforts to limit temperature rise to below 1.5 deg., an even more stringent target in terms of the emissions reductions it would imply. While it finds no explicit mention in the Paris Agreement, these temperature targets nevertheless imply specific limits on allowable emissions in the future, of course within certain bounds and considerations of uncertainty and error.

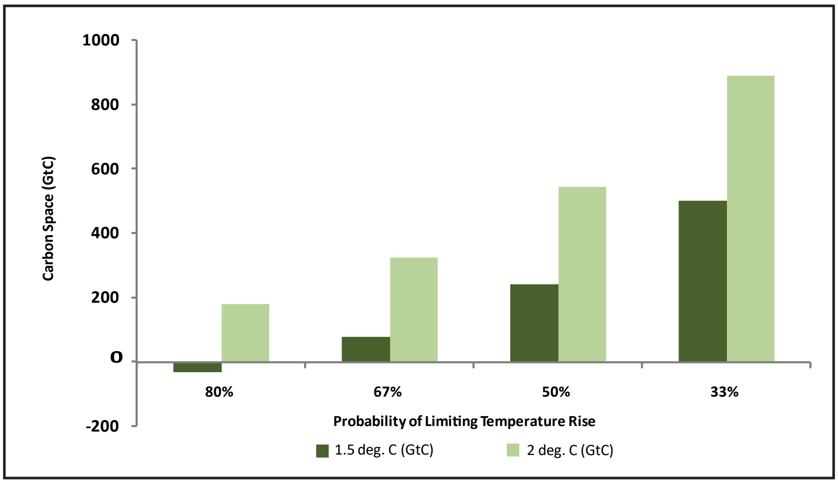
Between 1870 and 2012 the world as a whole has emitted about 667 Giga tonnes of Carbon (GtC). Each tonne of carbon emitted from 2013 onwards will add to this amount and by the end of the 21st century the cumulative emissions over this entire time horizon will determine the amount of global warming, i.e. temperature rise the world will experience. So for example, if the world emits about 800-900 GtC more between 2013 and 2100, there is a 70% chance that temperature rise will be beyond 2 deg. C; in fact it is possible that temperature rise may even exceed 3 deg. For each of the temperature targets therefore there is a corresponding value of 'allowable cumulative emissions' that will indicate the chance of either meeting or not meeting said target. These values for cumulative emissions for the entire time horizon (1870-2100) with the corresponding probabilities of meeting the 1.5 and 2 deg. C temperature rise targets is shown in Figure 1.

Figure 1. Carbon Budgets for 1.5 and 2 deg C Temperature Rise targets for Varying Probabilities of Meeting the Targets



It is evident that as the amount of carbon budget increases the chance of restricting the temperature rise to either 1.5 deg. C or 2 deg. C reduces. It is also evident from the figure that the amounts of cumulative carbon available to the world to restrict temperature rise to below 1.5 deg. C is far lower than that available to restrict temperature rise to below 2 deg. C, for the same measure of probability. However, it needs to be remembered that the values in Figure 1 include the amount of carbon that has already been emitted in the past, which is approximately 667 GtC. Therefore, the amount the world has at its disposal for the future is significantly less, as seen in Figure 2.

Figure 2. Carbon Space Available for the Future, 2013-2100. The dark green bars represent the future carbon space available for different probabilities of limiting temperature rise to below 1.5 deg. C. The light green bars represent the future carbon space available for different probabilities of limiting temperature rise to below 2 deg.



As is evident from the graph, for a good chance of limiting temperature rise to below 1.5 deg. C (80% probability), there is no carbon space left for the future; in fact, the world will have to remove about 32 GtC from the atmosphere even if it does not emit even a single extra tonne of carbon in the future. This target therefore is clearly an impossible one to meet, if we only consider current levels of technology, assuming that global political will exists to achieve such a target. A good chance (67 or two thirds of a chance) of meeting the 1.5 deg. C target leaves the world with 77 GtC between 2013 and 2100, which at the current rate of global emissions will be over by the end of this year. A very good chance of meeting the 2 deg. C leaves the world with 179 GtC between 2013 and 2100 which also will be exhausted by 2023, and that too assuming that countries have started working towards achieving the Nationally Determined Contributions (NDC) that they have pledged in the Paris Agreement. These two targets are also therefore almost impossible to meet. At the other end of the spectrum a poor chance of limiting temperature rise to 1.5 deg. C and 2 deg. C leaves 510 and 890 GtC respectively for the future. While these amounts of carbon space are large enough to provide some time and flexibility to countries to adjust their emission trajectories, adopt new technologies as they become available, etc. the fact remains that using these values as benchmarks to meet temperature goals would contravene, or at the very least weaken, the intent and spirit of the Paris Agreement. A poor chance of limiting temperature rise to below 2 deg. C leaves many countries, India included, very vulnerable to the potential impacts of climate change. For even a 50-50 chance of limiting temperature rise to below 1.5 deg. C, the amount of carbon space available to the world between 2013 and 2100 is 242 GtC. If we convert all the NDCs pledged by countries to what they mean in terms of actual emissions, they add up to 204 GtC cumulatively between 2013 and 2030 itself. So 80% of the carbon space available between 2013 and 2100 for a 50-50 chance of limiting temperature rise to below 1.5 deg. C will be exhausted by 2030 itself. Therefore, the working range available to the world to even consider benchmarking mitigation action seems to be between 325 GtC (for a good chance – 67% of limiting temperature rise to below 2 deg. C) to 545 GtC (for a 50% chance of limiting temperature rise to below 2 deg. C). At this juncture, this value of carbon space may provide the best possible chance of both – i) restricting the temperature rise to below 2 deg. C[1] and ii) providing a reasonable amount of carbon space to the world to effectively transition to non-fossil fuel sources of energy - then it can be used to estimate the potential share for different countries and regions.

1 325 Gt of carbon between 2013 and 2100 implies that at best there is a 73% chance of staying below 2 deg. C and similarly, a 51% chance at best of staying below 1.5 deg. C.

Allocation of mitigation targets in a top down manner would require universally accepted principles based on which this can be done. The inability to arrive at a consensus about such principles, in large measure due to the intransigence of the developed countries, was one of the reasons for the Paris Agreements, the architecture of which is bottom up, based solely on what each country puts forward as its commitment based on a self-assessment of its own capability and national circumstance. However, the scrutiny of the commitments made by the developing countries, especially by large emerging economies such as India, has been disproportionately high and this means that any claim or commitment made has to be justified to the rest of the world on the basis of some universal criteria. While, the over occupation of the carbon space by developed countries in the past negates any moral authority this group has in terms of asking for such a justification, the same argument cannot be made about the small island states and other developing countries. This latter group is extremely vulnerable to the impacts of climate change and has in the recent past at least joined hands with the developed countries in demanding mitigation action from the emerging economies. In light of this therefore, it would be useful for the country such as India to use a framework in which it can fit its mitigation commitment and it can use for this purpose principles of equity that have been the cornerstone of its negotiating positions since the Rio Conference in 1992.

For the purpose of demonstration, I have taken here emissions of the EU (28) region and India. This provides a comparative contrast of the mitigation burdens that these two parties to the UNFCCC have undertaken. If the entire carbon budget of 992 GtC, available to the world between 1870 and 2100 is divided equitably between all countries, i.e. on an equal per capita basis (using the 2013 population figures)[2], then India's share of this budget would be 175 GtC, and the EU's share would be 71 GtC. Between 1870 and 2012 however, India has emitted only 16 GtC, far less than its per capita fair share, whereas the EU has emitted 176 GtC, much more than its per capita fair share. This would mean that for India to get its fair share (the remaining 159 GtC), the EU and other countries that have overshot their per capita fair share would not only have to stop emitting carbon dioxide in the future, but would in fact have to find ways to remove it from the atmosphere. The EU for example, will have to remove 105 GtC of carbon dioxide from the atmosphere. Since the scale at which this is required is impossible at current levels of technological and scientific development, the carbon space physically available is only 325, and claims beyond this amount can only be rhetorical in nature. So, if only the remaining 325 GtC is divided on a per capita basis among all countries, India's share would be 58 GtC and EU's would be 23 GtC. On the other hand, Integrated Assessment Models that allocate mitigation targets based on economic criteria – highest mitigation where it is the cheapest to mitigate – end up penalising developing countries more. For example, if we take the cost of mitigation as the basis of allocation, then India's share for the future would be 14 GtC only while the EU's would be 94 GtC. If we combine the cost and equity criteria, then India's share jumps up to 41 GtC while the EU's reduces to 38 GtC. It should be remembered however, that all such estimations done considering only the carbon space available for the future, are essentially grandfathering past emissions and inherently therefore inequitable in nature. While the physical realities of the problem make it important for us to consider only the actually available carbon space, our claim to it and our commitments have to be made in cognizance of the fact that some technology transfer and finance has to be available to us, given that at the very least India would be giving up about 100 GtC of its fair share of carbon dioxide in physical terms. This giving up, is not simply because climate constraints necessitate it now, but because developed countries have over-occupied carbon space in the past. Table 1 shown below summarizes these estimates of carbon space available to India and EU.

2 The results vary only marginally if different population figures (from earlier years for example) are used

Table 1. Carbon Space between 2013 and 2100 based on different distribution criteria- for a total carbon budget of 992 GtC between 1870 and 2100

	Space to EU for the time period between 2013 and 2100	Space to India for the time period between 2013 and 2100
If the entire budget between 1870 and 2100 is allocated on an equal per capita basis and carbon dioxide already emitted in the past (between 1870 and 2012) is subtracted	-105	159
If only the available carbon space for the future (between 2013 and 2100) is allocated on an equal per capita basis	23	58
If the available carbon space for the future (between 2013 and 2100) is allocated based on a 'minimum cost of mitigation criteria*	94	14
If the available carbon space for the future (between 2013 and 2100) is allocated based on 'minimum cost of mitigation' criteria as well as equity criteria	38	41
Carbon space already claimed implicitly through the NDC up to 2030#	16	18

*Mitigation is undertaken first based on where it is cheapest to mitigate, i.e. in regions where the unit cost of reducing one unit of carbon dioxide is the least[3]

#This is based on an assumption of linear reduction in emissions to meet the 2030 target in the case of the EU and in case of India on the assumption that GDP will grow at 7% per year

The table shows quite clearly that developing countries such as India are in a severely disadvantaged position on the mitigation front. It is necessary therefore, that such countries have both a short term and a long-term strategy ready for the negotiations in order to secure their best interests for the future, which for countries like India are twofold – addressing the issue of climate change through global mitigation action in order to protect their vulnerable populations, and ensuring that they have enough space and flexibility to develop within reasonable and justifiable constraints.

Notwithstanding the almost unanimous celebrations after the adoption of the Paris Agreement in 2015, three important facts about the agreement are irrefutable.

Commitments for climate action made by all countries are voluntary and based on each countries' assessment of their own 'national circumstances'. These voluntary commitments need not, and indeed do not at their current levels, add up to what would be required to limit temperature rise.

The commitments made by countries are not legally binding. The commitments need only consider present national circumstances and there is no role for historical responsibility in measuring the adequacy and ambition of a country's mitigation plan.

These three facts make the commitment to keeping temperature rise to "well below 2°C" from pre-industrial levels virtually impossible, let alone the even more ambitious goal of "pursuing efforts to limit temperature rise to 1.5°C above pre-industrial levels", outlined in the very same Paris Agreement. The withdrawal of the United States from even this weak Agreement, in itself a somewhat exact repetition of what happened 20 years ago, is also likely to lead to consequences that are similar to what followed their refusal to ratify the Kyoto Protocol. A climate agreement that is highly inequitable and inadequate becomes somehow the cornerstone of climate action. This makes the fight for a scientifically sound and just climate plan an even bigger challenge than it previously was.

It is in this context that we need to understand the challenges before less developed countries such as India, who have as much to lose from an inequitable agreement for climate action as from having no agreement. A large section of India's population is extremely vulnerable to climate change. Take for example the number of people dependant directly on agriculture - Of the total workforce in India, about 59% are still dependent directly on agriculture - either as cultivators (32%) or agricultural labourers (27%)[4]. Among cultivators, 71% of the total number of landholdings are less than 2 hectares in size, although this makes

3 This minimum cost is obtained from various integrated assessment models and cost curves used in other modeling studies
4 Data Source: Census of India - http://censusindia.gov.in/Census_And_You/economic_activity.aspx

up for only 6% of the total land under agricultural cultivation[5]. This means that a large number of people are dependent on low value agricultural production, based largely on non-irrigated, rain-fed cultivation with low value of modern inputs, and are extremely vulnerable to climate variability, viz., fluctuations in temperature, rainfall etc. At the same time, roughly the same section of the population has little or no access to modern energy, infrastructure and services. For example, only 56% of the total households in India have access to electricity, only 39% have connections for drinking water within the premises of their house, and only 18% of the households have access to modern cooking fuels such as LPG (Liquified Petroleum Gas) or CNG (Compressed Natural Gas)[6]. It is quite evident therefore that it is in India's interest to do both - secure an effective climate deal and fight as much as it can for its right to develop. At this juncture, when developing countries are unable to withstand international pressure to ratify an inequitable climate deal and unable to prevent one of the biggest emitters from withdrawing from even this inequitable climate agreement, maybe the best option before such countries is to change the terms of engagement somewhat, within the framework of what they have already agreed to.

One way to do this is to declare unilaterally a long-term plan, a long term INDC of sorts. Since an INDC - self determined climate action that a country intends to undertake in a given time frame - forms the basis of the architecture of the Paris Agreement, a long-term declaration by a country such as India, would not deviate from the form of the climate deal that 192 countries have agreed to. However, to serve the purpose of protecting the interests of the poorest populations in developing countries, by forcing multilateral discussions back to the two main issues - adequacy and equity - the unilateral declaration will have to meet three basic criteria - i) It would have to be based on a scientific understanding of climate change. ii) It would need to have a concrete idea and argument for upholding the principles of equity and the way in which they shape self-determined targets. iii) The targets themselves would need to be such that they allow the country flexibility to decide its developmental future but at the same time be committed to concrete efforts to mitigate climate change.

Such a proposal is very much possible and is likely to impact multilateral discussion significantly, even though the ship of a perfectly equitable climate agreement may have sailed. Based on the estimate of carbon space given in Table 1, India can for example, declare unilaterally, that subject to global adherence to 325 GtC between 2013 and 2100, India would restrict its carbon space usage to 58 GtC in this time period, which is no more than its equitable share of only the available future carbon space. In doing this, it should be emphasized that giving up on the part of the budget that would have accrued to India had developed countries not over-emitted in the past, is in itself also an important contribution to the global mitigation effort.

Any further reduction from 58 GtC, has to be incumbent on finance and technology transfers. The numbers per se are only given here to illustrate a potential strategy for the future. Negotiators of the day, can, based on consultations arrive at a more nuanced and sophisticated framework for this purpose. However, the declaration of a long-term strategy is important, in the immediate future, as opposed to coming later as a desperate measure, as there has to be enough carbon space left for the future in order to build a viable argument. Going towards the global stock-take in 2023, less developed countries such as India must do what is necessary to ensure at least a fighting chance for the future and start setting the terms of engagement instead of allowing the developed countries to lead the negotiations.

5 Data Source - Agricultural Census of India - http://agcensus.dacnet.nic.in/NL/natt1table1.aspx
6 Data Source - Census of India - http://censusindia.gov.in/Census_And_You/availability_of_eminities_and_assets.aspx

BUSINESS, ORGANIZED LABOUR AND CLIMATE POLICY: FORGING A ROLE AT THE NEGOTIATING TABLE

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Abstract: Climate change policy has an impact across all levels and sections of society including the labour market, and yet climate change policy rarely provides for labour market planning. Strategies necessary to ensure that workforce is available in the number and with the skills required to meet the demands of the new low carbon marketplace, and to provide a fair and just transition for workers displaced by those policies are absent. Employers' organisations and trade unions are best placed to advise governments and to advocate in the interests of their membership; however, any action appears to have been of little effect. This paper examines the role of employers' organisations and trade unions in the process of developing climate change policy using case studies in six developed and two developing economies, including the European Union. The research finds that climate change was not generally a part of organisational policy; it was not being prioritized, and neither the employers' organisations nor trade unions have the capacity to take on this additional role. The paper also provides a rationale for the selection of ecological modernisation as the theoretical framework for investigating policymaking processes and its validity for framing policy on climate change.

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Introduction

The research for this paper considers the effectiveness of public policy and the role of stakeholders in the structures and processes of climate change related policymaking. The findings of the research are intended to provide guidance on the role and effectiveness of business and labour in climate change policy. The data for the research is obtained from a literature search, case studies across eight countries and the European Union, and a survey of the perceptions across employers' organisations and trade unions of their engagement in the process.

The literature search and case studies establish that domestic labour market planning is essential in responding to climate change; yet labour market and climate change policies are not linked. Secondly, although employers' organizations and trade unions are as influential as climate change activists within civil society, they are not effective advocates when it comes to substantively influencing climate change policy or attracting attention to the labour market impacts of climate change. The survey supports these findings, with employers' organisations and trade unions perceiving their engagement in the process has limited impact.

Strategies to manage GHG emissions are uniquely local and reflect many influences, such as the domestic economic, social, cultural and political situation of a country. All of these factors have an impact on the labour market in addition to the normal and customary turnover of labour. In the debate about climate change and the public policy intervention, the need and benefit of labour market planning is often overlooked. Adjustments to labour planning by the state and industry need consideration if the demands for labour by industry are to be met so that workers will be treated fairly during the transition to and in a new low carbon economy.

Research by advisory bodies such as Eurofound (2011a), CEDEFOP (2010), OECD (2013b) and ILO (2012) contends that social partners, employers' organizations and trade unions have an important role to play in the development of climate change policy and the transition to a low carbon economy. These contentions are not supported by the findings from the case studies and the survey. The institutional framework of the European Union (EU) confers authority on the social partners, although they are not necessarily the most capable or most representative organizations. In practice, except for a few (UK, France and Germany), their work program does not prioritize climate change but rather reflects the current issues of the day. EU member states are at different stages of economic and institutional development, therefore the contributions by the social partners and the outcomes of social dialogue across the member states will vary. This is also true for countries outside the EU.

The survey of perceptions of engagement across employers' organisations and trade unions finds a general preference for policymaking at the national level, with respondents generally perceiving the problem-solving capacity of climate policymaking to be weak. Employers' associations did not view policymaking as being particularly transparent or accountable, but were generally satisfied with its inclusiveness and equality. Trade unions, on the other hand, did not have such issues with accountability and transparency but were more concerned about issues of inclusiveness and equality. Here it may be possible to determine a sense of frustration amongst respondents with both the structures and the processes of climate policymaking. While they may be able to forge a seat for themselves at the negotiating table to a certain degree, what they can achieve once they are there is questionable.

Ecological modernisation (EM) was chosen as the theoretical framework for this research because of its increasing use in environmental policy analysis (Christoff, 1996; Spaargaren et al., 2009, Howes et al., 2010), and because it provides an appropriate framework through which to explore the roles of actors in society in the process towards achieving best practice environmental outcomes. Overlaying a template of EM on the case study countries brought to light the constraints placed on achievement of the ecological outcomes by policy processes themselves, and that the achievement of outcomes is dependent on the policy choices.

Research contention and methodology

This paper addresses the questions:

- Is the labour market impacted by climate change?
- What is the role of employers' organisations and trade unions in the process?
- Can a theoretical framework be useful in guiding the process?

The research is a qualitative study using a literature review, case studies and a survey to establish the role of employers' organisations and trade unions in the climate policy process in eight countries (the United Kingdom (UK), France, Germany, Australia, Canada, Singapore, India and Kenya) and the EU. The profiles were developed from a literature search of the governments, employers' organisations and trade unions in the countries selected. A survey was also conducted across a broader community of employers' organisations and trade unions to gauge the business and labour perceptions about their participation in climate-based policy making. The research adopted ecological modernisation as the theoretical framework.

The decision to use a qualitative approach was influenced by the sources of suitable data. There is extensive publicly available literature that provides a comprehensive discussion of the issues that are the subject of this study's research and public policy analysis. This research used the policy process review and case study method because those approaches are well suited to exploring and understanding the social aspects of climate change policy and the deployment of labour market behaviour.

The labour market impacts of climate change policy

The link between climate change and the labour market was formally acknowledged in 2009 when the Heads of State and Government adopted the recommendations of the UNFCCC Adaptation Working Group that climate change agreements extend the social dimension of policy and provide for a just transition and decent work (UNFCCC AWG LCA, 2009). A just transition is defined as the recognition of workers' rights, decent work, social protection and social dialogue (Worldwatch Institute, 2008). The four tenets of decent work as articulated by the International Labour Organization (ILO) are creating good jobs, guaranteeing respect for workers and the recognition of their rights, extending social protection and promoting social dialogue (ILO, 2011a). The opportunity for decent work and the quality of jobs is enhanced when labour market institutions, the education and training system and the industry communicate regularly, as well as when social partners are involved in the process of transformation (ILO

2012, Eurofound 2011b and OECD 2013, ILO 2015). Employers' organizations and trade unions play an important role in supporting local jobs and training as well as facilitating industry information valuable for the local labour market (Miranda and Larcombe, 2012).

The emergence of labour issues in formal climate agreements reflect the growing acceptance that climate change has impacts across the broader economy and society. While Nicholas Stern (2007) and Ross Garnaut (2008) established the bridge to understanding the economic impacts of climate change on a nation's economy, the research for the ILO (Worldwatch Institute 2008), the UK Government (GHK Consulting 2007) and the ETUC (2007) was instrumental in creating awareness of the employment and workplace impacts of climate change.[7]

The Worldwatch Institute's (2008) report for the ILO encapsulates the findings that are common across research on the subject and holds true today. Due to the impact of climate change on public policy and the economy, there will be a consequential impact on the labour market. Some jobs will be lost, some jobs created while some jobs will be changed. On balance, there will be modest net growth in employment and all sectors of industry will be affected. Rather than being an inherent part of a shift to a greener economy, outcomes for employment and incomes are largely determined by the policy instruments and the institutions that implement them (Worldwatch 2008, ILO 2012, OECD 2016). The research also finds that policy needs have to be tailored to the circumstances of the country and that there is no single policy template that can be applied in all circumstances.

Case studies

Profiles were constructed for eight countries (UK, France, Germany, Australia, Canada, Singapore, India and Kenya) and the EU. The profiles developed the climate change policy context and then the role of the peak employers' organisations and trade unions in the policy development process. This data was expected to allow an evaluation of the effectiveness of their contribution to the broader climate change policy process and, in particular, the labour market dimension.

Policy context

EU and three-member countries with industrialized and developed economies

In its Intended Nationally Determined Contribution (INDC) submitted to the Paris COP (UNFCCC 2015), the EU (UNFCCC 2015a) noted the IPCC advice that action by developed countries is necessary and they must as a group reduce their emissions by 80-95% from 1990 levels by 2050 and that the strategies intended to achieve this objective must be reported. It is also the only INDC among the countries profiled to extend their proposed emission reduction projections beyond the 2030 target. Its current strategy instrument is the 2030 framework for climate and energy which sets the targets for 2030, at least 40% cuts in GHG emissions from 1990 levels, at least 27% share for renewable energy and at least 27% improvement in energy efficiency (Europa 2016). The EU INDC committed targets were in each case a material extension beyond present achievements and were supported by well-structured action plans. The countries profiled from the European Union group are highly industrialized and mature economies. Each has adopted and is implementing the EU commitment.

Countries from other regions

The countries profiled for this section are Australia, Canada, Singapore, India and Kenya. Principal among the mitigation strategies of these countries was the shift away from fossil fuels toward renewables, energy efficiency and the role to be played by developments in technology. Adaptation measures were most advanced in the climate-exposed regions which drew attention to their exposure to extreme weather patterns, extremes of heat and cold and coastline management.

The strategic approach that underpins the INDCs submitted to the UNFCCC in 2015 by each of these countries reflects their unique domestic circumstance. The Australian Government has simply agreed to a target that is a mid-point of the targets of industrialized countries (UNFCCC 2015b); Canada is proposing stringent emission standards for the electricity and transport sectors (UNFCCC 2017); and Singapore, which has the least capacity to reduce resource consumption and introduce energy-efficiency measures has still set an ambitious target, committing

7 Also see OECD (2016), Taylor et al. (2016), Rademackers and van den Laad (2014).

to research and development to advance technology (UNFCCC 2015c).

The developing economies of India (UNFCCC 2015d) and Kenya (UNFCCC 2015e) are focusing on wind, solar and carbon sinks, essentially reducing the growth in emissions while addressing the extension of the energy accessibility across the population. However, each has qualified their commitment as being contingent on the achievement of an ambitious global agreement in Paris, the requirement for material, financial and technology support from developed countries and with consideration of the overriding priorities of poverty alleviation and dependence on economic development to support social programmes. The cost of India's proposed climate change initiatives must almost entirely be borne by the rest of the world if they are to be implemented.

The INDCs are in general fair and ambitious. Australia has been criticized for doing less than it is capable of; the contributions of both India and Kenya are conditional on financial and technology assistance and Canada's pledge will require new rather than scaled-up programmes. Only the EU extends the boundaries. While the aggregate of the INDCs of all Parties to the UNFCCC climate change agreements falls short by a significant margin of achieving the objectives of the Convention (UNFCCC 1992) and the Paris Agreement (UNFCCC 2015), the INDCs from the profiled countries demonstrate that climate change mitigation and adaptation strategies are embedded in domestic policy and programmes: it is only the capacity to deliver that is the variable.

In ecological modernization terms, the country profiles mostly demonstrate optimum models of EM in policy and practice. In the developing countries, policies reflect some commitment to the application of optimum EM (notably Kenya) but the practice fails to support the commitment, essentially due to the weak institutions of the state, the conditional nature of their commitments based on the contributions by other countries for technology and finance and that governments do not engage effectively with civil society.

Interestingly, the Kenyan government's policy represents a model of strong EM whereas the practice finds that the President Uhuru Kenyatta has delayed the climate change legislation approved by government on the grounds that civil society was not engaged sufficiently in the process and the ability to implement the government's climate change plan is contingent on other countries' agreement to transfer technology and to provide the necessary finance. The change from a conservative to liberal Canadian Government in 2015 has seen a significant policy shift toward a model of strong EM but the Canadian Government does not have the legislative authority over the provincial governments that are presently fossil fuel-dependent economies. The Australian Government, while declaring support for the international process and commitment to the objectives with reasonable targets for GHG emission reduction, is still considered to be only a moderate contributor to the global effort.

Employers' organisations and trade unions

International and regional peak bodies

It was seen across the employers' organisations and trade unions profiled in this study that many of the national organizations rely on the policy papers and research of the peak international organizations to guide their domestic advocacy on climate change which also influences the civil society contribution to the domestic policy and legislative process.

Labour market planning and the employment and workplace impacts of climate change have not been a significant policy issue for these organizations. The International Chamber of Commerce (ICC) and the International Organisation of Employers (IOE) have not commented on the labour market impacts of climate change. The ICC has not engaged in the green jobs activities of the International Labour Organization (ILO) and even the International Trade Union Confederation (ITUC) advocacy addresses only its decent work and just transition mantra. The Green Jobs campaign initiated by the ILO and supported by UNEP, IOE and ITUC goes some way further but maintains the relatively narrow focus of jobs that are considered green, potentially creating a demarcation between the green and not green jobs.

The ICC is the principle vehicle for business and industry stakeholders to interface with the negotiations for the international agreements generated through the UN system. It is the UN-nominated coordinator of the Business and Industry Major Group of the nine major groups through which stakeholders are coordinated. That said, it has not been given a mandate to represent all those stakeholders and so serves the dual role of secretariat on behalf of all stakeholders and advocate for the Chamber of Commerce movement.

ICC activities are guided by its Environment and Energy Commission, which is a committee comprised of interested members from national Chambers of Commerce and corporate members. The policy documents prepared by the Commission during 2015 framed the ICC advocacy in the lead, up to the Paris COP, and outlines their desired outcomes from the negotiations and the content of the Agreement. Important to note is that the ICC does not seek to represent the interests of business as employers, rather its mandate is *"to promote international trade and investment through a rules-based multilateral system"* (ICC 2015). Similarly, the IOE mandate is quite narrow and its members retain the right to advocate on their own behalf. This leaves the ITUC to lead the debate in many areas and much more broadly than the IOE and ICC accordingly is often unchallenged.

The IOE mandate is in respect of the interests of business as employers and with a particular focus on the employer interface with the ILO. It does not engage in either the ICC Environment and Energy Commission or the Business and Industry NGO (BINGO) as a stakeholder at the UNFCCC negotiations. The IOE is not an active advocate on climate change and, when required to comment, it defers to the formal position adopted by the ILO which supports the principles that underpin a just transition and decent work (ILO 2012). The IOE involvement with climate change has been limited to ensuring there is balance in ILO commentary and in matters such as the Green Jobs Report (Worldwatch 2008), the UNEP Green Economy report (UNEP 2011) and the ILO Guidelines for a Just Transition towards Environmentally Sustainable Economies and Societies for All (ILO 2015), and to be able to advise members when requested. Many IOE members are also representative of the broader business interests of members, not only as employers.

The ITUC is a vocal campaigner, albeit on the broader social agenda and the narrow just transition platform. The ITUC and its predecessor organizations have attended all climate change conferences of the UNFCCC and are convener of the Trade Union NGO (TUNGO). As distinct from the ICC the ITUC has a mandate to advocate on behalf of trade unions in the UN system and elsewhere. It is also very well networked with other CSOs of a like mind.

The discussion about whether the ITUC is effective in the climate negotiations requires considerable analysis of a range of factors that go beyond the scope of this research. Prima facie the ITUC is professional in its approach and has made climate change part of its work programme. However, its interest is clearly the achievement of its social agenda and the just transition of workers which it advocates can only be delivered by the effective management of climate change through mitigation and adaptation and through effective climate change policy.

In the EM context, these organizations have not advocated that employment and the labour market are issues that require special treatment beyond the ITUC advocacy for a just transition and decent work, which some would contend is an equity rather than labour market demand. However, as civil society the ICC and ITUC are formidable constituents and are recognized as such not only for their informed advocacy but for their extensive reach across their constituencies that are integral to the effective implementation of policy and influence in their domestic jurisdictions.

The regional organizations show an inconsistent interest in labour market issues. On the trade union side, the European Trade Union Congress are active and strong advocates on the labour market platform of decent work and a just transition. On the other hand, Business Europe is a stronger advocate of the broader business interests.

National peak bodies

The national employers' organizations and trade unions are not as a matter of course expressly engaged in the domestic climate change policy process. The organizations in Australia, Kenya, Singapore, India and Germany have no dedicated climate change or sustainability activity, while the Canadian, French and UK organizations are engaged. It is only the French organization MEDEF (Mouvement des Entreprises de France), the UK Trade Union Congress and the Canadian Labour Congress that advocate on the labour market impacts. The business associations on the other hand, the Chambers of Commerce in Australia, Canada, Germany and India, the UK Confederation of British Industry and MEDEF are active contributors to the climate change policy process on the business issues.

Multiple peak organizations are barriers to the effectiveness of advocacy in some of the countries. In two of the countries, France and India, there are multiple peak organizations representing their members to government and at regional and international organizations. In France, there are five peak trade union confederations.

India has a proliferation of peak business representative organizations and trade unions. Goyal and Sharma in their 2012 critique of the engagement with the government by the peak business organizations observe that they are of little interest to, nor are they influencers of government; rather, influence in policy rests with the CEOs of the major member companies who are invited by government to consult. The three peak Indian trade unions profiled in this study are very similar in their objectives and structure and, while membership numbers are large, they are still a small percentage of the workforce. They are also generally known to be the trade union branch of a political party, as the AITUC (All Indian Trade Union Confederation) is affiliated with the Communist Party and the INTUC (Indian National Trade Union Congress) with the Indian National Congress. The Confederation of Free Trade Unions of India boasts of its non-political affiliation and is emerging as a new force organizing those that are presently overlooked by trade unions and bringing together other unions as affiliates.

In Canada, the effectiveness of advocacy is compromised because there is no peak employers' organization. The business associations, employers' organizations and trade unions in the provinces and regions hold great authority and often act separately from the peak national organizations and in representation to government. The vast distances and areas impose regionally unique concerns that are often difficult to address within a national policy context. Earlier research into the role of employers' organizations and trade unions (Glynn 2014) concluded that *"the beneficial contribution to the process by employers' organizations is conditional in theory and interest and capability. The contention holds in theory and ambition in respect of trade unions, but the practice finds that they are required to direct their resources to those activities of current interest and in which the union can deliver an outcome."* (p. 197).

Survey – Perspectives of employers' organisations and trade union stakeholders

This section focuses on the perspectives of participating stakeholders. Survey respondents were identified using the Internet search terms 'employers' organization' or 'trade union' and 'participants' list', contacted by email and invited to participate in an anonymous online survey. The survey was conducted in 2016 and was in English only. A list of survey respondents is included in Appendix 1.

The results from employers' organizations were modest. The respondents presented a general satisfaction concerning interest representation at the national, intergovernmental and regional levels. Dissatisfaction with transparency and climate policymaking was not rated as particularly transparent at any level including the UNFCCC.

Trade unions responded in greater numbers than employers organisations, although the numbers of unions responding are not large given the total global labour movement. Trade union respondents appear to feel excluded from policymaking at the intergovernmental level and have issues regarding their equality of treatment. They were really only satisfied with policymaking at the national level but problem-solving and dispute settlement were consistent 'fails', equality and inclusiveness were also not high performers, nor was agreement.

EU respondents viewed their role in policymaking at both the national and regional level positively, from which it could be concluded that the respondents viewed their membership of the EU as making a positive contribution to their involvement in the governance of climate-related policymaking. This was not the case for respondents outside the EU where the results show a far less positive attitude regarding involvement in climate policymaking.

A number of conclusions can be drawn from the survey. There appears to be more confidence in climate policymaking at the national level than via UNFCCC which in part related to concerns around access and influence, and accountability and transparency, which is consistent with the findings across this research about barriers to civil society engagement. COP 21 in Paris was heavily criticized by CSOs, who argued "negotiating behind closed doors undermines the ability of civil society to ensure the accountability of governments and the UNFCCC process" (ECO, 2015)

The theoretical framework

In the period between the 2010 Cancun COP and the 2015 Paris COP (UNFCCC 2015), there was increasing concern among observers and interest groups that the climate agreements may not deliver their target of containing the increase in global temperatures. Civil society was becoming disenfranchised, negotiators could not agree on measures to address the ambition gap, there were claims for compensation from developing countries and disputes over intellectual property rights (Climate Action Network, 2012; Fisher, 2010; Eastwood, 2011). Could a theoretical framework such as ecological modernisation (EM) guide the policy development process and policy choices towards effective climate change policy?

To establish if significant gaps exist between the EM framework with the UNFCCC agreements and domestic climate change policy, a test was conducted in a sample of countries. The test sought to identify differences between the elements that make up EM and the climate change policies of a chosen sample of climate agreements and signatories (UNFCCC itself, EU, UK, China and India) thereby highlighting if and where they diverge from the EM model. A qualitative scoring has been attached to the elements of the climate policies and the EM framework. The identified assessment parameters of the EM framework presented in this research are innovation and technology, the market, interventions of the state, the role of civil society, and ecological consciousness. While EM theorists generally speak of EM on a scale of weak to strong, it was considered that policymakers would be better assisted by a more definitive measure. To that end, measures of low, medium and high were adopted in place of the weak to strong scale, and the values of 0, 5, and 10 were applied to low, medium and high (weak to strong) models of EM.

The test found there were differences; for example, whereas an ideal objective of EM is the decoupling of economic development and environmental protection, the UNFCCC seeks to achieve the multiple objectives of containing global warming, promoting economic growth and social development; the European Union and UK have added energy security as an imperative; and in India and China, the institutions of the state, market and civil society are weak. Until the 2015 Paris COP (UNFCCC 2015), the UNFCCC agreements also exempted some of the world's major GHG emitters (China, India, Brazil and Indonesia) from legally binding commitments to reduce GHG emissions.

Table 1: Ecological modernization template

	Ecological modernization	UNFCCC	European Union	United Kingdom	China	India
Targets/policy objectives	Decoupling economic development and environmental protection	Global warming $\leq 2^{0}$ C Economic growth Social development	40% GHG reduction by 2030	EU package, plus reduce GHG emission 80% by 2050	Reduce GHG emission by 45% 2050	Reduce emissions intensity of GDP 25% by 2020
Market	10	10/-10[4]	10	10	10/-5[5]	5/-5[6]
Innovation and technology	10	10	10	10	10	51
State	10	10	10	10/-5[2]	5/-10[3]	5/-10[3]
Civil society	10	10/-5[7]	10/-5[8]	10	09	09
Ecological consciousness	10	10	10	10/-5[10]	5[11]	5[11]
Ecological outcome	50	50/-15 = 35	50/-5 = 45	50/-10 = 40	30/-15 = 15	20/-15 = 5

Notes:

1. Government and market focus is on other priorities.
2. Government's Committee on Climate Change finds programmes insufficient to meet long-term targets.
3. Qualified commitment by the state prioritizes economic development and poverty alleviation ahead of climate change.
4. Market initiatives' effectiveness diminished by conditions imposed.
5. Strong support for the green market but poor regulations, measurement and controls over green compliance.
6. Market is only partially committed to green opportunities, weak institutions of the state, poor regulations, measurement and controls over green compliance.
7. Still to engage effectively with civil society.
8. Statutory role of EESC introduces stakeholders without necessarily demonstrating a stake in the outcome.
9. No effective civil society engagement or material activism.
10. Resistance to change within government agencies.
11. Not significant awareness and support across industry and society.

The spread in the scores is indicative of the diversity of the domestic situations which in each case are framed by policies designed to achieve the expressed outcomes. For the UNFCCC, the outcome of containing global warming to less than 2 degrees while also facilitating social development and economic growth, significantly influences the policy options and is the reason for a high spread in the scores. The EU and UK introduced an energy security mandate, and China and India are still pursuing a development agenda. In the scoring of the respective agreements and policies, the EU performance was strengthened by the effective implementation of policy by its member states, as demonstrated in the case of the UK. China and India did not achieve their optimum EM outcome. In EM, civil society is integral to the achievement of the ecological outcome. Of note in all these results is the role extended (or withheld) from civil society actors.

The test gives grounds to the contention that a theoretical framework could help evaluate the performance of climate policy using a set of measurable conditions (Moore, 2006). To that end, as established in the experiment, EM could serve to identify where there are gaps in the suite of policies and programmes that may inhibit the ability to achieve the targeted ecological outcome, recognizing there may be other factors, such as multiple objectives that could also create such a barrier but are outside the scope of the theoretical framework.

The INDCs submitted under the 2015 Paris Agreement (UNFCCC, 2015) provide for ratifying nations to commit to specific targets and timeframes concerning emission reductions. An examination of the INDCs of the countries profiled in this study provides an opportunity to explore the ability to guide the policy development process in pursuit of the emission reduction targets. The same scoring as adopted for the test above is applied to this examination.

Table 2: EM template overlaid on INDCs

	Kenya	Australia	Singapore	Canada	India	UK	France	Germany	European Union
Market	5	5	10	5	5	10	10	10	10
Innovation	10	5	10	10	5*	10	10	10	10
State	10**	5	10	10	5**	10	10	10	10
Civil society	10	5	10	10	0	10	10	10	10
Ecological consciousness	10	5	10	5	5	10	10	10	10
	45	25	50	40	20	50	50	50	50

Notes:

* Government is actively pursuing the introduction of new technology and finance from other countries through the technology transfer arrangements under the UNFCCC agreements.

** Subject to international assistance.

Overlaying the EM template permits a focus on the core issues necessary to the achievement of the desired outcomes and identifies those extraneous issues that can be used to evaluate policy priorities and choices. The table demonstrates for example, that for Kenya and India, policies are conditional on international technical and financial support and, in the case of India, institutions of the state are weak and the capacity to support the strategies is limited. Australia has not aggressively tackled the problem and Canada has a varied history. With the discovery of coal tar sands Canada withdrew from the Kyoto Protocol, although the country's recent change from a conservative to liberal government sees it revert to support for the international process.

In summary, the theoretical framework presented here has provided a set of conditions to contextualize the application of EM in practical policy contexts. To that end and as established in the exercise EM can serve to identify where there are gaps in the suite of policies and programmes that may inhibit the ability to achieve the desired ecological outcome, that there can be a tension between 'achieving the achievable' in environmental policy and subordinating the required ecological outcomes to external policy imperatives. The requirement that international agreements and regional/national level implementation of climate policies should facilitate economic growth overlooks the concern about the finite nature of available resources and subverts the requirement to change methods of production and consumption. The principle of common but differentiated responsibilities, while honorable and possibly even appropriate in 1992 when the Convention was adopted, provided an exemption for non-Annex 1 countries that are now major economies as well as the largest GHG emitters. The Paris Agreement has partially addressed this historical legacy, but CBDR may well continue to cast a shadow over the implementation of optimum EM models for developing countries.

Findings and conclusions

The findings of this research are intended to provide guidance for the climate change policy development process. The research addressed three questions in particular: is the labour market impacted by climate change; what is the role of employers' organisations and trade unions in the process; and can a theoretical framework be useful in guiding the process?

In respect of the labour market impact the research established that labour market planning needs to be included in climate change policy; while strategies are tailored to reflect the unique domestic economic, social and environmental circumstance, all strategies impact the labour yet the need and benefit of labour market planning is often overlooked; adjustments to labour planning by the state and industry need consideration if the demands for labour by industry are to be met and so that workers will be treated fairly during the transition to and in a new low carbon economy.

In respect of the role of employers' organisations and trade unions, research by leading advisory bodies contends that social partners, employers' organizations and trade unions have an important role to play in the development of climate change policy and the transition to a low carbon economy. However, and in practice for reasons of capacity and competing priorities, the social partners are generally not engaged in the climate policy development process, they do not have a plan to respond to the labour market impacts of climate change policy and are not sought after by government for advice.

The research found that a theoretical framework can be a useful guide in the policy development process. Overlaying the template of the theoretical framework of ecological modernisation on the international climate agreement and selected domestic climate polices identified both gaps and weaknesses in the policies and helped to identify where extraneous factors had introduced interference or barriers in the pathways toward the targeted ecological outcome. The policy objective may be to deliver a specified ecological outcome, but the policy choices generated are as a consequence of distinctive political, institutional and cultural features, the national economic importance of specific sectors and, for example, the extent of the environmental impact of particular industries.

The survey addressed perceptions of the climate change policy development and implementation process from a broad sample of employers' organisations and trade unions who generally observed the problem-solving capacity of climate policymaking to be weak, with a general preference for policymaking at the national level, notably amongst EU respondents. Employers' associations who participated in the survey did not view policymaking as being particularly transparent or accountable, and were generally satisfied with its inclusiveness and equality, whereas trade did not have such issues with accountability and transparency but were more concerned about issues of inclusiveness and equality. Here, it may be possible to determine a sense of frustration amongst respondents with both the structures and the processes of climate policymaking. While they may be able to forge a seat for themselves at the negotiating table to a certain degree, what they can achieve once they are there is questionable.

In summary and in response to the research questions, this research project concludes that:

- The labour market is impacted by climate change policy and that domestic policy does not generally reflect the need for labour market planning
- Employers' organisations and trade unions are not engaged in the climate policy process and do not advocate the need for labour market planning. This is a reflection of the limits of capacity and the competing priorities that require they attend to the immediate demands of members
- A theoretical framework can inform the climate change policy development process. The research identified that multiple policy objectives are a constraint on the achievement of the optimum ecological outcome from policy initiatives and there are barriers that mitigate effective civil society engagement.

Appendix: List of survey respondents

Participants	Employers' organization	Trade union	Other (please specify)	Total
Initial cohort	17	64	10	91
Level of activity				
Intergovernmental (e.g. UNFCCC)	0	2	0	2
Regional level (e.g. EU)	2	9	0	11
National level	5	32	6	43
Multiple levels	5	15	2	22
Other (please specify)	1	6	4	11
Region				
EU	5	23	3	31
Other	10	37	5	52
Gender				
Female	6	16	3	25
Male	10	40	4	54
I prefer not to respond	0	2	0	2
Total surveys commenced	13	57	6	76
Total surveys completed	9	41	4	54

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CLIMATE CHANGE – INDIA'S OPTIONS IN THE CHANGED GLOBAL SCENE

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Threat of climate change

The threat of climate change is now widely recognized as real. Climate change is not something that will affect us sometime in the distant future but we already face it now in terms of higher incidence and increased severity of extreme events, such as cyclones, floods, dry spells and unseasonal weather.

The sad fact is that India has very little if any, responsibility for this threat of climate change, but we are extremely vulnerable.

India's per capita emissions as seen in table 1 were way below global average.

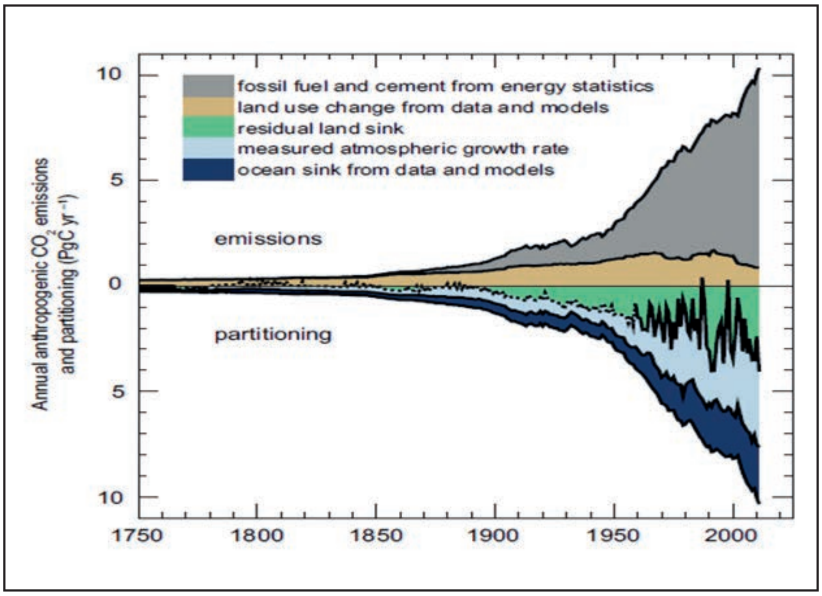
Our total cumulated emissions over 1990 to 2012 is less than 5 % of global emissions

Table 1: India's GHG Emissions in the Global Context

Parameters	Years	World	USA	China	India
Total GHG Emissions ($GtCO_2e$)	1990	32.4	5.7	3.2	1.2
	2012	46.9	5.8	10.7	2.9
Cumulated Emissions from 1990-2012 ($GtCO_2e$)	2012				
		864.4	141.3	133.6	42.1
GHG Emissions/Capita (tons/person)	1990	6.2	23	2.8	1.4
	2012	6.6	18.6	7.9	2.3

However not all the emissions made by mankind gets accumulated in the atmosphere. Our contribution to the Global stock of GHGs in the atmosphere is very small. Figure 1 shows how the total global emissions get accumulated in the atmosphere. The top half shows the sources of emissions and the bottom half the sinks. It is seen that nearly two thirds of the emissions get absorbed by the natural sinks, oceans and residual land sinks, and only one third gets in to the atmospheric stock.

Figure 1: Annual Atmospheric CO_2 Emissions and Where They Go



Source: IPCC AR-5 WG I TS Figure TS.4 https://www.ipcc.ch/report/ar5/wg1

Even if we take a conservative figure and assume that only half the emissions get absorbed in natural sinks and assume that the global natural sink capacity is allocated on an equal per capita basis to all people on earth in that year, we can calculate what is the contribution of each country to the global stock of GHGs in the atmosphere. Consideration of stock is important as it is the stock that leads to climate change. Table 2 provides these data. We can see that India's contribution to the stock is virtually nil. Yet we have great interest in a global compact as we are very vulnerable.

Table 2: Contribution to Stock of GHGs over 1991-2012

Groups	Accumulated CO_2 in the Atmosphere (1991 to 2012)	Share in the Total
Annex 1	251324	0.74
USA	109604	0.322
EU (28)	56588	0.166
Other Annex 1	85132	0.250
Non-Annex 1	88606	0.26
India	0	0.000
China	26024	0.077
East Asia	18093	0.053
Other Non-Annex 1	44488	0.131
World (184 Countries)	339930	1.000

Source: Parikh Kirit and Parikh Jyoti (2016)

We have taken many steps and we took a leading role in the Paris Agreement, which unfortunately is not very just.

- The industrialized countries deny any historical responsibility.
- Nor accept responsibility for adaptation burden of climate change. Essentially it says 'fend for yourself and bear the cost yourself'

India's Actions

At Paris COP India has committed to the following targets:

- 175 GW renewable capacity by 2022.
- 32 to 35% reduction in emission intensity by 2030 compared with 2005.
- Create addition sink of 2 to 3 GT by increasing green cover by 2030.

The costs are significant, although fortunately, the cost of solar has come down dramatically. Some people ascribe the cost reduction to the Paris Agreement but India had announced the 175 GW target much before the Paris COP.

Cost of Solar Technology

- Investment cost for solar technology is still Rs. 5 crores/MW compared to Rs 3.5 crores for a coal plant
- While a coal plant can generate 7000 hours of electricity per year, a solar plant can generate for no more than 2000 hours
- So, the upfront investment will be 5*7000/3.5/2000 = 5 times as much
- That amount of investment is not available for other sectors and services.

Hence, if adequate resources including financial and technology transfers are not available from developed nations, there will be a loss of GDP and human welfare. Earlier analysis carried out at Integrated Research for Action & Development (IRADe) shows that these losses are significant.

While the Paris Agreement comes with a promise of US$ 100 billion per year help to developing countries, not much of this money is seen yet. Unfortunately, the global scene has changed meanwhile.

Global Scene

The election of Donald Trump as US President has created many uncertainties. He is a climate denier, who wants to renegotiate the Paris Agreement and the USA may even renege on its modest commitments. Fortunately, a number of States and Cities in the USA are firm in their commitments and efforts to reduce GHG emissions. Also, the EU remains steadfast. China, which has now emerged as the largest emitter in the world has also made ambitious plans for reducing its GHG emissions. Thus, India may also consider various options for a rapid transition to a low carbon development strategy.

India's Options and Issues

As was observed in the Integrated energy policy (Parikh et al, 2006), India has meagre oil and gas reserves and even known extractable coal reserves would run out in 30-40 years if our coal consumption keeps growing like it has in the past. From the long-term perspective, renewables like solar are our main options, which necessitated the need to push for a solar mission. Nuclear can be important as a fall back source due to its high cost and associated safety concerns. The solar mission was launched in 2009 with a target of 20 GW by 2022. It was recognized that an effort at that level was considered necessary to create domestic capacity and for reaping benefits of scale, also recognizing that solar will need subsidy for some years. However, to ensure that subsidy does not prevent competition or incentive to cut costs, the process of reverse bidding was envisaged. As a result, while for the first auction for desired feed in tariff (FIT), the lowest bid came to Rs. 13.5/kWh when the expected FIT was Rs. 15. Over the years the price kept going down and the latest FIT bid was for Rs 2.4/kWh.

The Low Carbon Strategy for Inclusive Growth (Parikh et al, 2014) showed that we can reach emission intensity reduction of 30-35 % by 2030 by following a strategy of energy efficiency for lighting, appliances, equipment, industry, buildings and transport system as well as renewables. Prime Minister Modi stepped up the renewable targets dramatically to 175 GW by 2022. He has also announced that by 2030 all motorized vehicles sold in the country will be electric vehicles (EV).

Absorbing renewables like solar and wind that do not provide electricity on demand but only when the sun is shining or the wind is blowing, poses the problem of meeting the demand when these plants are not generating. A number of options are available to provide the balancing power, each involving variable costs.

- Natural gas based plants are flexible and can be brought on stream in minutes. The capital cost is also relatively low and so they are often used as peaking plants. However, natural gas can be expensive. India imports it as our domestic production is not adequate and today we have many stranded gas-based plants operating at a very low load due to shortage of gas.
- Hydro plants are also extremely flexible and can be brought on in minutes. If a hydro plant has water storage it could serve as a balancing plant. If, however, it is a run-of-the-river plant with no pondage, it does not provide an option for flexible generation. However, hydro plants generally have a high capital cost and often raise social and environmental concerns due to submergence and resettlement, particularly when construction of a dam is involved.
- It is also possible to flexibly operate coal or nuclear plants. The rates at which their generation could be ramped up varies but one can build plants with adequate ramping rates. Flexibly operating coal based plants involve some costs as the rate of coal consumption per kWh increases and also the life of the plant may be shortened.
- A number of alternatives are possible for storing energy or electricity. Pumped storage schemes involve pumping water back in to the reservoir to be used later when renewable power is not available. This involves having a pond at the bottom and a reversible turbine. Although, we may have limited sites where pumped storage is feasible. Similarly, compressed air storage is also being talked about.
- The most common option is battery storage, which however, is an expensive option. Much research around the world is going on to develop cheaper and smaller batteries. Thus, a power system with a large share of renewable capacity will have to face the problem of balancing power and the additional cost involved.

What Can Make India's Emissions Peak at 4 T/ capita?

If the world is to keep the global warming to less than 2°C as was agreed at the Paris COP, all industrialized countries have to reduce their emissions by 80% by 2050, keeping them below 2 T /capita. India would also have to contain its emissions. Considering the rate at which solar Photo-Voltaic (PV) costs are coming down, India can have a largely renewable based energy system. The question is what does it involve and what kind of scenario could we envisage?

We have developed a scenario with IRADe's Integrated Assessment Model version for ambitious emission reduction, IRADe-AER50. A version used for agricultural policy is described in Parikh, Ghosh and Binswanger (2016). It is an optimizing, multi-sectoral, inter-temporal model that maximizes present discounted value of household consumption over 2010 to 2050. Some features of the model are:

- Endogenous GDP, income Distribution, Top Down-Bottom-up model in that it covers the whole economy and incorporates specific technological options.
- Demand is endogenous with an empirically estimated non-linear demand system (Parikh et al, 2016).
- There is no free lunch in the model as production and imports must exceed or equal consumption, investment and exports. Also balance of payments constraint must be respected.
- Technological options for generating electricity by many different technologies, different options for transport, alternative energy efficiency buildings etc. are provided.
- Since many alternatives involve additional cost, investment has to be provided upfront for them.
- Government's targets for electricity consumption, LPG for cooking, pucca house for all, health and education for all by 2030 are imposed and resources provided for them.

Three major assumptions for the scenario are the following:

- We have assumed that solar PV plant cost will come down by 40 % by 2030 and 70 % by 2050. This is a conservative assumption compared to many projections of PV costs (Bloomberg 2017, IRENA 2016, EIA 2016, Fraunhofer-ISE 2015).
- Battery storage cost will come down from around $ 250 / kWh to $ 50 / kWh by 2050 due to substantial increase in demand from EVs and consequent mass production.
- The rate of progress of energy efficiency will double. We have seen how an LED bulb reduces lighting cost by 80 % compared to an incandescent bulb and by 40 % compared to a CFL. Also, the progress in air conditioner and appliance efficiency has been remarkable (Parikh Kirit and Parikh Jyoti, 2016). Based on this a reduction of 55 % by 2050 in household consumption of electricity for a given level of consumption expenditure is stipulated.

The scenario result shows the following:

- The emissions by 2050 are less than 2 T/capita. It peaks at 3.4 T/capita in 2043.
- The cumulated emissions over 2010 to 2050 is 130 GT, which is within the global space allocated on equal per capita basis between 2010 and 2050 based on the population of 2010, (WBGU, 2009)
- No further expansion of coal power takes place and in 2050 electricity generation from fossil fuel is just 15 %, from nuclear 17 % and rest from renewables.

What does this say?

- For India, which is short of fossil fuels, making renewables economic should be our highest priority. Thus,
- We should mount major R&D efforts to double PV efficiency and reduce battery cost. We have the human resources to do it and we should not rely on USA or China to do this if we want to ensure energy security.
- If we develop these technologies we can export to the rest of the world. This is a race we cannot afford to lose and sadly we have not even entered the race.
- This can make coal economically obsolete by technical development. One would not need to push renewables through subsidies.
- We should take many feasible actions to double energy efficiency improvement rates.
- A sustainable energy future is possible for India.

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INTERIM RESULTS OF THE CD-LINKS STUDY FOR INDIA[8]

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Introduction

The CD-LINKS study: *"Linking Climate and Development Policies Leveraging International Networks and Knowledge Sharing"*, is a collaborative research project funded by the European Commission. The participants comprise an International Consortium of 19 modeling teams across the globe, including two teams from India: TERI New Delhi, and IIM Ahmedabad. The author is an international advisor to the study.

Both TERI and IIMA have used linear programming, "bottom-up" engineering-economic models, i.e. "MARKAL" in case of TERI, and "Enduse" in case of IIMA. Each of these minimize the economy-wide energy system costs over the time-frame of the simulations with a given discount rate, to meet a vector of final demands for each year of simulation, subject to other externally imposed constraints.

Objectives

The Objectives of the study include:

- To explore national and global transformative strategies for climate change
- To synergize climate actions with Sustainable Development Goals (SDGs)
- To develop coherent national and global low carbon development pathways
- Linking the national projections done by national modeling teams to the global mitigation pathways via global models under >2deg C and >>>2deg C targets.

In other words, to arrive at consistent global and national GHG emissions trajectories, that would enable the limitation of global mean temperature rise to within 2 deg. C, as well as 'well below" 2 deg. C, hopefully attaining no more than 1.5 deg. C. These are to be accomplished while enabling the countries to realize their Sustainable Developmental Goals (SDGs).

Work Packages

The collaborative study has adopted the following work packages:

- **WP1:** Empirical assessment of the effectiveness of past and existing policies
- **WP2:** Assessment of international country pledges, national action plans and development policies
- **WP3:** Coherent national and global low-carbon development pathways
- **WP4:** Climate change as part of the broader development agenda –Systematic assessment of synergies and trade-offs between multiple policy objectives
- **WP5:** Future policies and related implementation challenges and opportunities
- **WP6:** Capacity building, dissemination and stakeholder engagement

This policy brief presents the interim results by the two Indian teams, as well as ranges of projections by the global models, covering WP 3.

Scenarios

The following scenarios have been agreed for modeling simulations by each of the country and international teams:

- **No Policy Scenario:** Counterfactual scenario to chart the development path in the absence of any climate policy
- **National Policies Implemented (NPi):** Scenario representing climate policies rolled out till 2016
- **INDC:** Scenario representing all climate policies and targets formulated in India's INDC submission
- **INDC-high:** Scenario incorporating climate and development policies for midcentury strategy towards decarbonization (to be submitted to IPCC)
- **INDC-low:** Scenario depicting a decarbonization pathway to meet the 'well below 2 deg.' world
- **NPi-high:** Early action scenario (beginning 2020) for INDC-high
- **NPi-low:** Early action scenario (beginning 2020) for INDC-low

8 Major source is a joint presentation by TERI and IIMA at the CD-LINKS review meeting at Potsdam Climate Institute, in May 2017.

These scenarios, it is hoped, will cover the entire feasible or possible range of GHG mitigation strategies.

Interim Overall Results

I now present the interim results (upto WP 3) by the global models for India, and the two Indian teams:

Table 1: Comparison of total emissions in 2051 in the Global Models and TERI-MARKAL and IIMA End-use (for >2deg.C):

Scenarios	GlobalModels	IIMA – AIM/Enduse	TERI – MARKAL
No Policy	108 - 153	185	264
NPi	99 - 147	160	209
NPi-high	37 - 114	134	190
NPi-low	25 - 86	127	175
INDC	88 - 136	145	193
INDC-high	88 - 117	132	187
INDC-low	32 - 91	126	172

The main reason for the divergence between the global models and the Indian modeling teams is that the carbon budgets given by global models are based on the efficiency principle of equal marginal abatement costs across countries. On the other hand, the simulations by IIMA and TERI are based on feasibility in light of national circumstances.

There are divergences also between the two Indian models. I summarize below the key differences in assumptions across the two models:

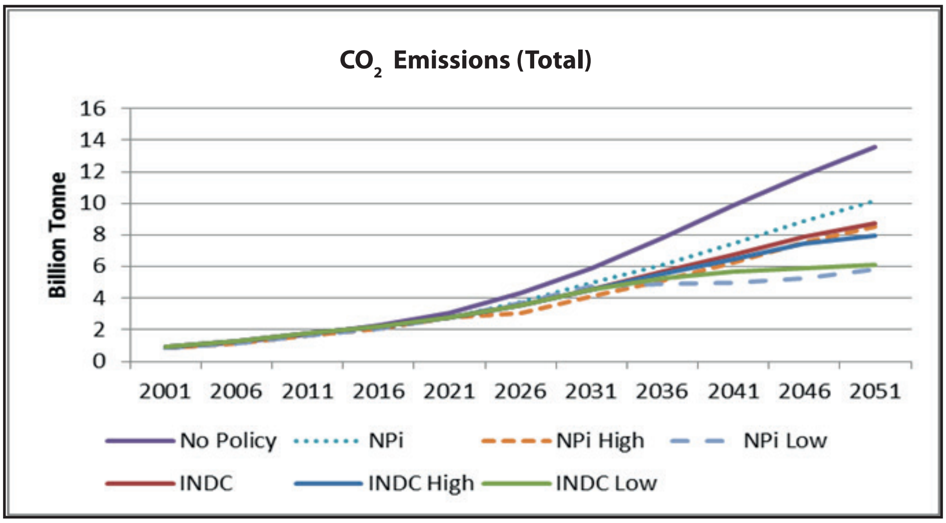
- **Population:** Similar assumptions across both models:
  - 1.7 to 1.75 billion in 2050
- **GDP Growth:** Based on growth assumptions in line with development aspirations
  - **TERI:** average GDP growth of 7.8%
  - **IIMA:** CAGR 7%
- Policies (INDC) and technology selection:
  - **Power:** Renewable energy targets already adopted are specified in each model
  - **Industry:** The PAT mechanism is included in both models
  - Need to ensure consistent prices and same exchange rates across global and national models

Both models have adopted exchange rates that are consistent with that of the global models.

Detailed Results of Indian Models: Comparisons of detailed results

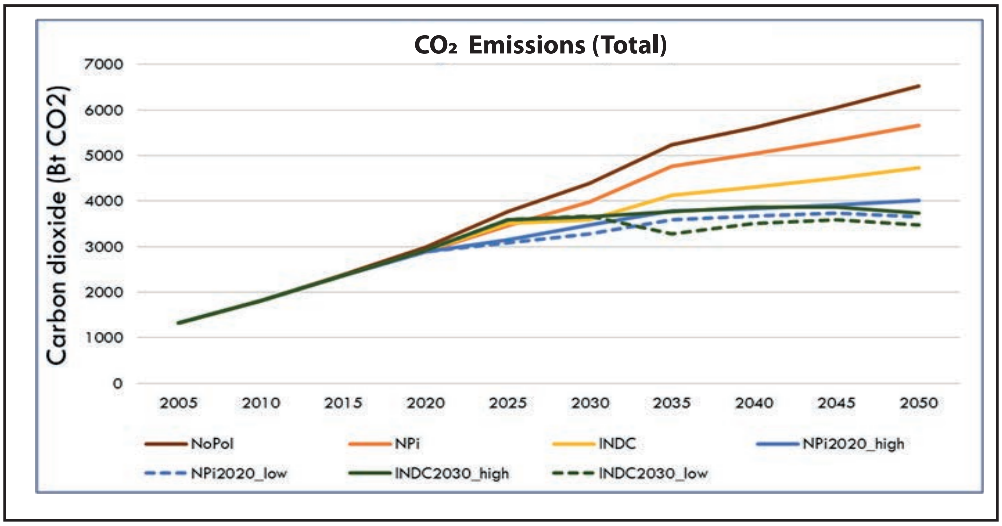
TERI-MARKAL and IIMA-Enduse

Figure 1: Total Emissions in the TERI-MARKAL Model:



There is a variation of almost 100 percent between the total CO_2 emissions in 2051 between the "No Policy" and the NPi Low scenarios.

Figure 2: Total emissions in the IIMA-Enduse Model:



While the highest emissions in 2051 are again given by the "No Policy" scenario, the lowest in this case is given by the INDC 2030 Low scenario. In each scenario, the emissions projected in the model are appreciably lower than in case of the TERI-MARKAL model.

The reasons for divergence in the CO_2 pathways are due to the following differences in model assumptions:

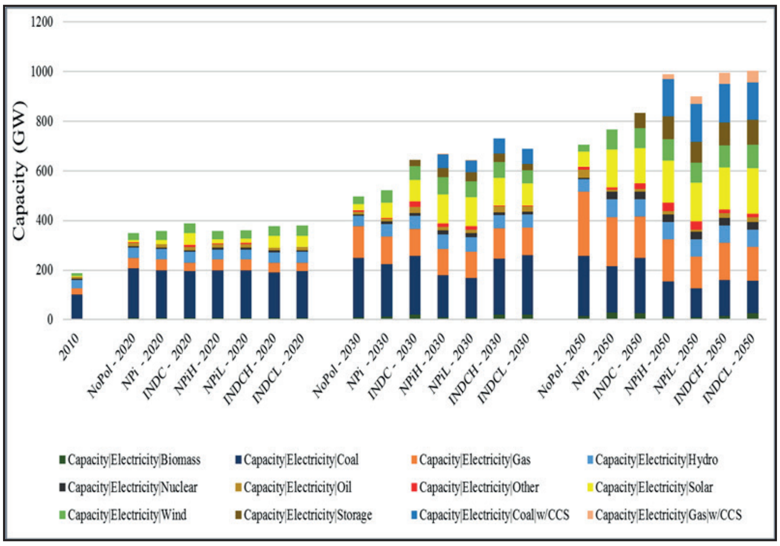
Asumptions of GDP Growth Rates:

- TERI-MARKAL: Average annual GDP growth rate assumed is 7.8%
- IIMA-Enduse: Average CAGR of GDP is assumed as 7%

Technologies adopted:

- TERI-MARKAL: Only commercially viable and implementable technologies are included
- IIMA-Enduse: Advanced, more efficienct and futuristic technologies are included.

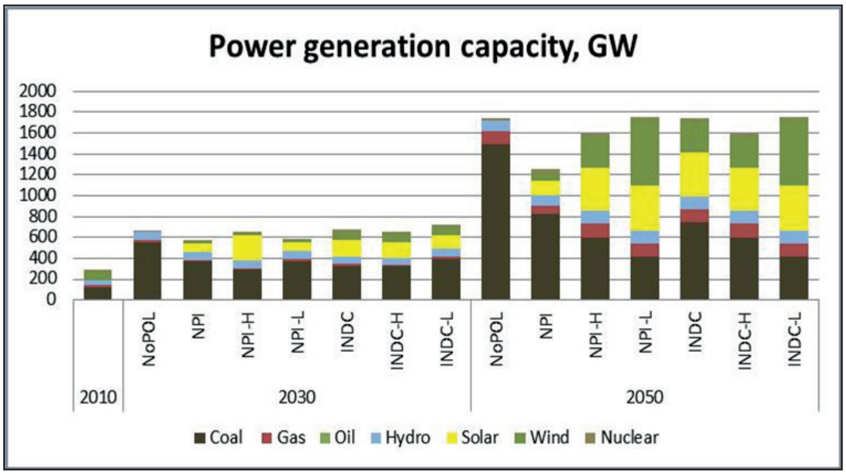
Figure 3: Capacity Addition in the Power Sector: TERI-MARKAL:



There is an increase in share of renewables across the different scenarios. Additionally, it is assumed that electricity storage is viable at scale in INDC, NPi(High and Low), INDC(High and Low) scenarios.

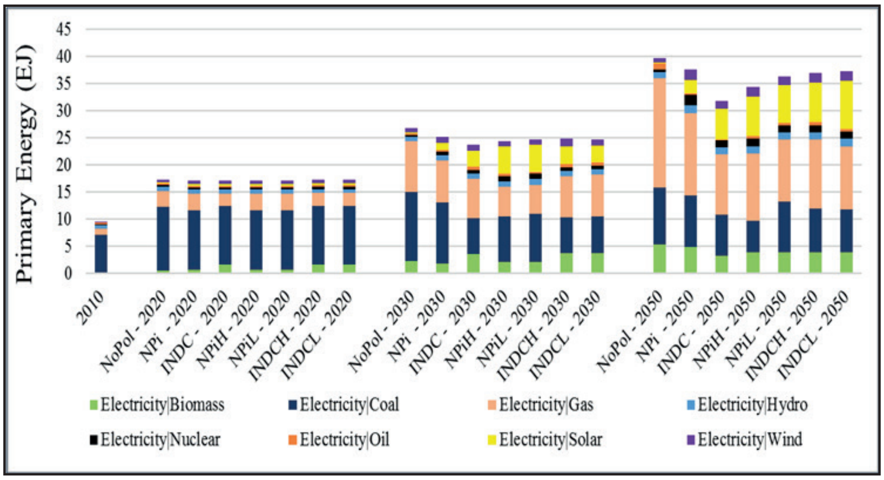
The TERI-MARKAL model does not include Carbon Capture and Storage (CCS) in any scenario owing to uncertainty in cost and reliability of technology (CO_2 leakage).

Figure 4: Total Capacity in the Power Sector: IIMA-Enduse:



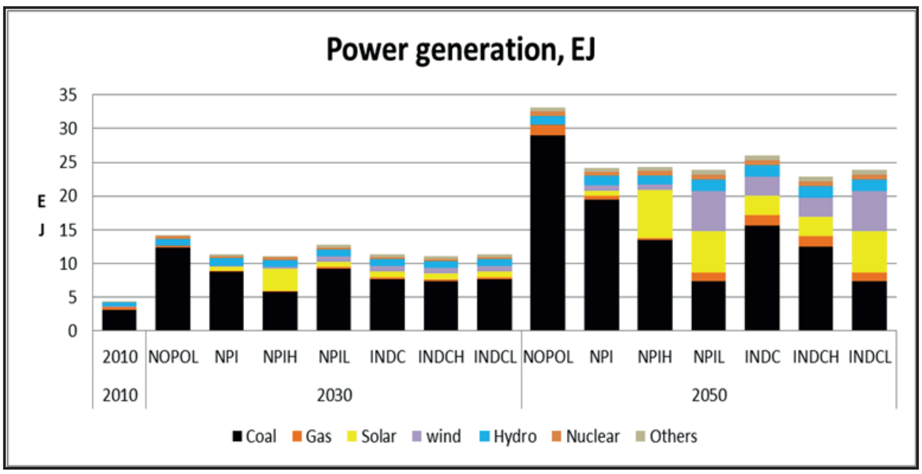
It may be seen that in the "No Policy" scenario, there is very low adoption of renewables or nuclear. Their penetration is enabled by policy in each of the other scenarios. The IIMA-Enduse model does include CCS as well as natural gas based power plants in the in Npi (High and Low), and INDC(High and Low) scenarios.

Figure 5: Power Generation: TERI-MARKAL:



The TERI-MARKAL model provides for (a) Renovation and Modernization of coal plants; (b) Shutting down inefficient coal plants; (c) Shift to super-critical and ultra-super critical coal power plants. Additionally, it envisages constraints on natural gas supply based on considerations of availability and infrastructure.

Figure 6: Power generation: IIMA-Enduse:



The IIMA-Enduse model reveals use of improved coal technologies such as Integrated Gasifier Combined Cycle (IGCC), Flue Gas Desulphurizers (FGD), super-critical (SC), and ultra-super critical (USC) coal technologies. The simulations reveal increase in share of natural gas. There is also addition of CCS in NPi (H&L) and INDC (H&L) scenarios.

Figure 7: Energy System Transformation in Industry: TERI-MARKAL:

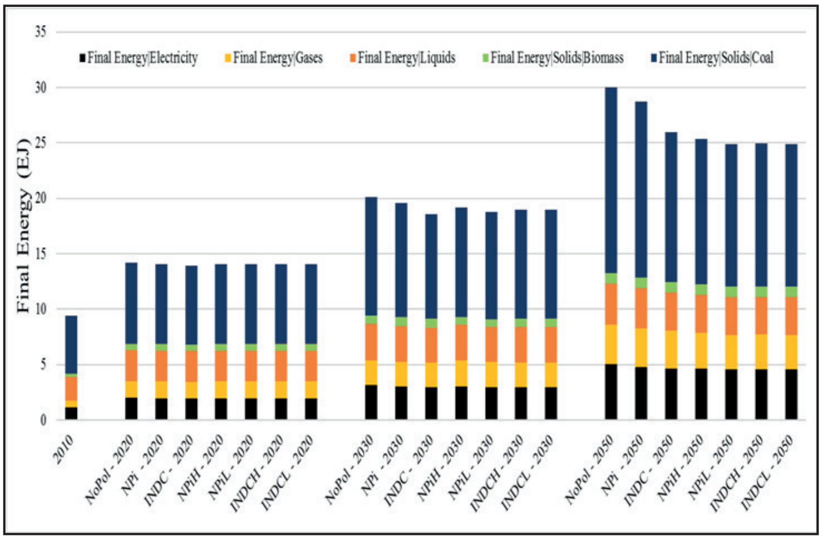
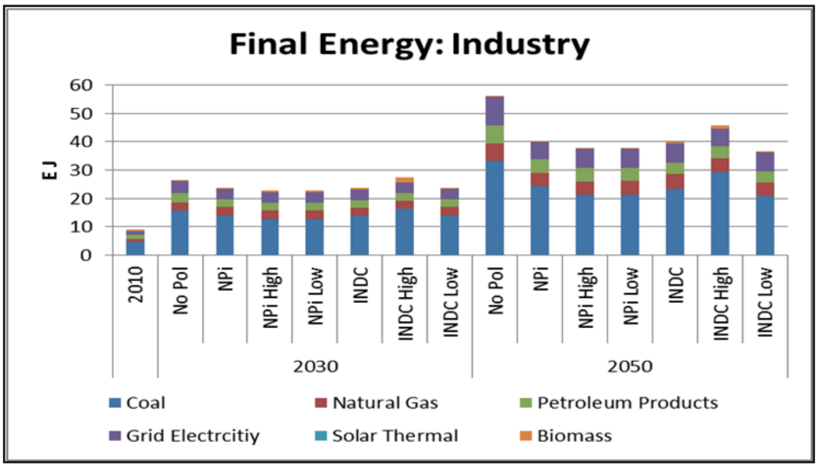


Figure 8: Energy System Transformation in Industry: IIMA-Enduse:



In both models, it is observed, across the scenarios, as follows: There is decrease in energy intensity per unit output in energy intensive units (aluminium, cement, chlor alkali, fertilizer, iron and steel, paper and pulp, textile) attributable to the "Perform, Achieve and Trade" (PAT) programme. There is also demand reduction of virgin material through reuse and recycling: in TERI-MARKAL, in respect of aluminium, Iron & Steel, and Paper; while in IIMA-Enduse, in aluminium, Iron & Steel, and Plastics.

Figure9: Energy System Transformation in the Transport Sector: TERI-MARKAL:

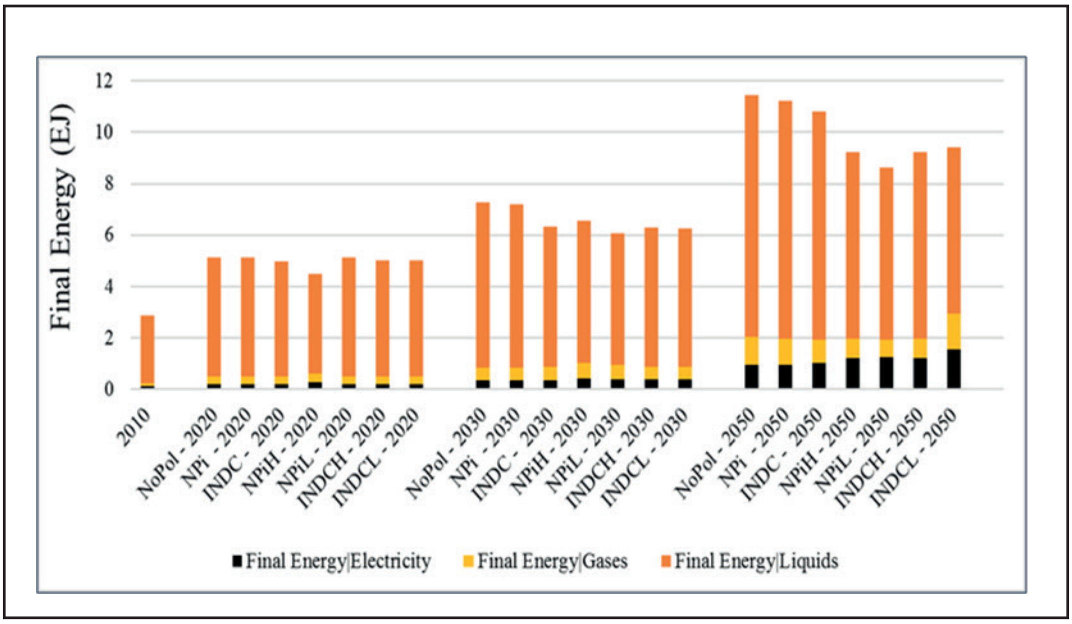
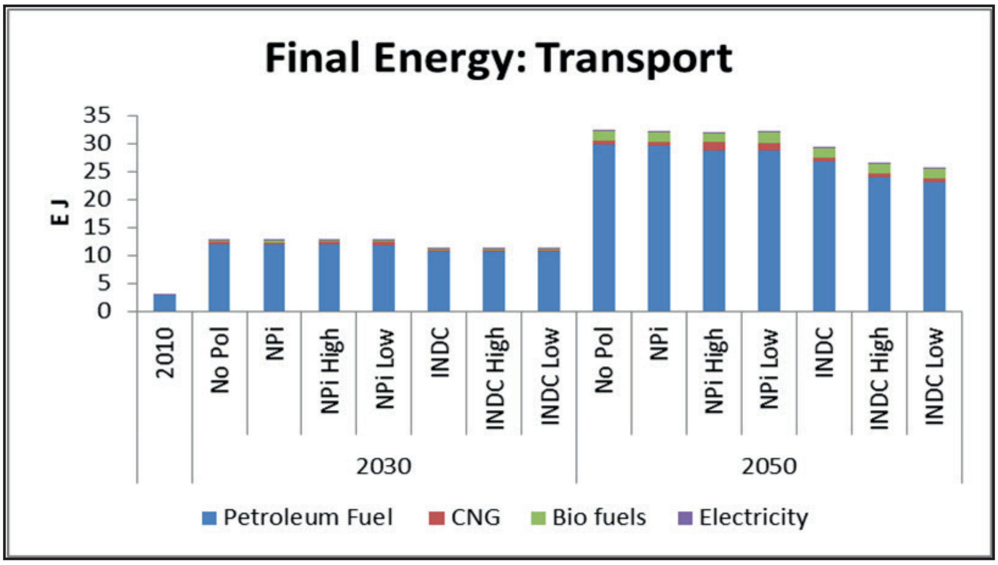


Figure 10: Final energy use in transport: IIMA Enduse:



Both models indicate shift to cleaner fuels (CNG), electrification of passenger vehicles (2-wheelers, 3-wheelers), shift to public transportation (metros, buses), and change in respective shares of rail and road transport: i.e. TERI-MARKAL indicates decrease in freight share of roads, while this is reversed in case of the IIMA-Enduse model.

Issues and Challenges:

The model simulations reveal some interesting challenges:

(i) A very high carbon tax, (or carbon price imposed by other instruments) is necessary for switching to options like electric vehicles (EVs).9

(ii) Increased energy system costs result in GDP losses of about 2-3%, without consideration of general equilibrium aspects.

(iii) Mitigation costs arise largely because of infrastructure related investments including grid strengthening, smart grids and ancilliary services, gas distribution infrastructure for cities, charging stations for Electric Vehicles (Evs), and refilling stations for CNG

(iv) Capacity addition in railways is mainly for freight traffic

(v) There is low utilisation of stock of existing coal based power plants

9 Use of non-linear general equilibrium models to compute GDP losses may indicate much higher GHP losses.

(vi) Some options will involve socio-economic-cultural changes, for example, move towards electricity based cooking

(vii) Elimination of secondary markets are necessary to enable move towards efficient stock.

Lower income categories are excluded from markets.

Key Insights

The large divergence in emissions projections of developing countries such as India from national models and those emanating from the global models arise not simply from differences in model structure, but primarily from divergence in perspectives about the proper normative basis of burden-sharing across countries. The approach in the global models, that of assigning the shares of permissible carbon emissions on considerations of economic efficiency alone are unlikely to find political acceptance by developing countries.

While formulating proposals for burden-sharing principles is not within the mandate or competence of energy-economy modelers, nevertheless these researchers may provide useful information to policy-makers on economic and technological implications of different normative principles at the global and national levels. A number of candidate normative principles have been proposed in the relevant literature, and in the next stage, the CD-LINKS study could usefully simulate projections of emissions and conjugate economic and technological consequences of these normative principles.

India faces a unique challenge in having to simultaneously undergo decarbonization, while embarking on rapid economic growth and social transformation. The simulations done so far reveal that it is highly improbable that India could meet its sustainable development goals, with a trajectory of GHG emissions of at least 172 gigatonnes in 2050.

ENERGY TRANSITIONS IN INDIA: ROADMAP FOR A POST PARIS WORLD

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In the context of the 2015 Paris agreement to combat climate change and India's nationally determined commitments, we examine the impending energy transitions in the country and the implications for the energy sector. Before discussing the future energy transitions, let us examine the energy transitions in the past.

Energy transitions in the past

During the last forty years India made a transition from traditional fuels to modern commercial fuels (mainly fossil fuels). This transition was characterised by large investments in centralised energy supply and distribution infrastructure and a focus on supply growth with mainly public sector and government investments. A number of large hydro and coal based thermal power plants were built. Figures 1a and b show the increasing share of coal, oil and gas in the primary energy and in the power generation supply mix. The energy grid has connected up the entire country though shortages persist and a significant portion of the poor do not have access to modern energy sources. The electricity sector has migrated from state controlled monopolies to unbundled and regulated entities with public sector and private sector companies.

Figure 1a: India's primary energy mix (% shares)

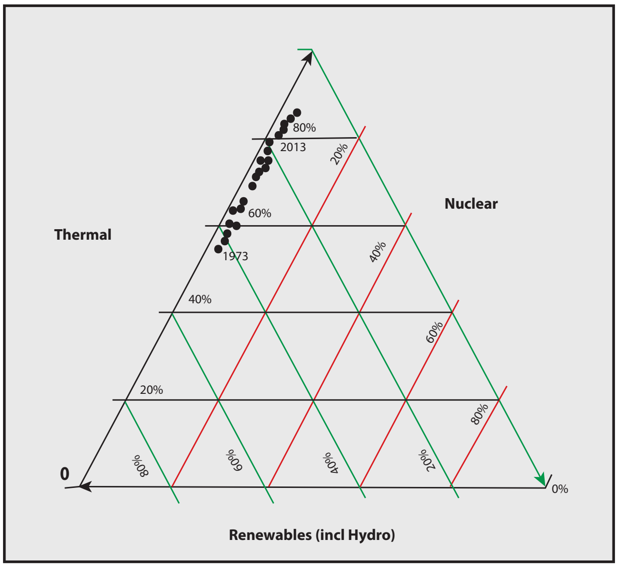
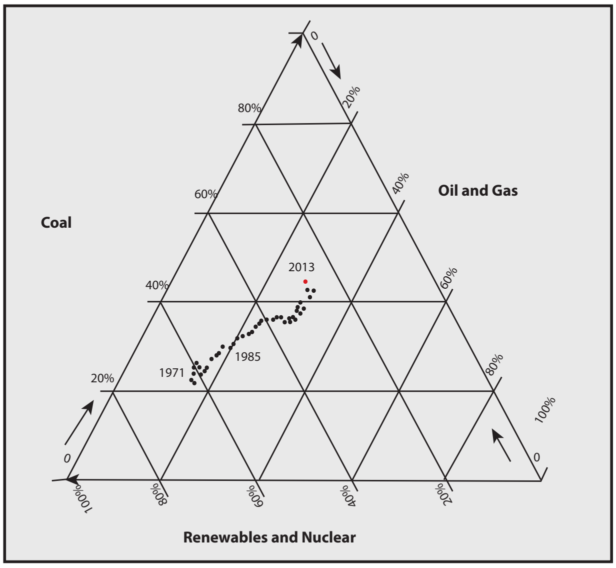


Figure 1b: India's electricity mix (% share)



India has achieved significant growth in its energy infrastructure which has propelled the growth of the economy mainly through the increasing use of fossil fuels.

Drivers for future energy transitions

The current energy supply mix in India is predominantly centralised and based on fossil fuels. The adverse impacts of climate change have resulted in a global consensus (national commitments at COP21 in Paris) to move away from fossil and policy support for ramping up renewables. There have been significant reductions in prices of Solar Photovoltaics and Wind power. In the Indian context the national solar mission and reverse bidding has led to a rapid decline in tariffs. Figure 2 shows the decline in Solar PV tariffs from Rs. 11/kWh to less than Rs. 3/kWh during 2011 to 2017. The initiative of the government for public procurement of LED lights (energy efficient lights) has been successful in bringing down prices of LED lights (including reductions in the market prices) as seen in Figure 3. Another major driver of change in the energy sector globally has been the improvement of drilling technology and fracking causing a reduction in prices of shale oil and natural gas. Developments in intelligent sensors, controls and the internet of things are another major driver that may make smart distributed energy systems viable.

Figure 2: Trends in the solar PV bid price (Data source: [1])

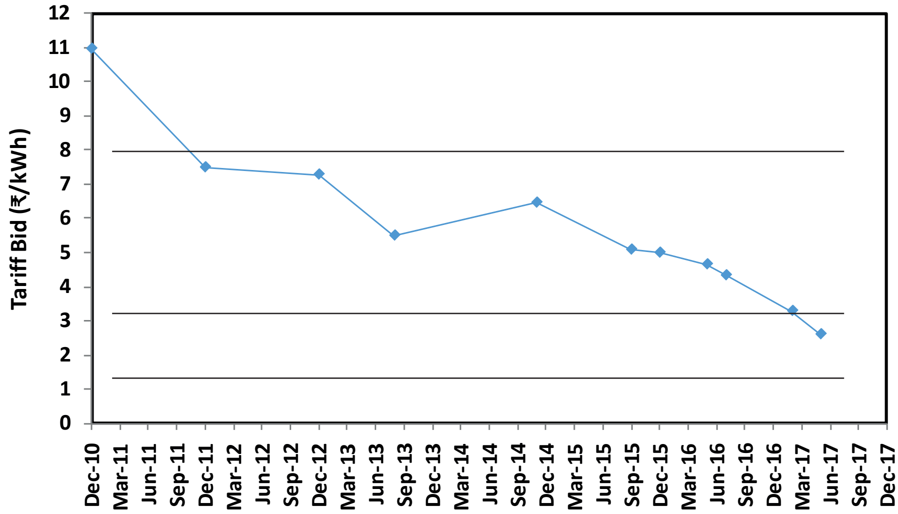
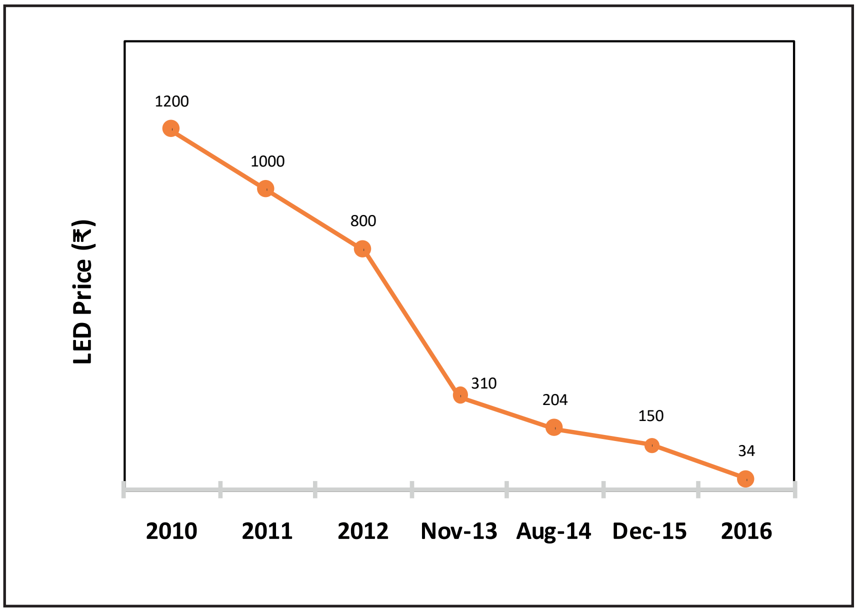


Figure 3: Trends in LED procurement price (Data source: [2])



Factors remaining unchanged

It is evident that the India energy sector is in the midst of a major transition. What remains unchanged?

Interestingly, despite all the transitions, income, energy and carbon inequality persist and increase. This remains the challenge for any development strategy. Global inequalities (between countries) and inequalities within the country combine to grow and result in an increasingly unsustainable global order.

Energy is a means to an end. There is an unserved demand for cheap 24/7 energy to improve quality of life of the people. This has to be the focus for any national strategy.

There are a multiplicity of factors and decision levels and inertia in institutions.

Challenges for the Energy Transition

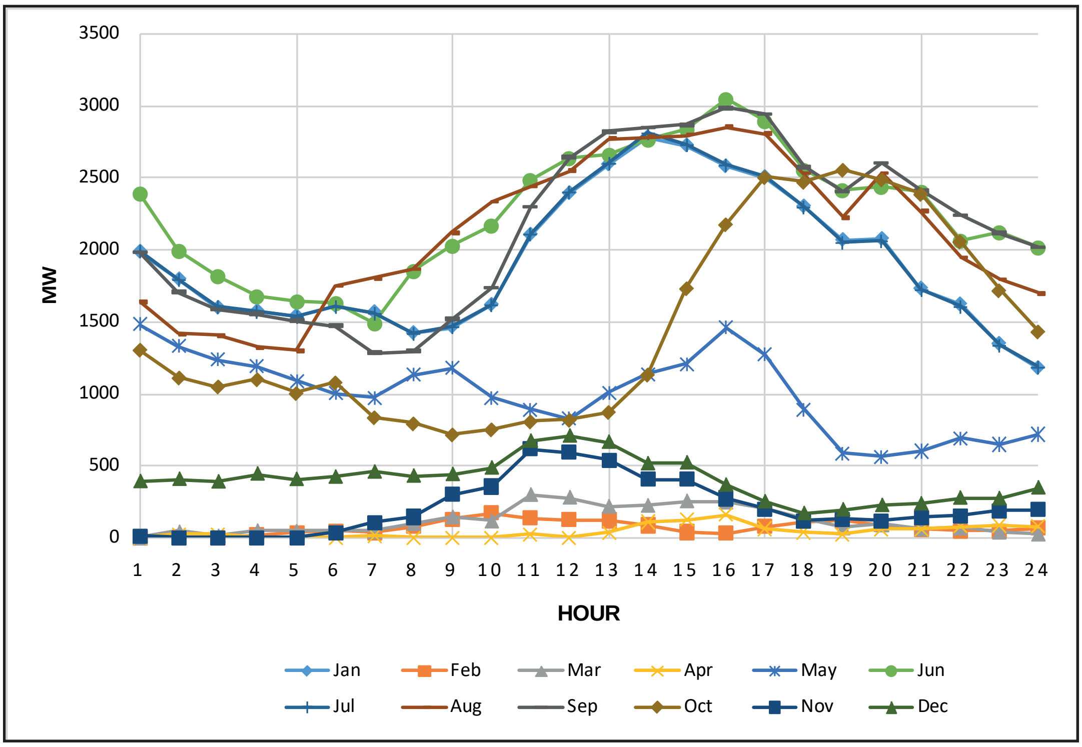
There are several challenges facing the Indian energy sector. Transitions can be analysed in three main classes – the electricity sector, the transport sector and the cooking sector. The electricity sector is a key energy sector (supply and secondary energy). The transport and cooking sectors are important demand sectors. Most analysis of transitions focus on the electricity sector.

The present energy infrastructure and business organisations are geared to large centralised fossil fuel based supply. In order to attract large investments, the Government is extending the same model to solar parks. As an example, India installed one of the world's largest solar Photovoltaics plants at Kamothi, Tamil

Nadu over an area of 10 km2 with an installed capacity of 648 MW and an investment of Rs. 46540 Million (investment of Rs. 72 million /MW). The plant uses robotics for automatic cleaning of the panels and was built in a period of eight months.

India has one of the highest growth rates planned for solar and wind (solar CAGR of 47% over the ten-year period 2012-22). India has already witnessed significant growth in grid connected PV installed capacity from 2 GW in 2012 to about 12 GW in 2017 (CAGR of 44%). The total (excluding large hydro) installed capacity of renewables in India was 57.2 GW (as of 31st March 2017) constituting about 17% of the installed power capacity and accounting for about 9-10% of the total electricity generation. Based on the planned capacity additions the share of renewables in the electricity mix will increase. The present renewable energy capacity is dominated by Wind power (32.3 GW out of a total of 57.2 GW [3]). Hence the renewable electricity generation shows significant seasonal variation, with the average generation during the monsoon months (July- September) being 7-9 GWh/month while the period from October to May has a monthly generation ranging between 4-5 GWh/month. The electricity demand during the monsoon months is usually lower than the other months due a reduced demand for agricultural pumping. Figure 4 shows the typical daily load curve for different months in Tamil Nadu in 2012. Apart from the marked seasonal effect it is also seen that the timing of the peak wind power supply varies widely in different months.

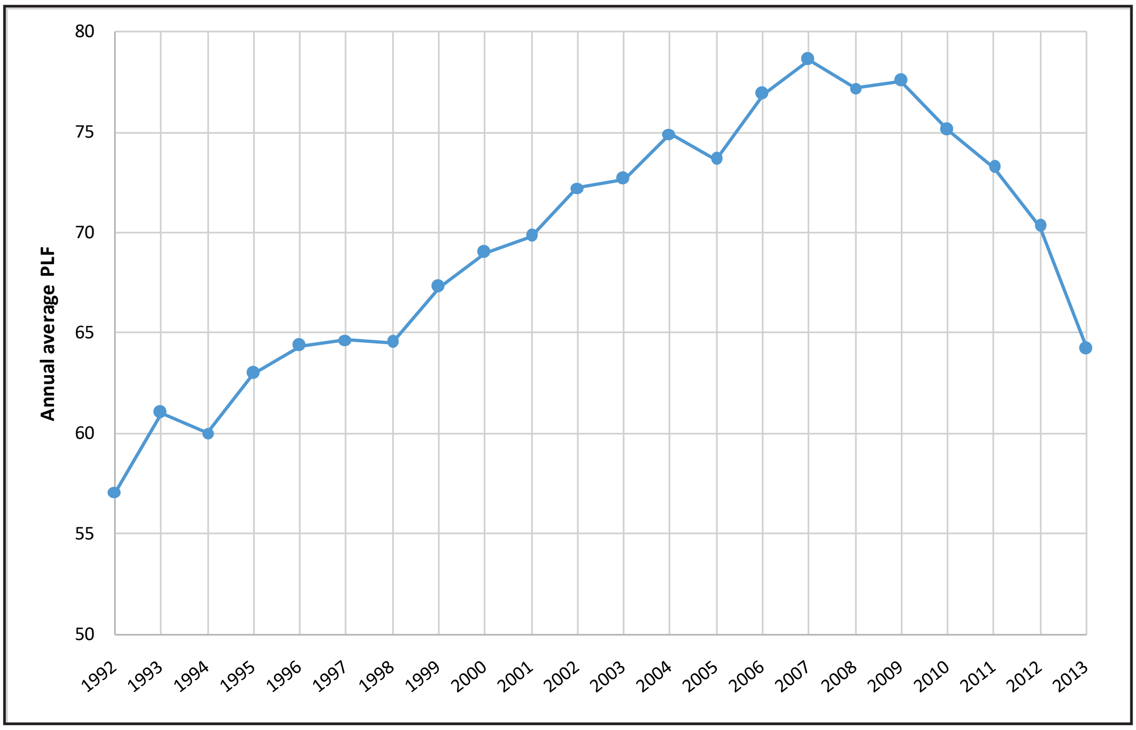
Figure 4: Tamil Nadu Typical Daily Wind Generation patterns in 2012 [4]



What has been the effect of the increased share of renewables in the electricity mix? Most grid connected renewables are always operated as must run (since solar and wind have no fuel cost). This implies that in periods of high renewable electricity generation, it is necessary to back down fossil fuel generation (usually coal based power generation). The annual plant load factor (PLF) of a power plant is the ratio of the annual electricity generation of the power plant to the maximum possible annual generation if operated continuously at its rated capacity. Investments in coal based power plants are made based on an assumption of the expected PLF over its lifetime. A higher PLF implies that the annualised capital cost is distributed over a larger number of units, resulting in a lower average price of electricity. Generators would prefer to operate their power plants at high PLFs. Figure 5 shows the variation of the average annual plant load factors for coal based power plants in India for different years. It can be seen that the average annual plant load factor increased from 55-60% in the early 1990s to 75-78% around 2005 and has been steadily declining since then. The present PLF of coal based power plants in

India in 2017 is 58.8% (back to the 1990s level) and continuing to reduce. The draft national electricity plan of the Central Electricity Authority projects that the PLF of thermal power plants would reduce to 48% by 2022. In the US the capacity factors for coal based power plants has declined to 52.7% in 2016 [6]. The reduced capacity factors make many of the coal based power plants unviable. 179 coal based power plants in India are older than thirty years. This accounts for about 24 GW of installed capacity. The transition to renewables would involve a strategy for identification of plants with high emissions and phase them out.

Figure 5: Average annual plant load factors for coal based power plants in India [5]



The electricity system must retain its capability to meet the daily and seasonal variability in the demand. Traditionally this has been done by hydro thermal scheduling with a merit order despatch. The integration of wind and solar needs new approaches. One of the methods proposed in literature is the duck curve (applied initially for California [7,8]). This involves subtracting the projected wind and solar electricity generation from the projected future system demand. The resultant net demand curve has to be met by the existing fossil and hydro plants.

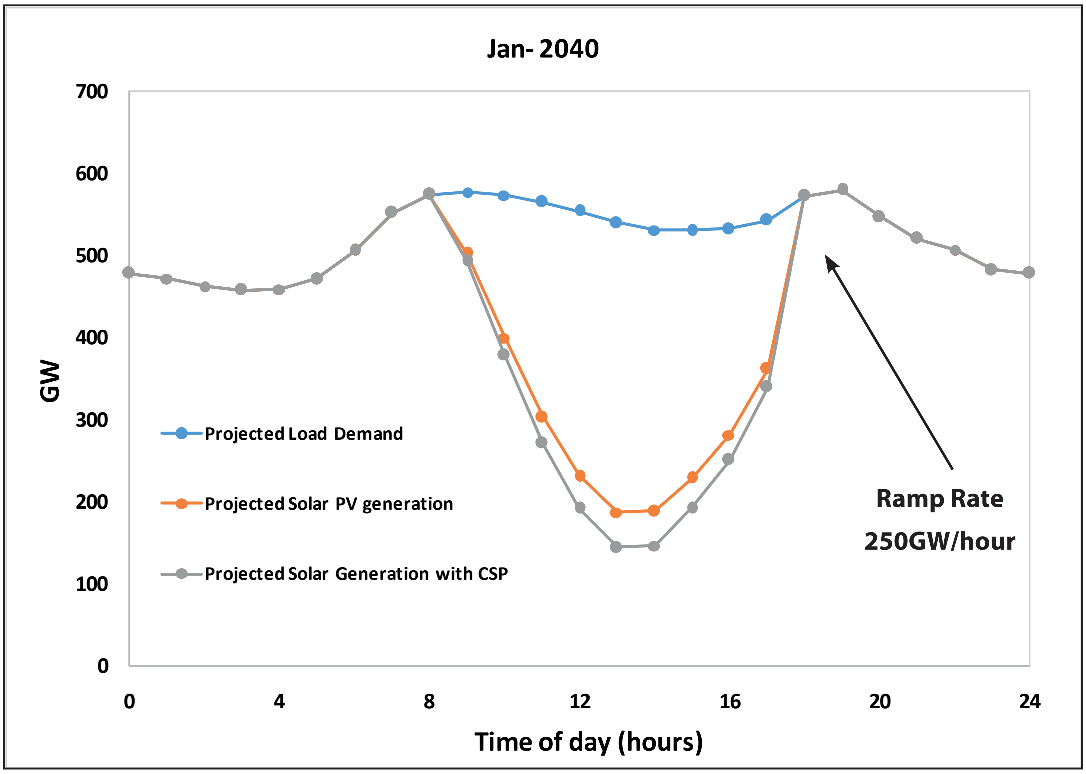
Table 1: Scenarios for Electricity Generation in 2022 and 2040 [9]

TWh	2012	2022		2040	
		BAU	Ambitious	BAU	Ambitious
Gas Power Stations	115	128	154	181	302
Coal power stations	708	1526	1482	2606	1984
Carbon Capture Storage (CCS)	0	5	5	137	137
Fossil Fuel Based Electricity	824	1659	1641	2924	2423
Nuclear power	27	82	87	164	237
Hydro Power Generation	144	214	214	248	324
Hydro and Nuclear	170	296	301	412	561
Solar PV	2	99	99	422	489
Solar CSP	0	11	14	105	185
Onshore Wind	32	129	129	390	423
Offshore Wind	0	6	6	62	92

TWh	2012	2022		2040	
		BAU	Ambitious	BAU	Ambitious
Distributed Solar PV	0	55	55	164	193
Other Renewable Sources	46	86	101	203	281
Renewable Based Electricity	80	386	404	1346	1663
Electricity imports	5	15	25	71	126
Total	1078	2356	2371	4753	4773

The recent Energy policy of Niti Aayog provides two scenarios of electricity generation in 2022 and 2040 [9]. Table 1 provides the results from this document. We have used the January 2016 load curve for a typical day and projected the growth in demand (with the same shape) to obtain the Jan 2040 projected load curve. Figure 6 shows the effect of the increased solar generation in 2040. It is clear that almost all coal based power plants will need to be shut down or backed down during the day. After 6 pm as the solar output reduces to zero the remaining power plants would need to quickly start meeting the entire load. Usually coal plants have a limit on the maximum ramp rate (rate of change in load) that it can provide. The projected ramp rate is 250 GW/hour which may be difficult for the existing coal based plants to provide. This would need steps to increase flexibility in thermal power plants, increasing the share of hydro or storage. As we increase the share of renewables we would reach negative net loads, implying that the renewable supply would exceed the overall system demand during some periods. All additional units would need to be stored and used later. At present the electricity storage capacity in the grid is very low (less than 1% of the supply). The most cost effective large-scale storage is pumped hydro. This adds about Rs 5/kWh to the cost of supply

Figure 6: Projected Increased Solar generation in Jan 2040



The challenge is to develop cost effective storage and incorporate flexibility in the electricity supply system. The problem with stranded assets – coal mine, coal based power plants and the resultant impact on the economy (loan repayments, unemployment) needs careful planning.

India has been successful in reducing the price of procurement of PV power plants through reverse bidding. However Indian PV cell and module manufacturers have not been able to compete effectively in this process. The operational module manufacturing capacity (as of December 2016) was

5286 MW (out of 6800 MW installed capacity) with an actual production of only 1300 MW. The low capacity utilisation is due to the inability of our PV manufacturers to compete globally. 88% of the PV modules supplied in 2016 were imported (with China accounting for 84% of the imports). In 2016-17 India spent 180 Billion Rupees (3 Billion US $) on PV module imports. This accounted for about 2.8% of the trade deficit.

The challenge for the energy sector is to ensure competitiveness of Indian renewable energy manufacturing companies to create growth in employment. There will need for different strategies for grid operation and regulation. Planning for the variability in the supply would need an emphasis on improved forecasting, control, demand response and storage. The recently launched UDAY (Ujwal DISCOM Assurance Yojana) is a scheme that aims to take cover the debt of the DISCOMS, improve the operating efficiency and make the DISCOMS profitable by 2019. It is not clear whether this scheme will be able to meet its goals. The impact of non-payment of loans related to the stranded assets as well as increased investments for storage, flexibility, guaranteed payments to renewable suppliers on the viability of the DISCOMS and the average price of electricity needs to be analysed. The equity impacts of alternative electricity supply mixes need to be assessed and appropriate transition strategies evolved.

Similar challenges are involved in the transport sector – changes in infrastructure, manufacturing capability, existing vehicle stock and related assets. The challenge of replacing aviation turbine fuel by a renewable fuel needs significant technology development and breakthroughs. The rapid ramping up of electric vehicles also needs careful planning and analysis.

Transitions in cooking fuel has not been adequately analysed. The present strategy is to extend LPG to substitute biomass based solid fuels. Alternate strategies with modern biomass gasifier cook-stoves or electric cooking are inadequately explored and have not seen any large demonstration programmes.

Conclusion

The Indian energy sector is in the midst of a major transition where the future growth is expected to be mainly from renewables. An analysis of the transitions in the electricity sector reveal challenges in grid operation with high renewables penetration. It is important to assess the impacts of alternative future energy scenarios in terms of equity, affordability and employment impact. We need to have strategies to support the competiveness of domestic manufacturing. Co-ordinated technology development and Research and development for the energy sector must be a priority. While we must meet our climate commitments, we need to ensure that we are not dependent on renewable energy equipment imports. If investments in India's energy sector can boost domestic industry there will be a positive feedback to economic growth. We need to carefully plan our transition strategies to ensure this.

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LOW CARBON TECHNOLOGY ROADMAP 2050 – INDIA

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Introduction

Since 2002, cement-producing companies from the Cement Sustainability Initiative (CSI), a project of the World Business Council for Sustainable Development (WBCSD), have collectively made significant progress on measuring, reporting and mitigating their CO_2 emissions, and sharing their progress with the rest of the cement industry. In 2009, recognizing the urgency of identifying technology to reduce the energy use and CO_2 intensity in cement production, CSI member companies around the world (representing about 30% of global cement production) worked with the IEA (International Energy Agency) to develop the first industry roadmap. This roadmap outlined emissions reduction potential from all technologies that can be implemented by the cement industry.

Need for Indian Cement Industry's road map and its evolution

Table 1 (given below) highlights the various performance parameters of World Cement Industry performance with 2006 as baseline, and Indian Cement Industry performance with 2010 as baseline, World Low Carbon Technology Roadmap for 2050 for Cement Industry aspirations for low demand and high demand scenarios for two demand scenarios.

Table 1: Performance Parameters for cement industry for various demand scenarios

Parameter	World	India	World	
	2006 – Baseline	2010 – Baseline	Roadmap 2050 (Low Demand)	Roadmap 2050 (High Demand)
% Clinker	79	74	71	73
% Alternative Fuels	3	0.6	37	37
Thermal Energy, Kcal/Kg Clinker	1004.78	725	789.47	765.55
Electrical Energy, KwH/T Cement	111	80	92	92
Kg CO_2/T Cement	800	719	426	352
Cement Production Million Tons	2559	217	3657	4397
CO_2 emissions, T	2047	137	2052	2521

Source: Cement Technology Roadmap 2009 & Technology Roadmap Low Carbon Technology for the Indian Cement Industry

From the above it can be clearly noted that 2050 target reduction in % Clinker, Thermal energy, Electrical Energy in the world roadmap are close to India's baseline in 2010. This reality has paved the way for developing an India-specific roadmap for the Indian Cement Industry.

Objectives

This roadmap aims to identify technologies (especially those with particular relevance to India), supportive policy frameworks and investment needs that could lead to direct emissions[10] reduction of about 0.28 tCO_2/t cement produced i.e.from 0.63 tCO_2/t cement in 2010 to 0.35 tCO_2/t cement in 2050, about 45% lower than current levels, a reduction of between 212 million tonnes of CO_2($MtCO_2$) and 367 $MtCO_2$ compared to a business-as-usual scenario. Such a reduction in emission intensity would limit the growth in CO_2 emissions from the cement industry to between 100% and 240% compared to the baseline level.

This roadmap outlines an action plan for specific stakeholders to show the short-term and long-term priorities to reach such emissions reduction. It also establishes a strategy to support industry in decoupling its expected future growth rates from growth in CO_2 emissions, primarily through the implementation of energy efficiency measures and equipment, switching to less CO_2-intensive energy sources, decreasing clinker-to-cement ratio and applying new technologies (wherever possible).

10 ***Direct emissions from cement manufacturing process. Does not include indirect emissions from the production of electricity.

Table 2. Key Indicators for Indian Cement Industry for 2 demand scenarios

		Low-Demand Case			High Demand Case		
	2010	2020	2030	2050	2020	2030	2050
Production (Mt)	217	416	598	780	492	848	1361
Per-capita consumption (kg/capita)	188	309	400	467	364	565	812
Clinker-to-cement ratio	0.74	0.70	0.64	0.58	0.70	0.64	0.58
Electric intensity of cement production (kWh/t cement)	80	76	73	71	75	72	70
Thermal intensity of clinker production (kcl/kg clinker)	725	709	694	680	703	690	678
Alternative fuel use (as a share of thermal energy consumption) (%)	0.6	5	19	25	5	19	25

Note: Data for 2010 is for financial year 2009-10 ending 31 March 2010. The electric intencity production does not include the reductions that may come from the use of WHR.

Roadmap approach and scope Roadmap partners

This roadmap has been developed by multiple partners bringing specialised expertise from India and around the world. The partners include WBCSD-CSI India, IEA, IFC, CII, NCB, CMA & CSI - Indian members.

Roadmap drafting

The roadmap is based on a set of 27 technical papers developed by CII and NCB. These papers are collectively titled "Existing and Potential Technologies for Carbon Emissions Reductions in the Indian Cement Industry"(WBCSD, 2012)[11]. The outcome from the papers have been fed into the roadmap modelling by providing India-specific, up-to-date information on technology performances and costs, their benefits in terms of thermal and electrical savings, and their emissions reduction potential[12].

Key findings

Although the Indian cement industry is one of the most energy efficient in the world, because the manufacturing process relies on the burning of limestone (calcium carbonate), it still produced 137 Million tonnes (Mt) of carbon dioxide (CO_2) in 2010 – approximately 7% of India's total man-made CO_2 emissions.

The Indian cement industry has made strong efforts to reduce its carbon footprint by adopting the Best Available Technologies (BAT) and environmental practices. Through this, it has successfully reduced total CO_2 emissions to an industrial average of 0.719 tonnes (t) of CO_2/t cement in 2010 from a substantially higher level of 1.12 tCO_2/t cement in 1996.

In the absence of policy actions or technology development, i.e. in a business-as-usual scenario, CO_2 emissions from the Indian cement industry are projected to reach between 488 MtCO_2 and 835 MtCO_2 by 2050. This represents a 255% to 510% increase compared to current emissions.

The technologies, policy frameworks and investment needs outlined in this roadmap could reduce CO_2 intensity in the Indian cement industry by about 45% by 2050, from the 2010 level. This would limit CO_2 emissions growth to between 100% (Low-Demand Case) and 240% (High-Demand Case) compared to the current level.

Key levers to reduce emissions in the Indian cement industry are increased rates of blending, leading to a reduction in clinker-to-cement ratio, increased use of alternative fuels, widespread implementation of waste heat recovery (WHR) systems, and a radical step change in new technology development to bring potential technologies from research and development (R&D) to deployment.

Captive Power Plants (CPPs) offer important energy security enhancement and emissions reduction opportunities. Assuming that CPP will continue to account for 60% of the cement electricity needs in 2050, as much as 80 MtCO_2 to 150 MtCO_2 could be saved through efficiency improvement and use of alternative energy sources.

The additional investment required in the Indian cement industry (based on net present value) to achieve the CO_2 emissions reduction set out in this roadmap is between USD 29 billion and USD 50 billion (INR 145 000

11 The technical papers are available at: www.wbcsdcement.org/india-tech-roadmap
12 The technical papers are available at: www.wbcsdcement.org/india-tech-roadmap

crore[13] and INR 250 000 crore), or 15% to 25% higher than in a business-as-usual scenario.

CO_2 reduction measures identified under the Roadmap activity

A total of 27 Technology papers are identified under this road map and are broadly classified under five key Technologies. The descriptions of the technologies considered and the proposed technologies are mentioned in the tables below:

Table 3: Technology papers along with the proposed Technologies Technology: Thermal and Electrical Energy Efficiency

S.I. No	Description of Technology Paper	Proposed Technologies
1	Electrical and Thermal Energy Efficiency Improvement in Kilns and Pre-heaters	• Low Pressure drop high efficiency cyclones • HT VFD for pre-heater fans • CFD Studies • Additional Pre-heater stages • Minimizing radiation losses through improved insulation • Adoptive and predictive control systems • Online automation systems for flame control, free lime and inlet NOx • On line Thermography • Kiln with zero waste concept • Heat Recovery from Kiln Shell radiation • Fluidized bed combustion Kilns • Co-generation of Cement and Power • Lime stone enrichment technology for utilizing low grade lime reserves
2	Latest generation high efficiency clinker coolers	• Enthalpy from hot clinker is recovered to pre-heat the incoming secondary and tertiary air • Recuperation efficiency to be increased to 75-80% • Vertical shaft coolers with recuperating efficiency >80%
3	Energy efficiency in grinding systems	• Replacing close circuit ball mills with • Semi-finished grinding in Ball mill with HPGR pre-grinder • HPG in finish mode • VRM • Horomill
4	Energy efficiency improvement in process fans	• Variable speed control for all LT & HT Fans • Replacing the low efficiency fans with high efficiency fans
5	Energy efficiency improvement in auxiliary equipment in the cement manufacturing process	• Pipe Conveyor • Centrifugal blower • Centrifugal Compressor • VFD for pumps and compressors • High efficiency pumps • Wobbler screen for crusher • Automation for auxiliary equipment
6	Energy efficiency improvement in Captive Power Plants (CPP)	• Energy efficiency by design • Energy efficiency by retrofit • Circulating fluidized bed combustion system (CFBC) in place of Atmospheric fluidized bed combustion system (AFBC) • Vacuum Pumps • Use of Low grade steam for vapor absorption machine (VAM) • Use of VFD in equipment with higher load variation
7	Energy efficiency improvement in electrical systems	• Energy Management System (EMS) • Use of EFF-1 (premium efficiency) motors • Light emitting diode (LED) and magnetic induction lamps for lighting • Maintaining near to unit power factor in CPP • Voltage optimization in motors and lightings • Frequency mode optimization

13 In this roadmap, INR denotes the Indian rupee and USD the United States dollar; an exchange rate of USD 1 = INR 50 has been used. INR 1 crore = INR 10 000 000 (USD 200 000).

S.I. No	Description of Technology Paper	Proposed Technologies
8	Utilization of advanced automation systems in cement manufacture	• Continuous monitoring of raw mix composition with the help of x-ray analyser • On-line bulk material analyzers based on Prompt-Gamma-ray Neutron activation analysis (PGNAA) to give maximum control over the raw mix • Using Industrial Robots for elemental analysis • Installation of mobile crushers for productivity improvement • Radio controlled mines machinery monitoring system • Adaptive predictive control system • Online shell scanner and refractory management • Online NOx control • Online flame control • Online free lime control • Flow measurement with advanced techniques • Online measurement of kiln health • Online Energy Management System (EMS) for drives and power generation • Remote monitoring and operation for split location plants
9	Increased Renewable Energy (RE) use for cement manufacture	• Wind Power • Biomass • Waste to Power • Solar PV • Solar Thermal • Small hydro power generation

Table 4: Technology: Co-processing of Alternative Fuels and Raw Materials Technology papers along with the proposed Technologies

S.I. No	Description of Technology Paper	Proposed Technologies
1	Retrofit uni-flow burner with advanced multi-channel burner	• Installation of multi-channel burners • Installation of online flame scanners and burning zone controllers • Plasma burners as a future technology
2	Increasing Thermal Substitution Rate (TSR) in Indian cement plants to 25%	
3	Alternative de-carbonated raw materials for clinker production	

Table 5: Technology: Clinker Substitution Technology papers along with the proposed Technologies:

Sl.No	Proposed Technologies
1	Reducing clinker factor in fly ash based Portland Pozzolona Cement (PPC)
2	Reducing clinker factor in slag based Portland Slag Cement (PSC)
3	Reducing clinker factor by using other blending materials
4	Reducing clinker factor by using low grade limestone
5	Belite cement from low grade limestone

Table 6: Technology: Waste Heat Recovery Technology papers along with the proposed Technologies:

Sl. No	Description of Technology Paper	Proposed Technologies
1.	Waste Heat Recovery	• Organic Rankine Cycle (ORC) • Kalina Cycle • Steam Cycle • Hot Water Flash Cycle

Table 6: Technology: Newer Technologies Technology papers along with the proposed Technologies:

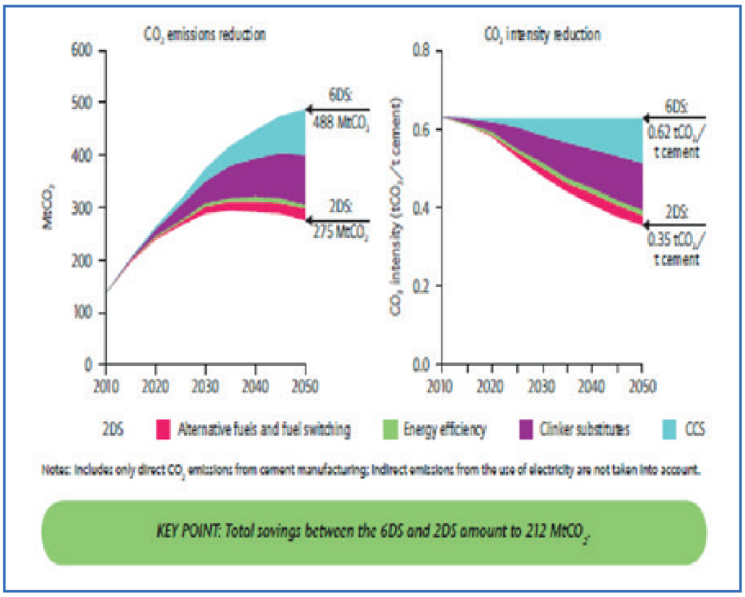
Sl. No	Description of Technology Paper	Proposed Technologies
1.	Fuel cell technology	• Thermal processes • Electrolytic processes • Photolytic processes
2.	Fluidized Bed Advanced Cement Kiln System (FAKS)	• Suspension Preheater (SP) with Suspension Calciner (SC) • Fluidized Bed Cement Kiln (FCK) • Fluidized Bed Quenching Cooler (FBQ) • Packed Bed Cooler (PBC) • Self-granulation
3.	Futuristic comminution technologies	• Aero-acoustics • Ultrasonic comminution • Microwave Energy • Electro-acoustical comminution • Ultrasonic field in a roller mill
4.	Carbon capture through algal growth and use of biofuels	• Post-combustion capture • Oxy-fuel technology • Pre-combustion capture • Carbon sequestration • Biological scrubbers
5.	Geopolymer cement	• Reactive solid component • Alkaline activator
6.	Use of nanotechnology in cement production	• Development of nano-cements and eco-friendly, high performance cements/binders manufactured with lower clinker content • Improvement in cement and concrete performance through incorporation of nanoparticles and chemical admixture • Better understanding of cementitious materials through nanoscale investigations of cement hydration reactions and hydration products to achieve cements and concretes with tailor-made performance • Development of activators/catalysts for low temperature clinkerization • Use of nanoparticles for the reinforcement of the cementitious matrix for improved flexibility and toughness • Application of photocatalytic $TiO2$ nanoparticles for self-cleaning concrete surfaces • Cement based nano-composites for various applications
7.	Developing national standards on composite cements	• Composite cement • Hydraulic cement • Portland composite cement • Particle size distribution
8.	Improving the burnability of raw mix by use of mineralizer	• Accelerates the de-carbonation and sintering reactions • Lowers the clinkering temperature • Broadens or narrows the sintering temperature range • Modifies liquid properties, such as viscosity, surface tension and so on • Increases the crystallization of the liquid phase • Increases clinker balling and ring formation tendency • Promotes clinker-refractory interaction • Alters the overall burnability and volatility conditions inside the kiln
9.	Opportunities for exploring development of energy plantation by the cement industry	• Bioethanol from molasses, sweet sorghum & cellulosic biomass • Straight Vegetable Oil (SVO) from jatropha • Biodiesel from jatropha

Table 7: Potential energy savings from implementation of different technologies indicated above are given below

	Saving from 6DS to 2DS							
	Low-Demand Case				High-Demand Case			
Total energy reduction (PJ)	2020	2030	2050	2050	2020	2030	2040	2050
Additional energy required for CCS (PJ)	65	196	304	377	77	235	395	485
Net energy reductions (excluding additional energy required for CCS) (PJ)	71	237	384	488	87	298	553	706
Reductions (PJ) from)								
Thermal energy efficiency	16	48	78	96	18	47	77	97
Electrical energy efficiency	5	12	18	22	3	4	6	8
Waste heat recovery	1	8	15	20	2	15	30	39
Clinker substitution	49	174	288	373	88	250	455	583

The direct CO_2 emissions and intensity reduction by each technology in the Low Demand Case is as given below:

Figure 1. Direct CO_2 emission and intensity reduction by each technology in the Low Demand Scenario



Achieving the aspirations of 2050 road map needs lot of Policy and Financial support as per the details given below:

Table 8: Policy Support Required:

Sl. No	Description of Technology	Policy Support
1.	Thermal & Electrical Energy Efficiency	• Improving Logistics, ensuring the availability and quality coal, quality raw materials and power • Grid connectivity for increased PLF of CPPs • Policies for increased Renewable Energy generation, such as attractive feed-in tariffs, accelerated depreciation, wheeling and banking policy etc. • Policy for offshore wind power generation
2.	Co-processing of Alternative Fuels and Raw Materials)	• Favourable waste legislation encouraging co-processing in the Cement Industry & guidelines on cost of alternative fuels • Legislation for source segregation, collection, handling and logistics of MSW • Liberalizing the procedural system for co-processing (permits, test runs, interstate waste transportation) • Consistency between legislation for Cement Kilns and for dedicated waste facilities • Industry specific guidelines for disposal of lime-bearing waste material for usage in cement industry

Sl. No	Description of Technology	Policy Support
3.	Clinker Substitution	• Modification of existing standards permitting higher absorption of blending materials • Provision for transportation of slag in closed wagons to prevent high transit losses • Developing standards for use of other blending materials • Developing standards of Portland Limestone Cement (PLC)
4.	Waste Heat Recovery	• Incentivizing the installation of WHR through fiscal incentives applicable for renewable energy as the payback period for WHR is very long. • WHR should be treated as a renewable energy source as it does not consume any additional fossil fuel
5.	Newer Technologies	• Fiscal incentives like concessional import duty etc • Policy incentives to the industries for deployment of the CCS (Carbon Capture & Storage) technology • Government funding for R&D of composite cement. • Development of Indian Standards using European standards as guidelines • Policy incentives for industrial sectors to promote bio-energy plantations and biofuel utilization. • Guidelines on land availability, utilization and local community development

Table 9: Cumulative Investment needs in the Indian Cement Industry 2010-50

Sl. No	Parameter	Investment in US $ Billion – 2D Scenario	
		Low Demand Case	High Demand Case
1.	New and Refurbished Kilns	123 to 150	222 to 274
2.	Clinker Substitution	1.6 to 2.0	2.7 to 3.4
3.	Alternative Fuels	5.6 to 5.9	12 to 13
4.	Carbon Capture	17 to 19	33 to 36
Total		147 to 177	270 to 326
Note: Investment for alternative fuels relates to onsite investment to store, load and feed kilns with AFR, and eventually the change of burners and / or emissions abatement systems Investments in Carbon capture do not include the cost of transportation and the eventual use or permanent storage of Carbon			

Financial Support Required

- Fiscal incentives to take care of high investment cost and to make the investments more lucrative with reasonable payback periods
- Reducing the import duties and taxes for Renewable Energy equipment/ technologies
- Fiscal incentives to support the higher investment and operating costsof waste pre-processing facilities
- Tax relief and fly ash utilisation subsidy
- Fiscal incentives for long distance transportation of fly ash
- Fiscal incentives on cost and transportation of slag
- Fiscal incentives on cost and transportation and other blending materials
- Can be established only after commercialization
- Fiscal incentives to the industries for deployment of the CCS technology and production of nanoparticles
- Fiscal incentives for Geopolymer cement as the manufacturing costs are very high
- Fiscal incentives are required to promote biofuels
- Renewable energy status with related incentives

Conclusion

Even though, the Indian Cement Industry's performance is better when compared with the major nations of the world, there is huge scope for improving its performance. This journey will not only reduce CO_2 emissions from Cement Industry, but also drive the journey towards raw material conservation, energy conservation, energy security, etc. But this journey needs lot of collaboration between different stakeholders of the Industry and greater support from the Government w.r.t. the Policy and fiscal incentives to make the aspiration a reality.

ESTIMATION OF WATER FOR ELECTRICITY PRODUCTION: SHARED SOCIO-ECONOMIC PATHWAYS BASED ASSESSMENT

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Council on Energy, Environment & Water (CEEW)

Electricity- Water Nexus issue in India

Electricity access is one of the foremost challenges faced by the policy makers in developing economies (Rao & Pachauri, 2017; Ahmed et al., 2014). At the developing stage, power generation is of critical importance for India, as nearly 288 million still have no access to the electricity grid (IEA, 2011). Moreover, rapid urbanisation, economic growth and modernization of lifestyle is also adding to the power requirements. To bridge this gap, very recently Sahaj Bijli Har Ghar Yojana or Saubhagya has been launched to supply electricity to all households by December, 2018 - providing free connections to the poor and at very low costs.

With the increasing power production, there arises a need to maintain a balance between economic development with sustainable development because along with so many positive impacts of increased electricity access, there are two negative implications. Firstly, local pollutants are mainly emitted from the use of coal in thermal power plants, as well as due to usage of bioenergy for meeting cooking needs of urban and rural households and have important implications for local health (Bell et al., 2013; Smith et al., 2013; Dholakia et al., 2013; Gunatilake et al., 2014). Also, electricity generation process releases a lot of CO_2 emissions which is a major contributor towards climate change (Doi et al., 2012; Edmonds et al., 2012; Chaturvedi et al., 2014a). Secondly, the power sector demands huge amount of water for cooling and other process in thermal power plants. Indian thermal power plants consume approx. 80% of total industrial water (CSE, 2012). India is already facing high or extremely high-water stress and increase in water consuming sectors could put extreme pressure on the total water availability in India.

Water use in power plants is majorly into cooling towers where the low-pressure steam is condensed and further reused to run the turbine. Also, water use coefficients vary with type of source being such as Coal-based, gas-based or nuclear-based. As per CEEW estimates, coal-based thermal power plants, which have a current share of 59% within the overall generation, require 3.8 litres of water to generate one unit of electricity. Whereas, a gas and nuclear based power plant requires about 1.6 litres and 6.4 litres per unit respectively. Among renewables, solar photovoltaic systems require about 0.1 litres of water for cleaning the dust off the panels. Thus, water use ability varies with the plant fuel type and understanding the future of electricity mix would better help us to estimate the future of power sector's water need. It is very critical to think of ways to either use water resources in efficient ways or to secure continuous water supply for uninterrupted power generation. To add to this, India has on numerous occasions been identified as a water-scarce country, and growth in the agricultural sector could itself put tremendous pressure on India's water resources (Chaturvedi et al., 2015).

Way to estimate long run electricity generation and associated water use

Understanding the importance of increasing power demand for the growing economy as well as extensive water use for cooling purpose in the thermal power plants, we modelled electricity demand for five Shared Socio-economic Pathways (SSPs) within the integrated assessment modelling framework of Global Change Assessment Model (GCAM). GCAM is an energy sector-focused partial equilibrium model with detailed modelling of the energy supply, transformation, and demand sectors. Purpose of SSPs is to visualise alternative futures of the world based on an insightful description of underlying social, economic and technological drivers, and provide a range of five scenarios that span the spectrum of underlying uncertainties which can shape the future world. SSP based scenario analysis is being increasingly adopted as a framework for climate policy scenario analysis. As a water saving policy, our analysis tests the notification given by the Ministry of Environment, Forest and Climate Change (MoEF&CC), for water consumption in TPPs that mandates that all new power plants will have to be based on CT technology and that older power plants will also have to convert to CT technology, which will be assumed to have been implemented by 2020. One scenario (SSP4) also tests the impact of the failure of this policy.

Pathways which shape the future: SSPs

SSP1: A Sustainable World

With good balance in terms of economic and population growth, society is assumed to have ample money in their hands. Thus, more investment would be made in creating a greener road for future. While living in a sustainable world where the energy mix would largely be comprised of renewable energy, we assume that policy makers recognise the water stress caused by increasing power production and consequently dry cooling is introduced in regions that face extreme and frequent water scarcity. Dry cooling being the most water- efficient, saving approximately 85% of the total water being used in wet cooling based plant. Strict implementation of water saving policy in SSP1 would be an added advantage.

SSP2: The Reference World

Here, we try to see the impact of water saving policy in the long run with the electricity production seeing no major shifts towards renewable or low carbon technologies. GCAM model endogenously determine the electricity mix based on the cost competition between all other technologies. With BAU situation, we assume that there will be full compliance of water saving policy as suggested by MoEFCC.

SSP3: The Regional rivalry situation

SSP3 being a situation which is fraught with regional tensions and rivalries and nation in such a case is driven by nationalistic concerns. So, increasing the share of nuclear based electricity in their generation to enhance their defence and deterrent capabilities, is assumed to be a better way to secure the country at first place. Such tendencies would increase the trans-boundary water conflicts, thus tries to secure water at the plant level. So, here we can see a strict implementation of water policy for converting OTC based to CT based TPPs. With low GDP in the country, adaptation challenges will be high and we could not assume the introduction of expensive technologies such as dry cooling into TPPs.

SSP4: Inequality situation

By the term unequal, we mean that the gap between the haves and the have-nots increases with time, which implies that even though in terms of average per capita electricity generation, SSP4 is similar to SSP2, the distribution across income groups as well as across states will be very different within India. We also assume that in this increasingly unequal India, it will be difficult to implement the policy to convert all existing TPPs and new TPPs to wet cooling technology. Inequality between states will compel the poorer states to not invest in the costlier CT technology, and a number of TPPs in the country will continue to be based on OTC technology.

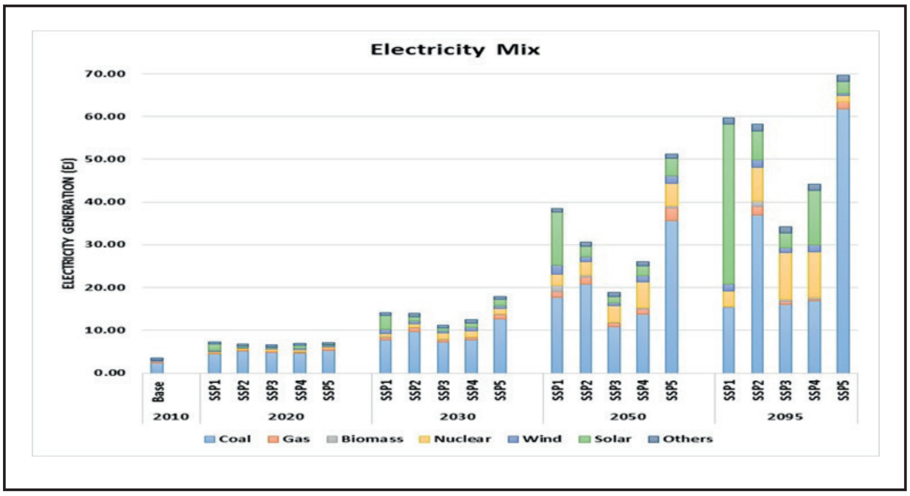
SSP5: High-growth fossil-intensive scenario

The SSP5 scenario is characterised by high income growth and increased electricity production. The resource-intensive lifestyle will mean the construction of many new but fossil fuel based power plants. Electricity generation is largely based on coal as India has significant domestic reserves of coal. The challenge for adaptation for the electricity generation sector will be low.

Power generation within different SSPs

The electricity generation mix ranges from a 65% share of solar and wind in 2095 in the sustainable world under SSP1 to an 88% share of coal in 2095 under the fossil-intensive SSP5 scenario. Electricity generation grows annually at an average of only 5.8% between 2015 and 2030 in SSP2 as compared to 9.2% under the high-income SSP5. Between 2030 and 2050, the average annual growth rates for the two scenarios are 2.6% and 5.4% respectively. The mix of electricity generation is also determined by the SSP narratives. We see that under SSP1, solar energy forms a larger part of India's electricity generation portfolio by 2050 and beyond. 62% of electricity generated in 2095 is based on solar energy. On the other hand, the resource-intensive lifestyle of SSP5 is mainly based on coal energy. All scenarios apart from SSP1 are fossil dependent. Even under SSP3, which has a higher share of nuclear energy relative to the reference scenario, coal is an equally important part of India's electricity generation mix. Under SSP2, our reference scenario, coal-based electricity accounts for a dominant 63% share in 2095, although the share of renewable energy increases in the long-term future.

Figure 1: Electricity generation mix across scenarios



Source: CEEW Analysis

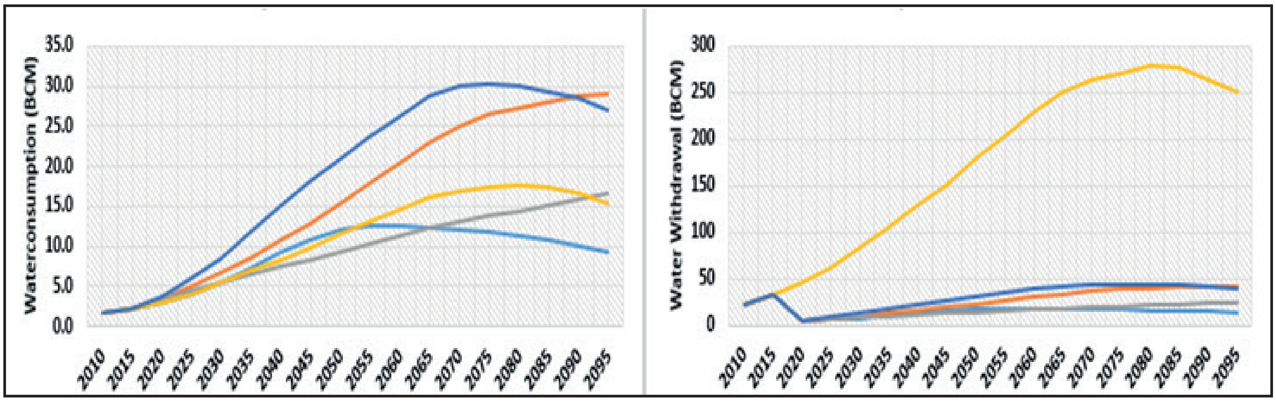
Future water use for power production

Water use within TPPs is in terms of either withdrawals or consumption. Withdrawals mean extracting water from the source for plant functioning, which after use is discharged back into the river but consumption forms the evaporative losses part in the whole process. Due to increased share of PV, increased share of dry cooling and strict implementation of MoEFCC's mandate- water withdrawals will never cross 2015 level across century. Whereas, consumption still increases to the mid-century by seven and a half times and then decreases owing to a greater share of solar in future, along with dry cooling technology.

In the absence of dry cooling technology, water consumption by India's electricity generation sector will grow by 4%-5.6% annually between 2015 and 2050, and will continue to increase across scenarios, putting additional pressure on the country's water resources.

As opposed to SSP1, more water consumption would be seen in SSP2 till the end of this century due to 3 major reasons; firstly, energy mix is determined endogenously in the model on the basis of cost competition and mix would be dominated largely by coal in BAU. Secondly, low carbon intensities technology would surely rise but not up to the level of SSP4. Lastly, due to the absence of any relevant policy regarding introduction of dry cooling techniques would result in excessive water consumption.

Figure 2: Long- term water use for electricity generation



Source: CEEW Analysis

In terms of water consumption, electricity generation will be more water intensive as nuclear-based TPPs have much higher withdrawal and consumption intensities as reflected in our India-specific data. Overall water consumption and withdrawals will be lowest across all scenarios till 2060 largely due to low GDP and consequently limited electricity production. SSP4 representing an unequal situation with water policy failure, will experience a jump in water-withdrawals from 22 bcm in 2015 to 179 bcm in 2050, and further to 249 bcm in 2095. This could further rise the conflicts between farmers, power plant operators and the state governments. As the SSP4 world is fraught with conflict and lack of cooperation, there will be increasing inter-state trans-boundary conflicts in India over the sharing of river water which is the main or exclusive source for water for inland power plants.

Water withdrawals under SSP5 increase to 45 bcm by 2075. Consumption of water in TPPs is highest under this scenario and increases by 6% per annum between 2020 and 2050, although after 2050 this growth is much subdued. However, challenges for adaptation are expected to be low as GDP in this scenario is high, making it possible for the government to spend resources on increasing water-use efficiency across sectors, particularly in the agricultural sector, as well as on increasing dry cooling in the electricity generation sector.

Conclusion

Energy access being the primary problem after generation, would get resolved by SSP1 and SSP5 due to higher per capita electricity consumption under both these scenarios. Electricity access-related challenges will be most pronounced under SSP4, which is the unequal scenario. Interestingly, average per capita electricity consumption under SSP4 will be similar to that under SSP2, the reference scenario. Affordability of electricity will be the biggest challenge under SSP3 due to very low per capita incomes even in the long run. To ensure consumption of electricity, policy makers will need to continue with electricity subsidy policies, which will add to the budgetary burden.

Our analysis clearly shows that the rules proposed by the MoEF&CC, will be critical in reducing water withdrawals from TPPs. Across scenarios, we see a significant decline in water withdrawals in the short run. In SSP4, we also test the failure of this policy, and it is quite evident that a failure to implement this policy will result in a continuous increase in withdrawals and will put more pressure on India's water resources.

The role of dry cooling will be critical, especially with a changing climate that exacerbates the challenges already faced in many arid and drought-prone regions in India. But in a low-income world, like that of SSP3, it will be difficult to invest in the costly dry cooling technology. Climate policy and the share of cooling technology can have significant implications for water withdrawals that need to be examined further.

Our attempt has been to understand the evolution of India's electricity sector and the associated water demands under various SSPs. We hope Indian experts and researchers will build on our work and develop a deeper understanding of India's energy, water, and climate scenarios under these alternative visualisations of the world.

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DEVELOPMENT OF FRAMEWORK TO ESTIMATE CROP-WISE, REGION-WISE ELECTRICITY USAGE FOR IRRIGATION

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Introduction

Energy supply to agriculture is not 100 % metered in India. In absence of metering there are no reliable estimates of energy consumed by agricultural sector or energy consumed by specific crops in a specific region. Only a few case studies can be found for a few specific regions and crops. Knowledge of such figures is essential for estimating the environmental cost of various crops, and better economic planning so as to promote optimum cropping pattern in various regions.

In this work we attempt to develop a framework to estimate region-wise, crop-wise, electricity usage, for irrigation using secondary datasets. The main secondary datasets considered were electricity consumption on agricultural feeders, Minor Irrigation Census data for water sources, Groundwater Survey and Development Agency data on well depth, theoretical crop water requirement from various sources, crops grown, cropped area and rainfall recordings from the Department of Agriculture. Three case studies on one feeder each in Nasik, Nanded and Kolhapur district of Maharashtra were done to verify the efficacy of the framework at the village level. In these cases, we find that the amount of irrigation water used by farmers largely abides by the theoretical requirement. Hence the cropping pattern and total electricity used in a region, whether at feeder level, taluka level or district level, can be used to find average energy consumption per acre by a particular crop within that geographical boundary. We also find that in regions having seasonal water sources and perennial cropping pattern farmers use water sources in many indirect ways which complicates the design of framework. Since farmer spend more for irrigation of high value crops, this may skew the data towards lower energy for high value crops. In regions like Nanded and Kolhapur where water is not a constraint due to perennial source like river, the area under water intensive cash crops is determined by the hours of available electricity.

Policy Implications

Energy and water are constrained resources today. Certain states like Maharashtra and Gujarat have a groundwater crisis. Agricultural usage constitutes 80% of water use and 20 % of electricity use in India. On the energy side, fossil fuel usage must be reduced. There is an uneconomical use of electricity and water due to subsidy for agricultural electricity usage, and very little charges for water usage in surface water schemes and none in ground water schemes. In the present scenario of partially metered or unmetered energy supply to agriculture there are no reliable estimates of energy consumption by a particular crop in a region. Since electricity for irrigation is highly subsidized, it is important to know what crops, and which farmers, the subsidy benefits the most.

It is also an important input for economic planning and government policy in promotion of crops. For instance, at present the Input – Output tables of the National System of Accounts use the entire electricity consumption for agriculture in India and apportion it to various crops proportional to crop wise area irrigated by tube wells and pump sets. The sugar pricing policy document calculates water productivity for sugarcane grown in various states. Energy, is not considered, even though it is likely that energy productivity in various states is even more dispersed than water.

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FINANCING OF SOLAR TECHNOLOGY: A COMPARATIVE ANALYSIS OF POLICY MEASURES ACROSS THE DEVELOPING AND DEVELOPED WORLDS

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Introduction

Renewable energy sources provide access to clean, secure, reliable and affordable energy, in a day and age when its need is more pronounced than ever before. While a full-fledged transition into a low carbon economy is yet to be achieved, renewable energy has attained mainstream status, with it accounting for the majority of power generation capacity additions today (IRENA, 2012). At the helm of this burgeoning renewable technology industry, is Solar PV, which is not only one of the fastest growing RE technologies but is also forecasted to be a major player in the global energy generation mix. As is the case with any resource, availability and accessibility are major proponents of reliability of the resource, both of which are assured with Solar PV technology. Solar power is available all over the globe and the technology, by design, is small and modular, making it ideal for usage, even in areas where conventional power generation fails. Another characteristic that contributes to the acceptance of the technology is the absence of fuel costs and minimal operation and maintenance costs, which allow the technology to be competitive with conventional sources. Other than helming the global RE scene, Solar PV also features discernibly low technology costs15.

Historically, any service driven, economy wide transition is rooted in competitive costs (Fouquet, 2010), however, competition between the newly introduced technology and its well-established counterpart is rarely unbiased, if left to market forces alone. It is in this capacity that policy and polity, especially domestic, make a play in the growth of an industry. In order to broadly capture the various policy frameworks that have driven the various Solar PV markets around the globe, this study has selected countries that display varied structures of polity and geography, whilst having achieved significant Solar PV integration into their respective economies. The first selected country is the United States of America, a developed nation with a relatively mature Solar PV market, which has been a world leader[16] at some point in history even as it continues to exhibit highly competitive costs. Compared to this, is the Solar PV market in China, a developing nation that has only been a new entrant on the RE scene but has taken over every other major player on account of both, capacity additions and cost reductions. The third Solar PV industry under study is that of Germany, a developed country which has been a major stakeholder of the Solar PV industry, with it being one of the initial countries to reach grid parity in the utility scale market. India and its Solar PV industry, on the other hand, is far from mature. As an industry in its nascent stages, a contextual backing of policy and regulatory measures across similar and distinct economies is relevant to the end of understanding the status quo and paving a successful way forward.

In light of the above, the main objective of this study is to identify the effect of federal policies on the major drivers of Solar PV technology cost. In order to do so, a review of the policy mechanisms in the markets selected (USA, China, Germany) is carried out. Finally, pertinent points are drawn from the global scenario to assess the implications in the Indian context.

The next section provides an overview of the cost breakdown of the technology on a global scale. Following that, the policy frameworks and their resultant impact in each of the selected countries is illustrated. The concluding section highlights the situation in the Indian context, drawing important parameters from the global sphere into the domestic parallel.

Cost Breakdown

The current global atmosphere is one in which a serious reckoning towards emissions and a consistently growing energy demand coexist, carving out space for alternate energy sources such as Solar. This recognition has resulted in the existence of several regulatory

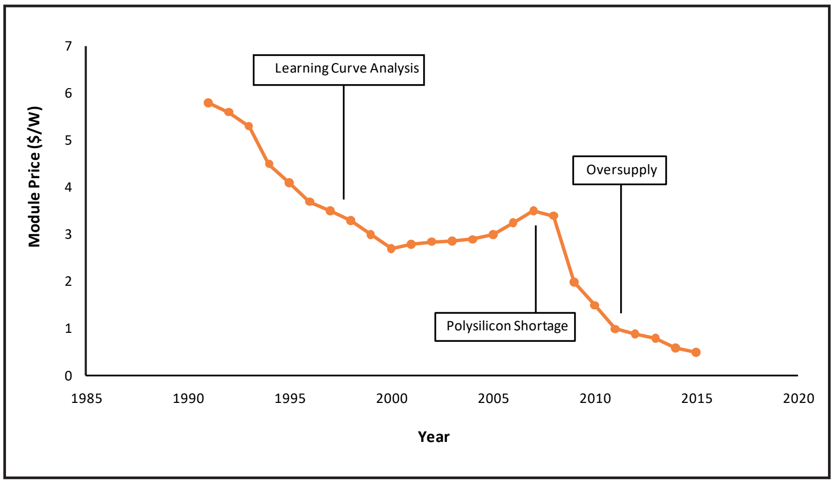
15 As compared to the rates at which the technology was introduced into the market; module prices have dropped from around $100 during its first manufacture in 1954 to less than a dollar in 2015.

16 In terms of total installed capacity.

measures in various markets, international and domestic, aimed at boosting the growth and integration of such technology into the energy matrix. However, growth via such measures have only been, in the past, successful at creating niche markets. Truly competitive, lower costs are essential to achieving any service driven market transition (Fouquet, 2010). Thus, the importance of cost in the growth of this industry is paramount, but before the trends are assessed, the constituents of cost and its major drivers must be identified.

Looking at Solar PV as a technology used on a global scale, the total cost is influenced predominantly by the capital cost, variable cost, discount rate, level of solar irradiation and efficiency. Of all of these, a preponderance of the total cost is accorded to the capital cost which, in turn, is composed of the Module cost and Balance of System cost. While the cost trends in some markets are shifting towards soft costs, on a global level the module still constitutes up to 50% of the total capital cost. Since module costs contribute in such capacity towards total costs, studying their historical trend on a global level, would be to a certain extent, representative of the trends in total solar PV system cost as well.

Figure 1. Global Module Cost Trends



As illustrated in the figure above, the module cost fell drastically from $6/W in 1990 to less than $1/W in 2015. This declining trend can be broken down into the initial fall from 1990 to 2000, the spike from 2000 to 2005, and the rapid decline of 78% from 2005 to 2015. The initial fall in prices can be attributed, in most part, to increased economies of scale and improved efficiency through Research and Development. Literature on the subject also attributes this decline the Swanson's effect[17].

The spike in prices witnessed in the early 2000's is attributed to the global shortage of polysilicon. However, the demand persisted despite the spike in raw material price, leading to producers earning more and, in turn, producing more. This factor, coinciding with the entrance of China into the PV market, led to the oversupply of PV modules, and a drop in the prices, in 2010. As illustrated through the most recent nosedive in prices, it is apparent that hardware costs are bound to reach a price floor in the near future. Adopting an overarching view, this decline of module prices can be attributed to increasing efficiencies, improved technologies, more competition, and economies of scale, all of which are driven by policy. The effect of the policy, is, however, dependent on the geopolitical environment of the country of implementation.

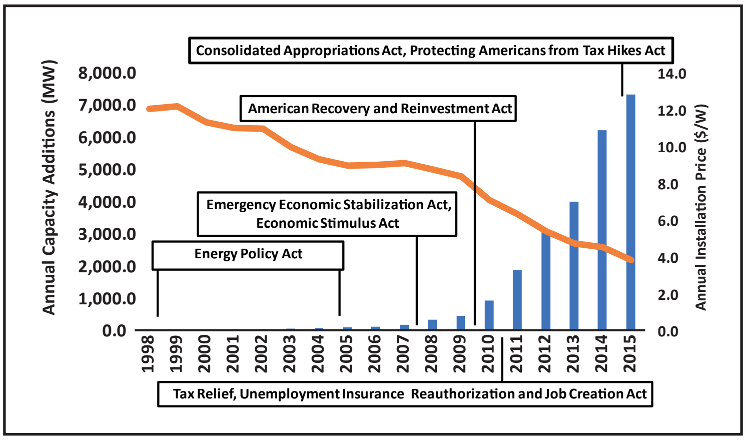
United States of America

Solar PV, as a technology. made its foray into the industry in 1954, in USA. From its inception till 1996, the total installed capacity amounted to 77 MW, which made it the global forerunner at that point in time. Even though it lost out on the pedestal of maximum total capacity additions post 1996[18], the solar PV industry in USA has continued to grow by leaps and bounds, with capacity additions almost doubling each

17 Also known as the learning curve analysis, it states that the price of the technology drops 20% for every doubling of production volume.
18 Japan took over, with deployment increasing exponentially in light of the Kobe earthquake and the Monju Nuclear power plant fire. After the disasters, solar PV was adopted as a predominant source of power generation. It held its position of world leader in solar PV deployment till the mid 2000's.

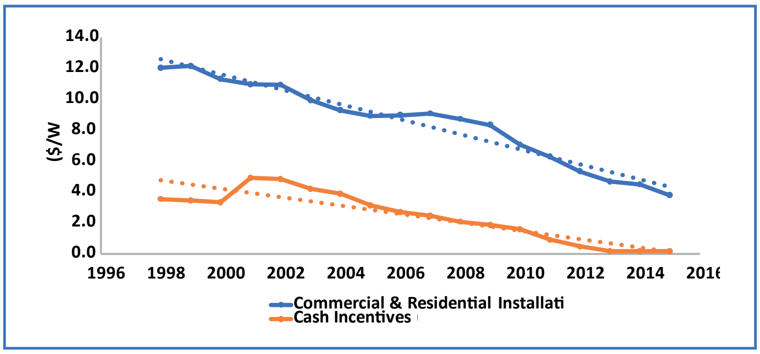
year in the last decade. While the industry has become currently more cost competitive[19], at least in some of the internal local markets of the country, it needed substantial support in its early years. The following figure highlights the historical trends charted by the annual capacity additions (blue bar) and annual installation prices (red line), with important policy drivers tagged in place.

Figure 2. Historic Trends and Policy Drivers-USA



The earliest policy actions that influenced the US Solar PV industry were passed in 1978, namely the Energy Tax Act and Public Utility Regulatory Policies Act. The former encouraged investments in RE technology through tax reliefs, while the latter opened up the RE market to commercial operation by allowing non-utilities to own and operate electricity generation units. This trend of policy measures continued through with the Economic Recovery Act of 1981 and the Tax Reform Act of 1986, further incentivizing investments in the technology and introducing the Accelerated Cost Recovery System[20]. While these policies set the foundation in terms of encouraging the growth of the Solar PV industry, things really took off with the introduction of the Federal Business Investment Tax Credit[21](ITC), through the Energy Policy Act, which came in two iterations, one in 1998 and the other in 2005. The spike in installations seen in 2006 is attributed to a rapid increase in demand for PV, driven by particularly high ITC rates from the Energy Policy Act of 2005. A modified version of the cost recovery system, the Modified Accelerated Cost Recovery System[22](MACRS) was introduced in 2008 as part of the Economic Stimulus Act. The ITC and MACRS are two policy mechanisms that have had far reaching impacts on the Solar PV industry. The acts passed following those already listed, as shown in the above figure, predominantly changed the rate at which the ITC or MACRS functioned or extended the validity of the mechanism. By 2010, the mechanisms were in place and their effect is reflected in the 15% decline in installation prices from 2010 to 2015.

Figure 3. Relation between Installation Price and Cash Incentives-USA

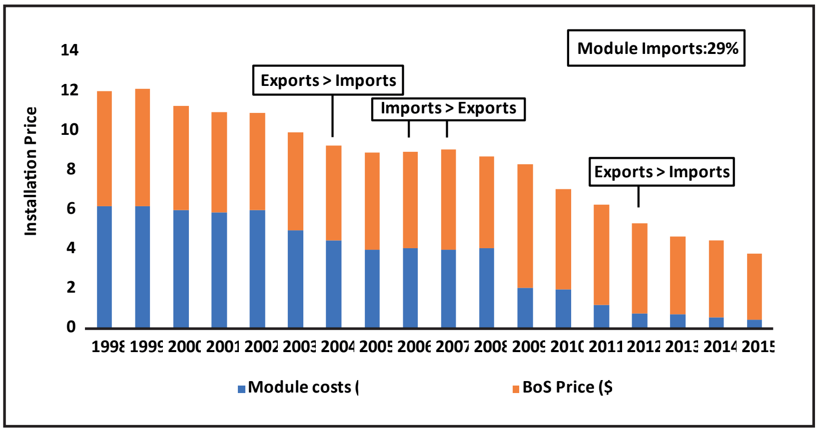


19 https://energy.gov/articles/us-utility-scale-solar-60-percent-towards-cost-competition-goal
20 A tax relief measure through which investments in solar equipment could be recovered through depreciation deductions.
21 At its introduction, it allowed Solar technology a 30% tax rebate. This rate was modified with the introduction of various laws at different points in the industry's history.
22 A 50% bonus depreciation was introduced in the year of inception and under every other iteration. However, it was increased to a 100% depreciation bonus claim under the Tax Relief, Unemployment Insurance Reauthorization and Job Creation Act. After it lapsed it was amended back to a 50% depreciation bonus claim.

Other than the effect on installed capacity, installation prices are also significantly influenced by policy mechanisms. However, the aim is for Solar PV to be cost competitive with conventional fuel sources without external aid, and thus achieve grid parity[23].

The above figure shows declining Solar PV installation prices even as cash incentives keep falling, which is characteristic of an industry with costs becoming competitive despite withdrawal of regulatory support.

Figure 4. Constituents of Installation Price-USA



The aforementioned decline in installation prices were driven predominantly by the fall in module prices till the early 2000's, as illustrated in the above figure. In more recent years, owing to rapidly falling module costs, installation prices have started depending increasingly on Balance of System prices. However, considering that the US solar PV industry depends on module imports to meet up to 29%[24] of its demand, it is important to take into account the influences of imports and exports on the module costs, and therefore, the installation prices. The United States has been meeting its domestic demand through in house production as well as imports, but till 2005, the US has been, in effect, a net exporter of PV modules. This status quo changed in the mid 2000's, when for the first time USA imported more modules than it exported. The PV imports rose each year, till 2013 when the import declined due to antidumping laws levied on Chinese manufactured solar cells. Thus, installation prices have been conclusively declining due to the cohesive impact of domestic and international factors.

The federal policy framework within which the USA Solar PV industry operates can be condensed into two central mechanisms, the ITC and MACRS. These regulatory measures have led to an increase in investments, which in turn have led to more deployment. This growth in the economies of scale is at least, in part, the cause of the price reduction of PV technology within the US market. However, it can be decisively accepted that the initial fall in prices were spurred by policy measures. The current robustness of the market is indicated by the continued fall in costs, in spite of the withdrawal of cash incentives. But the question of the industry having attained cost competitiveness cannot be answered conclusively, in light of the evidence. While this work accounts for federal level policy measures, the role of trade, imports and international policy are also contingent factors that must be evaluated. Furthermore, other than these external influences, the role of state policy[25] also drives the cumulative results seen at the federal level, and hence, must be accounted for.

Germany

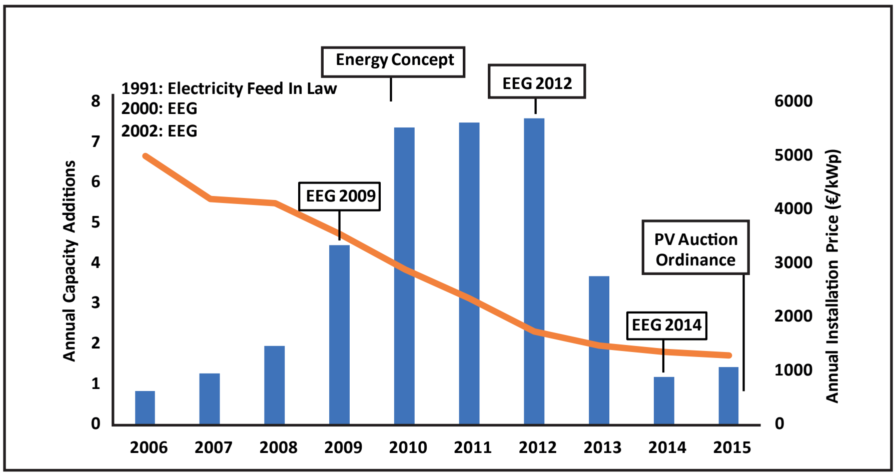
Germany, followed in the footsteps of USA, and took over from Japan as the world leader of the Solar PV industry, in terms of total capacity additions in 2005. The Solar PV industry has continued to grow and by 2016, Germany found itself with a capacity of over 40 GW.

23 Grid parity is said to be achieved when an alternate energy source can generate power at LCOE that is less than or equal to the price of purchasing power from the electricity grid. Some definitions include the influence of subsidization and tax, however, in this work this influence is not included in the definition of parity.

24 As of 2014, with China and Mexico being the predominant suppliers.

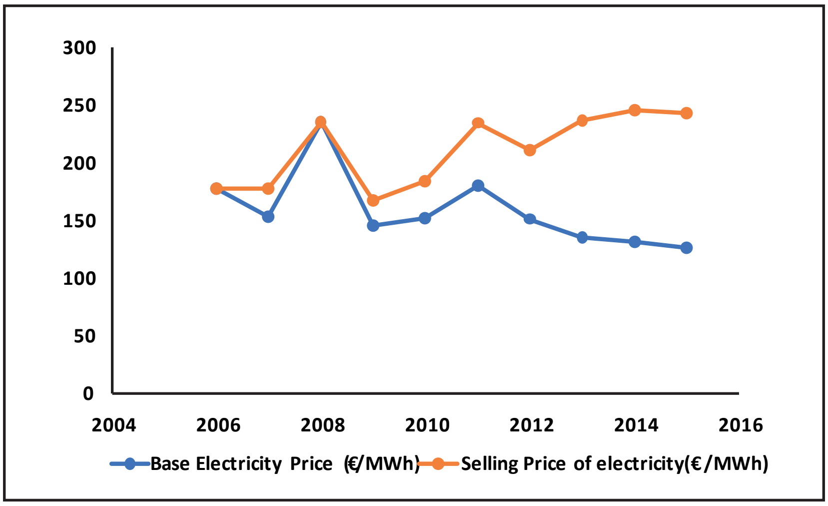
25 For example, California is the strongest Solar PV market within the US. While Feed in Tariffs don't play a major role from a federal perspective, it is one of the key proponents of Solar Policy within the California market.

Figure 5. Historical Trends and Policy Drivers-Germany



Germany shifted gears to RE technology in attempt to move away from its previously nuclear and oil intensive energy mix. Towards this end, policy mechanisms were set in action as early as 1991, in the form of the Electricity Feed in Law26. This was further built upon with the introduction of the Renewable Energy Act (EEG) in 2000, giving renewable priority on the grid and providing a guaranteed return on investment in RE electricity (Fraunhofer ISE, 2016). The consequent amendments in the EEG dealt with a change in the tariff awarded to solar PV sourced electricity, which was driven continually lower with each cycle. The 2002 EEG amendment introduced an EEG surcharge27 to be imposed on power consumers. 55% of this surcharge was attributed to Solar PV generated electricity. Under this policy framework, PV generated electricity was successively more expensive to the consumer. In 2010, the Energy Concept was introduced, which propelled Germany's energy transition through policy aimed at Research and Development and government set prerequisite capacity additions. The PV auction ordinance was introduced in 2015 with the intent of acquisition of RE source expansion targets while keeping costs manageable. This is illustrated in figure 5, with the blue bars representing annual capacity additions and the red line representing annual installation prices.

Figure 6. Difference between selling price of electricity and base electricity price-Germany

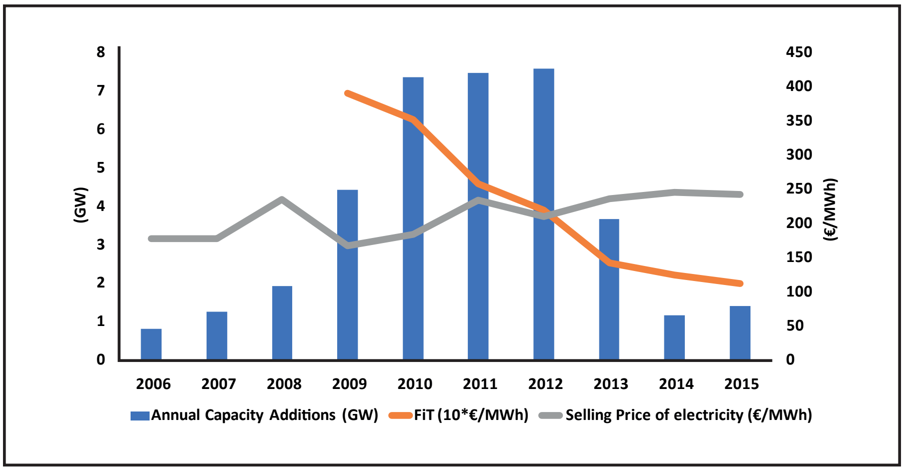


The policy processes in place, as discussed previously, have been driving up the cost of electricity for the consumer. Figure 6 corroborates this by illustrating the growing disjunct in the plot of base electricity price against the selling price of electricity. The difference in the two parameters is attributed to the EEG surcharge, which has been consistently growing in the past decade. Of the total EEG surcharge, up to 55% is attributed to Solar PV. The introduction of the EEG surcharge drives up the cost of electricity for the consumer to almost

26 Which allowed grid access to electricity from renewable sources.
27 EEG surcharge is the difference between the tariffs paid and the revenueearned from the sale of RE electricity.

double its base rate.

Figure 7. Feed in Tariff and Selling Price of Electricity-Germany



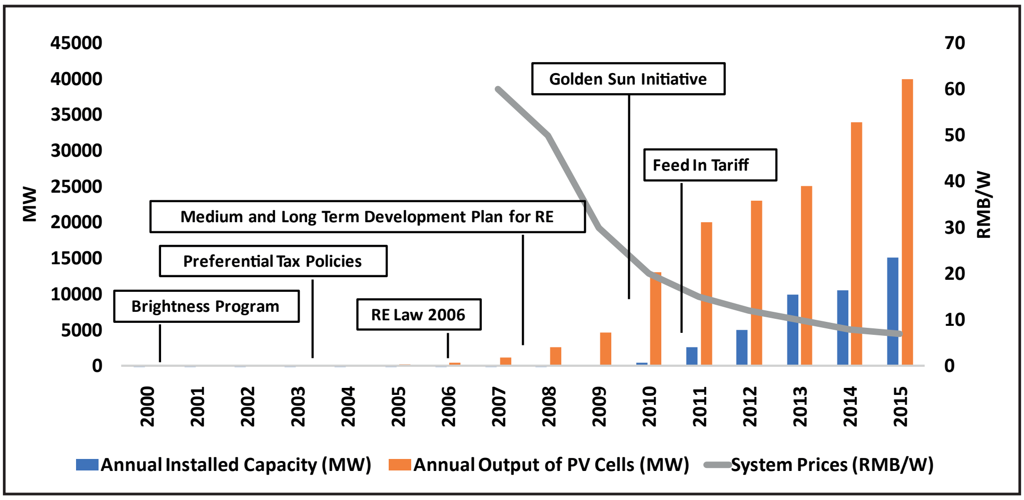
A withdrawal of state support is warranted only when the industry is sufficiently cost competitive with the policy in place. However, as figure 7 illustrates, the feed in tariff has been consistently reduced, even before any significant reduction in selling price has been achieved. The double-edged effect of the withdrawal of feed in tariffs against the increasing selling price is reflected in falling capacity additions, especially from 2012.

The reason for the continually increasing selling price of electricity is the RE surcharge, which is predominantly constituted by solar PV. Other than the high cost on the supply side, solar PV modules also continues to be relatively more expensive, owing to low domestic production and high imports. The recent anti-dumping laws also contribute to the high installation prices. In light of these factors and the resultant elevated prices, any withdrawal of state support is a premature action. The existence of measures that push up costs in the absence of state support results in the falling capacity additions witnessed in recent years.

China

China took over from Germany as the biggest market for solar PV in 2015, accounting for the highest cumulative capacity. The foray into solar PV, however, was a solution for rural and remote electrification projects, as opposed to harnessing solar as a mainstream component of the economy's energy mix. The Brightness Program[28] was a policy measure towards this end. The following regulatory measure of introducing Preferential Tax Policies allowed preferential custom duty rates to be applicable to Solar PV technology, which encouraged exports.

Figure 8. Historical Trends and Policy Drivers-China

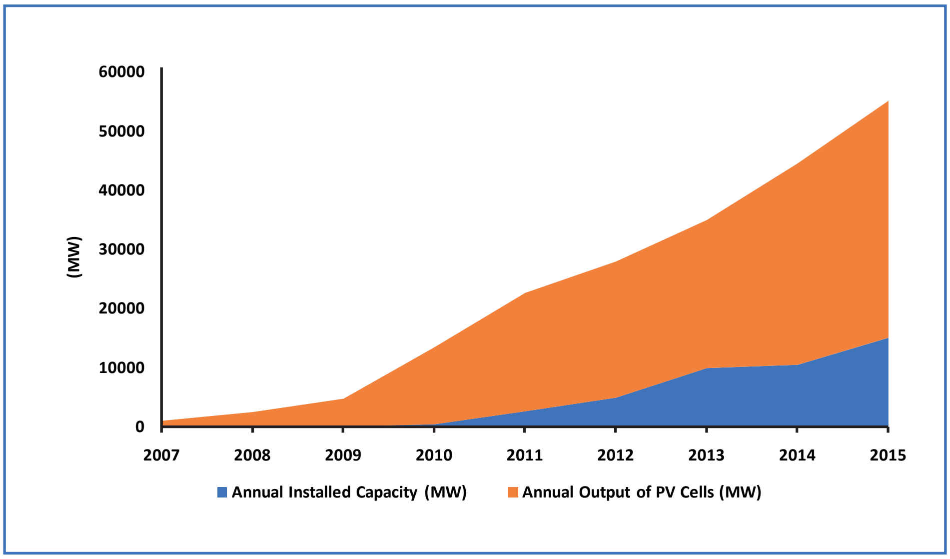


28 1065 villages were proposed to be electrified using RE sources, of which 655 were to be powered by solar PV.

The RE Law of 2006 was a planned step towards effective pricing of Solar PV generated electricity on the supply side, through the introduction of a RE surcharge[29]. By this time the production of PV had started to grow at a phenomenal pace, however, there wasn't a translation into domestic deployment. In light of this, the 2007 Medium and Long-Term Development Plan for RE and the 2009 Golden Sun initiative were comprehensive steps aimed at increasing deployment of the technology. All these measures did drive growth substantially, but it wasn't until 2011, with the introduction of Feed in Tariffs under the 12th five-year plan that the Chinese Solar PV industry really took off. Under this scheme, the quantity of generation was rewarded as opposed to the quantity of investment.

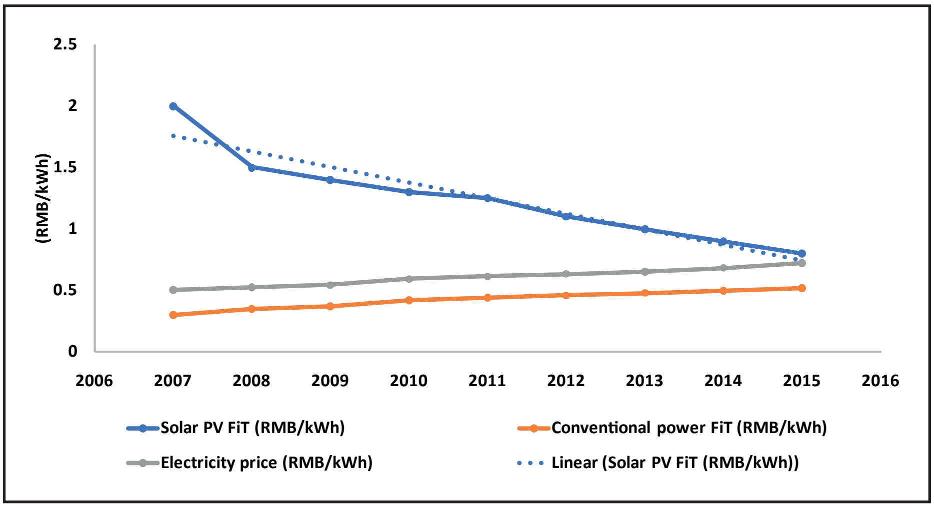
Even with these policy mechanisms, and the positive impact of Feed in Tariffs on domestic deployment, the difference between the annual output of PV cells and the annual installed capacity is substantial. As illustrated in figure 9, the amount of PV cells produced far outnumbers the amount installed. This can be explained by the fact that over 90% of manufactured modules are exported to international markets.

Figure 9. Comparison of Annual Installed Capacity and Annual Output of PV cells-China



Despite the extant disparity, and the problems it causes by association, the Chinese Solar PV industry has the singular advantage of lower costs. Owing to this, attaining cost competitiveness is more achievable a target than in most markets. As illustrated in figure 10, the sizeable gap between the Feed in Tariff offered for Solar PV and that offered for conventional sources has been rapidly decreasing since 2007.

Figure 10. Relation between PV Feed in Tariff, Conventional Feed in Tariff and Electricity Prices-China



29 RE surcharge is the revenue returned to the utilities to negate the higher prices paid for RE generated electricity.

This consistently declining gap allows for a forecast of coincidence, which is an indicator of generation side grid parity. Additionally, the PV Feed in Tariff also exhibits converging trend with the electricity price. The breakeven point of the two is indicative of retail side grid parity. The Solar PV industry of China is poised at the brink of achieving both generation and retail side grid parity.

In light of the above, the Chinese Solar PV industry is attaining cost competitiveness and large-scale deployment at a rate much greater than any of its predecessors. However, the focus of policy has been predominantly on manufacturing and production as opposed to deployment. This trend has only changed in the recent past, with Feed in Tariffs as the main policy intervention. The success, in some capacity, of the Solar PV industry in China may be attributed to the initial support on the manufacture side which then transformed to demand side support. This led to high production in the initial stages and a potential for high deployment now, with the costs driven down.

Conclusions and the Indian Context

The modularity of Solar PV systems is indubitably one of its more attractive characteristics vis-a-vis conventional technologies and even some new renewable energy technologies like wind and biomass. Due to this, the technology exerts a region independence, making it suitable in some form, for almost any location. However, this very quality affords a pitfall in the form of vast non-uniformity, with each project varying, in all respects – geography, technology, financial instruments, and policy. Despite this caveat, in a nascent PV industry like India, drawing lessons from existing systems is essential in order to ensure successful implementation.

Solar PV, as a technology, has already seen growth as a constituent of the Indian energy mix. In addition to this, India has committed to achieve a total of 175 GW of renewable energy installed capacity by 2022, under its Intended Nationally Determined Contributions[30], of which 100 GW is the target for Solar Power. In order to achieve this, several policy mechanisms were put in place, either at the federal or state levels. The major mechanisms, identified across both these spheres, are Feed in Tariffs, Accelerated Depreciation, Renewable Purchase Obligations, and Tax Exemptions. The approach towards integrating Solar PV into the energy mix is subject to variability from state to state. The following table identifies 5 states across the country, which have relatively higher installed capacities.

Table 1. State Level Policy Mechanisms- India

State	Installed Capacity	Major Policy Driver
Tamil Nadu	2015: 142.58 MW	Renewable Purchase Obligations
	2017: 1590 MW	
Gujarat	2015: 1000 MW	Feed in Tariff
	2017: 1159 MW	
Rajasthan	2015: 942.1 MW	Tax Exemptions
	2017: 1317 MW	
Andhra Pradesh	2015: 137.85 MW	Renewable Energy Certificates
	2017: 979.65 MW	
Maharashtra	2015: 360.75 MW	Renewable Energy Certificates
	2017: 430.46 MW	

The policy measures existent in India with respect to the Solar PV industry are predominantly deployment centric. However, for the Solar PV industry to emerge as a cost competitive and sustainable energy option in the long term, a significant increase in the investments in Research and Development are key, along with provisions for large scale manufacturing. While it can be argued that any such mechanism is redundant given that Chinese production of solar panels has already overtaken much of the global market, it can be seen from the experience of the American market in particular that these trends are reversible and also provide some space for ensuring the sustainability of this particular technology option as well as addressing concerns of labour absorption that may arise because of forgoing fossil fuel extraction at least to a certain

30 As part of the Paris Agreement

extent; the latter being especially relevant in case of developing countries.

Drawing from the international example of China, or even the domestic case of Gujarat, Feed in Tariffs have proven to be an effective policy measure in newer solar markets. However, the success of implementation is contingent on a robust production industry. China provides an illustration for the fact that full benefits of an FiT regime to both the state and consumers can only be realized if it is backed by large scale domestic production.

From the study of the other three countries, it is evident that state support for an increased deployment of renewable energy technologies is inevitable at least in the initial stages. How such support should be structured and eventually withdrawn however should be carefully considered at the outset itself to avoid conditions of large scale transfer of public funds to private developers in a situation of rapid and unanticipated cost reductions. Dangers of blanket incentives for long periods is already being seen in the case of India, especially with the first few rounds of bids under the National Solar Mission

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Comparative Techno-Economic Analysis of Rooftop PV (RTPV) Systems in Various States in India

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Abstract: The growth of RTPV has been sluggish compared to ground-mounted installations. This study analyses the techno-economics of RTPV in different states with their respective net-metering (NM)/gross-metering (GM) regulations and state policies to assess the financial performance of RTPV systems. States having abundant amount of solar potential such as Karnataka, Gujarat, Rajasthan, Maharashtra and Tamil Nadu are considered. The results of this analysis show that there is a lack of favourable consumer-end economics indicated by equity Internal Rate of Return (IRR) and payback period findings. According to our calculations, residential consumers with higher capital costs per kW and lower retail tariffs have the least favourable business cases for RTPV in India whereas commercial consumers with lower capital costs per kW and higher retail tariffs have the best business cases. Karnataka and Rajasthan have the most attractive business cases for all categories of prospective RTPV consumers. States such as Gujarat and Maharashtra procure excess RTPV-based generation at Average Pooled Purchase Cost (APPC) and states such as Tamil Nadu have no provisions to procure excess RTPV based generation. These states need to revise the NM/GM rate to ~Rs. 5.5/kWh to ensure the viability of business cases for RTPV across all consumer categories in India.

Keywords: Net-metering, rooftop PV (RTPV), gross-metering, feed in tariff (FiT), equity IRR, payback period

Introduction

The Government of India launched the Jawaharlal Nehru National Solar Mission in January, 2010 with the aim of adding 22 GW of solar energy by the year 2022 [1]. To further this, the Ministry of New and Renewable Energy (MNRE) is implementing a 'Grid Connected Rooftop and Small Solar Power Plants Programme' in the country [2]. In the 12th Plan period, the financial outlay for this scheme was Rs. 600 crores. Later, in 2015 the solar target was ambitiously revised to 100 GW out of which 40 GW needs to come from rooftop PV (RTPV) installations [3]. Following this, the Cabinet Committee on Economic Affairs revised this budgetary outlay to Rs.5,000 crore for implementation of 4.2 GWp of RTPV over a period of five years up to 2019-20 [4].

Till 2017, almost all states in the country have rolled out net-metering (NM)/gross-metering (GM) schemes to encourage domestic, institutional, industrial and commercial consumers to install RTPV systems ranging from 1 kWp to 500 kWp and even up to 1 MWp in some states [5]. These regulations along with annual orders on suo-motu determination of levelized tariff by different State Electricity Regulatory Commissions (SERCs) have created a plethora of business models which warrant detailed analysis and a documentation of best practices.

At present, the total commissioned rooftop capacity in the country stands at 1,660 MW [6]. Tamil Nadu is the leading state followed by Maharashtra, Rajasthan, Gujarat and Karnataka [7]. Industrial and commercial sectors have adopted more RTPV installations than domestic sector due to higher retail tariff rates. States are playing a critical role in the deployment of grid connected solar power [8] [9] [10]. This article explores the best business cases in the RTPV sector in India by making use of representative cases in five leading states viz. Gujarat, Rajasthan, Maharashtra, Tamil Nadu and Karnataka. The next section outlines the financial incentives and policy frameworks applicable for consumers willing to adopt RTPV systems as a means of energy security and worthwhile investments.

Background

For setting up an RTPV system in India, various financial and policy incentives are available through multiple channels. Some relevant ones are described in the following sub-section.

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RTPV Policy Regime in Indian States

To perform techno-economic assessments of various consumer categories of RTPV systems in Indian states, a policy overview in the five states of Karnataka, Gujarat, Rajasthan, Tamil Nadu and Maharashtra is presented to highlight the challenges and opportunities along with the key factors that need to be taken into consideration for financial analyses (Table 14). The benchmark cost of RTPV systems in the aforementioned states along with other pertinent financial parameters that are considered while performing techno-economic calculations in this study are shown in Table 15

Retail Tariff Structure of DISCOMs

DISCOMs have tariff schedules each year for consumers with the rationale for tariff design varying across states. The broad categories of consumers are domestic, industrial, commercial and institutional. However, retail tariff also depends on the connected load/contract demand of the consumer which divides them into HT (High Tension) or LT (Low Tension) categories. HT category is applicable for bulk consumers and use 11 kV or above while an LT supply is of 400 V for a three-phase connection and 230 V for a single-phase connection. A simplistic division of consumers is used for the purpose of this paper to enable a comparative study across the five states.

i. Residential consumers: LT category: domestic households

ii. Commercial consumers:

   a) LT category: small shops, offices, guest houses, hotels, etc.

   b) HT category: shopping malls, film studios, etc.

iii. Industrial consumers:

   a) LT category: small scale manufacturing units, medium, small and micro enterprises

   b) HT category: large industrial complexes

iv. Institutional consumers:

   a) LT category: govt. schools, administrative buildings

   b) HT category: govt. colleges and universities

The DISCOMs that are chosen are the primary public distribution utilities in the state which are regulated by the SERCs (Table 14). Private distribution utilities are not considered for this analysis since their operational parameters for RTPV are different. The retail tariff structure slabs for respective DISCOMs in the five states considered for analyses are presented in Table 15.

Specific case studies (for each category of consumer) which fall under the scope of each of the policies mentioned above are considered and the economic viability of RTPV systems is arrived at in the five states. Gaps in policies are identified and suitable policy recommendations are made.

Methodology

The objective of this research article is to compare the techno-economic performance of RTPV systems in five leading states in India, viz. Karnataka, Gujarat, Rajasthan, Maharashtra and Tamil Nadu. The focus on Karnataka is because most of the primary data obtained for this research has been obtained from DISCOMs in this state. Since RTPV is a decentralized distributed power generation system and can be adopted by various consumer categories, viz. residential, commercial, industrial and institutional, the economics vary significantly based on each specific application. Typical capacities and types of RTPV systems are taken into consideration and financial analyses are performed across the five states. The chosen sizes and types of RTPV systems in each consumer category are elaborated upon in the following sub-sections.

Residential RTPV Systems

In this study it has been revealed through stakeholder discussions with RTPV consumers (existing and prospective) and DISCOMs, that in the residential sector, households with annual incomes greater than Rs. 20 lakhs and independent plots are more inclined to invest in RTPV systems. The average sanctioned load of existing RTPV installations in Bengaluru, Karnataka is taken as 5 kW. This is also the cap on maximum installed capacity for domestic LT consumers with single phase supply. For others with three phase supply (5 kW to 50 kW sanctioned load) this is either equivalent to or less than 100% of their sanctioned load [22]. The average rooftop area for these installations is taken to be 80 m2. 1 kWp of RTPV is allocated 10 m2 of rooftop area taking Balance of System (BoS) into account [38][39]. The average monthly consumption is taken as 600 units out of which 40 units are from captive diesel generators [40].

These representative numbers and the parameters and restrictions listed in Table 14 and Table 15 are used to calculate the installed capacity and associated capital costs of RTPV systems for residential consumers (LT category) in the five states. HT consumers (large apartments or complexes) are not considered for this analysis. The roofs of these buildings are usually quite small compared to the number of floors and thereby households. There are also social barriers surrounding ownership and sharing of electricity and revenue generated from solar panels.

Commercial RTPV Systems

Typically, commercial establishments pay the highest tariffs amongst the gamut of consumers catered to by Indian DISCOMs. With global solar PV prices on the decline, the Levelized Cost of Electricity (LCOE) of RTPV systems is now cheaper than the rates paid by commercial consumers in most Indian states. Two representative cases in the LT and HT segments in the commercial space are considered in this research article:

1. Independent mini-supermarket with a sanctioned load of 40 kW, available rooftop area of 800 m2; monthly consumption of 8,000 units out of which 500 units are from a captive diesel generator during power cuts.
2. A shopping mall with a sanctioned load of 250 kW, available rooftop area of 3500 m2; monthly consumption of 60,000 units out of which 4,000 units are from a captive diesel generator during power cuts.

These representative numbers, parameters and restrictions listed in Table 14 and Table 15 are used to calculate the installed capacity and associated capital costs of RTPV systems for commercial consumers (LT and HT category) in the five states.

Industrial RTPV Systems

Two representative cases in the LT and HT segments in the industrial consumers' category are considered in this research article:

1. A packaging warehouse with a sanctioned load of 50 kW, available rooftop area of 2000 m2; monthly consumption of 9,000 units out of which 800 units are from a captive diesel generator during power cuts.
2. A ball bearing manufacturing unit with a sanctioned load of 300 kW, available rooftop area of 5,000 m2; monthly consumption of 85,000 units out of which 8,000 units are from a captive diesel generator during power cuts.

These representative numbers and the parameters and restrictions listed in Table 14 and Table 15 are used to calculate the installed capacity and associated capital costs of RTPV systems for industrial consumers (LT and HT category) in the five states.

Institutional RTPV Systems

Two representative cases in the LT and HT segments in the institutional consumers' category are considered in this research article:

1. A government primary school with a sanctioned load of 30 kW, available rooftop area of 500 m2; monthly consumption of 2,000 units out of which 200 units are from a captive diesel generator during power cuts.
2. A government arts college with a sanctioned load of 200 kW, available rooftop area of 4,000 m2; monthly consumption of 45,000 units out of which 4,000 units are from a captive diesel generator during power cuts.

These representative numbers and the parameters and restrictions listed in Table 14 and Table 15 are used to calculate the installed capacity and associated capital costs of RTPV systems for industrial consumers (LT and HT category) in the five states.

Techno-economic Assessment

LCOE is calculated by determining the total amount of electricity generated by the RTPV system over its lifetime (taking degradation into account) i.e. 25 years and all numbers being discounted to Present Value (PV) and the total cost of the RTPV system over its lifetime being divided by the total amount of electricity generated [41][42].

Where,

$$LCOE = \frac{\sum_{t=1}^{n} \frac{(I_t+M_t+F_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t = *Investment expenditures in the year t*

M_t = *Operations and maintenance (O&M) expenditures in the year t*

F_t = *Fuel expenditures in the year t (considered to be 0 in case of solar PV)*

E_t = *Electricity generated in the year t*

r = Discount rate

n = Lifetime of the system (25 years in case of solar PV)

The revenue model has then been calculated by taking into account the savings of the consumer due to displacement of grid-based electricity and diesel, and revenue from electricity sales through NM/GM scheme to the DISCOM. This analysis is based on Discounted Cash Flows (DCF) over the useful life of the plant, taking into consideration the time value of money. The cash flows are discounted over the lifetime and Net Present Value (NPV), internal rate of return (IRR) for project as well as equity, and payback period for each system are calculated. In this, future monetary earnings are discounted back to get their present value using a discount rate that varies across states since the opportunity cost of capital is different. These relationships and equations form an integral part of CSTEP's in-house CSTEM tool [43] which is used for all these calculations.

Assumptions used in the model are as follows:

- Long-term equity gains are tax free in India which is why income tax on RoE is assumed to be zero
- For average retail tariff calculation, the component of fixed costs is not embedded in the overall billing cycle and is assumed to be constant during the useful life of the system
- After 10 years, inverter replacement costs are added to the calculations along with the salvage value of the plant and inverter, a parameter not considered in the Commission's analysis in all the five states. Salvage value therefore, is assumed at 10% while the annual escalation in the cost of the inverter is taken to be 2%
- Retail tariff is assumed to rise at an annual rate of 3%
- Only half of diesel-based consumption is assumed to be replaced by RTPV generation since power cuts occur after sunset as well
- Some SERCs do not define every financial parameter required for techno-economic assessments of RTPV systems. In these cases, CERC prescribed parameters are considered

Results & Discussion

Results based on the aforementioned methodology are presented and discussed in the following sub-sections.

Residential RTPV Systems

The installed capacities and corresponding capital costs of residential RTPV systems with and without MNRE subsidy in the five states are depicted in Table 12.

A summary of the techno-economic assessment of residential RTPV systems in the five respective states is presented in Table 1.

Table 1: Techno-economics for residential RTPV systems

State	LCOE (Rs./kWh)	FiT (Rs./kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Without Subsidy							
Karnataka	5.55	7.08	6.5	21.38	34.12	1.16	8
Rajasthan	5.75	5.4	6.3	20.45	30.69	1.38	7
Gujarat	5.45	APPC	4.5	14.96	17.42	0.32	22
Maharashtra	7.14	APPC	5.6	14.25	18.12	0.76	12
Tamil Nadu	5.97	-	3.77	7.38	6.04	-0.41	-
With Subsidy							
Karnataka	3.92	7.08	6.5	35.39	76.67	1.99	4
Rajasthan	4.21	5.4	6.3	32.51	66.69	2.06	4
Maharashtra	5.39	APPC	5.6	23.53	43.18	1.62	6
Gujarat	4.54	APPC	4.5	20.69	30.31	0.58	7
Tamil Nadu	4.64	-	3.77	12.05	13.39	0.45	15

In spite of a reduction in NM/GM rates in Karnataka and a restriction of sanctioned load being imposed on the capacity of an RTPV installation, the state still performs the best amongst the five states in terms of techno-economics of residential RTPV systems. With reducing capital costs, the move to switch to GM along with a capping the installed capacity to 100% of the sanctioned load reflects a fine balance between consumer expectations on RoE and the ability of DISCOMs to pay for rooftop electricity. This has overall improved the market for domestic households in Karnataka, which is stated as one of the objectives of the present policy.

Rajasthan is another state with favourable techno-economics for residential RTPV systems. Although the FiT is lower than the calculated LCOE of an RTPV system, the higher retail tariffs which are offset because of electricity savings and NM lead to equity IRR crossing 30% in the state with a payback period of only 7 years.

In Gujarat and Maharashtra, surplus energy at the end of billing cycle is purchased at APPC by DISCOMs. Apart from this, the retail rates in these two states are much lower than the LCOE of RTPV systems. Hence, equity IRRs hover in the range of 17%-18% and payback periods are more than ten years. Stakeholder consultations in these two states revealed that residential consumers are more likely to invest in other market instruments rather than RTPV systems because of the lukewarm financial performance.

Tamil Nadu is the state where there is no FiT scheme which lead towards the poor performance. Any excess generation at the end of a billing cycle is not considered for monetary compensation. Apart from this, the retail tariffs are also significantly lower than the LCOE of RTPV systems. Hence, residential RTPV installations in this state has a negative NPV and the payback period is never reached. Therefore, a further capital cost reduction or introduction of a FiT up to Rs. 5.5/kWh for net export will be needed to achieve a minimum equity IRR of 16% to create a viable business model.

Except Tamil Nadu, availing the MNRE subsidy leads to highly profitable business cases in the rest states with equity IRRs greater than 30% as shown in Table 2. Even with the subsidy in Tamil Nadu, residential consumers obtain payback periods of more than 15 years in the residential RTPV sector.

Commercial RTPV Systems

The installed capacities and corresponding capital costs of commercial RTPV systems without MNRE subsidy in the five states are depicted in Table 13.

A summary of the techno-economic assessment of commercial RTPV systems – LT and HT consumers – in the five states is presented in Table 2 and Table 3 respectively.

Table 2: Revenue Model for LT commercial RTPV systems (supermarket)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Rajasthan	5.34	5.4	8.75	32.86	66.61	24.08	4
Karnataka	5.11	6.61	8.49	32.54	66.33	20.64	5
Maharashtra	6.64	APPC	7.59	24.92	45.71	20.96	6
Tamil Nadu	5.56	-	8.01	23.25	38.15	26.15	6
Gujarat	5.08	APPC	4.5	19.12	26.18	4.72	8

Table 3: Revenue Model for HT commercial RTPV systems (shopping mall)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Karnataka	4.68	5.67	8.45	37.03	80.38	142.35	4
Rajasthan	4.87	5.4	8.35	36.32	77.57	154.48	4
Maharashtra	6.08	APPC	8.3	31.97	66.99	173.49	4
Tamil Nadu	5.06	-	8	26.93	48.45	183.9	5
Gujarat	4.71	APPC	4.35	22.84	35.28	38.67	6

In all four states (except Gujarat), commercial RTPV consumers (both LT and HT) have achieved grid-parity making RTPV installations viable projects for investors. Apart from LT consumers in Gujarat, all other business cases have equity IRRs greater than 30% and positive NPVs. Higher retail tariffs have also contributed in improving the business model for these consumers under NM wherein self-consumption is offset by cheaper source of electricity using RTPV. Rajasthan and Karnataka are the states with the most favourable business cases in the commercial RTPV sector followed by Maharashtra and Tamil Nadu.

In case of Gujarat where grid parity has still not been achieved, the major factor for longer payback periods and lower NPVs is the low retail tariff rate. At electricity tariffs comparable to other states (above Rs. 7.00/kWh), the bill savings create adequate revenue to render the model economically viable. Therefore, low tariffs may continue to act as a barrier for commercial consumers (both LT and HT) towards further adoption of RTPV in the state.

For consumers making use of diesel generators to compensate for power shortages, RTPV adoption holds significant importance as solar based electricity holds potential to offset diesel consumption and also turns out to be a cheaper source of electricity than diesel. The results show that the net income for prospective commercial RTPV consumers is directly proportional to the quantity of diesel abated which thereby improves business cases. The results also show that the equity IRRs for commercial consumers is much higher than that of residential and industrial consumers because of the higher retail rates in this sector.

Industrial RTPV Systems

The installed capacities and corresponding capital costs of industrial RTPV systems without MNRE subsidy in the five states are depicted in Table 14.

A summary of the techno-economic assessment of industrial RTPV systems – LT and HT consumers – in the five states is presented in Table 4 and Table 5 respectively.

Table 4: Revenue Model for LT industrial RTPV systems (packaging warehouse)

State	LCOE (Rs./kWh)	FiT (Rs./kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Karnataka	5.11	6.61	6.48	25.41	45.14	15.93	6
Rajasthan	5.34	5.4	6.45	24.99	43.1	18.9	6
Maharashtra	6.64	APPC	6.49	21.41	35.82	19.65	7
Gujarat	5.08	APPC	4.89	22.21	33.52	8.31	7
Tamil Nadu	5.56	-	5.98	17.56	24.12	18.8	8

Table 5: Revenue Model for HT industrial RTPV systems (ball bearing factory)

State	LCOE (Rs./kWh)	FiT (Rs./kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Rajasthan	4.87	5.4	7	32.88	66.64	160.79	4
Maharashtra	6.08	APPC	7.9	31.86	66.47	209.06	4
Karnataka	5.11	5.67	6.65	27.68	51.52	115.46	6
Gujarat	4.71	APPC	4.35	27.78	48.11	68.86	5
Tamil Nadu	5.06	-	6.35	22.97	37.36	170.07	6

Apart from LT industrial consumers in Tamil Nadu, all industrial consumers in the other four states have viable business cases with equity IRRs more than 30% and payback periods less than 7 years. This is again because in Tamil Nadu, any excess generation from RTPV systems at the end of the billing cycle is not considered to be eligible for monetary compensation.

Although the equity IRRs are lesser compared to commercial consumers, the business cases in all five states for industrial RTPV consumers are favourable enough considering the amount of capital involved in setting up larger RTPV systems and reducing dependency on diesel based generation.

Institutional RTPV Systems

The installed capacities and corresponding capital costs of institutional RTPV systems without MNRE subsidy in the five states are depicted in Table 15.

A summary of the techno-economic assessment of institutional RTPV systems – LT and HT consumers – in the five states is presented in Table 6 and Table 7 respectively.

Table 6: Revenue Model for LT institutional RTPV systems (govt. primary school)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Karnataka	5.11	6.61	7.61	26.82	51.31	9.86	6
Rajasthan	5.34	5.4	7	24.18	42.25	9.92	6
Gujarat	5.08	APPC	4.72	17.41	22.54	2.73	9
Maharashtra	6.64	APPC	5.9	15.75	22.47	5.08	9
Tamil Nadu	5.56	-	5.75	13.92	17.03	5.61	21

Table 7: Revenue Model for HT institutional RTPV systems (govt. arts college)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Rajasthan	4.87	5.4	7	31.62	62.94	99.97	5
Karnataka	4.68	5.67	6.4	29.11	56.12	74.54	5
Maharashtra	6.08	APPC	6.5	25.4	47.31	96.64	6
Gujarat	4.71	APPC	4.35	24.73	40.05	36.55	6
Tamil Nadu	5.06	-	6.35	22.03	34.98	104.38	6

The representative govt. primary school has a high sanctioned load compared to the actual consumption. This is because in most govt. primary schools there are hardly any heavy loads with lights and fans being the primary electrical appliances. However, the sanctioned load is kept high with the provision of allowing computers and other appliances to be installed in the near future. However, as of today, the large rooftop areas allow for larger RTPV installations and the subsequent generation significantly exceeds the consumption. Hence, Karnataka and Rajasthan have excellent business cases because of the higher NM/GM rates. However, Gujarat and Maharashtra have longer payback periods and lower equity IRRs since excess electricity is bought back by DISCOMs at APPC that is invariably lesser than the LCOE of RTPV systems. Tamil Nadu is the worst performer with payback periods crossing 20 years and equity IRRs less than 20%. This is because the excess generation at the end of the billing cycle is not considered for monetary compensation. In these three states, the FiT needs to be increased to more than Rs. 5.5/kWh to make competitive business cases for LT institutional consumers to adopt RTPV systems.

In case of the HT institutional consumer sector, the representative case is taken to be a govt. arts college which has large rooftop area and consumption commensurate to the sanctioned loads. Since the generation from RTPV systems in this sector does not exceed consumption and there is also a heavy dependence on diesel based generation which can be partially offset by RTPV, the business cases for RTPV in all the five states for HT institutional consumers is very good with best and worst equity IRRs being ~63% and ~35% respectively.

Conclusions & Recommendations

Of the 40 GW RTPV target for 2021-22, only ~1.7 GW is installed in India so far. Apart from the technical constraints, the financial aspects of RTPV systems are a concern for implementing agencies in many states in the country. The techno-economics of RTPV systems for various consumer categories in the five leading states are the focus of this research article. Conclusions and subsequent recommendations are presented in this section.

RTPV systems in urban areas reduce system congestion because of localized generation and self-consumption. Residential consumers contribute heavily to the electricity demand and a majority of the 40 GW target for India is expected to come up on domestic rooftops. However, the results of this study show that the business cases for residential RTPV systems in India are the least favourable amongst all consumer categories. Without the MNRE capital subsidy, amongst the five representative states in this study, Karnataka has the best equity IRR (~34%) with a payback period of 8 years. Rajasthan has a similar scenario with an equity IRR of ~31% and a payback period of 7 years. These are the only two states which have FiTs announced for DISCOMs to procure RTPV-based generation from consumers. Gujarat and Maharashtra DISCOMs procure excess RTPV-based generation at APPC which is lower than the LCOE of residential RTPV systems. Hence, these two states have long payback periods and lower equity IRRs. Tamil Nadu has the worst business case for residential RTPV systems (payback is not reached and NPV is negative) because there is no provision for DISCOMs to procure excess RTPV-based generation in the state. Availing the 30% MNRE capital subsidy leads to better business cases in Karnataka, Rajasthan, Gujarat and Maharashtra with payback periods dropping to less than 8 years and equity IRRs becoming more than double of what they were without the subsidy. In spite of this, Tamil Nadu still has a payback period of 15 years and equity IRR ~13%, thereby highlighting the need for a revision of the state's RTPV policy.

In order to make viable business cases for residential RTPV systems across India, states like Gujarat, Maharashtra and Tamil Nadu need to fix FiTs above Rs. 5.50/ kWh for DISCOMs to purchase excess RTPV-based generation. However, considering the poor financial health of most DISCOMs in the country, determination of a suitable FiT needs thorough analyses of the DISCOMs' finances, accurate demand forecasts, Annual Revenue Requirements (ARRs) and average realisation rates. These exercises provide the authors of this research article with future scope of work continuing from the present research on RTPV penetration in India.

Capital subsidies are usually provided to enhance the adoption rate of commercial technologies in the nascent phase of market introduction. Although the solar industry is witnessing tremendous growth in India, ~1.7 GW of RTPV installations suggest that the rooftop segment is still in its infancy and some consumer categories need the capital subsidy. However, stakeholder consultations revealed that availing the subsidy is a tedious process and prospective consumers would rather rely on attractive NM/GM rates and timely payments from DISCOMs. To make the MNRE subsidy a more effective instrument, measures need to be taken to streamline the processes to avail the subsidy and reduce the complexities which deter prospective consumers today.

Commercial, industrial and institutional consumers have lucrative business cases for RTPV adoption in most cases. The aforementioned determination of a suitable FiT for NM/GM is key to bridging the gap for LT commercial consumers in Gujarat and LT industrial and institutional consumers in Tamil Nadu.

The results of this study show that Tamil Nadu has the least favourable RTPV policy regime with no provisions for DISCOMs to procure excess RTPV-based generation. However, the maximum amount of RTPV installations in India till date are in the state, contradicting the results of this study. Stakeholder consultations revealed that 90% of these installations are installed by HT industrial consumers in the state. This shows that contrary to popular opinion, consumers who are aware of their business cases have an appetite for RTPV systems in India. The results of this study show that Karnataka's tiered FiT structure based on capacity of the RTPV system – which takes economies of scale into account – is responsible for the state having favourable business cases for all categories of consumers. This model can be replicated in other states in India to foster RTPV growth in the country.

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APPENDIX I

Table 12: Comparison of RTPV policies in different states

State	RTPV policy	Restrictions	Salient features
Karnataka [22]	Shifted to GM for domestic consumers, hospitals and educational institutions while retaining NM for industrial and commercial consumers	Not more than sanctioned load	1. Energy Accounting and Settlement: *For domestic category, hospitals and educational institutions:* GM *For industrial and commercial consumers:* NM as per the following rates:
Gujarat [23][24]	NM	Up to a maximum of 50% of consumer's sanctioned load	1. Energy Accounting and Settlement: *For net importer*: net consumption billed at existing tariff *For net exporter*: surplus energy after adjustment of consumption at the end of billing cycle shall be purchased by the DISCOM at the Average Pooled Power Purchase Cost (APPC) rate of the year in which the SPG was commissioned. Provided the consumer is not an obligated entity under RPO and does not take credit under REC mechanism. If so, then purchase price at which DISCOM buys further reduces to 85% of APPC 2. Residential & government installations qualify for DISCOM's RPO For industrial and commercial consumers, installations are credited towards meeting the consumer's RPO (if REC is not availed) and surplus credited towards DISCOM's RPO 3. CDM benefits: 100% retained by consumer
Rajasthan[25][26]	NM with FiT for exporting more than 50 units	80% of Sanctioned Load Cumulative capacity of all solar systems installed shall not exceed 30% of distribution transformer capacity.	1. Energy Accounting and Settlement *For net importer*: net consumption billed at retail tariff *For net exporter*: this is accompanied with a Feed-in-tariff of Rs.5.40/unit (without AD Benefit) and Rs. 4.85/unit (with AD Benefit) 2. RPO benefits are credited towards meeting DISCOM's RPO if eligible consumer is not an obligated entity 3. CDM benefits are retained by DISCOM provided that are passed on to the consumers through Annual Revenue Requirement (ARR)
Tamil Nadu [27]	NM with Generation Based Incentive (GBI) for domestic households	Not more than sanctioned load	1. Energy Accounting and Settlement *For net importer*: net consumption billed at retail tariff *For net exporter*: Surplus electricity fed into the grid shall be capped at 90% of the electricity consumption at the end of the settlement period. Excess energy beyond 90% cap shall be treated as lapsed 2. No CDM benefits

State	RTPV policy	Restrictions	Salient features
Maharashtra [28]	NM	Not more than sanctioned load (in kW) or contract demand (in kVA), subject to the cumulative capacity of the relevant Distribution Transformer (DT) (with a provision of ±5%)	1. Energy Accounting and Settlement: *For net importer*: net consumption billed at retail tariff *For net exporter*: Surplus electricity credits are passed on to the next billing period and purchased by the DISCOM at APPC at the beginning of the next settlement period 2. If consumer is an Obligated Entity, the solar energy generated shall be accounted to meet the consumer's RPO. If not, accounted for the DISCOM's RPO 3. RTPV systems under NM shall not be eligible for REC 4. CDM benefits are retained by the consumer

Table 13: Parameters prescribed by different SERCs for RTPV installations

Parameters	Gujarat [24]	Rajasthan [29]	Maharashtra [30]	Tamil Nadu [27]	Karnataka [31]
Capital cost (lakhs/kW) – Domestic [32]	0.47	0.54	0.54	0.65	0.50
Capital cost (lakhs/kW) – LT (Commercial, Industrial, Institutional)	0.42	0.49	0.49	0.59	0.45
Capital cost (lakhs/kW) – HT (Commercial, Industrial, Institutional)	0.38	0.43	0.43	0.52	0.40
Assumption:*Capital cost for Commercial, Industrial and Institutional consumer is assumed on the basis of the capital cost assigned for Domestic consumers. For LT category the capital cost is 90% of the cost of Domestic category and for HT category the cost is 80% of the cost of Domestic category.*					
Operation & Maintenance (O&M) (in lakhs/kW_p)	0.01075	0.007	0.01378	0.007	0.007
Annual escalation in O&M	5.72%	5.85%	5.72%	5.72%	5.72%
Insurance cost (% of net asset value)	0.35%	0.35%	0.35%	0.35%	0.35%
Capacity Utilization Factor (CUF)	19%	20%	19%	19%	19%
Degradation Factor	1%	0.8%	0.8%	0.8%	0.8%
Useful life	25	25	25	25	25
Debt : Equity	70 : 30	70 : 30	70 : 30	70 : 30	70 : 30
Loan tenure (years)	10	12	12	10 (+1)	12
Interest rate on loan	12.85%	12.76%	11%	11%	12%
Working Capital (WC) requirements	O&M for 1 month + 1-month receivables	O&M for 1 month + 2 months receivables	O&M for 1 month + 2 months receivables	O&M for 1 month + 2 months receivables	O&M for 1 month + 1 month receivables
Interest on WC	11.85%	12.26%	11.00%	11.50%	12.50%
Rate of depreciation	6% (first 10 years)	5.83% (first 12 years)	5.83% (first 12 years)	5.83% (first 12 years)	5.83% (first 12 years)
	2% (next 15 years)	1.54% (next 13 years)	1.54% (next 13 years)	1.54% (next 13 years)	1.54% (next 13 years)
Salvage value	10%	10%	10%	10%	10%
Return on Equity (RoE)	14%	16%	20% (Pre-tax)	20% (Pre-tax)	16%
Discount factor	10.65%	10.78%	10.81%	9.24%	13.20%
FiT (Rs./kWh)	APPC	5.4 (without AD) 4.85 (with AD)	APPC	No FiT	Refer to Table 12

Table 14: DISCOMs chosen for analysis

State	DISCOM chosen for analysis
Karnataka	Bangalore Electricity Supply Company (BESCOM)
Gujarat	Torrent Power Limited (TPL)
Rajasthan	Jaipur Vidyut Vitran Nigam Limited (JVVNL)
Maharashtra	Reliance Energy Limited
Tamil Nadu	Tamil Nadu Generation and Distribution Corporation (TANGEDCO)

Table 15: Comparison of retail tariffs in the selected states (electricity charges per kWh)

		Karnataka [33]	Gujarat [34]	Rajasthan [35]	Maharashtra [36]	Tamil Nadu [37]
Domestic	LT	0-30 units: Rs. 3.25 31-100 units: Rs. 4.70 101-200 units: Rs. 6.25 201-300 units: Rs. 7.30 301-400 units: Rs. 7.35 401-500 units: Rs. 7.40	0-50 units: Rs. 3.20 50-200 units: Rs. 3.90 >200 units: Rs. 4.90	0-50 units: Rs. 3.85 51-150 units: Rs. 6.10 151-300 units: Rs. 6.40 301-500 units: Rs. 6.70 >500 units: Rs. 7.15	0-100 units: Rs. 1.90 101-300 units: Rs. 5.40 301-500 units: Rs. 6.80 >500 units: Rs. 8.60	0-100 units: Rs. 0 101-200 units: Rs. 3.50 201-500units: Rs. 4.60 >500 units: Rs. 6.60
Commercial	LT	0-50 units: Rs. 7.50 >50 units: Rs. 8.50	Rs. 4.50 (<15 kW)	1-100 units: Rs. 7.55 100-200 units: Rs. 8.0 200-500 units: Rs. 8.35 >500 units: Rs. 8.80	0-20 kW: Rs. 6.80 20-50 kW: Rs. 6.95 >50 kW: Rs7.60	0-100 units: Rs. 5 >100 units: Rs. 8.05
	HT	0-1 lakh units: Rs. 8.45 > 1 lakh units: Rs. 8.55	1-400 units: Rs. 4.45 >400 units: Rs. 4.35	Rs. 8.35	Rs. 8.30	Rs. 8.0
Industrial	LT	0-500 units: Rs. 5.25 >500 units: Rs. 6.50	Rs. 4.70 (<50 kW) Rs. 4.90 (>50 kW)	0-500 units: Rs. 6 >500 units: Rs. 6.45	0-20 kW: Rs. 6.0 >20 kW: Rs. 6.50	0-500 units: Rs. 4.0 >500 units: Rs. 6.0
	HT	0-1 lakh units: Rs. 6.65 >1 lakh units: Rs. 6.95	1-400 units Rs. 4.45 >400 units: Rs. 4.35	SSI: Rs. 7 MSI: Rs. 7.30	Rs. 7.90	Rs. 6.35
Institutional	LT	0-200 units: Rs. 6.50 >200 units: Rs. 7.75	0-200 units: Rs. 4.10 >200 units: Rs. 4.80	Rs. 7	Rs. 5.90	Rs. 5.75
	HT	0-1 lakh units: Rs. 6.40 >1 lakh units: Rs. 6.80	1-400 units Rs. 4.45 >400 units: Rs. 4.35	Rs. 7	Rs. 6.50	Rs. 6.35

Table 16: Installed capacities and capital costs for typical RTPV systems (LT residential consumers)

State	Maximum installed capacity (kWp)	Capital Cost (Rs. Lakhs)	
		Without subsidy	With subsidy
Karnataka	5	2.50	1.75
Gujarat	2.5	1.18	0.83
Rajasthan	4	2.16	1.51
Maharashtra	5	2.70	1.89
Tamil Nadu	5	3.25	2.28

Table 17: Installed capacities and capital costs for typical RTPV systems (LT and HT commercial consumers)

State	LT (supermarket)		HT (shopping mall)	
	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)
Karnataka	40	18.00	250	100.00
Gujarat	20	8.46	125	47.00
Rajasthan	32	15.55	200	86.40
Maharashtra	40	19.44	250	108.00
Tamil Nadu	40	23.40	250	130.00

Table 18: Installed capacities and capital costs for typical RTPV systems (LT and HT industrial consumers)

State	LT (packaging warehouse)		HT (ball bearing factory)	
	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)
Karnataka	50	22.50	300	120.00
Gujarat	25	10.57	150	56.40
Rajasthan	40	10.44	240	103.68
Maharashtra	50	24.3	300	129.60
Tamil Nadu	50	29.25	300	156.00

Table 19: Installed capacities and capital costs for typical RTPV systems (LT and HT industrial consumers)

State	LT (government primary school)		HT (government arts college)	
	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)
Karnataka	30	13.50	200	80.00
Gujarat	15	6.34	100	37.60
Rajasthan	24	11.66	160	69.12
Maharashtra	30	14.58	200	86.40
Tamil Nadu	30	17.55	200	104.00

CLIMATE CHANGE IMPACTS AND ADAPTATION IN INDIA: RESEARCH PRIORITIES[34]

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The obsession of climate negotiations on greenhouse gas (GHG) emission mitigation – despite very poor record of achieving any significant emission reduction over the past two decades, has historically denied due space for climate change adaptation, and is now threatening to also side-line more important and relevant deliberations on loss and damage due to climate change. Without providing any details, the Paris Agreement acknowledges the importance of adaptation and suggests creation of adaptation fund with US$ 100 billion per year starting from 2030. The proposed fund is roughly equal to the OECD budget for Overseas Development Assistance (ODA). However, this could only be a fraction of adaptation costs in poor and vulnerable countries. Also, it is not clear whether the adaptation fund will come at the expense of development assistance or as additional budget to facilitate climate proofing the development in the vulnerable countries. Though the Paris Agreement explicitly acknowledges the need for addressing loss and damages – which technically speaking are the unavoidable impacts due to climate change, there is no explicit proposal for financing such costs. The developed countries also managed to remove from the Agreement reference to liability and compensation in the context of loss and damage. In all, the discussion on impacts, adaptation and loss-and-damage remains fuzzy in the global negotiations. It is against this backdrop that this note provides an overview of the status of research in this crucial field of knowledge with focus on agriculture sector in India. The note is structured as follows: The following section takes stock of climate change impact studies with an attempt to understand knowledge gaps and research priorities. The subsequent section discusses the status of adaptation research and possible approach for mainstreaming climate change policies.

Climate Change Impacts

For both mitigation and adaptation policy formulation, one of the crucial inputs needed is the potential impacts due to climate change on various climate sensitive sectors. For mitigation, such information would provide the required justification for de-carbonizing the energy systems. On the other hand, in the context of adaptation, knowledge on climate change induced impacts will be helpful in prioritizing the adaptation in the most needed sectors and regions. Further, climate change impacts estimated with proper accounting of adaptation will be helpful in identifying the factors that ameliorate the adverse effects of climate change. Where do we stand with regard to research on climate change impacts in India? The following discussion highlights some of the issues concerning climate change impacts with focus on agriculture.

Methodological Concerns

The climate change impacts have traditionally been assessed in terms of physical impacts (such as yield and area changes), or the associated economic impacts. Over the years there has been steady increase in both categories of studies, but significantly larger increase in physical impact studies than the economic impact studies. Further, there has been proliferation of 'statistical' methods as a preferred method of impact estimation – both for physical as well as economic impact assessment.

Statistical models relaying on cross-sectional data have been in use from mid-nineties in the field of climate change impact literature. Referring the cross-sectional statistical model based approach as Ricardian approach, Mendelsohn et al. (1994) in their study of climate change impacts on the US agriculture compare farms across different places – each of which is adapted to local climatic conditions, to empirically estimate equilibrium climate response of farms to climate. One of the main advantages of the Ricardian approach (also referred to as hedonic approach in the literature) is that it would take into account the full range of farm level adaptation possibilities. However, in practice it is very difficult to control for

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all factors that affect long-term farm profitability. The omitted variables lead to misspecification of the model and bias the estimates of the effects of climate change. To overcome some of the limitations of the cross-sectional models, there has been a steady growth of panel fixed-effects models on the lines proposed by Deschenes and Greenstone (2007). As comprehensively reviewed by Dell et al. (2014), there has been extensive use of panel fixed-effects models for studying climate change impacts in many sectors including agriculture, labour productivity, industrial output, health, energy, crime etc. The panel approach enables assessment of the influence of weather shocks on many outcomes of interest, being at large free from statistical bias and with significant precision. However, in addition to possible limitation of failing to control for time-varying omitted variables that are correlated with weather shocks, the panel fixed-effects models estimate impacts due to weather shocks, and not necessarily impacts due to climate change.

In line with the global trends, there has been increasing use of statistical models in Indian agriculture context too – both for physical impacts assessment (see for example, Auffhammer et al., 2006; Auffhammner et al., 2012; Lobell et al., 2011; Krishnamurthy, 2012; Birthal et al., 2014; Gupta et al., 2014; Pattanayak and Kavi Kumar, 2014; Saravanakumar, 2015) and for economic impact assessment (see for example, Guiteras, 2009; Kavi Kumar, 2011; Birthal et al., 2014; Kar and Das, 2015). While these studies could be accurately assessing the impact of weather shocks, attributing to climate change context could be misleading for several reasons highlighted by Dell et al. (2014). Even though the panel models correctly identify the causal effect of weather shocks on contemporaneous economic outcomes, they may not estimate the structural equation of interest for understanding the likely effects of future climate change. Further, the estimates from panel fixed-effects models may not reflect either the upper bound or the lower bound for the climate change effects. The effects of weather shocks (as estimated by the panel fixed-effects models) will be larger than the effects of climate change if adaptation plays dominant role. On the other hand, the effects of weather shocks will be smaller than the effects of climate change if variation in temperature and precipitation become more intense.

Other Concerns

Some of the other concerns associated with climate change impact assessment include:

- **Which climate variables matter:** There is considerable uncertainty with regard to the choice of climate variables in the model specification. While most studies in India still use standard climate variables such as mean temperature and annual rainfall as primary variables of concern in the model specification, there is increasing evidence in the literature to suggest need for incorporating other variables like maximum temperature, minimum temperature, standard deviation of rainfall etc. to effectively capture the climate sensitivity. For example, in a study on the rice crop cultivation in India, Pattanayak and Kumar (2017) show that magnitude and distribution of simulated impacts of historical changes in climate on rice yield are significantly different when estimated based on a model that includes maximum temperature when compared to a model that includes only minimum temperature. Thus, there is still considerable scope for research on appropriate model specification in climate impact research.
- **Need for comprehensive impact estimates:** Despite several years of research in the field of climate change impacts, there are still not many studies on estimating economy-wide impacts due to climate change in India. In fact, with the exception of the agriculture sector, there have been very few studies assessing aggregate impacts of climate change on other climate sensitive sectors such as forestry, health etc. Such aggregate studies are needed to put in perspective the critical importance of climate change problem.
- **Aggregate vs. disaggregate impacts:** While much research still needs to be done on assessing aggregate impacts of climate change across sectors and at macro level, there is significant evidence in the literature to suggest that aggregate impacts could be misleading if used for adaptation purposes. Pattanayak and Kumar (2017) for example show in the context of rice crop that regional impacts (of historical changes in climate) are over-estimated when simulated using an all-India yield response function as against those based on region-specific

yield response function that incorporates the features of regional crop calendar and regional crop management practices.

- **Impacts at policy relevant levels:** As adaptation needs are becoming more and more real, the climate change impacts are needed more at policy relevant scales. For effective policy making, there is an urgent need to improve our understanding about the impact distribution across geographic regions as well as various socio-economic groups.

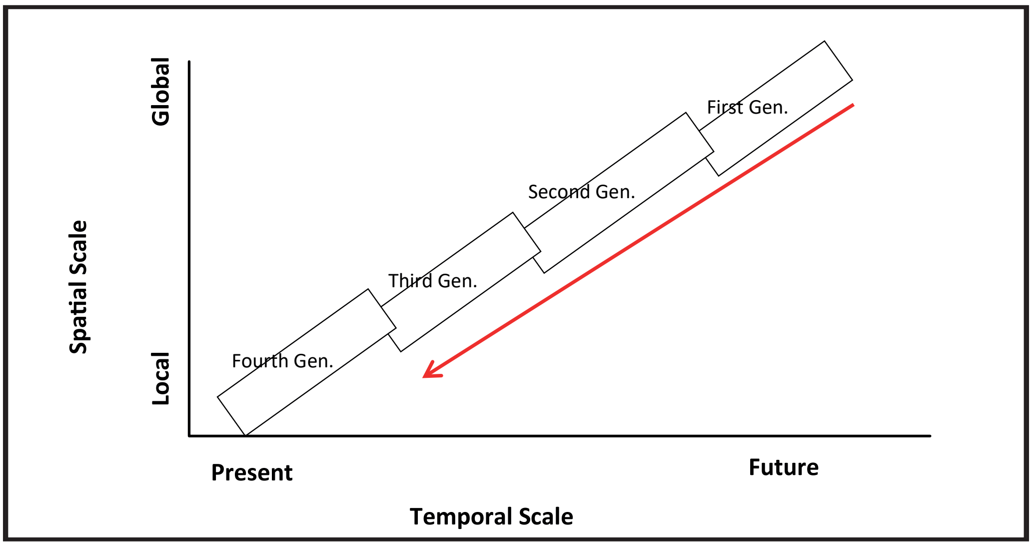
Adaptation Research

Research on adaptation in the climate change context has evolved over the past two decades in line with the shift in the climate change policy from greenhouse gas mitigation. Klein et al. (2017) provide a comprehensive summary of the evolution of climate change adaptation research juxtaposing it with the changing climate change policy context. In particular they identify four generations of adaptation research so far. These four generations of adaptation research are summarized below along with their broad features:

- **First generation of adaptation research** examined potential impacts of climate change along with costs and benefits of adaptation
- **Second generation of adaptation research** explored the role of social factors in exacerbating vulnerability to climate change. This strand of research also focussed on understanding the role of adaptive capacity and factors that could improve it.
- **Third generation of adaptation research** focussed on distributional and financing issues as well as the policies/institutions to support adaptation activities.
- **Fourth generation of adaptation research** is examining how adaptation actually works at the ground level. With the focus on implementation, this strand of research is exploring the approaches to 'mainstream' climate change adaptation.

One way to understand the evolution of these different generations of adaptation research could be to view them with reference to the temporal and spatial scales that these studies deal with. The figure below provides a visual representation of the progress in adaptation research. While the first-generation studies focussed on adaptation needs at aggregate geographical regions and in distant future, the fourth-generation studies are more concerned about adaptation at specific locations, and in response to the weather/climate shocks that are experienced currently.

Figure 1: Schematic Representation of Evolution of Climate Change Adaptation Research



In the Indian context, there have been varying degrees of focus on these strands of adaptation research. While there were only a few studies that systematically analysed the role of adaptation in climate change impact studies (i.e., the first generation of adaptation research), a large number of studies focussed on vulnerability assessment. Many of the vulnerability assessments, however, tend to capture generic vulnerability rather than vulnerability in the climate change context. Studies that could be classified as those in the third generation of adaptation research are still evolving. A major challenge concerning these studies remains in establishing climate change connection. Notwithstanding such concerns there has been a proliferation of studies in India that broadly fall in the category of fourth generation adaptation research studies. In their pursuit to implement the climate change action plans, many state governments are currently implementing several adaptation activities across India. However, the climate change context is often unclear in these activities, and as a result many such activities could be seen as activities implemented to bridge the existing 'development deficit'.

Mainstreaming

The adverse effects of climate change are manifested through changes in development outcomes (e.g., through increased population that is poor or malnourished). However, the development outcome of the society is at large affected by a host of factors or stressors that may have little direct bearing with climate. Thus, climate is only one amongst several factors determining development outcome of a society. In reality, at more local scale, there could be multiple stressors that determine the aggregate vulnerability of a system.

Assessing the society's vulnerability to climate change in isolation therefore is not warranted. Such assessment would undermine the role of other stressors in exerting direct or indirect (through interaction with climate) influence on the societal welfare. The foremost consequence of this is the significant underestimation of the aggregate vulnerability to climate change. Further, this would lead to inappropriate choice of policies and measures. Moreover, while involving additional costs, the overall effectiveness of adaptation could be limited given the specific nature of the adaptation measures. The choice of inappropriate policy could prove significantly costly, especially for the developing countries, where climate change impacts will be more severe and the basic resources to tackle the problem are limited.

Similar arguments can also be made with regard to risks imposed by the natural disasters such as droughts, cyclones, floods and sudden onset events like flash floods, hailstorms etc. While event specific response strategies cannot be ruled out, it could be prudent to enhance the resilience of the society to absorb the adverse impacts caused by such natural disasters. Further, there are close linkages between the changes in climate and the frequency and magnitude of the climate induced natural disasters.

Need for 'Mainstreaming'

The present-day vulnerability to natural disasters is significantly high in developing countries and the available evidence suggests that the climate change will have large adverse effects on several climate sensitive sectors in the developing countries. Though there are several proposals for adaptation funding in developing countries, the prospects do not look very bright. The scope for accessing international funding for large and fast developing countries like India is further limited.

In view of this, the best available option that developing countries may have is to 'mainstream' climate change adaptation policy into their existing and future development policy and planning. Incremental resources put towards climate change specific measures, while continuing on the overarching developmental goals (such as poverty eradication, reducing food insecurity) may be required. An approach that aims at improving development prospects, while making the economy and its poorer population more climate resilient could be synergistic. Socio-economic development has the potential to reduce the existing development deficit and in turn adaptation deficit, both of which could in turn augment the capacity of the country to adapt to climate change and natural disasters. Mainstreaming will also enable a more integrated approach towards achieving development objectives and avoids a piece meal approach.

There are several other contexts where mainstreaming is often advocated – examples include, gender, environmental change etc. Thus, mainstreaming is not new in the development policy context, even though there has always been a lack of conceptual clarity on how mainstreaming could be achieved and what institutional structure will facilitate mainstreaming. These two issues are discussed briefly below.

Mainstreaming – Approaches

Based on various country experiences with regard to mainstreaming climate resilience into development planning, Pervin et al. (2013) identify three broad approaches that can be seen parallel to the evolution of mainstreaming approaches mentioned above.

i) Climate Proofing Approach – aims to protect development interventions that have been planned in isolation without taking climate change into context. It simply aims at making the development intervention resilient to the climate variability and climate change.

ii) Climate-first Approach – aims to address incremental change in existing climate related risks. Typically involves designing pilot intervention strategies that are climate resilient and (if found effective) subsequently scaling up to sectoral and/or national plans.

iii) Development-first Approach – keeps climate resilience as an integral part of the development planning process from the very beginning.

In the context of planning in several regions in India and other developing countries, the mainstreaming is being attempted through the first two approaches.

Institutional Structure for Mainstreaming

In India, the State Action Plan on Climate Change (SAPCC) and State Disaster Management Plan (SDMP) are the formal institutional platforms at state-level to mainstream climate risk and disaster risk into development planning. Few recent studies (Dubash and Jogesh, 2014; Bahadur et al., 2016) that studied the SAPCC and SDMP, respectively of different states provide useful insights about the process. The plans prepared either in the climate change context or the disaster management context should not run parallel to the development plans that the state governments make. For effectively addressing the climate risk and the disaster risk it is important to synergize different plans into development planning.

The SAPCCs are typically prepared by a nodal agency (such as Department of Environment) with inputs from various other departments. However, given the long-term nature of the climate change problem, the Planning Department could have also taken-up the process. Such ex-ante option could run the risk of greater capacity shortfalls in climate change knowledge than environment departments. Also, there could be greater acceptability among different departments for the coordinating role done by DoE. In such ex-post option, the state planning departments should consider and integrate the outcomes of the climate plans into development planning exercise, as is being attempted currently in the context of some states such as Kerala. Further it must be noted that, like the planning process, the SAPCC as well as SDMP should be seen as dynamic processes that are periodically revised. For this purpose, as well as effective implementation of the plans, an appropriate institutional structure may be conceived and nurtured. Dubash and Joseph (2016) provide a detailed account of the evolution of institutions for climate policy at the national level. Drawing inferences from this experience, it seems appropriate to establish a high-level agency (say, Chief Minister's Council on Climate Change) to not only send clear signal to all the line departments the critical importance accorded to climate change concerns, but also to establish effective coordination across different departments and ministries. It is also critically important to take regular inputs from academic institutions and think tanks to ensure that the mainstreaming activities to retain a focus on climate change.

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AN ENQUIRY INTO THE LOSSES AND DAMAGES FROM FLOODS IN INDIA: SOME PRELIMINARY OBSERVATIONS

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Loss and Damage (L&D) from climate related natural disaster is emerging as one of the key themes in research on climate change although their inclusion in the global climate debate was rather recent. The concept as such emerged in the global climate negotiations during 1991 primarily to compensate the small island states for the impacts of sea level rise. Within the United Nations Framework Convention on Climate Change (UNFCCC), while the term got first mentioned in the Bali Action Plan (COP 13), re-emergence was only after the publication of the fourth assessment report which highlighted that mitigation efforts alone are insufficient to avoid all impacts of climate change. Thereafter, in Cancun during the year 2010 (COP 16), the role of adaptation gained some ground and the world programme in L&D was established under the Subsidiary Body for Implementation. On a more formal note it was only during the Doha round of negotiations (COP 19) that the institutional arrangements were arrived at to address L&D under UNFCCC. Again, a landmark was the publication of the Fifth Assessment Report, which envisaged a greater role for adaptation and disaster risk reduction due to high certainty of an increasing trend in incidence and intensity of climatic aberration and extreme events.

L&D refers to the residual impact from climate extremes, which are beyond the capacity of a society to cope with or adapt to. Therefore, while adaptation and mitigation activities undertaken at the global and local level are important, it must also be recognized that no matter whatever may be the scale of mitigation and /or adaptation, society is bound to witness some outstanding losses that are unavoidable. This was on account of the following reasons, the first is that locked-in historical emissions and consequent rise in global temperatures are likely to increase the occurrence of extreme events and hence the associated L&D. The second is that certain adaptation measures may not be implemented due to the presence of a tradeoff between the costs and benefits of these adaptation measures over different periods of time. This is to say that some adaptation measures are not implemented and may create future L&D because they are costlier to implement in the immediate run and only show tangible benefits over a substantial period of time.

The treatment of adaptation here also requires a more detailed introspection with the question being which activities qualify as adaptation to climate change. This is a question which is difficult to answer as it will be almost impossible to draw a boundary and qualify interventions that fall within these as adaptation to climate change and those that lie outside of it. This is exactly where further complexities come in: adaptation is hypothesized to be a function of the risk and vulnerability faced. Therefore, it is always plausible that there exists a set of activities that although don't have a direct link with adaptation to the impacts of climate change, indirectly reduce the incidence of risk and vulnerability (either through decreasing / diversifying the exposure or by building the resilience of the vulnerable). Such mechanisms are also termed as generic adaptation measures and examining the role of these in dealing with impacts of climate change remains neglected in literature barring a few studies. It is important to note here that the enhancement of development capacity through generic adaptation measures not only helps in building greater resilience of the vulnerable but also aids in building resilience to future impacts.

The society incurs two types of costs due to the L&D: (i) economic; which is the impact on goods and services that are traded in the market, and (ii) non-economic that refers to the affected goods and services for which market does not exist. It is again classified into direct and indirect costs. The direct L&D are the immediate consequences of the disaster mostly the immediate damages or destruction to assets or stocks, due to the event per se (e.g. crop loss, houses damaged, impact on ecosystem services, etc.). The indirect ones refer to those that are motivated by the consequences of the disaster, e.g., impact on health, psychological trauma, etc.

Therefore, the total economic impact extends beyond the directly measurable ones and often significant secondary and indirect effects are more important in the long run prospective. For example, the destruction of productive assets and public infrastructure inhibits economic activity, while the increased demand for public expenditures for relief and recovery disrupts fiscal planning and prejudices public and private capital investment. Although ex-post disaster L&D assessment is carried out by government agencies across the world, it should be noted that several economic and non-economic indicators are not accounted for in the process.

L&D from climate related natural disasters have been exhibiting an upward trend over the past few decades on a global scale and so also is the case in developing countries and small island states. India is not an exception to this pattern and the scenario is likely to continue in the foreseeable future due to climate change as per the observations of the Intergovernmental Panel on Climate Change (IPCC). India has been historically vulnerable to the incidence of extreme events with average annual economic loss in India, due to disasters being estimated to be approximately US$9.8 billion (GAR-UNISDR, 2015). A significant share (close to US$ 7 billion) of this is accountable to the incidence of floods. With this backdrop we examine the nature and trend of reported L&D due to floods in India based on secondary data collected from Central Water Commission (CWC) of Government of India on several L&D indicators for the time period 1953-2011. However, one general concern is regarding missing data: some of the L&D indicators are not reported or calculated for the events and the reason for their non-inclusion in the data set is not very clear.

Given the caveats, on an average 32.43 million people were affected (3% of India's total population as per the Census of 2011) with the minimum people affected being 3.61 million and the maximum going up to approximately 70.45 million. Further, approximately 0.03% of the total net sown area (3.79 million ha) was destroyed per year, due to floods corresponding to a monetary loss to the tune of INR (Indian Rupee) 11.15 billion. Floods killed an average of 1.65 thousand people between 1953 and 2011, with a minimum of 0.04 thousand and maximum of 11.32 thousand. About 1.25 million houses were damaged per year representing an economic loss of INR 5.57 billion. It is found that on an average INR 18.68 billion was lost due to damaged to public property. With regards to reported economic L&Ds, the mean value was INR 35.4 billion, with minimum and maximum damages at INR 0.07 billion and INR 325.52 billion, respectively. It's coefficient of variation was 165.14%, indicating a high variability in the distribution of L&D figures among the states. While damaged to public property accounts 53% of the total economic L&Ds, crop loss and houses damaged represent 31% and 16%, respectively. Disaggregating the L&D to the level of states unravels some interesting aspects. It is observed that around 17 states have experienced floods for more than forty years during the study period (1953-2011), and these states are Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Uttar Pradesh, West Bengal, Himachal Pradesh, Manipur, and Tripura. The states where flood occurs almost every year are Bihar (59), West Bengal (58), Assam (57) and Uttar Pradesh (56). A higher number of people affected in the states were: Bihar (386.94 million), Uttar Pradesh (404.01 million), West Bengal (223.6 million), Odisha (148.5 million), Andhra Pradesh (117.47 million) and Assam (163.37 million). While an increasing trend has been found for all the states, a steeper slope is observed in the states like Andhra Pradesh, Assam, Bihar, Himachal Pradesh, Kerala, Maharashtra, Manipur, Odisha, Tripura and Uttar Pradesh. This also confirms the observations that as in the case of global case overall extreme events are increasing; L&D from floods in India are also rising (both in terms of the country as a whole and also at a disaggregated level across the states). In sum it can be said that a wide variation does exist in the reported loss and damage and area affected across the states over time

Given this, these two questions emerge: (i) What is the driving force for the increase in the reported L&D? and (ii) How big is the impact of these on the economy on a formal note?

The overall trends are not very clear as far as the whole country, India is concerned but changes exist over time. There is evidence that both significant increase and decrease in the damage due to floods are observed across the entire dataset. Comparison of five most flood prone states of India Andhra Pradesh, Bihar, Odisha, Uttar Pradesh and West Bengal shows: (i) an increase in public utilities affected and total damage in Andhra Pradesh and Odisha with changes in the distribution of impacts, (ii) population affected has increased in Odisha and West Bengal while it has decreased in Uttar Pradesh, (iii) share of crop area affected has increased and so also damage to houses in West Bengal while it decreased in Uttar Pradesh, (iv) Bihar, Odisha and Uttar Pradesh report a decrease in the value of crop affected while crop damage normalized by the cropped area has declined for the states of Bihar and Uttar Pradesh. So, coming to the question what is causing an increase in the reported L&D due to floods in India, there are two drivers: (i) climate change is causing an increase in the intensity and occurrence of these events (the risk angle) and (ii) economic development is resulting in higher elements being at risk that is driving the volume of L&D (the exposure side). Turing over the next question of how big has been scale of these direct losses the following points are noteworthy: (i) the volume of losses due to floods have exhibited a significant increased over the period 1953-2011, (ii) while we don't find any evidence of intensification of flood events during the period, nevertheless they have significantly eroded a small portion of the state GDP for the top five most flood prone states of India, (iii) although no single event amounts to one percent of the state GDP, the incidence is rather regular with wide variation existing in percentage of area affected due to floods across the states, (iv) while numerically we observe the share of losses and damage to state gross domestic product significantly increasing over time even if magnitude is low and (v) no statistically significant trend observed for percentage of flood area affected normalized by geographical area of the state and crop area affected. Evidence suggests that higher losses are partly driven by the growth trajectory of the state.

Further, analyzing this in terms of a counterfactual framework, it emerges that at the states' level, trend rate of growth of GDP is approximately four percent for the entire time period with incidence of floods turning as an insignificant coefficient in terms of impact. However, the important finding that comes out is that the treatment effect is significant and negative across different models and functional forms. More importantly controlling for intensity of floods does not change the results for the treatment effect and therefore although small in magnitude past flood events have negatively affected the state GDP for the five most flood prone states of India namely, Assam, Bihar, Andhra Pradesh, Uttar Pradesh and West Bengal. In summary, due to the absence of any clear signals from the climate part the observed affects have been largely driven by the growth story (exposure). The economic story is rather straight: growth and development have increased elements at risk across all sectors with notable increase in public utilities affected signifies the cumulative effect of intensification. However, further research is required to establish the manifestation of climate-economy interface on observed impacts and to identify the exact impact of disaster risk reduction and management interventions on the exhibited outcomes

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CLIMATE CHANGE VULNERABILITY AT HOUSEHOLD LEVEL IN URBAN AND RURAL AREAS OF NEPAL

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Abstract: The effects of climate change are particularly adverse for sectors like agriculture and water management, which are dependent on climatic variables. Subsistence farmers in developing countries like Nepal, where agriculture is mainly rain-fed, and who have very few resources, and weak adaptive capacity, may be unable to cope with changing climatic conditions. These factors increase farmers' vulnerability to climate change. Local level vulnerability assessment is very important to formulate suitable policy measures to address their livelihood. Household level vulnerability to climate change depends on different factors, so there is still uncertainty in the methodology to measure vulnerability. However, this research has adopted the concept of integrated vulnerability assessment and used an indicator method for analysing the vulnerability of farmers of an urban area – Devchuli municipality of Nawalparasi, and a rural area- Kagbeni VDC of Mustang districts of Nepal utilizing the data collected from 148 households and VDC profiles from these study areas. Different socioeconomic and biophysical factors were collected and classified into three classes (Exposure, Sensitivity and Adaptive Capacity). Household analysis of vulnerability indicated that poor households are vulnerable anywhere due to low adaptive capacity, regardless of where they are located. Policy measures should focus on improving the adaptive capacity of rural households.

Keywords: Climate Change, Vulnerability, Adaptive Capacity, Exposure, Sensitivity, Principal Component Analysis (PCA).

Introduction

The impact of climate change affects developing countries more severely than developed countries because of their generally low adaptive capacities (IPCC, 2007). Rural communities in developing countries like Nepal are more vulnerable to climate change and its impacts due to their limited capacity to cope with hazards associated with changes in climate (UNFCCC, 2009).

Vulnerability has been considered as a function of adaptive capacity, sensitivity and exposure (Fusseland Klein 2006; IPCC 2001; Kelly and Adger 2000). Adaptive capacity is the ability of people to cope with or adjust to the changing context. It is explained mainly by socioeconomic indicators. Sensitivity is the degree to which a system is affected adversely or beneficially - by climate stimuli, and exposure is the nature and degree to which a system is exposed to significant climatic variation (IPCC, 2001).

This study focuses on the communities of urban and rural areas of Nepal. Vulnerability to climate change depends upon adaptive capacity of a wide range of attributes, and adaptive capacity is explained by socio-economic indicators. The importance of indicators varies from place to place. The study intends to compare the vulnerability and importance of adaptive capacity of urban and rural areas of Nepal. So, Devchuli municipality of Nawalparasi was chosen as an urban area and Kagbeni VDC of Mustang district as a rural area of Nepal. Both of these study areas lie in the same political region of Nepal but are in different geographic regions. Devchuli lies in the southern region of Nepal where population density is increasing due to suitable weather for settlement, fertile land and access to services and facilities. Instead, Kagbeni lies in mountain district-Mustang, northern part of Nepal where the temperature is cold, and it is a semi-arid region. Their adaptive capacity and adaptation practices are different than Devchuli.

Methodology

Study area and data sources

This study covers 2 sites – Devchuli municipality of Nawalparasi district and Kagbeni VDC of Mustang district. These two sites were selected on the basis of their location, settlement of the people and access to services and facilities. The southern part of Nepal has plain areas, and has access to services and facilities. So, the population density is also higher in Devchuli compared to Kagbeni.

Devchuli municipality has a total area of 15.77 square kilometers and the total population is 15494, with a large favorable agricultural land (12.3 Sq. Km). Climatically it lies in a sub-tropical zone. On average, 2300ml rain occurs annually. People have migrated from different places to Devchuli municipality. So, it has a heterogeneous ethnic composition, but Kagbeni has a homogenous and indigenous Gurung community. Kagbeni VDC is situated in the Lower Mustang, with an area of 285.45 sq. km and a total population of only 1140. The cultivated irrigated land constitutes 2.98 square kilometres. Climatically, Kagbeni falls in alpine climatic zone.

This study is based on the primary data collected by household surveys conducted in two phases, and secondary data collected from respective VDC offices. Eighty-four households from Devchuli and 64 households from Kagbeni VDC were selected for the study.

Selection of vulnerability indicators

Vulnerability to climate change was analysed for the ward level by a complex inter-relationship of multiple factors: exposure, sensitivity and adaptive capacity. Many variables of these components cannot be quantified directly. In this study, selection of indicators for adaptive capacity was based on the CARE climatic vulnerability and capacity analysis methods and DFID sustainable livelihoods framework, where adaptive capacity is taken as a function of asset possession by the households (Nelson, et al., 2010b).

Exposure

Exposure is the nature and degree to which a system is exposed to significant climatic variation (IPCC, 2001). Historical changes in climate variables (maximum and minimum temperature, rainfall amount, rainfall days and 24-hour extreme rainfall) and occurrence of extreme climatic events were taken as indicators of exposure for this study. The coefficient of the trends of climate variables was calculated. This chapter has considered floods and drought as climate change events for this study.

Sensitivity

Sensitivity is the degree to which a system will respond to a change in climatic conditions (IPCC, 2001; Paavola, 2008). Marshall et al. (2009) and Daze, Ambrose, & Ehrhart (2009) have taken sensitivity indicators based on the livelihood impacts of climate change related disasters. Fatalities due to natural disasters, property damage (land, houses and crop) due to natural disasters and share of non-agricultural income of a family are considered as sensitivity of a household.

Adaptive capacity

Adaptive capacity is the ability of people to cope with or adjust to the changing context and is explained by socioeconomic indicators. These indicators have been divided into five types of livelihood assets- human, social, physical, natural and financial. All of these indicators are not directly related to climate shocks only, but support to combat climatic shocks through different ways.

Table 1: Indicators for adaptive capacity

S. No.	Assets	Indicators
1	Human	Knowledge of climate risk, Agriculture and vocational training, education level of family members
2	Social	Women's savings and loans groups, membership in CBOs
3	Physical	Access to services and facilities (road, market, school and medical centre), Irrigated Land, House type, device to access information
4	Natural	Reliable water resources, settlement in un-inhabitant areas
5	Financial	Livelihood Diversification Index, Diversified Income Sources

Calculation of the vulnerability index

Data in this study were at different scales, from zero to hundred. So, Normalization was done by using the formula:

$$\text{Normalized Value} = \frac{(\text{Actual value-Mean})}{(\text{Standard deviation})}$$

Then, weights should be allocated to these indicators. The literature indicates that there are three methods used to assign weights to indicators: (1) arbitrary choice of equal weight, expert judgment and statistical methods such as principal component analysis or factor analysis. Principal Component Analysis (PCA) was used to generate weights chosen for the study.

Results and discussion

Exposure

Table 2 shows the weights and coefficient trend of the exposure indicators across the two study sites. Weights represent the importance and relation of indicators to exposure. The coefficient of both maximum and minimum temperature parameters shows increasing trends in both areas but Kagbeni shows a slow decreasing trend for annual maximum temperature.

Table 2: Weights and coefficients for indicators of exposure

Indicators	Devchuli	Kagbeni
Annual maximum temperature	-0.663 (0.006)	-0.559 (-0.001)
Annual minimum temperature	0.026 (0.016)	-0.079 (0.07)
Rainfall amount	0.797 (7.119)	0.920 (1.508)
Rainfall days	0.546 (-1)	0.846 (-0.05)
Extreme rainfall	0.730 (0.233)	0.554 (0.1)
Natural disasters	0.27 (1.75)	0.41 (2.1)

Source: Department of Hydrology and Meteorology, Nepal, Field Survey 2012/13
(Note: Figures in parenthesis indicate the coefficient trend of indicators)

Sensitivity

Table 3: Weights and VDC mean values for indicators of sensitivity

Indicators	Devchuli	Kagbeni
Fatalities	0.910 (1)	0.95 (1.18)
Land damage	0.968 (48.33)	0.93 (27.09)
Household damage	0.998 (14.44)	0.93 (2.1)
Crop damage	0.996 (466.67)	0.99 (230.5)
Non-agriculture based income	-0.231 (56)	-0.491 (75.76)

Table 3 shows that indicators of sensitivity have contributed to the sensitivity index as per the assumption. Although the number of natural disasters and damage looks high in Devchuli, all the indicators show high values in Kagbeni if we compare it by percentage. Household damage, land and crop damage due to flooding and drought in Devchuli and Kagbeni are the major problems related to sensitivity. Both study sites are facing drought frequently in recent years. Over the last decades, they tackled drought 8 times during the summer season in Devchuli.

Adaptive Capacity Index and Vulnerability Index

Devchuli

Figure 1 and 2 display the ward-wise index values for adaptive capacity and its five components and vulnerability of Devchuli. Most of the assets types are positive in ward number 8, 5 and 6 in Devchuli, so the overall adaptive capacity is also high in those wards. Financial assets and human assets are the two most important determinants of adaptive capacity, followed by social assets in Devchuli –households of ward number 1, 5 and 8 have positive score on those assets.

The higher the value of vulnerability index, the higher the vulnerability of wards. According to the ward-wise vulnerability index of Devchuli municipality, ward number 7 and 3 are the most vulnerable wards, while number 5 and 8 are the least vulnerable. Ward numbers 3 and 7 are along the river. The frequency of natural disasters, for instance, as well as house, land and crop damage due to disasters are common in these wards. So, they have high exposure and sensitivity with low adaptive capacity, resulting increased vulnerability.

Kagbeni

The mean values of individual indicators in figure 2 shows that ward number 7 and 8 rank first and second in terms of possession of all assets, followed by ward number 9 and 6 in Kagbeni VDC. Ward number 1 stands last in terms of all the asset categories (except financial assets) and thus has the least adaptive capacity.

All wards of Kagbeni VDC are highly exposed to climate change parameters and sensitive to climate related disasters. Different wards have different adaptive capacities. Based on that, the vulnerability of wards is different to one another. Ward number 1 has highest vulnerability index followed by ward number 3 and 4, as adaptive capacity is low in those wards. In contrast, adaptive capacity is high in ward number 7 and 8, so they are less vulnerable to climate change

Figure 1: Ward-wise index scores for vulnerability and it's components in Devchuli

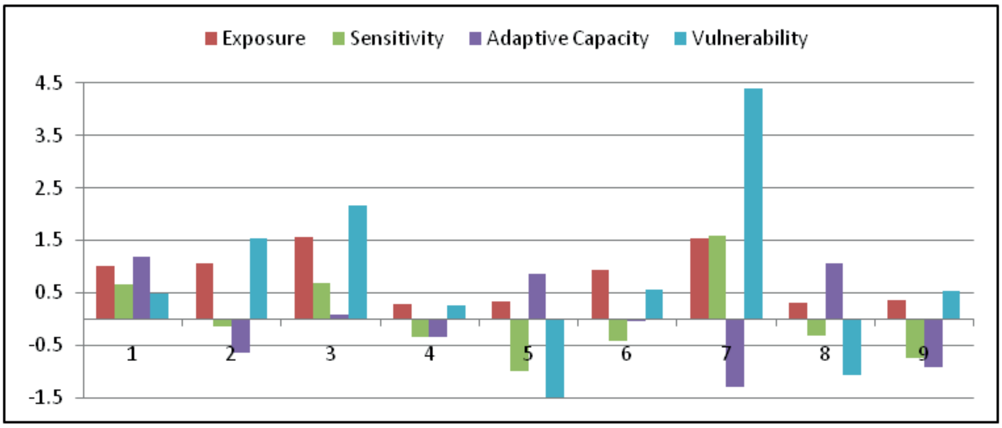
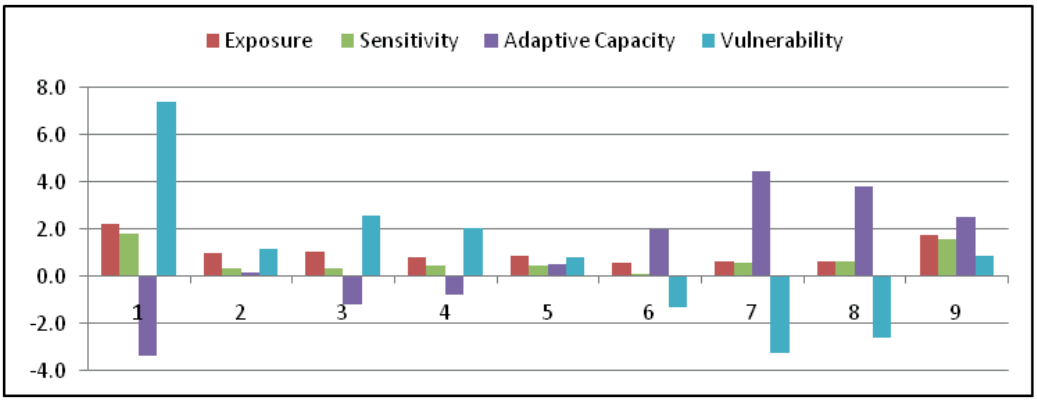


Figure 2: Ward-wise index scores for vulnerability and it's components in Kagbeni VDC



Conclusion and recommendations

Biophysical elements that determine exposure, for instance, temperature, rainfall, rainfall days, extreme rainfall and natural disasters are the most important components to determine the vulnerability; - they are beyond the immediate influence of the policy makers. Adaptive capacity is the component which is directly focused on for policy implications, out of three components. Adaptive capacity has indirect implications on sensitivity. Improving adaptive capacity helps to improve the sensitivity of the community. For instance, improving knowledge of farmers about climate change and literacy rate (physical assets) may decrease fatality, land and crop damage in the community. Improving the irrigation facilities (physical assets) in the community decreases the sensitivity of crops to droughts.

Both study sites are similar in terms of exposure to flooding and drought, but different for sensitivity and adaptive capacity. The urban area- Devchuli, is less sensitive and has high adaptive capacity, but the mountainous rural VDC –Kagbeni, is more sensitive to climatic disasters and has low adaptive capacity. So, Kagbeni is more vulnerable than Devchuli. Kagbeni is far behind, mainly for transportation facility, access to technology, social networks, hospitals and markets. So, efforts from government or non-governmental organizations in Kagbeni should be geared towards improving road facilities and house types (physical assets). Also, policy should emphasize the non-agriculture livelihoods option because it helps to improve the cash income of the community and reduce their dependency on natural resources.

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THE GROWTH EFFECTS OF NATURAL DISASTERS: DOES THE LEVEL OF DEVELOPMENT MATTER?

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Introduction

In general, the nature and scope of impact of natural disasters are considered to be limited to the geographical region where disasters strike. However, the direct damages (human deaths, injuries and property losses etc.) caused by the initial impact of natural disasters may instigate indirect damages (loss of potential wages and capital) at macro level in terms of forgone production and/or agricultural output and thereby affecting a country's GDP. Therefore, to explore the macroeconomic consequences of natural disasters may provide valuable insights and ultimately help the policy makers in effectively ascertaining the costs and benefits associated with investing in Disaster Risk Reduction. The theoretical relationship between natural disasters and economic growth is rather ambiguous. The neo-classical growth theories propagate negative effects of natural disasters while Schumpeter's creative destruction theory suggests positive growth effects in the short run. The inability of the existing growth theories in explaining the relationship between natural disasters and economic growth directs us to rely upon the empirical research. Though, the literature exploiting the macroeconomic growth effects of natural disasters is inconclusive as well (Cavallo, 2009) with studies reporting seemingly contradictory results. There is handful of studies exploring the growth effects of natural disasters on multiple sectors of the economy. The seemingly contradictory disaster literature is quite surprising since most of the researchers exploring the relationship of natural disasters and economic growth have used five-year growth rates and a common data source i.e. EM-DAT. However, it is relatively a new research area which is still in early stages of development.

In this backdrop, our study aims to explore the macroeconomic consequences of natural disasters separately by disaster types and macroeconomic indicators. The study also examines whether large or severe disasters significantly reduce the economic growth in comparison to typical or moderate disasters. Furthermore, following few key studies (Fomby et.al., 2013; Loayza et.al., 2012; Noy, 2009) in the literature, we consider the difference between developed and developing countries to investigate whether the macroeconomic impact disasters damages is influenced by the level of development.

Data and Methodology

This study employs a panel of 102 countries over the period 1980-2015, which includes 29 OECD and 73 Non-OECD countries. Three dependent variables representing economic growth are used - per capita growth rates of real GDP, agricultural and non-agricultural value added. Following review of literature, we have included three sets of explanatory variables: (a) natural disasters variables, (b) control variables i.e. standard determinants of economic growth (viz. government consumption, inflation, education domestic credit, trade openness) and (c) proxies of external shocks (viz. terms of trade and period specific dummies) other than natural disasters. The data for all the variables, except for natural disasters, were obtained from the World Bank[37].The data on natural disasters were obtained from the Emergency Disasters Database (EM-DAT)[38]. We have taken natural disaster intensity variables for different disaster types namely droughts, floods, earthquakes and storms representing the total number of people affected including human deaths per thousand of total population for each country-year. To differentiate between moderate and severe natural disasters, we have constructed dummies based on disaster intensity. The disaster dummies (for each disaster type) take value of 1 if disaster intensity is greater than 0.01 percent in case of moderate disasters and 0.1 percent in case of severe disasters.

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37 Data obtained from World Development Indicators 2016.
38 EM-DAT is maintained by Center for Research on the Epidemiology of Disasters (CRED).

In disaster literature, there is no methodological unanimity in estimating the growth effects of natural disasters. In general, the selection of appropriate estimation method was mostly dependent on the nature of available data and the diagnostic tests portraying potential problems in the estimation. Many studies exploring the relationship of natural disasters and economic growth used fixed effects models. Fixed effects panel data model allows for controlling the unobserved time invariant heterogeneity across cross-sections and the time variant shocks that are common for all the cross-sections. Several lags of the dependent and independent variables can be used as instruments to counter the endogeneity problem and the negative bias of the estimators which may arise especially in dynamic panel models. In this backdrop, we have used generalized method of moments (GMM) estimators for dynamic panel models which are based on differencing regressions to control for time invariant effects and using lags of dependent and independent variables as instruments. We have used the system GMM approach over differenced GMM, which combines the regression equation in levels and regression equations in differences into one system. It is done to remove the potential biases associated with difference estimators and to avoid the problem of weak instruments which may often lead to poor small sample properties and relatively larger standard errors in fixed effects estimation(Arellano & Bond, 1991; Kiviet, 1995)

.A series of diagnostic tests have been conducted to obtain statistically robust results.

We have used the following model specification:

$$Y_{i,t}=\beta_0 Y_{i,t-1}+ \beta_1 ND_{i,t} + \beta_2 X_{i,t}+ \mu_i + \theta_t + \varepsilon_{i,t}$$

where, the subscripts i and t stand for country and year, respectively. $Y_{i,t}$represents the respective dependent variables and $Y_{i,t-1}$ is the first lag of $Y_{i,t}$. ND represents the natural disaster variable/s and X represents the set of control variables. θ_t represents year fixed effects. μ_i represents country specific heterogeneity and $\varepsilon_{i,t}$is the error term.

Summary of Findings

Natural disasters have diverse effects on macroeconomy which differs across economic sectors and disaster types. The combined disaster variables are not significant in most cases however, the results changed significantly when segregated into different disaster types. Typical floods have positive impact on agricultural growth and even the growth of other sectors of the economy. In general, water is critical for agriculture, but excess supply of water maybe harmful for the crops. In this sense, the positive effects of floods on agricultural growth are quite surprising. This, however, may be attributed to the timing of occurrences of floods i.e. the effects of floods are on only one cropping season out of multiple seasons in a year. As highlighted by Loayza et.al.(2012), the abundant supply of water throughout the country may have positive effects on subsequent growing seasons and thereby increasing the total agricultural output. Following a flood disaster, the agricultural growth may also increase due to the reduction in agricultural production and subsequent increase in the prices of agricultural products, especially in unaffected areas. Consequently, as pointed out by Fomby et al.(2013) and Cunado and Ferreira (2014), the positive impact of floods on agricultural growth may trigger higher GDP growth especially in agriculture based economies. However, for severe floods, the growth effects are found to be negative, suggesting that the damages and destruction caused by the severe floods outweighs their positive effects on agricultural output. The impact of floods is even stronger in magnitude in developing countries.

Droughts have negative effects on the agricultural growth but fails to show significant impact on any other economic sector. Severe droughts, though, found to be significantly decreasing the GDP growth as well in case of developing countries. The scarcity of water certainly has negative impact on the agricultural output, provided the critical importance of water for agricultural. In general, the impact is more severe in subsequent years (or cropping seasons) following a drought event mainly, because it is slow on-set disaster. There were many empirical studies reporting strong negative impact of droughts on agricultural growth (Dercon, 2004; Hlavinka et al., 2009). Storms have negative impact on the GDP growth as well as agricultural growth in developing countries. Severe storms show similar results though the effects are relatively stronger than typical or moderate storms. Earthquakes seems to be decreasing the non-agricultural growth in developing countries while for the full sample of countries, their effects are positive. The positive effects of earthquakes and for that matter floods may also be aligned with the Schumpeter's creative destruction theory, indicating that the damages and destruction caused by these events may trigger greater investment in reconstruction and/or upgradation of houses and public infrastructure. This may ultimately enhance the country's GDP in the short to medium run. Severe earthquakes show negative impact on non-agricultural growth while fail to significantly affect any other economic sector. Overall, it is observed that while typical or moderate disasters may have positive relationship with economic growth, severe disasters do not exhibit such relationship.

Concluding Remarks

This study aims to ascertain the growth effects of natural disasters on major macroeconomic indicators. Using system GMM approach for dynamic panel models, we conclude that natural disasters have diverse macroeconomic consequences which differ across economic sectors depending on the disaster types and their respective intensities. The moderate disasters can have positive effects on medium-term economic growth but severe disasters always show negative relationship with economic growth. In line with few earlier studies, the growth effects of natural disasters are statistically stronger in developing countries than developed countries. This would imply that the developing countries are in urgent need of investing more in DRR to not only safeguard the people and assets but also to ensure sustainable development goals in the aftermath of natural disaster. The findings of this study may help policy makers in effectively ascertaining the probable costs and benefits of investing in DRR strategies, which in fact is one of the four priority actions highlighted in the Sendai Framework for Disaster Risk Reduction (SFDRR).

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CLIMATE CHANGE AND INDIAN AGRICULTURE: IMPLICATIONS FOR FOOD SECURITY

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Introduction

Climate change impacts on agriculture are being witnessed all over the world, but countries like India are more vulnerable in view of the high population depending on agriculture, excessive pressure on natural resources and poor coping capabilities. The projected impacts are likely to further aggravate yield fluctuations of many crops impacting food security. For every one degree increase in temperature throughout the growing season, the production of wheat in the country may reduce by 4-5 million tonnes according to the study conducted by IARI, New Delhi. Similarly, rice yields may decline by 6% for every 10^{0}C rise in temperature. Study by Bapujirao et al (2014) indicated that rise in minimum temperature is happening during kharif season @ 0.190C 10 yr-1 and this rise was found to have a negative impact on paddy yields over 50.3% cultivated area. Warming during rabi season has serious implications for production of rabi crops like wheat, mustard and chickpea in the Indo-Gangetic plains. It is to be noted that the contribution of rabi season to total food grain production is increasing in recent years. Negative impacts on mustard, ground nut, potato, maize and sorghum are also reported due to warming. Horticulture crops are particularly vulnerable to temperature, unseasonal rainfall, hailstorms and pest and diseases incidence caused by climate variability. Besides direct effects on crops, climate change is likely to impact natural resources like soil and water. Increased rainfall intensity in some regions would cause more soil erosion leading to land degradation. Increased temperatures will also increase crop water requirement. A study by CRIDA on major crop growing districts in the country for four crops, viz., groundnut, mustard, wheat and maize indicated a 3% increase in crop water requirement by 2020 and 7% by 2050 across all the crops/locations. Irrigation requirement in arid and semi-arid regions is estimated to increase by 10% by every 1oC rise in temperature.

Economic impact

Though the medium term (2010-2039) impacts on food production are in the range of 4.5 to 9 per cent, long term (2070-2099) impacts could reduce yields by 25 per cent or more. Since agriculture makes up roughly 18 per cent of India's GDP, a 4.5 to 9 percent negative impact on production implies a cost of climate change to be roughly up to 2 per cent of GDP per year. Since maintaining agricultural productivity is critical for the well-being of the poor, climate change losses could hit the poor most. In the absence of rapid and full adaptation, the consequences of long-run climate change could be even more severe on livelihood security of the poor (Guiteras et al. 2007). Rainfed agriculture in particular, is likely to be more vulnerable. Reduction in number of rainy days will result in longer dry spells affecting rainfed crops in semiarid and arid regions. Vulnerability mapping of Indian agriculture to climate change by CRIDA indicated that districts with very high and high vulnerability to climate change are in Rajasthan, Gujarat, Maharashtra, Karnataka and MP (Figure 1). These areas are also witnessing high ground water exploitation and facing water quality issues.

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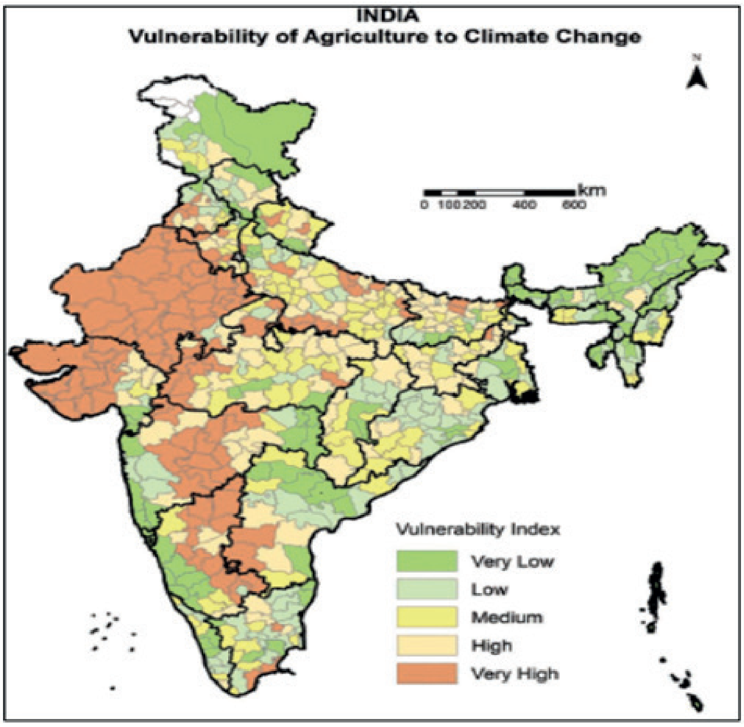
Figure 1: Vulnerability Atlas of Indian Agriculture to Climate Change, 2021-2050

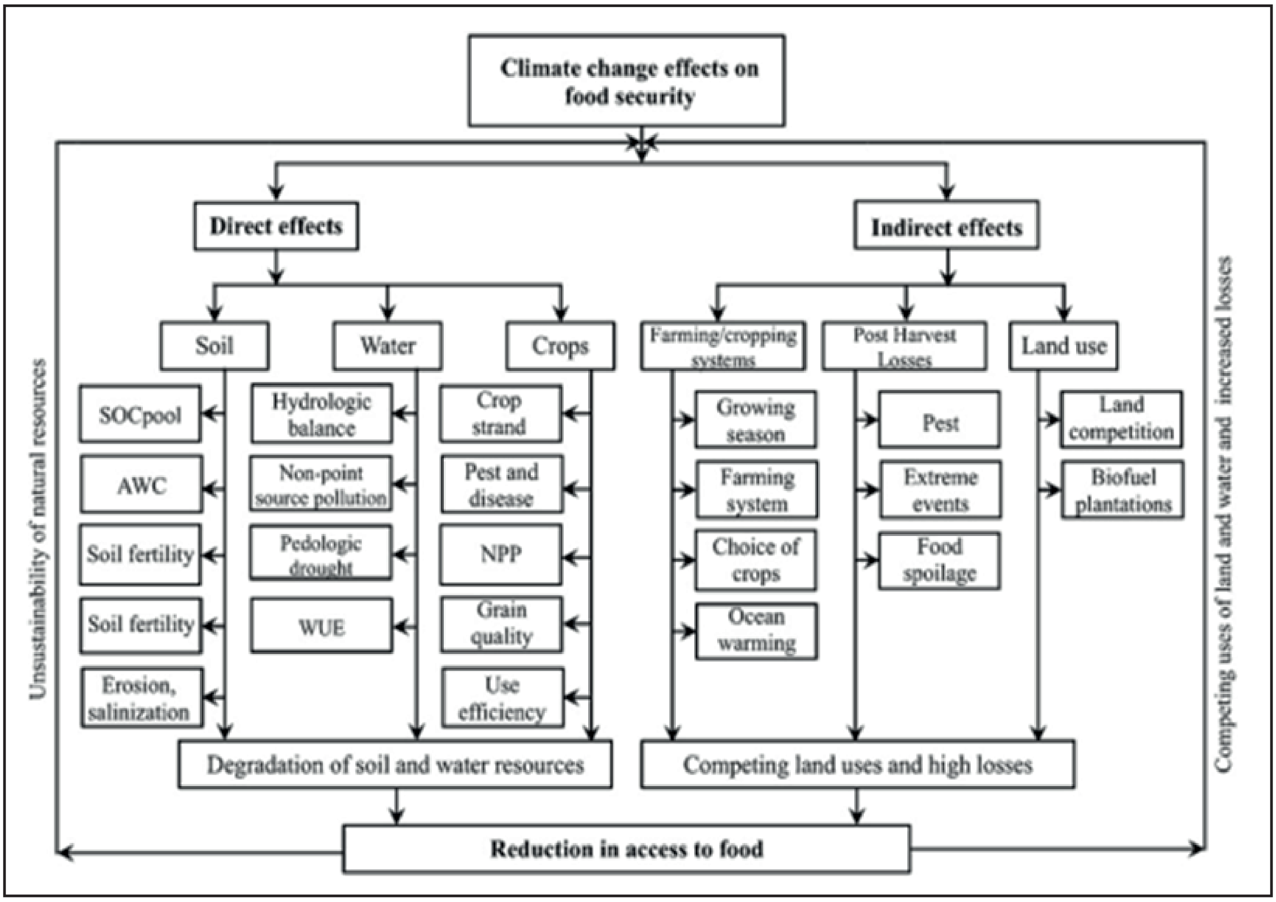


Source: Rama Rao et al, 2013

Implications for food security

Food security means when all people all the time have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs. Food security has three components i.e. Availability, Access and Absorption. Several modeling studies were carried out on climate change impacts on food production, but mostly on wheat and rice and to some extent on pulses and coarse cereals. Short term impacts on many food crops in the range of 6 to 10 per cent can be offset by adaptation measures based on available technologies like advancing planting dates, heat tolerant varieties, efficient water management, conservation agriculture and protected cultivation etc. But addressing long term impacts requires investments on strategic research and extension and helping farmers in risk management through innovative insurance products. However, there are very few studies on how climate change impacts the access to food, particularly in India. The fourth assessment report of IPCC puts the number of people in the world who are likely to suffer from hunger by 2080 at 200-600 million depending on the scenario used. No such specific data is available for India. Undoubtedly, future climate change and variability could significantly influence the economic access to food in India both in rural and urban areas. Droughts, floods and extreme weather events not only reduce crop yields but also affect the incomes and livelihoods of farmers and farm labourers due to loss of wages and increase in prices. The nutritional quality of foods like protein and mineral content could also be influenced by climate change impacts like elevated carbon dioxide and depletion of carbon and micro nutrients in the soils. It is well known that deficiency of micro nutrients like iron and zinc causes hidden hunger. Rattan Lal (2013) described the complex relationship between climate change and food security in the flow chart (Figure 2).

Figure 2: Direct and indirect effects of climate change on food security



SOC: soil organic carbon, AWC: plant available water capacity, WUE: water use efficiency, NPP: net primary production.
Source: Rattan Lal, 2013

Adaptation and mitigation

A comprehensive strategy of utilization of existing knowledge, strengthening R&D in key areas and evolving a policy frame work that builds on risk management and providing incentives to sustainable use of natural resources will be required for successful adaptation by farm sector to climate change. The goal of this strategy is to minimize the risks associated with farming and enable farmers to cope with these risks.

The main adaptation strategies include development of new genotypes; intensifying search for genes for stress tolerance across plant and animal kingdom; intensifying research efforts on marker assisted selection and transgenics development for biotic and abiotic stress management; development of heat and drought tolerant genotypes; development of new land use systems; evolving new agronomy for climate change scenarios; explore opportunities for restoration of soil health; use multipurpose adapted livestock species and breeds; development of spatially differentiated contingency plans for weather related risks, supply management through market and non-market interventions in the event of adverse supply changes; research on short, medium and long range weather forecasts for reducing production risks; development of pest and disease forewarning systems covering range of parameters for contingency planning. Documentation and utilization of indigenous knowledge also forms an important strategy towards climate change adaptation.

While adaptation measures are important, we must also focus simultaneously on mitigation measures so that we contribute to a reduction in the pace of global climate change (Venkateswarlu and Arun Shanker, 2009). The important mitigation options include efficient water and nutrient management options to enhance use efficiency; evaluate carbon sequestration potential of different land use systems including opportunities offered by conservation agriculture and agro-forestry; identify cost effective methane emission reduction practices in ruminants and in rice paddy. However, we need to assess the socio-economic implications of proposed mitigation options before developing a policy frame work.

Globally, weather insurance plays an important role in mitigating climatic risks. In several developed countries this strategy has worked successfully as these countries have excellent long-term weather data, farmers have large holdings and have a business approach for farming. In India, the small holders are generally more prone to risks but they are averse to buying insurance policies. The crop insurance scheme has made some progress, but there is a long way to go. Considering the climate trends being witnessed in recent years all over the country, weather based insurance is an important alternative for mitigating risks in agriculture for Indian farmers. Research institutes and insurance companies should develop crop wise data on the weather sensitivity so that appropriate policies can be designed which are friendly to farmers, at the same time keep the insurance companies viable. The Government also should share the premium burden. Instead of spending huge amounts of money on rehabilitation after the disaster, it is prudent to spend on premium subsidy.

Building state of the art infrastructure for research and training of scientists in frontier areas and tools, increasing climate change literacy to different levels of stakeholders, mainly farmers; enhancement of national capacity on decision support systems, developing best weather insurance products for vulnerable areas and farmers and carbon trading in agriculture; and international collaboration are some other key areas through which we can tackle challenges of climate change.

Technology and policy options

No single strategy is adequate to address the complex issue of climate change and its nexus with food security. The National Academy of Agricultural Sciences has brainstormed the issue in 2013 and brought out key recommendations (NAAS, 2013). Following are few technology and policy directions which need immediate attention:

1. Prioritization and focus on vulnerable hotspots: Investments on climate change adaptation have to be focused in scientifically identified vulnerable regions. Unlike other development schemes, climate change adaptation programmes need to be tailored to the needs of the vulnerable regions and communities. To enable this, a robust micro-level collection of weather data on a continuous basis is a pre-requisite. The Government of India should strengthen the weather observatory network in the country and also initiate documenting extreme weather events and their economic impacts. This is essential for both short and long-term planning of climate resilient agriculture. Data availability is a major constraint in India, a national data sharing policy in urgently needed for easy access of weather, crop and market data for all user groups.
2. Investments on technology generation and dissemination: Climate change and variability manifest in terms of increased incidence of abiotic stresses like droughts, floods, cyclones, cold and heat-waves etc. Research on development of multiple abiotic stress tolerant crop varieties needs to be strengthened with adequate financial support and state-of-the art research infrastructure. The government of India made a good beginning by launching National Innovations on Climate Resilient Agriculture (NICRA), but this needs to be strengthened and expanded with focus on capacity building of young scientists. The best output can be achieved if public-private partnership is ensured in development and dissemination of stress tolerant crops and varieties.
3. Prudent use of natural resources: Prudent management of natural resources like land and water are key to achieving resilience in agriculture against climate change. Continued emphasis on on-station and on-farm research is critical in land use planning, environmental services and efficient use of surface and ground water. The best-bet practices in natural resource management can only be promoted widely with a matching policy by the Government. This is largely a public-sector domain and effective inter-institutional and departmental collaboration will produce the best results.
4. Leveraging the ongoing schemes and missions: Several on-going schemes of the Government of India under the Ministries of Agriculture, Rural Development, Environment & Forests, Earth Sciences and Water Resources have strong components

which contribute to climate resilient agriculture. What is important is to prioritize region specific interventions which can minimize climatic risks at farm level and achieve economy scale in implementation and impact through convergence of resources from these schemes. Clear-cut convergence guidelines at state, district, block and village level are to be prepared for achieving this goal.

5. Livelihood diversification and risk transfer: Despite the best efforts in climate change adaptation, extreme climatic events pose immense risks to small and marginal farmers, which leads to total loss of income at times. Promotion of non-farm source of income and enterprises through credit flow and skill development is the only way to minimize such negative impacts. The livelihood diversification efforts should be linked to the national livelihood and skill development missions. Weather-based crop insurance need to be promoted as a risk transfer mechanism widely with built-in incentives and awareness creation among farmers.

6. Financing adaptation costs: It is essential to pool financial resources under different ministries for promoting technology and institutional interventions towards climate resilient agriculture through National Mission on Sustainable Agriculture (NMSA). Additional funds from private sector and international organizations can be ploughed in to upscale successful adaptation strategies. The state governments should be persuaded to commit adequate resources for financing climate change adaptation as the issue has gained significant attention in all most all states.

7. Capacity building: There is an urgent need to build the capacity of different stakeholders on climate resilient agriculture; structured training programmes need to be designed and implemented at all levels with a time frame. Climate resilient agriculture should become an important component of all farmers' training programmes, organized by primary extension service providers. There is a need to utilize the indigenous knowledge of farmers in coping with climate variability.

8. Mainstreaming CC adaptation in planning: The key principles of climate change adaptation have to be mainstreamed into the planning system at the state and central level. Each policy initiative need to be analysed in terms of its implication in promoting or negatively impacting climate resilient agriculture. Investments in agriculture, rural infrastructure and water resources have to be tailored to the needs of the vulnerable regions and communities in all such plans.

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IMPACTS OF CLIMATE VARIABILITY ON CROP YIELDS – AN EMPIRICAL STUDY FOR KARNATAKA

Kamal Kumar Murari[1], Sandeep Mahato[2], T. Jayaraman[3], Madhura Swaminathan[4]

Abstract: A long-term analysis of the agricultural production of major crops shows an increasing tendency. This suggests that climate change may not be the only influencing factor for the productivity, but must be attributed to multiple factors, these include technological, institutional, and access to better extension. Nevertheless, studies on climate variability, at global-scale and in India, suggested that year to year variation in climate has an influence on agricultural productivity. One of the immediate consequences of climate variability is the occurrence of extreme weather events, which are expected to increase in the future as global warming intensifies. Recent literature also points to the negative effect of extreme temperature on yield of major crops in different geographical regions in the world. Taking this as a background, this policy brief highlights the evidence from the literature that is related to exposure to extreme temperature and crop yields. In doing so, we present key findings of Jayaraman et al. (2017), a report recently submitted to Karnataka Agriculture Price Commission, providing an assessment of the influence of extreme temperatures on crop yield in selected crops of Karnataka. Further, this policy note identifies limitations of such studies and suggest policy measures to overcome these limitations in response to provide a definitive and robust assessment of the impact of climate extremes on agricultural productivity.

Introduction

Rainfall and temperatures are the most important environmental conditions for the plant growth. These environmental conditions have a potential to limit the productivity. Much of the literature until recently has focused on the change in the mean values of climate variables as the determining factor for agricultural yields. Within these precipitations takes a pride of place as the key factor for changes in productivity of crops. However, more recent literature has pointed to the significance of other climate parameters that capture aspects of climate variability including the distribution of rainfall over a period of time as well as the exposure to extreme temperatures during various phases of crop growth. The study of crop yields in relation to such parameters is important, particularly to understand the potential the impact in yields in the context of global warming.

Plants response to temperature differ for crop species (Hatfield et al., 2011), but for most crop sufficient warming condition (i.e. atmospheric temperature being around the optimum level) is an important factor for proper growth in different phenological stages- i.e. the stages of plant growth (Asseng et al., 2011). Effect of temperature is generally well understood up to the optimum temperature for crop development. If temperature crosses the optimal level, it produces a negative impact on the crop growth and exposure to a temperature exceeding critical value may produce a devastating effect on the crop growth and thereby impact the productivity (Hatfield and Prueger, 2015). Different crops have different temperature response during their phenological or growth stages. The reproductive period is the phenological stage that has a higher thermal sensitivity (Tiexeria et al., 2013). Exposure to extreme temperature during the reproductive periods might lead to faster development that results in shorter plants, faster grain filling, and grain maturing, and consequently responsible for the reduction in yield (Lobell et al., 2012). However, the effect of exposure to an extreme temperature above the optimum period is less known. Studies show negative temperature sensitivity of crops when the daytime temperature is above 30°C, the magnitude of the negative impact depends upon the crop and geography (Lou, 2011). Existing crop models also have not been able to capture the mechanism of impact of exposure to extreme temperature on crop physiology (Lobell et al., 2012).

Recently, the effect of exposure to extreme temperature on crops has been well explored in literature, though

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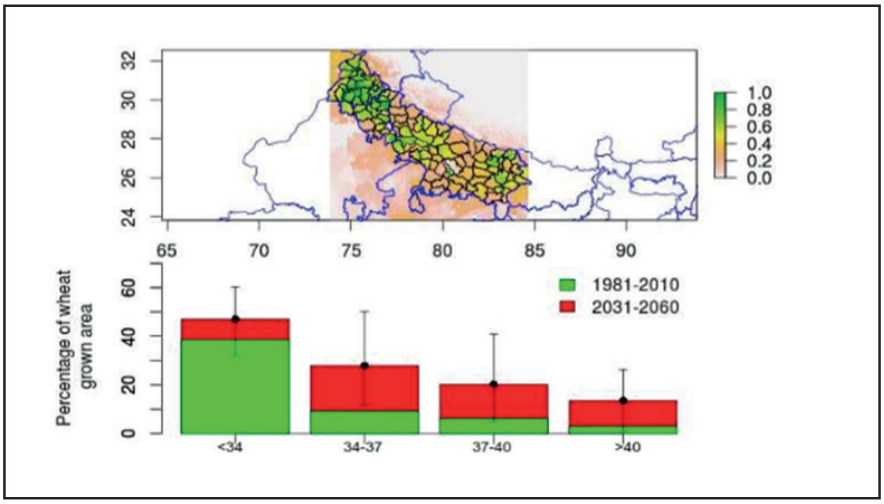
limited to major growing regions of crops such as wheat (Lobell et al., 2012; Powell and Reinhard, 2016), rice (Welch et al., 2010), maize (Schenkler et al., 2009; Lobell et al., 2013), and cotton for United States (Schenkler et al., 2009). There is very little work of impact of exposure to extreme temperature for different geographical regions and crops other than that are mentioned in the previous sentence.

In this article, we provide an overview of studies providing evidence of exposure to extreme temperature periods in the observed and future periods, for global regions and Indian regions (section 2). This is followed by a background of temperature trends in Karnataka. In section 3, we present a summary of methodological approach and findings of our recently published report (Jayaraman et al., 2017), submitted to Karnataka Agriculture Price Commission, evaluating the impact of extreme temperature on selected crop yield in the state. Section 4 highlights the issues that were identified in Jayaraman et al. (2017), which needs to be addressed to overcome the limitations of the crop-climate studies and the relevant policy implications.

Exposure to extreme temperature during crop growing season

Tiexeria et al. (2013) sowed the first spatial assessment for the exposure to extreme temperatures in the major crop growing regions for the observed period (that is 1971-2000) and the future periods (2071-2100). According to the authors, a large part of the cropped areas of the world will be under high heat stress risk. At the global scale, this ranges from 5 Mha (Millions Hectare) of the cropped area for maize and about 120 Mha of suitable growing areas of wetland rise. Gourdji et al. (2013), in a similar study, indicated that in the future roughly 31, 16 and 11 % of the wheat, rice, and maize harvested area will be exposed to temperatures higher than the crop-specific critical thresholds for at least five days during the growing season, respectively. Lobell et al. (2012), while studying the impact of exposure to extreme temperature on wheat producing regions of Indo-Gangetic Plains (IGP) area suggested that the March is the most common wheat harvesting month in the region and is exposed to daily temperature higher than 33°C, which is critical temperature for wheat in the region. Figure 1 shows the exposure to an extreme temperature in the Indi-Gangetic regions during the wheat harvesting season (March and April months). A future number of extreme temperature days are obtained from a set of 5 CORDEX- Regional Climate models in India. The figure reports that the districts, which are major wheat growing regions, as shown in the top panel, will be exposed to more number of extreme temperature days. This suggests that Indian wheat will be exposed to extreme temperature days. An extrapolation the results of Lobell et al. (2012) for the IGP-region, we can expect a decrease in wheat yield in the region due to the exposure to extreme temperature if other crops growing factors remain unchanged.

Figure 1: Exposure of extreme temperature days in the observed period (1981-2010) and a future period (2031-2060).



The study is confined to major wheat growing districts (as shown in top panel), a legend for the top panel shows the coverage of wheat sown area as a fractional coverage of the net sown area. The bottom panel shows 30 year's average wheat grown area as a percentage of net sown area, exposed to at least two days of temperature specified in the axis label, for observed and future periods. The red bars show the ensemble average of 5 CORDEX models and the error bar shows inter-model variation. (source: author's analysis)

In the context of Karnataka state, Rao et al. (2016) found regions of Karnataka to be highly vulnerable due to higher exposure to extremes and having low adapting capability from the shocks of the adverse climatic events. Longer term temperature analysis indicates a statistically significant trend that ranges from 0.6 to 0.75 °C per century for sub-divisions of the state (author's analysis). Increasing trend in the state suggests the possibility of warmer seasons and extreme temperature in the future, which is a serious concern for agricultural productivity (Jayaraman et al., 2017). District-wise temperature analysis suggests a trend in the seasonal average temperature for Kharif and Rabi seasons and these trends are higher than their corresponding sub-divisional averages. This indicates the possibility of occurrence of extreme days with a temperature higher than the crop specific threshold temperatures (Jayaraman et al., 2017). An analysis of the impact of exposure to an extreme temperature in crops in Karnataka is an important issue, this aspect is not well discussed in the literature.

Findings of climate-crop study for Karnataka

Global warming and the consequent rise in global temperatures affects temperatures at the regional scale in Karnataka, as may be expected from climate science. This, we must emphasize, is a trend that will persist over the longer term, as even after the world successfully reaches the stage of rapid emissions reductions, the effect of the greenhouse gas emissions that is already in the atmosphere will persist and some further temperature increase will be inevitable. One of the immediate consequences of such warming of the atmosphere is the increased frequency of extreme climate events including heat waves, droughts, and floods, which might intensify due to warming of the climate system. With this background, we presented the findings of the regression assessment of crop yield and extreme temperatures (Jayaraman et al., 2017).

This study was supported by the Karnataka Agricultural Price Commission, recently undertaken to evaluate the relationship between extreme temperatures and crop yield at the sub-district (taluka) level for selected crops. The crops studied were paddy, finger millet (ragi), sorghum (jowar), groundnut, and pulses. The results are derived from fixed-effect regression models for panel data at the taluka level. Taluka level fixed-effect was used because district level fixed-effect might be heterogeneous in terms of agro-climatic regions. Exposure of extreme climatic condition, which might be varying at a district scale, might misrepresent the climatic impact.

Jayaraman et al. (2017) observed an inverse linear relationship between yield variations and variations in Extreme Degree Days (EDD), defined as days with a temperature higher than the critical temperature for a crop. It noted that the negative effect of extreme temperature (EDD) on yield was larger than the effect of rainfall variability. In some cases, the coefficient of extreme temperature was more than twice that of rainfall. Further, robustness checks for the coefficients were also performed in the study using quantile regression method. The sign of the coefficients for EDD is consistent for 25, 50, and 75 quantiles of the estimation. This suggests that the negative relationship of EDD and crop yield holds for the different quantile levels.

Policy implications

In this section, we provide a summary of issues and lesson learned. We also provide a brief account of policy implications of the report Jayaraman et al. (2017) in the context of the impact of climate change and climate variability on the crops.

As noted in the earlier section, Jayaraman et al. (2017) showed the effect of exposure to extreme temperature periods in yields of the selected crops in Karnataka. However, it is important to note that over the longer term, from 1970, agricultural productivity measured in terms of yield (kg/ha or tonnes/ha) has risen significantly in cereals. The trend however for oilseeds and pulses has been more uncertain over this same period. Clearly, climate change cannot be the source of this discrepancy but must be attributed to a number of other factors. There are considerable yield gaps in agriculture in Karnataka, especially in relation to rain-fed farming. Such yield gaps again indicate that climate is not yet a determining factor in enhancing agricultural productivity. We also note that yield data shows a very wide dispersion for similar values of temperature and precipitation. This also reinforces the view that climate variability is not yet a determining factor in productivity.

With specific reference to climate and its variability, Jayaraman et al. (2017) show clearly that exposure to extreme heat is the most important climate effect currently observed in agriculture in Karnataka. This study is perhaps the first of its kind in southern India and for crops other than wheat. It focuses on climate and climate variability, and clearly shows that exposure to extreme heat is the most important effect of climate change currently observed in agriculture in Karnataka. Yield is consistently (statistically significant) lower in cropping seasons where exposure to temperatures above the critical thresholds is high. Climate-associated reductions in yield are significant for major crops, especially for monsoon (kharif) paddy, irrigated and unirrigated, winter (rabi) sorghum (unirrigated), and pigeon pea (tur) cultivated in the kharif season. The findings point to the need for further research to develop new crop varieties that cope with heat stress.

Jayaraman et al. (2017) have also shown the need for continued and more intensive analysis to better understand the impact of climate variability in agriculture. In this connection, the following issues should be addressed for more robust assessment of the impact of climate variability on crops.

1. Improved data collection and co-ordination of existing data sources within the government is an essential and urgent requirement. Detailed fine-grained data is an essential requirement. While some efforts are already under way in this respect, not much progress appears to have been made in the capacities to enhance availability and analysis of this data.
2. Daily rainfall and temperature data are essential for understanding the role of monsoon break days and exposure to heat stress in agricultural production. However, such datasets are not easily available at district or taluka scale. Although, IMD (India Meteorological Department) has made the daily scale gridded data available, however, these data are subjected to interpolation, which might underrepresent the incidence of extreme at the required scale (that is district or taluka).
3. Agricultural production, cropped area, and productivity data need to be available in a centralized repository disaggregated at Village or panchayat level or at least the taluka level. Without such a data repository, research and knowledge efforts will be spent disproportionate time on data collection and cleaning taking away from greater concentration on scientific analysis.
4. Panel studies at village level are also necessary to explore the impact of climate variability, especially since the impact of climate shocks and the processes of response and eventual recovery are spread over time. While the role of climate shocks and natural disasters in leading to so-called poverty traps is discussed in the literature, little serious analytical study, beyond the anecdotal, can be undertaken without such panel data.

We list below some additional policy measures which we believe are relevant.

1. As a matter of governance, it is essential that the government departments and ministries concerned with agriculture and rural development play a key role in developing the knowledge required and in determining the nature of interventions and the implementation of such interventions to deal with the impact of climate change and climate variability in agriculture. While separate institutions for disaster management and climate change may play a moderate role, especially in awareness generation or in some co-ordination activities, they do not possess the depth and sweep of knowledge and capacities that are available with departments of agriculture and rural development and related ones dealing with water, irrigation, livestock, fisheries and so on. Within this, it is also essential that a more active role for agricultural teaching and research institutions in policy-making be developed.
2. The development of new varieties that will cope with heat stress is one of the prime research requirements for the future. While such research is undoubtedly underway, the government needs to play an active role in interfacing with the agricultural research capacities in the country to ensure that the particular requirements.

3. Drought and water availability, in general, is one of the critical current issues for agriculture in the state. While this observation is not novel, it must be emphasized that improvement of the efficiency of water use and water management is critical. However, care needs to be taken that measures undertaken to this end do not end up further burdening the small and marginal farmers and the labouring population.

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APPLICATION OF DECISION SUPPORT SYSTEM FOR AGROTECHNOLOGY TRANSFER (DSSAT – A CROP SIMULATION MODEL) TO ASSESS THE IMPACTS OF MEAN TEMPERATURE RISE ON WHEAT YIELD

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Abstract: India ranks third in the production of wheat in the world and a large number of agricultural households are engaged in its cultivation. Climate variability, long term climate change, and the resultant increase in mean maximum and minimum temperature pose threat to the yield of these cultivators. Various studies (Pee 2013, Jayaraman 2011, D B Lobell, Cassman, and Field 2010, Hobbs and Morris 2011; Mahato 2015) have quantified the impacts of extreme temperature on wheat yield. The already existent yield gaps, along with the adversities imposed by global warming presents a challenge to the future of wheat cultivation in India. (Lobell 2010) Therefore, it is pertinent to estimate the probable adverse impacts to adapt accordingly and prepare for the future.

The present study attempts to determine the impacts of a future two-degree Celsius rise in mean temperature on wheat yield. It uses Decision Support System for Agrotechnology Transfer, DSSAT: a process-based crop simulation model, to simulate wheat yields for four successive Rabi seasons (2010-11 to 2013-14) in the Papda village of Raisen District in Madhya Pradesh. After calibrating the model, the correlation between the model simulated yield and recorded farmer yield is established with a systematic bias. The Pearson correlation coefficient is more than 0.7, which indicates the ability of DSSAT model to simulate in the study region effectively. After the bias correction of model simulated yield and increasing the mean temperature by two-degree Celsius, we found a 13.5 % decrease in the average yield with a maximum decrease as high as 43%. These results corroborate our hypothesis that the increase in temperature adversely affects wheat yield. Lastly, the recommendations for further improving the simulations by using field data and the scope for further enquiry are provided.It shall be noted that the aim of this exercise is to assess the utility of crop models, which are largely restricted to model, non-disturbed fields, in real plots.

Keywords: Climate Change, Agriculture, Crop Modeling, Statistical Modeling, Yield Gap, Wheat, Impacts, Mitigation and Adaptation, Agronomy, Vulnerability, DSSAT, ICRISAT, Irrigation,

Objective:

The focus of the majority of the impact assessment studies is to determine regional impacts. Statistical models are extrapolated and crop models are up scaled to meet this objective. This regional aggregation results in averaging out of many factors, hides the disparity between individual cultivators and differential impacts.

The present study aims to measure the impacts of probable future temperature variability on wheat cultivators by using a process-based modeling approach at a plot level. It includes review of literature that has used similar methods in the global context as well as in India. We have discussed statistical models and crop models, and their utility and applicability in various scenarios. The primary aim is to determine potential differential impacts on wheat yield of a probable temperature increase on different cultivators.

Methodology

The study uses secondary agricultural input data collected by International Crops Research Institute for Semi-Arid Tropics (ICRISAT) as part of its Village Dynamics in South Asia (VDSA) project. The data is taken from Papda village in Raisen district of central Madhya Pradesh. The village is located at an elevation of 530 m at 230 25’ 38.64” North and 780 29’ 1.32” East.

Model Setting, Data sources

Papda village lies in the north-eastern limb of the Vindhyan range and the westerly flowing Narmada river forms the southern boundary. The village lies in the drainage basins of the Ganga and Narmada rivers.

Four successive years of cultivation data from 2010-11 to 2013-14 is taken from the household survey of Papda village. The list of total plots along with the number of wheat plots in each year is given in Table 1.

5 The major portion of this study was completed as a Master’s Dissertation in TISS Mumbai under the guidance of Prof T Jayaraman and Dr Kamal Kumar Murari.
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Table 1: Number of total plots and wheat plots in Papda from 2010-11 to 2013-14

Year	Total number of plots	Number of wheat plots
2010-11	74	38
2011-12	96	42
2012-13	78	41
2013-14	75	34

Source: ICRISAT VDSA Database. URL: vdsa.icrisat.ac.in

The weather file in DSSAT (.WTH) requires the information of 4 variables namely Solar Radiation (SRAD), Daily maximum temperature (TMAX), Daily minimum temperature (TMIN) and Daily Rainfall (RAIN). The daily rainfall data is taken from ICRISAT VDSA database. Daily Solar radiation and temperature data is calculated from hourly data collected by Renewable Resouce Data Centre (RReDC) of the National Renewable Energy Laboratory (NREL) in the United States. These daily values for 5 years (2010-2014) are imported into the weathermen software inbuilt into DSSAT. They are synchronised by weatherman to be incorporated in simulation experiment.

The soil profile database is taken from global high-resolution soil profile database for crop modeling applications developed collaboratively by International Research Institute for Climate and Society, Michigan State University, International Food Policy Research Institute (IFPRI). The database in the .SOL extension, required by DSSAT, is incorporated by choosing the coordinated of Papda, Raisen and matching them with the nearest possible coordinates available.

The initial conditions require information of 1) moisture content and 2) Nitrogen Concentration along with the date on which the measurement is done. Due to limited information on moisture content, 70% moisture content is used in all the plots and is acknowledged that this will result in the distortion of yield because uniform condition is chosen. The initial nitrogen concentration is calculated by using the crop production of last kharif season and the amount of nitrogen fixed by the crop is calculated by using the formula:

Nitrogen (kg/ha) = (Yield in previous Season * Protein percentage of crop/6.25)

To generate stochastic weather, we first calculated the mean monthly temperatures using the 5-year data. After that, we used the RNORM function in R to generate 50 sets of random numbers whose mean is 2 deg. Celsius more than monthly means. This generated 50 sets of random yearly weather data whose mean is increased. We used these 50 sets to make 10 weather (.WTH) files with each. WTH file consisting weather data for 5 years. Ceteris paribus, these weather files were used one by one to simulate wheat yield to check the impact of temperature modification.

Assumptions

The following assumptions were made to simulate yields:

- The cultivar is chosen as 'DEFAULT' from the available list in DSSAT because of unavailability of cultivar coefficients for varieties used in Papda.
- The sowing depth is taken uniformly for all the cultivators across all years as 4.5 cm and row spacing is assumed 22.5 cm.
- The Soil profile is same for all the cultivators and is given in Figure 7. However, the initial conditions are different for each plot because of different nitrogen content and hence all the coefficients are recalculated and are different.
- The irrigation is simulated automatically by the model for all cultivators for all years. The water is automatically supplied by the model, if and when, required by the crop.
- The method of fertiliser application is chosen as "on the seed" from the dropdown list given in the model because the cultivators sowed using Seed Drill.
- The simulation start date and measurement date for initial conditions (moisture percentage and nitrogen concentration) is chosen as 10 days before the planting date for all the cultivators.

Key Findings

There is a consistent systematic bias in simulated yields for all the four years. The probable reasons for the bias are the assumptions that we took due to the limitations of data. The relationship between observed and simulated yield is shown in figure 1 through figure 4. The Pearson's coefficient and p-value for the observed and simulated values of 4 years is given in Table 2.

Figure 1: Observed vs Simulated Yield (2010-11)

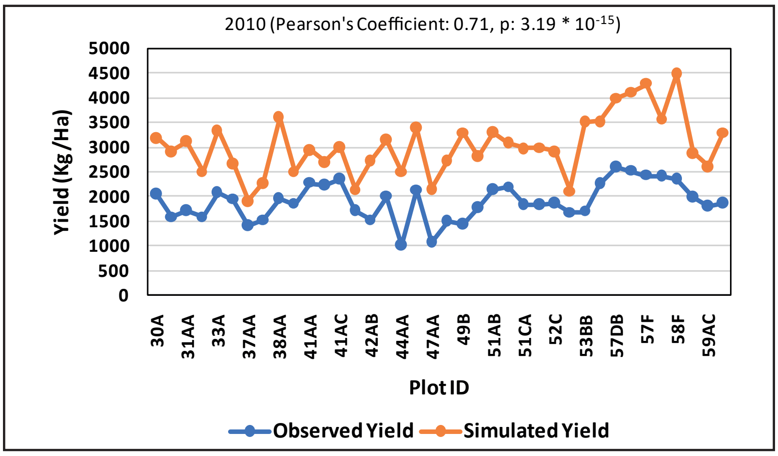


Figure 2: Observed vs Simulated Yield (2011-12)

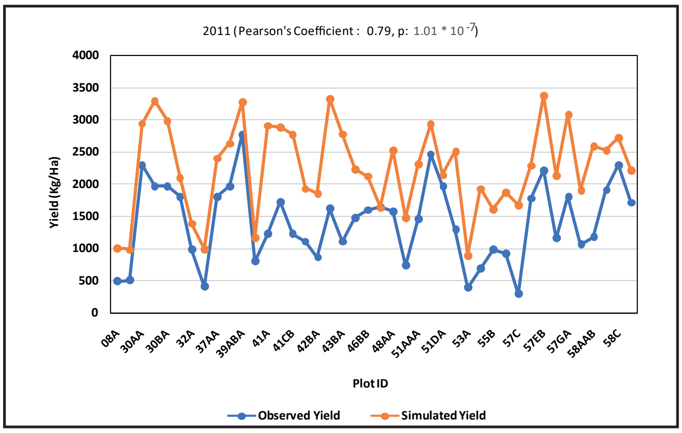


Figure 3: Observed vs Simulated Yield (2012-13)

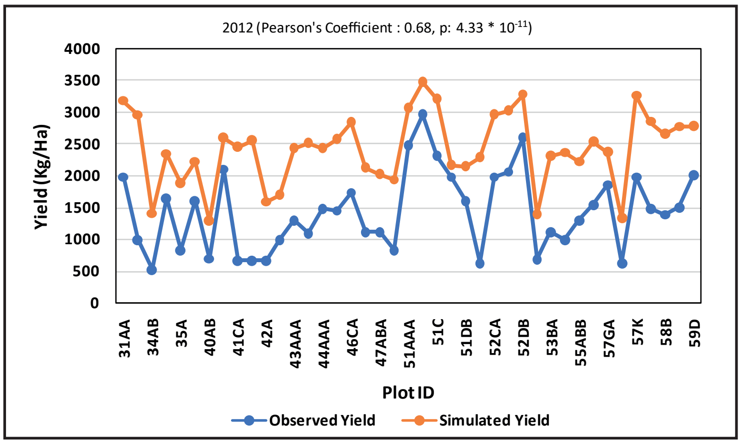


Figure 4: Observed vs Simulated Yield (2013-14)

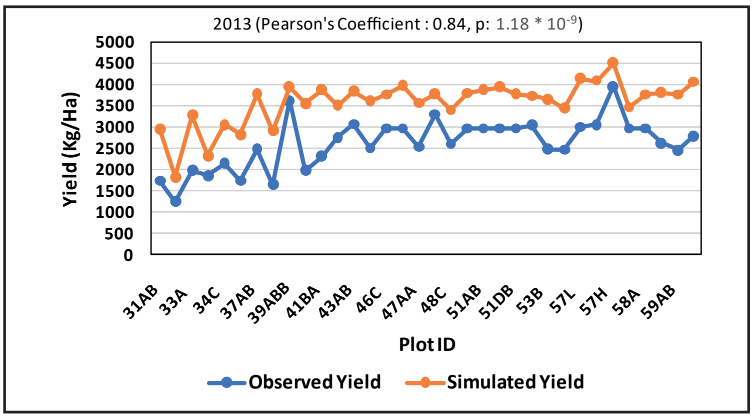


Table 1: Pearson Coefficient and p-values for 4 years

Year	Pearson's Coefficient	p-Value (for two-tailed test)
2010-11	0.71	$3.19 * 10^{-15}$
2011-12	0.79	$1.01 * 10^{-7}$
2012-13	0.68	$4.33 * 10^{-11}$
2013-14	0.84	$1.18 * 10^{-9}$

Effect of Temperature Increase

The distribution with the red curve shows the yield at original temperatures and the 10 grey lines show the yield distribution under stochastically increased temperatures. The yield distribution figures clearly show for the year 2010 and 2013 that the yield has been decreased for all the 10 random scenarios with increased mean temperatures. For 2010, the shift is greater for the cultivators with higher yields than for those with lower yield. This might be because the cultivators with already lower yields have little scope to further lose their yield.

Figure 5: Distribution of yields: 2010 (original vs increased temperature)

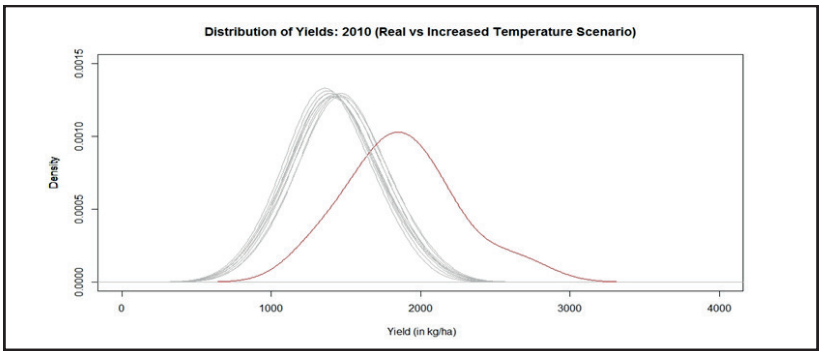


Figure 6: Distribution of yields: 2011 (original vs increased temperature)

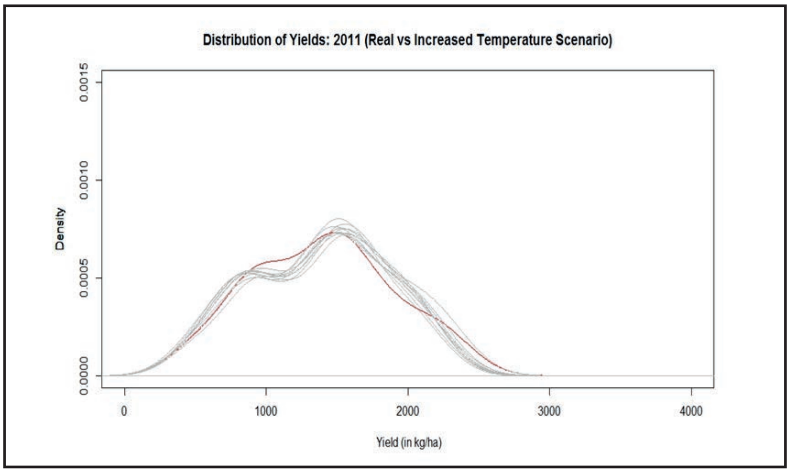


Figure 7: Distribution of yields: 2012 (original vs increased temperature)

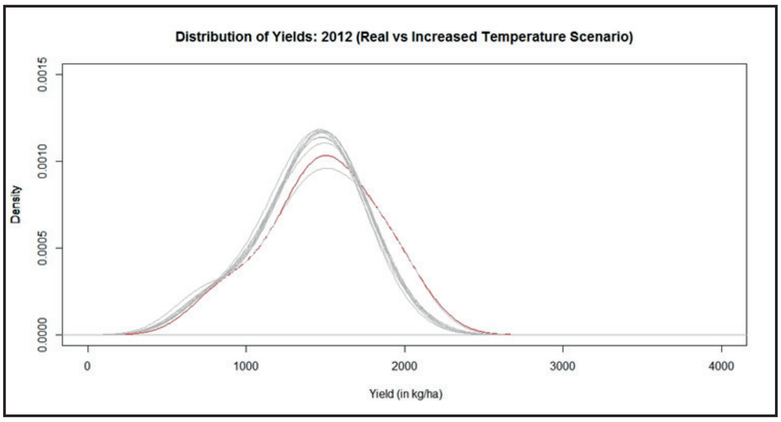
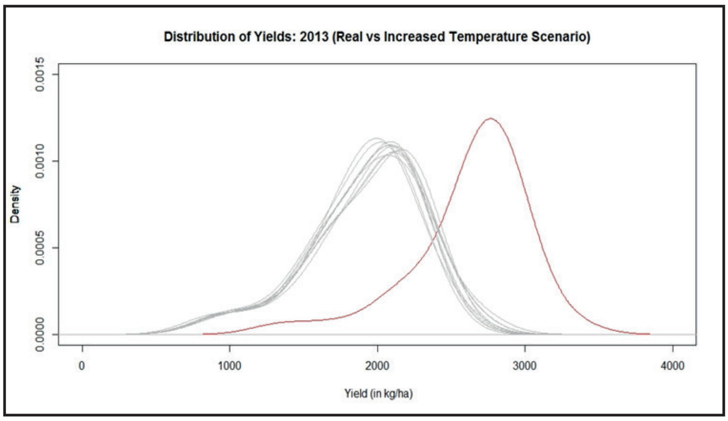


Figure 8: Distribution of yields: 2013 (original vs increased temperature)



The distribution curves of 2011 and 2012 do not replicate this shift. This is still a point of enquiry. The only point to mention is that the rainfall for the year 2011 was 1623 mm; significantly higher than the mean rainfall of 1136 mm of the district. This might be the reason for increased resilience in case of higher temperature, offset by the increase in precipitation. However, we do not have evidence to back this argument.

Conclusion

Majority of the studies using crop simulation models, use data from non-stressed and undisturbed fields with ideal management conditions to calibrate the model for local conditions. Nevertheless, it is important that these models are used so as to assess the impacts of global warming in an increasingly vulnerable environment for crops. Therefore, this study tries to use the cultivation data from actual fields with differing management practices to simulate yields. This is one of the first attempt to use crop models without calibration from ideal field data.

The results indicate that a process-based crop model can be effectively used for simulating yields in the case of data from real fields. The bias in yields clearly reflects the gap in actual input and the input given to the model. Therefore, there is a huge scope for improvement in case of simulated yields by making the quality of input variables better. The cultivar coefficients, irrigation information and plot wise sowing details may lead to greater convergence between the observed and simulated yields.

The yield distribution curves for 2010-11 and 2013-14 clearly show that yields are negatively affected by increased mean temperature. There is a scope for further enquiry as to why yield response in 2011-12 and 2012-13 do not match with that of the other two years. These models can also be used to test the effect of increasing temperature variability in addition to the increased mean.

There is further scope of generating stochastic weather by a random weather generator rather than the process used in the present study. The data from climate models can also be included in the model to check the response of various crops in case of different RCP scenarios.

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COMPARISON OF SIMULATED AND EMPIRICAL WEATHER RESPONSIVENESS OF CROP YIELDS

Malcolm N. Mistry[1], Ian Sue Wing[2]& Enrica De Cian[3]

Introduction

Agriculture is one of the sectors most challenged by climate change, and is likely to remain as the sector most affected in the future under global warming (Lobell et al 2011, Hertel and Lobell 2014). Consistent global-scale evaluation of crop productivity is essential for assessing the likely impacts of climate change and identifying system vulnerabilities and potential adaptation strategies (Schlenker and Roberts 2009).

Over the recent years, research groups around the world have developed several process-based Global Gridded Crop Models (GGCMs) to simulate crop productivity and assess climate change impacts at relatively high spatial resolution over global domain (e.g. ISI-MIP, Hempel *et al*2013).

While crop models are currently the best tools for assessing the impacts of climate change on crop yields and subsequent food production, the different and often contrasting methodologies and assumptions in their simulations invariably lead to a wide range of impact assessment (Müller *et al* 2017, Lobell and Asseng 2017). Understanding the drivers in divergence of crop models' yield responses to weather is therefore a need of the hour. Undertaking a comprehensive comparison of crop yield responses to key meteorological parameters (temperature and precipitation) over the coterminous United States (U.S.) counties[4], our study poses some key questions:

Q.I How similar is GGCM-simulated and observed yield responses, under not only adverse extremes, but the full range of weather conditions over crops' growing seasons?

Q. II To which characteristics of GGCMs can the divergence between simulated and observed responses be attributed?

Q.III What do simulated and observed response functions imply for the impacts of climate change-driven shifts in temperature and precipitation on future U.S. crop yields?

Data and Methodology

The study focuses on U.S. agriculture, while examining yields of rainfed maize, wheat, and soybeans simulated by six GGCMs[5] from the Inter-Sectoral Impact Model Inter comparison Project Fast-Track (ISIMIP-FT) exercise (Warszawski *et al* 2013, Rosenzweig *et al* 2014), comparing 1981-2004 hind cast yields over the coterminous United States (U.S.) against U.S. Dept. of Agriculture (USDA)[6] time series for greater than 1,000 counties (Fig. 1).

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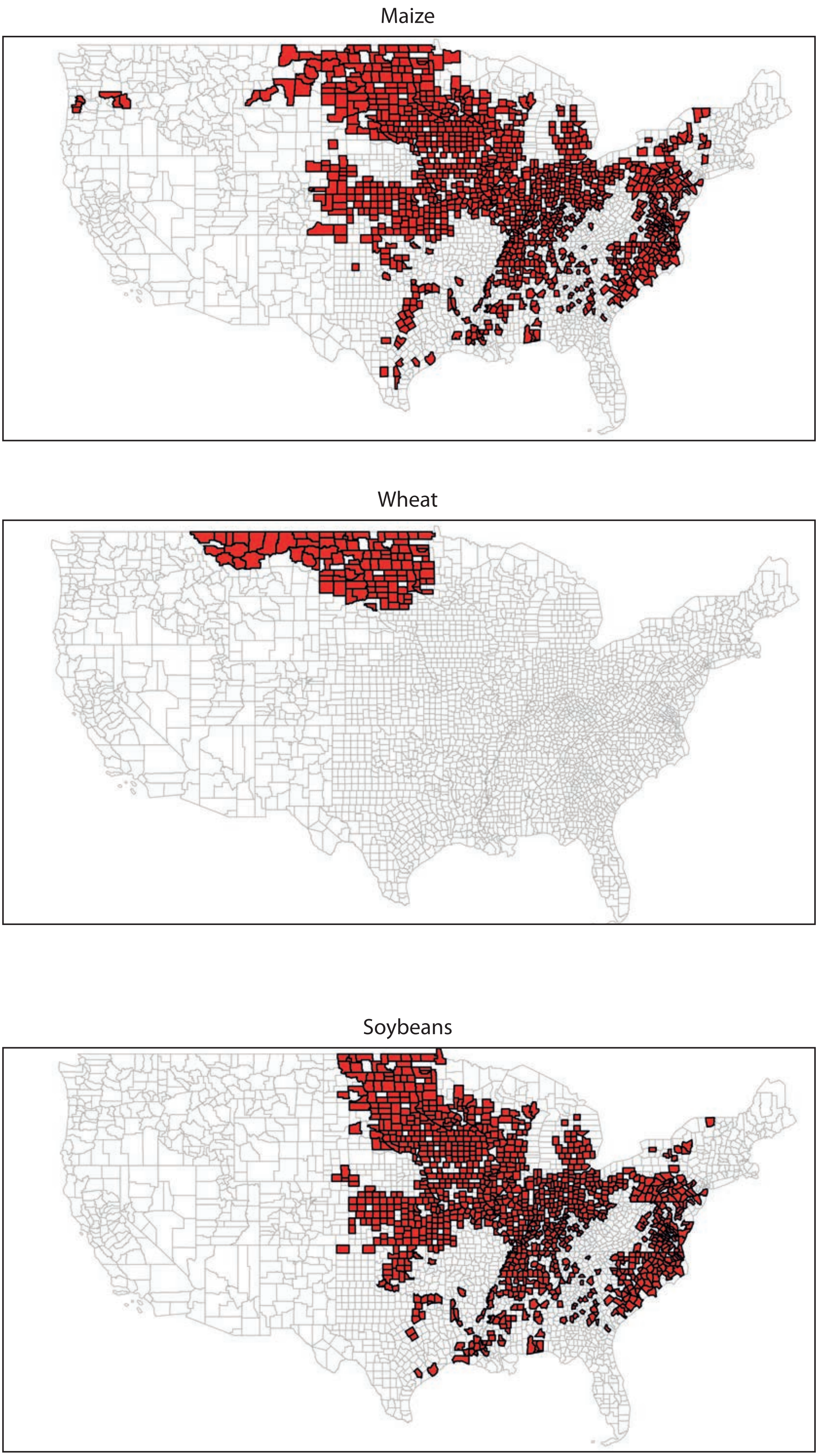
4 A U.S. county is an administrative unit within a state, with the majority of counties used in the study roughly equivalent to the average size of an Indian district (circa. 3000 km2).

5 The six GGCMs used in our study areGEPIC (Liu et al 2007), GAEZ-IMAGE (Bouwman et al 2006), LPJ-GUESS (Sitch et al 2003), LPJmL(BONDEAU et al 2007, Sitch et al 2003), pDSSAT(Elliott et al 2013, Jones et al 2003) and PEGASUS (Deryng et al 2011).

6 Historical U.S. county crop yields were obtained from the USDA National Agricultural Statistics Service's Quickstats 2.0 database (http://quickstats.nass.usda.gov/), which provides survey data.

Fig. 1: Geographical area used in this study. In red, U.S. counties across three rainfed crops: maize, wheat (spring+summer) and soybeans.



We quantify the potentially nonlinear influence of weather-shocks on yields using a semi-parametric cross-section/time-series regression model, following the empirical climate-change impacts literature (Schlenker and Roberts 2006, 2009, Deschênes and Greenstone 2007, 2012, Lobell *et al* 2011, Burke and Emerick 2016, Schauberger *et al* 2017). For each dataset, we specify the dependent variable as the natural logarithm of annual yield (y). The explanatory variables are a vector of location-specific effects (μ, which capture the influence of unobserved time-invariant local characteristics such as topography and soils), a time-varying function $f(t)$, which captures the influence of unobserved time-varying shocks, and the vectors of weather exposure covariates ξ_j^T and ξ_k^P (as intervals-bins- of daily temperature and precipitation in the crop growing season); appending a random disturbance term ε:

$$y_{i,t,m} = \mu_i + \gamma_g f(t) + \Sigma_j \beta_j^{-T} \xi_{i,t} + \Sigma_k \beta_k \xi_{k,i,t} \varepsilon_{i,t,m}$$

We estimate eq. (1) via ordinary least squares on the observational dataset of USDA yield and PRISM[7] weather, the six datasets of GGCM yield outputs and HadGEM2-ES (Jones *et al* 2011) weather inputs (from ISIMIP-FT); and multi-model panel consisting of the combined inputs and outputs of the six GGCMs.[8]

Of interest in eq. (1) are the estimated parameters β_m^T and β_m^P, vectors of semi-elasticities that capture the average percentage shift in county-level ($m = USDA$) and grid-level ($g \in m$) yields relative to their conditional mean quantities in response to an additional day in a given interval of temperature or precipitation. Each element of these vectors captures the marginal effect of an additional day of exposure within the corresponding interval (e.g., the average effect of one more day with $25-27°C$ versus $> 30°C$ average temperature). Together, the elements flexibly trace out the aggregate response of yields to temperature and precipitation as piecewise linear splines. The latter are statistically identified from the contemporaneous covariation between observed yields and meteorology within each interval, as well as the distribution of temperature and precipitation exposures across intervals in our transformed datasets.

Summary of Key Findings

Our econometric specification (eq.1) is able to explain 75%of the cross-section/time-series yield variation, with the weather responses (temperature and precipitation bins) accounting for between 0% and 60%. GGCM and USDA yield responses are by and large both consistent with empirical findings on the negative effects of exposure to high daily temperatures and as well as smaller magnitude responses to low precipitation (cf. Schlenker and Roberts 2009, Tack *et al* 2015). While divergence in yield responses to different exposures of temperature and precipitation vary across GGCMs and between GGCMs-USDA, we find that no GGCM exhibits a consistent positive or negative bias relative to the USDA response.

Translating the yield responses to future climate change impacts on yields under current management practices, our findings imply that the GGCMs tend to be more pessimistic while projecting negative impacts on future crop yields (Table 1).

Table 1. Mid-(2033~2065) and end-century (2067~2099) (in parenthesis) projected % change in aggregated production under Representative Concentration Pathway (RCP) 8.5 warming scenario simulated by HadGEM2-ES, due to extreme high temperature (T>30 °C) days

GGCM	Maize	Soybeans	Wheat
GEPIC	-47% (-72%)	-35% (-55%)	-9% (-52%)
GAEZ-IMAGE	1% (3%)	4% (7%)	0% (-4%)
LPJ-GUESS	-26% (-45%)	-42% (-63%)	-7% (-42%)
LPJmL	-35% (-59%)	-33% (-52%)	-46% (-66%)
pDSSAT	-32% (-54%)	-64% (-86%)	-30% (-35%)
PEGASUS	-38% (-62%)	-40% (-61%)	-37% (-44%)
Multi-GGCM	-32% (-53%)	-35% (-56%)	-33% (-42%)
USDA	-32% (-54%)	-39% (-60%)	-53% (-73%)

The projected % change in production is aggregated for the sample of counties shown in maps of Fig. 1. The disparity in GGCMs' yield responses is found to be largely attributable to heterogeneity in GGCMs'

7 PRISM daily data (1981~2004) accessed from http://www.ocs.orst.edu/prism/

8 The multi-model econometric specification generates multi-model average responses, $\overline{\beta}^T$ and $\overline{\beta}^P$, controlling for variation among GGCMs via a model-specific indicator, γ:

responses[9]; ultimately driving the divergence in the projected impacts of climate on future crop yields.

Concluding Remarks

Using a novel application of cross-section/time-series statistical techniques from the climate economics literature to large, high-dimension, multi-model datasets, this study provides a first glimpse into the origins and implications of this divergence through an inter-method comparison, both among the GGCMs, and between GGCMs and historical observations. The six GGCM simulations we examined did not reproduce the cross-county, inter-annual distributions of historical USDA yields. Notwithstanding this, our econometric analyses indicate that GGCMs broadly capture the major stylized facts of weather impacts on crop yields that have been identified by the empirical climate change economics literature.

Yet the responses of individual GGCMs differ substantially from one another and relative to their observationally-derived counterpart. Simulated yields are generally more temperature sensitive than observed yields, but can be more or less sensitive to high temperature or low precipitation extremes, depending on the particular model and crop. We find that such behavior is attributable to differences in how models simulate heat stress and cultivar adaptation. GGCMs incorporating the latter (former) mechanism tend to be more (less) sensitive to weather shocks.

By relying solely on meteorological inputs, and ignoring confounding factors such as the CO_2 fertilization effects, exogenous future adaptations or additional endogenous adjustments such as shifts in cultivars and crop calendars represented within models, our projections of future yield impacts (under RCP 8.5 scenario) provide insights into how GGCMs' characteristics can amplify or moderate climatically-driven yield declines.

Our study is not void of caveats though. The primary being the small number of GGCMs on which our analyses and results are based. The GGCMs used in our study are neither fully representative of the wide array of simulation models that are currently part of the next phase of inter-model comparison exercises (ISI-MIP2, the Global Gridded Crop Model Inter-comparison (Elliott *et al* 2015), nor were calibrated specifically to U.S. agriculture. Without a larger sample of harmonized model simulations currently available, little can be done to increase the statistical power of our assessment. Nevertheless, we hope is that the inter-method comparison techniques developed here can contribute to improving the evaluation of the results of these exercises (Müller *et al* 2017), with the goals of more rigorously pinpointing the origins of GGCMs' emergent crop yield responses, and thereby strengthening the empirical basis of global-scale assessment of future climate change impacts on agriculture.

9 The key GGCMs' parameters that lead to the divergence in responses were found to be heat stress and implementation of adaptation (such as cultivar change and dynamic cropping dates).

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8th International Conference on Climate Change At TISS

Conference Summary Report

Climate Action: Mitigation and Adaptation in A Post Paris World

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4th-5th August 2017

Day 1- 4th Aug, 2017

Opening Remarks and Welcome Address

Opening Remarks: Dr. Tejal Kanitkar, Chairperson, Centre for Climate Change and Sustainability Studies (CCCSS), School of Habitat Studies, Tata Institute for Social Sciences: The 8th Annual Climate Change Conference began with opening remarks by Tejal Kanitkar, who welcomed the participants and gave a brief history and overview of the Centre for Climate Change and Sustainability Studies (CCCSS).

Welcome address: Dr. Amita Bhide, Dean, School of Habitat Studies (SoHS), Tata Institute for Social Sciences: Prof Amita Bhide. She began her address by speaking about the cutting-edge research done by School of Habitat Studies addressing the contemporary challenges facing our society. She commended her colleagues for successfully organizing this annual conference, and in the process building the foundation of the entire discipline at TISS and for their strategic intervention over the years in climate change negotiations, adaptation and mitigation. She elaborated that climate change studies holds value as it has the tough task of negotiating a mine field of issues such as development strategies, the context of international and national political economy and at the same time thinking of vulnerabilities at multiple scales.

Post the Welcome Address, Dr. Tejal Kanitkar introduced the inaugural panel and handed over the proceedings to the Chair.

Inaugural Panel: International negotiations and domestic climate action – Interconnections and Contestations Within and Outside The Paris Agreement

Session Chair: Prodipto Ghosh
TERI, New Delhi

Mr. Ghosh started the discussion by briefly introducing the relevance of the Paris Agreement, especially in the context of the withdrawal of the United States of America from the Agreement and their dismantling of domestic structures pertaining to climate change mitigation. He indicated however, that other major players have clearly signalled that they will fulfil their obligations and commitments. However, the challenge of maintaining the temperature rise below two degrees will imply dealing with the realities of burden sharing, as well as the importance of financial and technological resources to achieve the targets. The Paris Agreement leaves some room for discussion on these issues at some future date.

Navroz Dubash, Senior Fellow, Centre for Policy Research, New Delhi

Prof Dubash began by thanking the organizers for bring the community working on climate change together through their annual conference. He elaborated how the Paris Agreement is different from other international agreements due to the bottom up approach it adopts. This allows more room for national constraints to play a decisive role in the setting up of the Nationally Determined Contributions. The important question according to him was whether the developing world risks being pressured into declaring more than what they are comfortable with? Prof Dubash suggested that the Paris Agreement has the potential to shift norms and expectations. It opens up space for interesting conversations within countries of what sustainable development and their NDCs should look like. On the question whether the Paris Agreement is equitable, Dubash commented that in terms global allocation of carbon, the agreement may seem inequitable. However, if viewed from the perspective that it allows every country to determine how much to emit based on their national constraints, it seems equitable. With regards to the USA decision to withdraw from the agreement he opined that it may be a good thing for two major reasons: 1) Mobilization of domestic actors both state and local bodies and civil society in the United States around the issue of climate change and 2) It gave an impetus to progressive politics. If the United States had stayed in the Agreement and had lowered their pledge, it would have been bad for the Agreement.

Jyoti Parikh, Integrated Action for Action and Development (IRADe), New Delhi

According to Dr Parikh, the Nationally Determined Contributions are a game changer as countries came to the table with what they wanted. India did so in quantitative terms, and faced the issue of target setting directly. In the international arena, the United States repeated what they did in Kyoto. Perhaps this issue may become an important voting issue during the next elections in the USA. However, in the USA and a few other countries, Jobs and the economy are the major issue in elections and not climate. Population, economic growth, power, technology, investment, core consumption is a few of the considerations when trying to do this. There are many tools to help predict trends in these areas, and help Ministries make a comparative analysis. More attention needs to be paid to conduct more modelling exercises like Dr Kanitkar's in order to make the process more rigorous and accurate.

T. Jayaraman, Professor and Chairperson, Centre for Science, Technology and Society, Tata Institute of Social Sciences, Mumbai

Professor Jayaraman, referring to Mr. Dubash's presentation pointed out that the all-round enthusiasm of the Paris agreement while understandable should not imply that the agreement is flatly a counter to science. Scientists largely agree that the total committed NDCs will not keep us below 2 deg. Celsius rise in temperature. The question that then needs to be raised is if we objectively cannot limit the temperature rise to 1.5 deg. Celsius, why does the Paris Agreement commit to it? John Kerry, United States Secretary of State in Marrakesh has been on record saying that the negotiators at Paris knew that the targets were insufficient but they hoped that it will a send a strong signal to the market and to business. However, no one can say whether this will work or not. But to think of running the entire global economy in this manner is a serious concern. We should instead plan for a 2 to 2.5-degree Celsius rise in temperature. These would mean huge expenditure outlay for developing countries. The Paris Agreement only refers to adaptation finance and leaves out working out the details for a later period. What we need currently is to rethink seriously about adaptation mitigation linkages and this cannot be done on the basis of borrowed paradigms from the past. We need to seriously think about climate change and infrastructure and realize the importance and need of cooperation, knowledge exchange, and rigorous estimates of what adaptation should look like. With a 2.5-degree Celsius rise in temperature, many communities will no longer be able to reside where they currently are. This requires a new vision of universalism and a new globalism. With the levels of mitigation and adaptation currently, many communities need to "think the unthinkable, and speak the unspeakable". There needs to be a shift in the frame of thinking, so as to not be alarmist, nor dismissive.

Session I: Climate Action - Mitigation: Up to 2030 and Beyond Session

Chair: Kirit Parikh
Chairman, IRADe, New Delhi

The Mitigation Burden- Time for A New (I)NDC?

Dr. Tejal Kanitkar
Chairperson,
Centre for Climate Change and Sustainability Studies TISS, Mumbai

Dr. Kanitkar began her presentation with a focus on the carbon budget calculations for staying below the 2-degree Celsius rise in global average temperature. The mitigation efforts under the Paris agreement are aimed at keeping the global temperature rise below 2 degrees Celsius above pre-industrial levels this century. Further efforts are to be pursued to restrict temperature rise to 1.5 degrees. In terms of the total carbon budget (1870-2100), a good chance (67%) of staying below 1.5 degrees would mean remaining within 744 GtC. A good chance of staying below 2 degrees would mean remaining within 992 GtC. A good probability of limiting temperature rise translates to available carbon space for the future ranging between 325 to 545 GtC. Dr Kanitkar stressed that the world realizes now that the negotiations today are more about numbers than they ever were, this being clearly reflected in the NDCs. In this context, Dr Kanitkar proposed a strategic shift. According to her, India should declare a long term

INDC, beyond its current NDC. Doing so will provide a chance to force the discussions back to adequacy, articulate an equity framework (within the confines of unilateral declarations), provide breathing space to us for mitigation and adaptation. Future allocation of the carbon budget was projected for five cases: if there is per capita allocation of entire budget, per capita allocation of available space, allocation based on minimum costs, allocation based on minimum costs + equity, and NDC till 2030. For India, an equitable allocation of available space allows to claim at least 40 Gtc beyond 2030 which in turn is subject to a global adherence to 325 GtC. As the total economic activity increases, total cumulative emissions will also increase. For a 6.5% growth rate, the cumulative emissions are projected at 74 GtC; bringing this figure down to 40 GtC implies a change in energy intensity. This target is not impossible, however significant role in this case continues to be that of technology. Dr. Kanitkar argues that declaring a long term INDC i.e. beyond 2030 in terms of the carbon budget not only acknowledges the results of climate science but is also a means to articulate our view of equity in concretely operationalized terms while still respecting the consensus of the Paris Agreement.

Scenarios for low carbon development Strategies

Dr. Prodipto Ghosh, Distinguished Fellow,
TERI, New Delhi International Project Advisor for CD LINKS

Dr Ghosh began his presentation with a brief discussion on the CD LINKS project. The project CD LINKS basically aims at linking climate and development policies and leveraging international networks and knowledge sharing. The presentation particularly focussed on the scenarios for low-carbon development pathways that have been created by TERI and IIMA. The International Consortium of 19 modelling teams under this project worked with seven scenarios and accordingly allocated the carbon budget under each scenario which were subsequently compared with the carbon budget given by the IIMA and TER-MARKAL Model. The Global Models budget is based on the principle of equal marginal abatement costs whereas the IIMA and TERI simulations are based on a bottom up approach, feasibility in light of national circumstances- consistent with the logic of Paris Agreement. The key drivers of the two Models (IIMA and TERI) include Population, GDP trend and Policies (INDC) and technology selection. The CO2 Pathways projected up to 2050 differ for the two models given the difference in the assumption for the drivers. Recommendations for the transformation of the energy sector covered capacity addition in the Power sector, Power Generation (increase in renewable electricity generation and storage, increase in efficiency of thermal power plants), Industry (decrease in energy intensity per unit output, reduction in demand for virgin raw materials through reuse and recycle), Residential and commercial (shift to cleaner energy for cooking, switching to energy efficient appliances), Transport (cleaner fuels, electrification of passenger vehicles, shift to public transport, change in rail-road share). Some of the challenges pointed out are high carbon tax particularly for switching to alternatives like EVs, the possibility of 2-3% loss in GDP without general equilibrium conditions, and infrastructure related investments would imply high mitigation costs. A unique challenge for India is outlined by the fact that it has to decarbonise and simultaneously proceed on a path of rapid growth and development.

Low Carbon Road Map for Industries- Focusing on the Cement Sector

K.N. Rao, Director,
Energy and Environment, ACC Limited, Mumbai

India is the second largest cement producer in the world and yet accounts for one-tenth of China in terms of production. Given our low infrastructural capacity and the need to build more of it, what should our strategies be considering future demands and consumption? What needs to be done to continue to grow in the future? Mr. Rao advocated for a paradigm shift in the manufacturing of cement and concrete. Arguing for greater emphasis on research and development and innovation as the driving forces to transform the production activity, he claims that the cement industry can reduce CO2 emissions by 45 % by 2050. New technology, identification of new cement, alternative fuels such as fly ash, agricultural residue, municipal solid waste, and non-hazardous waste- can all be substitute to fuels that can greatly eliminate the CO2 element. Further, alternative raw materials, thermal and electrical energy efficiency, waste heat recovery, have been identified as key factors building a low carbon map. Highlighting the Cement Sustainability Initiative, he argued that the most of the cement power plants in India are captive which are highly inefficient, suggesting that the Cement plants should move away from captive power production.

Fossil fuels to renewable energy - Politics of the transition

Ashim Roy, Vice-President,
New Trade Union Initiative (NTUI), New Delhi

Unfortunately, Mr Ashim Roy's flight was delayed and he was not able to join us in time for his presentation. He joined us on Day 2 and participated in the proceedings of the conference.

Session II: Climate Action – Adapting to Climate Change: Finance, Politics and Regional Planning

A Sustainable Development Framework for India's Climate Policy

Sujatha Byravan
Center for Study of Science, Technology and Policy (CSTEP), Bengaluru.

A very larger section of our population still lives in very poor standards of living. They are deprived of even basic facilities, such as, access to clean and safe drinking water, clean air, etc. These are developmental issues that need to be looked into at the earliest. The effect of these issues will be worsened with the impacts of the changes in the climate. As such, there is a need to incorporate these issues while working out climate policies for the country. The study that was conducted by her, examined two primary cases for India's development by 2030. One, the Business as Usual (BAU) approach, and two, the Sustainable Development (SD) approach. The areas covered included the energy use and the production sector, which is responsible for a major chunk of the Green House Gas emissions. The results have shown that the Sustainable Development approach is feasible and hence should be incorporated in India's NDC. Although going for SD will require a bit more investment, the benefits of using it are immense.

Socio Economic Implications of Climate Change

Purnamita Dasgupta,
Chair & Head, Environmental Economics,
Institute of Economic Growth, University of Delhi Enclave, Delhi, India

The discussion was primarily focused on how poverty and inequality fit in with consumption expenditure related to GDP. The population of India will not stabilise till 2045. Floods and other disasters are becoming more intense and frequent. As such, the living condition of majority of the population is pitiable. Even access to basic facilities, such as, sanitation, is not available to many people. Now this can be looked at in two ways. One, the convenience of having access to better sanitation facilities. Two, the health cost that are related with the lack of such facilities. The benefit-cost ratio of having eco-san toilets, both in terms of convenience as well as averted health issues, is more than the benefit cost ratio of double pit or pour flush toilets. Adaptation, as a concept, goes much beyond Sustainable Development Goals. The focus, hence, should be that it both adaptation and the SDGs are in sync with each other.

Climate Impacts and Adaptation in India- What is Required?

Dr. K.S. Kavi Kumar.
Madras School of Economics, Chennai

The discussion was about giving priorities to all sectors that are sensitive to climate change. To do so, looking at panel models and what they assess is important. Panel models assess the impact of weather shock on economic outcomes. However, although these models can correctly identify these factors, it cannot determine the effects that changes in the climate will have. The impacts, say in agriculture, are measured as yield deviation had the 'old climate' prevailed during the period of study. In India, there are no damage estimates of the effects of climate change. Since, access to weather or climate data is difficult, studies mostly focus on primary variables such as temperature, precipitation, etc. There is a need to incorporate variables like degree days, seasonal rainfall and others. The speaker identified the four generations of adaptation studies, which start with a broad idea about adaptation and the potential impacts of climate change and go on to how it can actually be put to practice. Sudden variations in the climate lead to changes in the cropping pattern. As such, it may be the cause of agricultural distress. This leads to rural-urban migration. There has been significant migration by people from rural areas in search of alternative livelihood opportunities. This, hence, may be seen as a coping mechanism by the rural population.

Perspectives on Evaluating Vulnerability and Adaptation Requirements

K. Narayanan
Indian Institute of Technology, Mumbai

The talk began with the concepts of vulnerability and adaptation and how they are measured. The livelihoods that are vulnerable to the effects of the changes in the climate and how they can be identified and what adaptation strategies should be in place in order to help them cope with the adversities. There was also an emphasis on the role played by the policies that are formulated and the important institutions such as market, government, etc. After the identification of the groups of people who are vulnerable and the factors that determine the extent of the vulnerability, the focus shifts to the adaptation strategies that have been adopted in the past and the new strategies that can be put in place. There are essentially four methods for assessing vulnerability, namely, historical narratives, statistical analysis, GIS and mapping technique and comparative analysis. The concept of vulnerability should be looked into by putting in the framework of climate change, its impacts, adaptation strategies and other things such as social indicators.

Adaptation is important in that, it helps people cope and deal with the adversities of the climate. However, sometimes, people adopt maladaptation practices to cope with the adversities. A very common example of that is using an air conditioner to cope with the increasing temperature. Hence, there is a need to make adaptation practices sustainable and better contextualised.

Session IIIA: Climate Action: Climate Policy and Politics Session

Chair: Sudhir Chella Rajan
IIT-M, Chennai

Business, Organized Labour and Climate Policy Forging a Role at the Negotiating Table

Peter J Glynn
Bond University, Australia

This research project explored the role of employers' organizations and trade unions in the development of climate change policy. It also examined how a theoretical framework can guide the policy development process. The presentation looked only at the first of those questions, the role of employers' organizations and trade unions. The contention was that the labour market is impacted by climate change policies; that as governments adopt policies and change laws to manage GHG emissions, the specifications for the goods and services produced change, and therefore what workers do must also change. Given that, the assumption is that representative organizations, employers' organizations and trade unions are advising governments on those aspects, and that these considerations are incorporated into the governments' strategies. What the

research found is that while there are some examples of best practice, generally Governments strategies for climate change do not have a labour market component, and Employers organisations and trade unions are neither informed about the issue and do not engage in the process. According to Dr Glynn's assessment, the labour market is impacted by the climate change policy of different governments. Some examples of government policy to reduce GHG emissions are energy efficiency initiatives that reflect the labour market impact: France's policy of low energy consuming buildings which had action agendas with respect to quality and quantity of labour required; publicity and promotion of the occupations in demand; incorporating green growth in all training; and the training of teachers. As well as the UK's Green Deal, intended to reduce emissions from domestic and commercial dwellings by implementing energy-efficiency measures. Currently it is only in Europe that employers' organisations and trade unions participate in labour market planning in respect of climate change, and this is essentially lead by the governments. Although trade unions at the peak regional and global levels are engaged in the policy process, although only advocating for a just transition and decent work. They are also effective influences in civil society advocacy. Mr Glynn concluded that the domestic climate policy process would benefit from input from non-state actors.

Decomposition Analysis of Factors Influencing Emissions and Their Impact on Mitigation Targets Committed in Paris Agreement

Kashmira Pawaskar
Research Assistant
Center for Climate Change and Sustainability Studies, TISS, Mumbai

Kashmiraa Pawaskar's study aimed to analyse the trends and impacts of the four major drivers, namely economic activities, the nature of economic activities, energy efficiency and fuel mix. This was done using a decomposition analysis. The sample set of countries included USA, Germany, China, Brazil, Bangladesh and Ethiopia. Some of the key findings from the decomposition analysis were: Germany's emission growth is negative; China's energy intensity improvement comparatively higher; Developed countries fuel mix is greener during this period. The study also sought to understand how these changes in the drivers, influencing emissions, would impact the NDC. This was done by creating four scenarios: Business as Usual (BAU), Potential change in energy efficiency, Potential change in Fuel Mix and Potential change in energy efficiency and fuel mix. For the US, it was observed that an improvement of energy efficiency by 3.4% is possible without the need to additionally invest in changing fuel composition. For Germany, an increased share of RE in gross final energy consumption is possible, with its share up to 60% by 2030 and 80% by 2050. In the case of China, an increased share of non-fossil energy to the total primary energy supply is possible by around 20% by 2030. Further, a balanced approach incorporating healthy energy efficiency and fuel mix is required. Brazil would require meticulous policy implementation against deforestation, reduced land use emissions – increase emissions in fossil fuel. Further RE can constitute 45% of the country's fuel mix by 2030. Finally, Bangladesh's 5% promised emission reduction can be increased to 15% with adequate international assistance in form of technology and finance. In conclusion, the NDC Targets of developed countries are not ambitious. Efficiency improvements not enough in the case of countries such as China. A structural shift is required as developing countries face barriers to meeting their NDCs. Counter impact of GDP – Germany vs US. Finally, a balanced approach incorporating both increased energy efficiency and cleaner fuel mix are required.

Climate Change in the High North Conflict or Cooperation?

Prantik Mitra
Climate Sciences and Policy, TERI University

The objectives of this study were to consider whether there is a possibility of conflict in the Arctic over disputed territory and claims of sovereignty, along with the possibility of a multilateral cooperation. The impact of this new energy factor leading to a shift in the order of global energy security was also considered. A dyad analysis for the United States, Canada, Russia, Norway, and Denmark has been assessed so as to draw inferences about future bilateral relations from past events and structural characteristics formative of countries' current dyadic interstate relationships. The study concluded the following: Cooperation amongst the various countries, and not conflict is the way forward; Joint Management of Arctic resources must be considered. Energy Justice-not just conceptual recognition, but distributional and procedural; Recognition the laws of the sea-particularly UNCLOS; Assets management and licensing in the new drilling areas must be established; And finally, it is the responsibility of OECD and Arctic Council for the safe extraction and transportation of oil as well as the determination of fair share of profit.

Electricity-Water Nexus: SSP Based Assessment

Poonam Nagarkoti
Council on Energy Environment and Water, New Delhi

In the Indian context, the focus must be on the Linkages between economic, social and environmental aspects of sustainable development. According to Nagarkoti, to understand India's future scenario, the following gaps in the research must be addressed: lack of India specific datasets representing water use: Water consumption and withdrawal coefficients; implications of water efficient technologies, for thermal cooling, on water consumption and withdrawals. The study presented had three specific objectives: modelling of India's electricity generation sector, constructing a unique dataset on thermal cooling technology distribution and associated water consumption and estimating water requirements for India's electricity generation sector. These goals were modelled and estimated across five different shared socio-economic pathways (SSPs): 1) Sustainable (SSP1): which involves a good balance in terms of income growth and population growth, more investment in renewable energy and dry cooling technology and implementation of water saving policy. 2) Business-as-usual (SSP2): Model endogenously determines the electricity generation based on the cost of generation and implementation of water saving policy 3) Fragmentation (SSP3): Poor outcomes in terms of income growth and environmental indicators; Increasing share of nuclear based electricity and implementation of water saving policy 4) Inequality (SSP4) : Highly uneven GDP growth rate between different sections of society with only rich states investing in will invest in low carbon technologies and water policy failure 5)Conventional (SSP5): High income growth and electricity production and implementation of water policy. The following conclusions were observed: Highest electricity access is observed in the conventional scenario, followed by the sustainability scenario. Affordability of electricity will be biggest challenge under fragmented scenario. Within BAU, coal continues to be dominant (approx.63%) by 2095. Resource intensive lifestyle of conventional scenario is mainly based on fossil fuel based electricity in future. Finally, energy security challenges predominate in conventional scenario. The way forward for India must include solving the issue of energy access through alternative paths, a sustainable energy mix in future with reduced emissions, the enforcement of water policy to ensure substantial savings and finally, a spatial distribution of power plants and the critical role of dry cooling must be considered.

Session IIIB: Climate Action - Vulnerability and Adaptation

B. Venkateshwaralu
V.N. Marathwada Agricultural University, Parbhani

The Wet and the Dry: Development Planning in the Era of Climate

Sanjana Krishnan
TISS, Mumbai

The presentation sought to address the issue of rising urban population in Mumbai and the risk climate extremes pose to urban development. Climate Science predicts that sea level rise of about 24 cm to 66 cm for the Maharashtra coastline accompanied by increase in wave heights, increase in wind speeds, and greater storm surges for Mumbai. In Mumbai, A 50 cm rise in sea-level rise would render informal communities uninhabitable; as a result of coastal shifting there is also structural instability of infrastructure built on landfill. Master plans are the traditional instruments used by urban local governments in India as forward planning tools. The latest development plan for Mumbai for the year 2014 – 2034, is based on three pillars of sustainability- economic, social inclusivity and environmental sustainability. The DP is the central document in which land use and all aspects of planning is done. Ms Krishnan then went on to detail her findings. According to her, though flood preparedness plans are available at the state level, they are not implemented at the city level. No efforts have been made for minimizing vulnerability by identifying vulnerable areas and providing adaptive infrastructure. Affordable Housing as per the Development Plan is planned on salt pan land. Salt Pans are more susceptible to the risk of flooding and are alongside mudflats and creeks. This is counterproductive to reducing the risk of flooding. While coastal region submergence and flooding (due to increased sea level, bigger waves, and storm surges) is expected up to the high tide line, land use has not been planned for this. Existing transport networks and hubs have poor adaptive capacity to flooding. She then critiqued the use of mangroves as adaptation tools as evidence about their utility for protection from sea-level rise is mixed. Adaptation strategies are being reduced to issues such as dealing with government inefficiencies, building citizen consciousness and providing sturdy infrastructure. Similarly, it is being confused with environmental issues like the destruction of mangroves or pollution. While these measures are extremely vital, they are not climate change adaptive measures, they are the basics needs for development. Adaptation is essentially a spatial concept, and the measures needed for adaptation has to be additional to these.

Climate change vulnerability at household level in urban and rural areas of Nepal

Madhav Giri
Tribhuvan University, Nepal

Dr. Giri began his presentation by highlighting that climate change adaptation in urban, rural and Himalayan area is the location specific and critical to identify vulnerable entities. Local level adaptive capacity and practices are very important to formulate suitable policy measures to address their livelihood. Vulnerability is understood as a function of three components: exposure, sensitivity and adaptive capacity, which are influenced by a range of biophysical and socio-economic factors. Where, Exposure – stressor and the nature and extent of changes to a region's climate variables (e.g., temperature, precipitation, extreme weather events). Sensitivity- human–environmental conditions that can worsen the hazard, ameliorate the hazard, or trigger an impact. Adaptive capacity is the potential or ability of a system, region, or community to adjust to the effects or impacts of climate change. The capacity to adapt is context-specific and varies from country to country, from community to community, among social groups and individuals, and over time. His study included three areas of Nepal which were Kagbeni (Mustang), Kathmandu and Devchuli, Nawalparasi. His did primary data collection using Household Questionnaire Survey (64 households in Kagbeni and 84 households in Devchuli municipality), Focus Group Discussions (3 FGD in Kagbeni and 9 FGD in Devchuli), and also took key informant interviews. The secondary data was collected using the available literature and DHM. Access to road, markets & health centres, education and house are the main priorities to address vulnerabilities. It was assessed that adaptation practices such as agricultural farming (Apple cultivation, maize and vegetable production), shifting agricultural calendar, practicing rotational grazing, changing mud roof type into stones and cemented roof, community sanction on collection of natural resources (Ban Samiti, Mukhiya system) and social safety nets should be used in high mountain areas. It was concluded that adaptive capacity and adaptation practices vary in accordance with location and communities even at the household level. Adaptation practice is significantly influenced by all 5 assets in both study areas. Kagbeni needs to focus mainly in access to services and facilities. Access to transportation, medical and market are the main constraints. Devchuli needs to focus in financial assets and indigenous people. Policy measures needs to focus to increase poor people's access to technologies, skills for sustainable agriculture production.

Climate Change and Vulnerability Index For Four Selected Villages: A Case Study Of Karnataka

M. Balasubramanian
Institute of Social and Economic Change (ISEC), Bengaluru

Climate change has differential impacts and varies from rich and poor, higher caste (different caste system in India) and lower caste, etc. Vulnerable communities or socially disadvantaged group for example scheduled caste and scheduled tribe (socially, economically and politically discriminated) have been highly affected due to climate change. In India, a focus on the marginal, vulnerable, displaced, environmental refugees and migrants is missing in the context of access and conservation of natural resources. His objectives were to analyse the impacts of climate change on SCs/STs in Karnataka. To assess this a household study of vulnerability to climate change was conducted in selected districts in Karnataka. Villages in districts with the highest and lowest Scheduled caste and scheduled tribe population in Karnataka. Were chosen. Kolar, Raichur, Udupi and Mandya were chosen. Household vulnerability to climate change was analysed through ordinal logit regression model. His study found that the more than 80 percent of household respondents are earning less than ten thousand in this study area. This study had revealed that the drought and prolonged drought was the major climate shocks within the four study villages. The ordinal logit regression results of the study show that the marital status, caste, agriculture production, temperature experience and landholding are statistically significant at 5% and 10% level. Moreover, employment, temperature experience, climate change experience odds ratio is high in the study area. Yarjanthi (Raichur district) is highly vulnerable, followed by Bhoovanahalli (Mandya district) and third moderate vulnerable Gowdathatagadde (Kolar) and fourth less vulnerable Shiriyara (Udupi) of Karnataka. He concluded by saying that planning and implementation of adaptation to climate change is very weak against vulnerable communities. There is a gap between national planning and local implementation, where the vulnerable communities are adversely affected due to climate change.

The Growth Effects of Natural Disasters: Does the Level of Development Matter?

Vikrant Panwar
IIT-Roorkee, Uttarakhand

The study aimed to reconcile the apparently contradictory results reported in the literature and explore the growth effects of natural disasters separately by disaster types and economic sector. The outcome of this study may assist the policy makers to ascertain the costs and benefits associated with investing in Disaster Risk Reduction (DRR). The panel dimensions included 102 countries over the period 1980-2015 (36 years), which includes 29 OECD and 73 Non-OECD countries. Data was organized as non-overlapping five years periods. Data Source had data on natural disasters which were obtained from the EM-DAT database, maintained by the Center for Research on the Epidemiology of Disasters (CRED). Data on all other variables were obtained from the World Development Indicators. He assessed that developing countries are in urgent need of investing more in DRR to not only safeguard the people and assets but also to ensure sustainable development goals in the aftermath of natural disaster. The findings of this study may help policy makers in effectively ascertaining the probable costs and benefits of investing in DRR strategies, which in fact is one of the four priority actions highlighted in the Sendai Framework for Disaster Risk Reduction (SFDRR).

SPECIAL LECTURE: Low Carbon Options for India in the Context of Current Global Political Developments

Kirit S. Parikh, Chairman
IRADe, New Delhi

Dr. Parikh began his presentation by stressing on the fact that India is not historically responsible for climate change. India's contribution to global emissions since 1990 till 2012 has been around 4%. Paris agreement does not take historical responsibility into account and therefore how a country decreases its emissions is their own responsibility. United States had been the largest emitter until recently when it was displaced by China. It will be difficult for India and other nations to bring down the emissions by themselves, hence sufficient pressure needs to be put on the US and China. Even in the past with the Kyoto protocol US got away from its obligations because of the money and muscle power it wields in the international arena and especially over small nations who will not oppose its choices. However, with Donald Trump being elected as the President, has created an opportunity for political mobilization on the issue of climate change. Despite our very little historical responsibility, we still need to take ambitious and effective action and perhaps even go beyond NDCs. Dr. Parikh asserted that railways have always played a good role in pushing freight away from the road. He has also written this in his books and reiterated it in a number of other studies. Although trucks provide timely door to door service, but dedicated rail corridors have contributed to energy efficiency. All these changes have however, not come about through market mechanism, but through government action. Electronic vehicles (EV) is another good measure. On the other hand, EVs pose a huge challenge. EVs are not picking up momentum across the world because of heavy and costly batteries. Besides, a smarter grid is required to cater to the changing needs of the EVs. However, for us, pushing EV and public transport is important not only for climate change but also for local pollution and congestion issues. Dr. Parikh also briefly described the IRADE MODEL-a top down-bottom up model- the results of which suggest that with technological development and R&D efforts, it is possible to make coal economically obsolete. Also, it is possible to double the Solar PV efficiency and reduce battery cost. Not just develop solar and wind but also develop a grid that can easily absorb these technologies. With all such efforts, Dr. Parikh concluded that it is possible to reach our goals with mitigation efforts.

Day 2- 5th August, 2017, Friday

Special Lecture: Regional Earth System Prediction as a Decision-Making Tool for Adaptation and Mitigation

Prof. Raghu Murtugudde
Atmospheric and oceanic science and earth system science, University of Maryland

Prof. Raghu Murtugudde's lecture focused on how certain regional earth system models can be better adapted for decision making by addressing the problem of climate extremes. The lecture touched upon the type of data which can be useful for regional predictions and how they can aid decision making for adaptation. He emphasized the need for a bottom up approach to modelling and contrasted the utility of weather forecasts and decadal weather projections for citizens. The former includes weather forecasts by institutes such as IITM - which span over a prediction period of 15-20 days- and are directly beneficial to farmers to adapt to local conditions. The latter includes multi-decadal projections-such as the ones provided by the IPCC- which are largely useful for raising awareness about climate. However, they are ill suited for the purposes of local adaptation. This is particularly important in the case of the tropics, weather forecasting and climate modelling in general is a challenge. Starting with Earth System Modelling (ESM), he observed that while the resolution of such models has improved over years, there is the presence of uncertainty in predicting temperature changes. At the same time, there has developed a greater clarity over the nature and range of such uncertainty. The analysis of climate and weather feedbacks have also improved. Another issue regarding global ESMs pointed out by him was the need for better resolutions at smaller scales. The question for policy makers and scientists was to utilize results of Global and Regional ESMs at a local level. This is important as the impacts of global changes occur at the regional level. Macro scale data must be used in conjunction with micro scale data to make such predictions using empirical models. And with repeated use, users can develop skills as to how much to trust the reliability of the model results. This necessarily is an exercise that must involve multidisciplinary expertise. Additionally, models such as Climate-Weather. Research and Forecasting (CWRF) improve seasonal climate prediction. However, despite such extensive use, in India there is still some skepticism about models. This is unlike the case in China, which has adopted different model simulations and projections to guide adaptation. What needs to be emphasized therefore, is the choice of models best suited for different regions. The next half of his lecture focused on how a bottom up approach can be best used in tandem with regional models for decision making. In particular, the presenter demonstrated a regional model created for Chesapeake Bay in the USA. The project was funded by the NOAA. It was a top-down/bottom-up interactive tool where the user could change input parameters and look at the response. The tool was meant for online as well offline use. Multiple scenarios could be generated for optimization problems or for decision making processes.

Session IV: Climate Science - Impacts, Risk analysis and attribution

Chair: Dr. Raghu Murtugudde
University of Maryland, USA

Hydro-Climatic Simulations and Their Applications

Dr. Subimal Ghosh, Associate Professor.
Department of Civil Engineering, Indian Institute of Technology Mumbai.

In his presentation, Mr. Ghosh highlighted the essential standard practices to procure climate data from available resources which includes: Getting climate simulations of precipitation and temperature from multiple climate models; Perform Bias Correction based on observed data; Use bias corrected output in hydrological models, such as SWAT, VIC etc.; and Calibrate based on limited number of observed streamflow data. Dr. Ghosh then discussed the problems associated with such approach. This is reflected first in terms of bias correction and secondly with regards to hydrological modelling. In the case of bias correction, the simulated data is sometimes forced to be merged with observed data resulting in errors. Dr. Ghosh found that bias correction assumes a stationary bias when in reality it is non-stationary. With regards to hydrological modelling, a majority of hydrological models do not incorporate irrigation and anthropogenic intervention in the water cycle. In the case of irrigation, the model is often demand driven and therefore inaccurate. Dr Ghosh also stressed the need for providing realistic information to water managers for optimal decision making and adaptation. And then proceeded towards estimating abstraction and recharge levels through formulae given by the central water commission, India. For Flood management Dr Ghosh declared the need for a real time hydrological situation for initial condition, upstream reservoir operation and proper coupling of hydrological and hydraulic systems.

Dynamics of Equatorial Atmosphere and Oceans

Dr Sridhar Balasubramanian
Associate Professor at IIT Bombay, Mumbai

The presentation started with an explanation of parameters affecting earth systems and their dynamics. This included: Fluid motion over atmosphere and ocean; Change in density of space and rotation of the earth i.e. Coriolis force which complicates the dynamics of fluid motions; and Presence of wind patterns, cloud formation and other intra seasonal phenomena. Dr. Sridhar explained the heat budget of the earth and the feedback between atmosphere and oceans happening through the ocean surface. He also detailed how the evaporative heat flux cools the ocean, as the atmosphere directly above the ocean is not saturated with moisture. He then went on to detain the following processes in a general circulation model (GCM): Thermodynamic equation; Equation of motion; Radiation Transfer; Equation of water vapor; and Heat balance and hydrology of the earth's surface. Finally, he remarked that there is a need for understanding the basis and use of parameters and process dynamics at various spatial and temporal scales. He explained that field experiments will give a clearer picture about the associated fluxes. As well as the fact that the role of sub surface dynamics and vertical mixing needs to be understood at high spatial resolution in order to move towards a more dynamical model approach.

Session V: Climate Change Adaptation - Sector Specific Strategies

Chair: K.S. Kavi Kumar, MSE, Chennai

Climate Variability and Climate Change Impacts on Agriculture

B. Venkateswarlu, Vice- Chancellor,
V.N. Marathwada Agricultural University, Parbhani

The presenter started off by highlighting how climate change manifests in terms of changed rainfall pattern, temperature rise, elevated CO2 levels, rise in sea level, glacier melting and extreme weather events, and went on to illustrate the impact of climate change on agriculture. Of these manifestations, what affects agriculture are rise in temperatures (more so night temperature), erratic rainfall, increasing spatio-temporal variability of rainfall, decrease in rainy days (most models project increase in total rainfall in future) as well as extreme events. In the immediate run, we are already experiencing climate variability impacts on agricultural production. Water deficit/excess is a major issue during kharif season due to reduction in rainy days, longer dry spells and heavy rainfall events. Whereas high temperature is also a factor in sensitive crops (Paddy). Temperature rise is a major issue during rabi, particularly if planting is delayed in double cropping systems. Untimely rains, sudden drop/ rise in temperatures and humidity are known to cause high pest incidence. The impacts of climate change on food security affect all dimensions. Availability is impacted due to reduced production. Accessibility is affected because of price volatility caused by declining production and extreme events impacting livelihoods and loss of wages. Kharif crops are to be impacted more by rainfall variability while Rabi crops will be affected by rise in minimum temperatures. In terms of specific impacts on food security the following scenarios are likely to play out:

- Wheat is likely to be negatively impacted in Rabi due to terminal heat stress – 1 degree rise in temperature results in loss of 4 million tonnes of wheat.
- Rice will be impacted by both, temperature and water availability.
- Legume crops like soybean and chickpea are likely to benefit due to increased temperature/CO_2 if water availability is not limited.
- Negative impacts on horticulture through impact on flowering and pest and diseases.
- Potato production would gain in northwest zone.
- Warming would reduce milk production by 1.6 million tonnes by 2020.
- Rise in sea surface temperature leads to change in breeding season and distribution zones in marine fisheries. Water shortage to impact freshwater catch.
- There would be a significant negative impact on commercial poultry due to heat stress.

The other impacts of climate change in agriculture are to be seen in terms of farm level impacts. These include:

- Re sowing needed due to inadequate rains.
- Yield losses due to temperature/pests and disease outbreak.
- Total crop loss due to floods/cyclones.
- No surplus for reinvestment.
- Loss of fodder- impacting livestock sector

He concluded by saying climate change is a reality. Climate variability will impact availability of food supplies and price volatility in the short term. However, warming beyond 2-3 degree Celsius will have a significantly negative impact on food supplies. The best way to address this scenario is to make significant investments in technology and change the existing policy framework governing the use of natural resources.

Assessing Climate Induced Migration and Policy Responses in South Asia

Harjeet Singh, Action Aid International, New Delhi

Sanjay Vashist, Climate Action Network South Asia

The presenters (based on studies from different developing countries) began by providing estimates of displacement and migration caused by climate change. They estimated that 90% of disasters in the last decade have been climate related. A conservative estimate according to them would put the figure in India to about a billion people who have been displaced. Climate Change has caused a multiplier effect on migration. South Asian countries have been slow to recognise the role of climate change as an additional push factor, and the level to which it is driving migration. The question is not simply that migration is an adaptation strategy employed by people but also a question of whether the migration is safe or unsafe one. The impact of such migration is particularly felt by women, elderly people, trapped communities i.e. those who are left behind. At the same time, international literature does not provide a clear definition on climate migration and displacement. The presenters then provided some recommendations to address this situation which included: Developing definitions; Obtaining data with a focus on gender; Enhance resilience to climate change; Ensure people protection and human rights; Planned relocation; Move people from coastlines; Create alternative channels to develop co-operative approaches between countries; and Build displacement scenarios based on warming levels.

Impacts of floods on State Finances - A Study of five States in India

Unmesh Patnaik, Assistant Professor
Centre for Climate Change and Sustainability Studies, TISS, Mumbai

The presenter began by saying that loss and damage (L&Ds) from rapid and slow-onset disasters have increased over time and also likely to be non-decreasing in the future. While growth theory predicts that natural disasters should have a negative impact on economic development, there is no clear-cut evidence in literature about the exact relationship. A significant proportion of this is contributed by floods (close to $7 billion). This is most regularly observed in the following 5 states- Andhra Pradesh, Assam, Bihar, Odisha and West Bengal. For these states, there is a wide variation in reported loss and damage and area affected across the states over time. He then elaborated the research question of this study which were as follows: What has been the nature of loss and damage over the years across these flood prone states? How have they impacted the state level GDP? The results of his study can be summarized as follows: Although no single event amounts to damage of 1% of the state GDP, the incidence is regular; there is a wide variation in percentage of area affected due to floods across the states. Share of losses and damage to state gross domestic product significantly increase over time even if magnitude is low (coefficient value 0.02); there is no trend observed for percentage of flood area affected normalized by geographical area of the state and crop area affected; there is evidence that higher losses are partly driven by the growth trajectory of the State; controlling for intensity of floods does not change the results for the treatment effect. Although small in magnitude past flood events have negatively affected the state GDP for the 5 flood prone states; the losses due to floods have significantly increased during the 1953-2011; Floods have significantly eroded a small portion of the state GDP for the 5 flood prone states; further research in analysing climate- economy linkages are required

Impacts of Climate Variability on Crop Yields - An Empirical Study for Karnataka

Kamal Murari, Assistant Professor,
Centre for Climate Change and Sustainability Studies, TISS, Mumbai

Sandeep Mahato, PhD candidate TISS, Mumbai

The study was based on analysing the impacts of climate variability and its impact on crop yield. In crop studies, among climate variables, precipitation and mean temperature have been considered as the key factor. Very recently there has been a shift of focus of studies from mean to exposure of extreme temperature. However, most studies of extreme temperature and crop are limited to wheat and maize only and are studies for major growing regions. Very limited evidence is available for other crops and geographical regions. In particular what was looked at was the impacts of temperature changes on crop yield. Effects of temperature are generally well understood up to the optimum temperature for crop development. Effects above these optimum temperatures are much less known. The questions investigated within this study were as follows: Is there evidence of increasing exposure to temperature? What is the impact of extreme temperature on wheat crops? Are there impacts of extreme temperatures on other crops in Karnataka? The approach adopted for crop-climate impact study were: Agronomical plot scale experiments, Crop model based experiments for plot scale and regional scales, Statistical assessments using careful data of temperature and yield; Remote sensing based assessment using variables that are proxy to the yield. Some observations and conclusion based on the date analysed were as follows:

- There was increasing evidence that crops will be exposed to extreme temperatures.
- Historical data suggest that North Karnataka has an exposure to temperature higher than 35°C during crop growing season. Exposure to temperature higher than the crop specific threshold temperature has a negative impact on the crop yield.

The negative effect of extreme degree days is higher than the seasonal rainfall and average temperature. There is a possibility that effect of extreme heat can negate the effect of good rainfall to crop.

The negative effect on yield is significant for major crops, especially for Kharif rice both irrigated and unirrigated, Rabi unirrigated jowar, and tur cultivated in the kharif season.

Session: VI-A: Climate Action -Sector Specific Strategies (Agriculture and Fisheries)

Chair: B. Venkateswaralu

Economic and Non-Economic Loss and Damage from Droughts in Western India: Role of Crop-insurance and Irrigation

Dr. Chandrasekhar Bahinipati, GIDR, Ahmedabad

The objective of the paper was to examine the main roles played by the crop insurance and irrigation schemes in mitigating loss and damages from droughts especially in the Western Indian context. The area of study was the Kutch region of Gujarat. The presenter stressed the importance of accessing the non-economic impact of droughts which are sparsely reported and more prevalent in Western India due to various reasons. According to the presenter irrigation and insurance schemes has played a major role in reducing the impacts due to loss and damage caused due to climate change. They used the probit model to identify the determinants of loss and damage intensity. The study observed a higher non-economic loss and damage from droughts. While irrigation reduces their potential impact, crop-insurance failed to mitigate loss and damage, including both economic and non-economic loss. The study recommends the estimation of non-economic loss and damage, which is currently unaddressed by policy, and suggests for revision of existing insurance mechanisms for better risk management.

Simulated vs. Empirical Weather Responsiveness of Crop Yields

Malcolm N Mistry
Università Ca' Foscari, Venice, Italy

The presenter gave an overview of the types of crop models- mechanical and statistical, in order to explain the use of different models and the concepts underpinning them. One of the key issues according to the presenter was the presence of changes in crop yields projected by different models in response to the same meteorological factors. The study upon which the paper was based examined yields of rain-fed maize, wheat, and soybeans and was simulated by six GGCMs as a part of the Inter-sectoral Impact Model Inter-comparison Project-Fast Track (ISIMIP-FT) exercise. The study compares hind-cast yields (between 1981 and 2004) against U.S. Dept. of Agriculture (USDA) time series for about 1,000 counties. RCP 8.5 scenario was used in the model. Based on data from the larger literature on climate change impacts, they estimated that crop yield responds to temperature and precipitation exposures for both GGCMs and observations. They found that up to 60% of the variance in both simulated and observed yields is attributable to weather variation. Majority of the GGCMs have difficulty reproducing the observed distribution of percentage yield anomalies, and exhibit aggregate responses that show yields to be more weather-sensitive than in the observational record over the predominant range of temperature and precipitation conditions. This disparity is largely attributable to heterogeneity in GGCMs' responses, as opposed to uncertainty in historical weather forcings, and is responsible for widely divergent impacts of climate on future crop yields.

What Determines Adaptation Responses in Marine Fishing Communities?

Krishna Malakar, IIT Bombay

The presenter began by giving the following overview of the issues impacting fishing communities and adaptation: Indian marine fishing community faces multiple climate and non-climate related stresses, such as unpredictable and extreme weather events, declining fish stocks and pollution. Prompted by these changes, some community members have adopted strategies such as motorization and mechanization of their boats and using GPS (Global Positioning System) for navigation, to ensure a greater fish catch as well as safety in the sea. They have taken the Koli community around Mumbai in their case study to find how they have adapted to the growing disturbances which are posing a threat to their livelihood. Capacity to adapt is crucial for retaining livelihoods. Given this context, the paper attempted to measure and develop indices denoting the strength of adaptation and adaptive capacity of the community. Adaptive capacity of the community is measured through indicators for human, physical, economic and social capitals. The results of the study facilitate identification of the coastal areas in urgent need of policies and actions to develop adaptation and adaptive capacity of the community. Such that the cultural identity of the concerned community can be preserved and there can be proper planning for the future generation.

Application of Decision Support System For Agrotechnology Transfer (DSSAT – A Crop Simulation Model) To Assess The Impacts Of Mean Temperature Rise On Wheat Yield.

Himanshu Pathak
TISS, Mumbai and Kerala State Planning Board

The presenter focused on the importance of crop models especially DSSAT to model agricultural productivity. The paper presentation began by highlighting the need for model based solutions, especially crop models to know yield gaps. The presenter also pointed out advantages of using crop models, which are based on simulation, over the use of statistical models. In the paper, the author illustrated the differential impacts of climate change using agriculture management information provided by ICRISAT longitudinal village level database. Soil profile data of the entire region (Up to 200 mm depth) was taken from ISRIC 10km x 10km grid. The past climatic parameters were obtained through satellite data and future climate scenarios were interpreted using Climate Model data. The information was then conglomerated in DSSAT to provide the gap in yields of different class of cultivators. Therefore, the study enabled crop modelling to estimate climate variability impacts on different farm size holdings.

Session VIB: Climate Action - Climate Action: Energy and Mitigation

C.E.Karunakaran, Tamil Nadu Science Forum, Chennai

Study of Causal Relationship Between Road Transport Infrastructure, Energy Use, Economic Growth And CO2 Emission In India

Namita Singh, Trupti Mishra, Rangan Banerjee IITB, Mumbai

Ms. Singh's result showed that there is a unidirectional causation between transport, energy consumption as well as one between economic growth, road transport and CO2 emissions. Ms. Singh's suggestion for policy framework was that since transport is the backbone of many other sectors, we cannot altogether curb transport emissions; hence we need measures such as electric mobility mission plan and auto fuel policy.

Financing of Solar Technology: A Comparative Analysis Of Policy Measures Across The Developing And Developed Worlds

Maria Chirayil
Centre for Climate Change and Sustainability Studies, TISS, MUMBAI

Ms. Chirayil selected four countries- India, China, Germany and the USA, and identified their federal policy for solar technology and reviewed them and their job implications. She noted that the global trend of module cost has been on a decline and with every doubling of production value there is a decrease in the price of the module. For United States Ms. Chirayil found out that from 2009-2010 there was a 15% decline in installation capacity. For modules, the imports were greater than exports in 2006.The conclusion Ms. Chirayil drew for US were- 1) Solar technology has been based on increasing both investment and deployment and 2) the initial fall in price was spurred by the policy. For China, it was found that feed in tariff played the most important role in pushing solar to the forefront. Domestic deployment increased only after feed in tariff mechanism came into being. It was concluded that there was a focus on manufacturing followed by demand side support. Germany adopted solar for phasing out nuclear power. The base electricity charge has been low but Renewable energy surcharge is double the price. The cost of solar module is still comparatively high. A premature withdrawal of state support was seen. For India Feed in tariff mechanism, accelerated depreciation, renewable purchase obligation played an important role in the progressing solar technology. Current policy in India is deployment centric and major investment in R&D and large-scale manufacture is required.

Techno-Economic Analysis of Rooftop Photovoltaic (RTPV) Systems for various Indian States

Jaymin Gajjar
Centre for Study of Science, Technology and Society, Bengaluru

The paper made an inter-state comparison of RTPV system. It found that in India the states which have the best economic potential for Solar Rooftop were – Rajasthan, Gujarat, Maharashtra, Karnataka and Tamil Nadu. India has set a target of 40GW RTPV to be achieved by 2022. 1.5GW so has been the total installed capacity by June 2017. Tamil Nadu has been the leading state in RTPV installation. Mr. Gajjar compared Installed Capacity across 3 sectors-Residential, Commercial and Industrial and noted that in the Residential Sector Karnataka was more profitable in terms of RTPV installation than Tamil Nadu, owing to low tariff retail and 30% subsidy for RTPV in Karnataka. Similarly, Mr. Gajjar concluded that Karnataka was also the leading state in the commercial sector and Rajasthan was leading in the Industrial sector. Thus Rajasthan, Karnataka and Maharashtra were found to be the most conducive for RTPV growth.

Development of Framework to Estimate Crop-wise, Region-wise Electricity Usage for Irrigation

Akanksha Doval and Priya Jadhav
IITB, Mumbai

Ms. Doval's objective was to estimate agricultural water and energy usage based on cropping patterns, water sources, irrigation methods and agro-climatic conditions. The motive behind her study was that electricity supply for agricultural energy consumption is not 100% metered and is highly subsidized. The limitations of the study were the absence of data availability to estimate crop wise energy consumption. Ms. Doval took 3 case studies for her study and focused on a particular irrigation method in each study. 1) Nashik - old dawachwadi feeder with the main source of irrigation being surface, groundwater. Here, Ms. Doval compared estimated energy with actual energy feeder and found a sufficient gap between them. 2) Kolhapur - lift irrigation schemes; It was selected as better data was available. 3) Nanded - Trikut feeder; Energy per unit crops for different units was computed. Ms. Doval found out that for similar crops the water usage by different farmers is approximately the same which is quite closer to the theoretical crop water requirement. The results also showed that the energy consumption data at feeder level is fairly reliable and even though Minor Irrigation (MI) Census seems like a good concept in theory, it fails to capture the actual water usage scenario at ground. Closing Remarks: Mr. Karunakaran in the end reflected how the policy makers should be made aware of the true cost of fossil fuel energy. The current National Energy Policy is aggressively promoting Renewable Energy and by 2040 primary commercial energy share of fossil fuels will drop from 81% to 78%.

Session VII: Climate Change Mitigation & Adaptation - Strategies for the Future

Navroz Dubash
Senior Fellow, Centre for Policy Research, New Delhi

Energy Policy in the Era of Climate Change - Way forward

Rangan Banerjee, Forbes Marshall Chair Professor
Department of Energy Science and Engineering, IIT Bombay

The presentation sought to address the following three questions: What are the energy transitions that we have had in India? What are we likely to have? What are the driving factors? In the last thirty-forty years there has been significant energy transition, particularly away from the traditional fuels. Much of this transition has come from Public sector and government investment. The transitions in primary energy mix was depicted using tri-plot with coal, oil and natural gas, and renewables and nuclear as the three variables for the period between 1971 and 2013. In the 1970s primary energy was significantly renewable indicating the dominance of traditional biomass for cooking, thereafter there is an upward trend for coal and oil and natural gas and a downward trend for renewable and nuclear. In the case of power generation supply mix, 40 % of the supply came through renewable in the 70s, currently 80%

comes from fossils. The presenter claimed that the whole issue of climate change, Paris commitment and the global move away from fossils has driven the energy transition. Further, reduction in prices of shale oil and natural gas, technological developments and significant drop in prices of Solar PV and wind were identified as some of the key drivers for the transition. India has one of the highest growth rates in solar and wind. However, the lag in the manufacturing of Solar PV was caused by low capacity utilization and its inability to compete with the international producers on multiple grounds – technical efficiency, costs, etc. This had necessitated a significant increase in the Solar Module imports. Currently, 88% of the domestic supply was met by imports, mostly (84%) from China. Further, in an attempt to increase the contribution from wind and solar in the energy mix, it is also important to acknowledge the large variations that are inherent in these sources of energy. There is a need to put other flexible sources in the supply mix to maintain the quality of supply. Other aspects that require emphasis according to the presenter were regulations, provisions for affordable electricity, improving forecasting, the possibilities of configuring decentralised distribution, self-sufficiency in terms of technology as well as analysing the equity impact of the alternative strategy and the impact on growth. Finally, on the question of whether technologies themselves can provide the solution, he stated that what has unfortunately remained unchanged through all this is income inequality, energy and carbon inequality. Energy should therefore be seen as an enabler for quality of life, a means to an end.

Transformative Climate Action - Possibilities and Potentials

Sudhir Chella Rajan, Professor
Department of Humanities and Social Sciences, IIT, Chennai

Prof Rajan argued for a model of transformative change in a global setting. “Sustainability” for a long time was focused on the question of environment-ecology and economy. He stated that element of society has brought sociologists back in the picture. Defining transformative change as rapid and early society wide change in our ways of living driven by a collective ethical commitment to address planetary boundaries, he cited IPCC as an example of global transformative change. IPCC has been a remarkable institution influencing a sizable public through a future oriented knowledge producing network. The new networks and processes produced by IPCC have helped set up models for other kinds of networks. It is an attempt to make science and policy engage with each other and makes complex science simple and understandable for policy makers. He stated that the study is primarily aiming at identifying pathways to shift lifestyles and consumption patterns towards more sustainable alternatives. His approach is more people-centric in the sense that it concerns with inspiring people to become more aware and adopt “sustainable modes” of living. Focusing on the example of passenger transport, he emphasised that regimes of mobility are defined by socio-spatial conditions as much as technology. Transformation is not only a matter of public action, but bringing about real cultural transformation that would entail innovation in the very design of the institutions of polity and economy.

Closing remarks by the Chair: Climate change debate being shaped by the North is something that has been substantially challenged worldwide. Dealing with climate change as an objective should be consistent with other sustainable development objectives. Further, dealing with real issues is not just about tweaking policies. It has to be about transformation- institutional, lifestyles, looking at problems in a different perspective - imagine and rethink. We need to talk about transformations.

Concluding Session: The future research agenda for climate change

In the final session Prof Jayaraman invited all participants to comment on what they think should be the future direction of climate change research. The broad research agenda which came up for discussion during the session included- Climate Negotiations, the kind of demands that might be imposed on India, the politics of climate negotiations in the near future, and the potential challenges that will be faced by researchers working on the subject. A summary of the issues raised by various participants in the conference on these themes are mentioned below

- *Anas Raheem (CCSS, TISS)* - We do not have the adequate funds on the table.Climate Finance therefore is an issue that must be researched and spoken about more clearly in our efforts to address at the international level in a post-Paris world.

- *Johnathan James Guy (CPR)* – The overall focus in climate negotiations and indeed the way forward will revolve around the questions of Climate justice as well as distributional justice. This would involve the co-benefits approach and the different ways in which distribution and equity can be achieved.
- *T. Gangadharan (KSSP)* – There is a Historical responsibility of the developed world to contribute more towards mitigating climate change. However, we also have the responsibility within India to act upon the situation in the immediate run. We have to make use of and leverage our market to the developed world in order to get more work on climate done. It is also important to note that at the political level climate change has not received much attention within our country. Therefore, the onus does remain on us, the people of India, to initiate and engage in a wide range of discussions at the political level on the different aspects of climate change.
- *Prantik Mitra (TERI University)* – There must be a change in the leadership roles assumed by different countries in the global scenario. It is clear that the US is not taking up the mantle and therefore others must step up. This is an opportunity for the developing world and China is doing so currently. There is also additionally the issue of the gap in research on issues pertaining to climate change. This gap is between the absence of synergies in research between the social sciences and the sciences. This is a key research agenda which must be pursued forward.
- *Darryl DMonte* – We are, I think missing the G word- Gandhi- highly unfashionable to even name him now days. Meeting the needs of the last person. The last person in our society could be a woman or a child. Millions of people are without electricity, cooking fuel- ensuring equity through meeting their needs.
- *B. Venkateswarlu (Vice Chancellor, Marathwada Agriculture University)* - Common people are not aware of this discussion. It is our responsibility to relate to their livelihoods. Question of the whole development model itself. Do we need to follow the same model of the west (example of urban Malls in the context of utilizing space and energy) Can we set our own agenda?
- *Pankaj (IITB)* - Consider the efficiency in the water usage - irrigation - energy required increases with increasing depths. China - agriculture 20% contribution to GHG emissions. There is a need to work on that.
- *Tejal Kanitkar (CCSS, TISS)* – We need to think from different perspectives, beyond our own discipline. Become much more critical of things seemingly objective. Being critical about knowledge available in the public domain is important.
- *Anand (Development Studies, TISS)* - When it comes to negotiations on foreign policy level, the bargaining chips of different countries are different. How many strings can you pull at these negotiations?
- *Ashim Roy (Vice- President, NTUI)* - Decentralized politics that is coming up and this indicates a real shift in momentum. We need to figure out this within the areas that we research - how does climate change, environment engage with this? Can we bring up an interface for a more participatory development framework?
- *John Dsouze* - (With reference to the ACC Cement presentation) who are the dominant players in the field? More intelligence, research and scenario building are required to be done in all sectors.
- *Parjanya Joshi (CCSS, TISS)* - There is a need for increased outreach towards the larger public which could be achieved by leveraging the mainstream entertainment industry. Not enough movies are being made on climate change. "Inconvenient Truth" has made conversations happen.
- *Kashmira Pawaskar (CCSS, TISS)* - Learning sustainability in the corporate world is different from what we learn at this institution. How can this gap be bridged to foster optimal utilization of the knowledge produced and the funds allocated towards climate action?

Closing remarks by Prof. T. Jayaraman

In his concluding remarks Prof T Jayaraman, stressed on the following points which will be important for future direction of climate change research. Firstly, we must continue to focus and follow the international climate change negotiations. Secondly, while we have broad action plans on climate change, we need investment in serious work on sector specific issues. This would necessitate exploring a plurality of approaches. Thirdly, in the coming years it will be important to distinguish between development deficit and adaptation and above all we must always center it on the politics of it all

Closing Remarks by Dr Tejal Kanitkar

Dr Kanitkar in her closing remarks thanked the Rosa Luxemburg Stiftung for providing the grant for this conference and making this conference possible. She also thanked the faculty and the students of Centre for Climate Change and Sustainability Studies, and the technicians who contributed in various capacity to make the conference possible. She thanked all the participants and also elaborated on some of the future events which have been planned by the Centre, in the months to follow.