FOSSIL FUEL PHASE OUTS TO MEET GLOBAL CLIMATE TARGETS: INVESTIGATING THE SPATIAL AND TEMPORAL DIMENSIONS OF JUST TRANSITIONS

by

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Abstract

Fossil fuel industries currently employ millions and contribute to local and national economies. However, to keep global warming well below 2°C, fossil fuels need to dramatically decline. Scholars in many academic fields are focusing on “just transition” strategies for mitigating the impact of fossil fuel industry declines on workers and their communities. The research on this topic is nascent, and limited to conceptualizing and defining the role of stakeholders in just transition planning, and investigating renewable energy jobs as an option for fossil fuel workers. In this dissertation, I conducted a systematic review of the academic literature on just transition to synthesize identified elements of just transition. Next, I collected a novel employment factors dataset and combined it with an integrated assessment model to analyze the energy sector employment implications of climate policies. I also assessed whether ‘local’ renewable jobs can be created for fossil fuel workers in key coal producing countries. Finally, I collected several novel datasets to quantify and compare the scale of current socio-economic dependency on coal at the district level in India. Three primary insights emerge from this research. First, just transition literature to date has focused on coal workers in OECD countries and is largely normative. The existing literature provides key elements of a just transition that vary in spatial scale, justice forms, and timeframe. Second, while renewable energy jobs could offset fossil fuel job losses in the aggregate in most countries, this is not true everywhere. Moreover, it may not always be feasible to create ‘local’ renewable jobs for fossil fuel workers. This highlights the need to focus on non-renewable industries for fossil fuel workers’ job transition. Third, there can be large variations in the scale and type of socio-economic dependency on fossil fuels within a country. Overall, this dissertation shows the need for a more holistic understanding of the implications of fossil fuel industry declines on workers and communities.

Lay Summary

Fossil fuel use needs to decline rapidly to meet global climate targets. As fossil fuel industries decline, this will have implications for fossil fuel workers and communities. An emerging body of “just transition” research examines how to mitigate the impacts of this transition for workers, but remains limited in scope.

In this dissertation, I reviewed existing just transition literature to synthesize key elements of just transition. I collected new datasets to analyze whether renewable energy jobs are a feasible option for fossil fuel workers. I gathered other datasets to understand how socio-economic dependency on coal varies at the local level in India. I found that just transition strategies require a more holistic understanding of spatial, temporal, and justice aspects of transition. I show that renewable energy jobs may not always be a ‘local’ job option for fossil fuel workers, and there are other aspects of just transition beyond jobs that require attention.

Preface

Four original stand-alone research chapters (Chapter 2-5) are included in this dissertation and are published or are intended for publication in peer-reviewed journals. I am the primary responsible person for all these Chapters. In all of the research chapters, my contributions include: 1) identification of research objectives and specific research questions, 2) developing the study design including methodology, 3) undertaking research activities, 4) conducting primary and secondary data collection and analysis, and 5) preparing the manuscripts.

My Ph.D. supervisory committee comprises of Dr. Hisham Zerriffi, Dr. Kathryn Harrison and Dr. Jessica Jewell. My PhD committee has played a big role in shaping my doctoral research objectives. They have also provided invaluable feedback to my several research proposal drafts and guided me to hone my research questions. My Ph.D. supervisor, Prof. Hisham Zerriffi, contributed to my dissertation in many ways. He helped with data analysis in terms of providing new ways to examine data, offering competing interpretations of results. He also helped me think about the limitations and future applications of my work. My supervisory committee members also provided very helpful comments to several drafts of my chapters included in my dissertation.

Chapter 2 – Synthesize and conceptualize elements of just transition that scholars in different academic fields identify

In this chapter, I conducted a systematic review, applied the JUST framework to the just transition elements, and wrote the manuscript. Dr. Kathryn Harrison & Dr. Hisham Zerriffi helped me refine my research focus and reviewed several versions of the Chapter draft. A working paper closely based on this dissertation chapter has been published as part of the ***Smart Prosperity Institute's*** *Clean Economy Working Paper Series* in April 2020.

Pai, S., Harrison, K., & Zerriffi, H. (2020). *A systematic review of the key elements of a just transition for fossil fuel workers.* Smart Prosperity Institute. 20(4). https://institute.smartprosperity.ca/transition-for-fossil-fuel-workers

Chapter 3 – Analyze the energy sector employment implications of keeping global warming Well-Below 2°C, globally and in different regions

In this chapter, I designed the study, conducted the literature review, performed data collection, and wrote the manuscript. Dr. Jessica Jewell, Dr. Hisham Zerriffi, Dr. Johannes Emmerling and Dr. Laurent Drouet contributed to the conceptual development and providing valuable insights for interpretation of findings. They also provided valuable comments on several drafts of this Chapter. I conducted the analysis along with Dr. Johannes Emmerling and Dr. Laurent Drouet. A paper closely based on this dissertation chapter has been accepted in an interdisciplinary journal.

Chapter 4 – Assess the feasibility of renewable jobs replacing local coal jobs in top coal producing countries

In this chapter, I designed the study, conducted the literature review, performed data collection and analysis, and wrote the manuscript. Dr. Hisham Zerriffi and Dr. Jessica Jewell contributed to the conceptual development and provided valuable insights for interpretation of findings. They also provided valuable comments on several drafts of the Chapter. A paper closely based on this dissertation chapter has been published *Environmental Research Letters* in January 2020. Three anonymous reviewers for the *Environmental Research Letters* offered constructive comments on the manuscript, which included comments on scope, analysis, writing and the structure.

Pai, S., Zerriffi, H., Jewell, J., & Pathak, J. (2020). *Solar has greater techno-economic resource suitability than wind for replacing coal mining jobs.* Environmental Research Letters, 15(3). https://doi.org/10.1088/1748-9326/ab6c6d

Chapter 5 – Assess the socio-economic dependency on coal at a local level in India

In this chapter, I designed the study, conducted the literature review, collected the primary data and conducted the analysis. Dr. Hisham Zerriffi contributed to the conceptual development and provided valuable insights for interpretation of findings. Dr. Hisham Zerriffi, Dr. Kathryn Harrison and Dr. Jessica Jewell reviewed multiple draft of the manuscript and provided valuable comments. A short paper based on the key dataset has been published in *IOP SciNotes* journal in January 2021. Two anonymous reviewers for the *IOP SciNotes* offered constructive comments on the manuscript, the dataset scope, and the structure of the paper. A paper based on the full dissertation chapter will be submitted to an interdisciplinary journal in the field of energy transitions and policy.

Pai,S., & Zerriffi, H. (2021). *A novel dataset for analyzing socioeconomic developments in the Indian coal industry.* IOP SciNotes 2(1). https://doi.org/10.1088/2633-1357/abdbbb

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List of Abbreviations

CIL	Coal India Limited
CSR	Corporate Social Responsibility
DMF	District Mineral Fund
GHI	Global Horizontal Irradiance
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
NDC	Nationally Determined Contributions
NLC	Neyveli Lignite Corporation
OECD	Organisation for Economic Co-operation and Development
PPCA	Powering Past Coal Alliance
PRISMA	Preferred reporting items for systematic reviews and meta-analysis
SCCL	Singareni Collieries Company Limited
SSP	Shared Socioeconomic Pathways
UNFCCC	United Nations Framework Convention on Climate Change
WB2C	Well-Below 2°C
WITCH	World Induced Technical Change Hybrid

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It takes a village to finish a PhD. Mine was no different. There are so many people who helped me along the way. In particular, I want to thank some special people who made this PhD possible.

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Dedication

This dissertation is dedicated to all first-generation college students. It isn't easy. But it's so rewarding to navigate the long road to graduation and live your parents' dreams.

Chapter 1: Introduction

In December 2015, world leaders from nearly 200 nations met at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties in Paris and collectively agreed to combat the climate change crisis by reducing global greenhouse gas emissions. At the end of the conference, global leaders pledged to keep global temperature rise below 2°C or even 1.5 °C (compared to pre-industrial levels) (UNFCCC, 2015). During the Paris talks, individual nations, including some fossil fuel producing economies, declared that in the long run they would reduce their energy dependence on fossil fuels and increase the use of renewable energy.

Three years after the Paris conference, the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 °C underscored the urgency of this transition. This report found that use of fossil fuel-based energy needs to decline rapidly (in a matter of decades) in order to keep the world temperature rise below 1.5 °C (IPCC, 2018). At the same time, the share of renewable energy sources such as solar and wind needs to increase rapidly in the coming decades (IPCC, 2018). However, recent analysis shows that the current national policies of many nations are inconsistent with meeting both 2°C and 1.5 °C targets (SEI, IISD, ODI, E3G, & UNEP, 2020).

While current national climate plans are not sufficient to meet global climate targets, some national and state/provincial governments have initiated explicit plans to phase-out different fossil-fuel industries or introduced policies such as carbon taxes that might implicitly result in fossil fuel industry contractions. For instance, nearly 32 national governments including Canada, Germany, and the United Kingdom (UK), and several sub-national governments from the United States (US), have joined the Powering Past Coal Alliance (PPCA), which is a global alliance whose mission is to work towards phasing out coal-fired electricity generation by 2030 in Organisation for Economic Co-operation and Development (OECD) countries and by 2050 in all countries (Jewell, Vinichenko, Nacke, & Cherp, 2019). More recently, even major fossil fuel dependent economies such as China have pledged to substantially reduce fossil fuel production and use in the coming decades and become net zero carbon emitters (Normile, 2020; O'Beirne et al., 2020).

As clamour for climate action grows and countries carve out policies to reduce their fossil fuel dependency, different stakeholders such as federal and local governments, international organisations, advocacy groups, and trade unions have suggested that such climate policies should be backed with strong just transition policies to ensure fossil fuel dependent workers and their communities are not left behind (ILO, 2015; Powering Past Coal Alliance, 2018; SEI et al., 2020; UNFCCC, 2015). Such calls to implement just transition strategies are growing by the day. Just transition plans are seen by many as important tools to overcome possible political resistance from workers and communities against climate policies, and to ensure justice in transition (Healy & Barry, 2017; Johnstone & Hielscher, 2017).

Until a few years ago, academic literature on energy transitions largely focused on conducting techno-economic analyses to meet climate targets (IPCC, 2018; Jacobson et al., 2017; Jacobson, Delucchi, Cameron, & Frew, 2015; Lund & Mathiesen, 2009; Pleßmann, Erdmann, Hlusiak, & Breyer, 2014). These techno-economic studies typically focus on energy technologies and analyze least cost or cost-effective ways in which low-carbon technologies can diffuse in order to meet climate targets. While these techno-economic studies have made important scientific contributions to understanding options and feasible pathways for technologies to meet climate targets, they ignore socio-economic and political dimensions of energy transitions. However, given the global interest in the topic among different stakeholders, a body of literature has emerged focusing on ‘just transitions,’ which seeks to understand the impacts of fossil fuel industry declines on fossil fuel workers, their communities, and dependent regions, and find solutions for minimizing these impacts (Carley, Evans, & Konisky, 2018; Evans & Phelan, 2016; Haggerty, Haggerty, Roemer, & Rose, 2018; Johnstone & Hielscher, 2017; Olson-Hazboun, 2018; Vona, 2019; Weller, 2019)

To date, research on just transition for fossil fuel workers and their communities has broadly focused on conceptualizing and defining just transitions (Heffron & McCauley, 2018; McCauley & Heffron, 2018; Newell & Mulvaney, 2013), incorporating views of and defining the roles of different actors in the just transition process (Abraham, 2017; Carley et al., 2018; Cha, 2016, 2017; Olson-Hazboun, 2018), and exploring renewable energy jobs as an option for fossil fuel workers (Cameron & Van Der Zwaan, 2015; Eisenberg, 2019; Louie & Pearce, 2016; Pollin & Callaci, 2019; Van der Zwaan, Cameron, & Kober, 2013; Wei, Patadia, & Kammen, 2010). Many of these studies focus on OECD countries, are normative, and are descriptive. A few studies involve empirical work. However, these studies have largely focused on jobs as a proxy for understanding just transition. In fact, most of the empirical work has focused on assessing whether renewable energy jobs can be an option for fossil fuel workers. While some studies have assessed whether renewable energy jobs can offset fossil fuel job losses in terms of absolute numbers (Cameron & Van Der Zwaan, 2015; Van der Zwaan et al., 2013; Wei et al., 2010), others have quantified the costs associated with retraining fossil fuel workers in renewable jobs (Louie & Pearce, 2016; Pollin & Callaci, 2019). Neither kind of study examines the spatial dimensions of job transitions (where jobs will be lost or gained within a country) and have methodological and data limitations.

Thus, there is a need to synthesize the conceptual and empirical literature on just transitions emerging from various fields, understand just transition issues in major non-OECD fossil fuel dependent economies, and fill the methodological and data gaps in the empirical literature.

In this dissertation, I contribute to the growing just transitions literature by filling these gaps. First, I conduct a systematic review to synthesize and conceptualize the global just transitions literature (Chapter 2). Next, I collect a novel 50-country dataset and use an Integrated Assessment Model (IAM) to analyze whether renewable energy jobs can offset fossil fuel industry job losses resulting from climate policies at a global and national level (Chapter 3). Then, I conduct a spatial analysis to assess the feasibility of renewable energy jobs replacing 'local' coal jobs in top coal producing countries (Chapter 4). Finally, focusing on India, a major non-OECD coal producing country, I conceptualize and analyze the socio-economic dependency on coal at a local level in India (Chapter 5).

The sections below are structured as follows. First, I first explain why just transitions research matters. Then I examine the origins of the just transition concept and describe the results of a literature review to identify knowledge gaps. Finally, I explain my dissertation objectives.

1.1 Why just transition matters

Job losses due to industry change are not unique to the transition from fossil fuels. Collapses of industries (globally or regionally) have occurred in the past for a wide variety of reasons, including relocation of production, collapse of demand, over-harvesting of resources, and technological change. For example, from the 1980s onwards the textile industry in the US –

which was badly impacted by cheap textile imports from China – declined rapidly. This resulted in over a million people losing jobs in the US (Minchin, 2009). In Canada, the Atlantic cod industry collapsed due to overfishing in the 1990s, resulting in severe job losses in eastern Canada (White, 2003). Within this context, what is the justification for a "just transition" for fossil fuel workers and their communities?

Two broad categories of argument have been made. The first is that governments have an ethical duty to support affected workers because many of these workers have sacrificed their health to provide the fuel necessary for their countries' growth and prosperity (Abraham, 2017; Haggerty et al., 2018; Healy & Barry, 2017; Johnstone & Hielscher, 2017; Olson-Hazboun, 2018; Vona, 2019). For example, Cha (2017, p. 199) writes, "Fossil fuel communities and workers have been exploited to fuel economic development. This history means an affirmative duty exists to help transition these communities and workers to a clean energy economy." Although this kind of argument can be made for workers in other industries that face decline due to any reason, in the case of fossil fuel workers, their industries might be shut down directly due to policies formulated by governments. Thus, some argue that governments have a duty to support fossil fuel industry workers.

The second, more pragmatic, argument is that if fossil fuel workers and their communities are accommodated, it might help increase general acceptability of climate policies among these communities (Healy & Barry, 2017; Evans & Phelan, 2016; Snyder, 2018; Vona, 2019). Scholars argue that in order to ensure that fossil fuel workers and their communities do not impede energy transitions, it may be important to create just transition plans for these workers and their communities (Cha, 2017; Eisenberg, 2019; Haggerty et al., 2018; Healy & Barry, 2017;

Johnstone & Hielscher, 2017; Snyder, 2018). This is because fossil fuel companies and their partisan allies often deploy a "jobs vs the climate" argument (Evans & Phelan, 2016; Snyder, 2018; Vona, 2019) to mobilize the support of fossil fuel-dependent communities (who are understandably anxious about losing employment) and prompt them to support candidates who favor the fossil fuel industries (Cha, 2016, 2017; Healy & Barry, 2017; Snyder, 2018; Vona, 2019). For example, in the 2016 US presidential election, when pro-fossil fuel candidate Donald Trump campaigned on a platform to save the coal industry and coal jobs, he got tremendous support from coal communities. After being elected, President Trump pulled the US out of the Paris climate agreement (Healy & Barry, 2017; Snyder, 2018). Apart from democratic countries, even autocratic states like China have faced political resistance when attempting to close down coal mines "from a powerful coalition of local cadres, mine bosses, workers and farmers" who depend on coal mining for their living (Wright, 2007).

1.2 History of just transition

The concept of just transition was born in the US in the 1970s when Tony Mazzocchi, a trade union leader representing the Oil, Chemical and Atomic Workers' Union sought the support of environmental groups to help fight the Shell company over safety and health issues affecting workers (Morena et al., 2013). At that time, Mazzocchi and other unionists acknowledged that the industries in which their members were working were causing severe environmental problems. They advocated "just transition" action that would preserve workers' livelihoods, while addressing health and safety issues and protecting the natural environment. Their advocacy was shaped in opposition to the growing discourse of 'jobs versus the environment' that industry was advancing in the US in response to proposed environmental regulations (McCauley &

Heffron, 2018; Morena et al., 2013). Since the mid-2000s, this concept has begun to be featured in climate change negotiations and is being advocated by many environmental groups and trade unions. As the just transition concept was adapted to the climate change discourse, for some the meaning of just transition changed. For some scholars just transition means focusing exclusively on fossil fuel workers and their communities (in line with the labour focus of the original concept) (Johnstone & Hielscher, 2017; Vona, 2019; Weller, 2019). But for others, just transition is not only about fossil fuel workers, but also about climate, environmental, and energy justice for all (McCauley & Heffron, 2018; Heffron & McCauley, 2018).

My dissertation focuses on the original labor-focused concept of just transition, specifically focusing on just transitions for fossil fuel workers and their communities in the context of possible future fossil fuel industry declines. Here, I define just transition as a process required to secure the livelihoods of fossil fuel workers and their communities in a low carbon economy.

1.3 Summarizing the just transitions literature

Scholars in fields such as energy transitions and policy, geography, law, labour, economics, and energy modelling are beginning to focus on issues related to just transitions in their respective fields. So far, the literature tends to discuss just transition at a conceptual level, although some empirical studies are beginning to emerge. Here, I outline each field's approaches to describing and analyzing just transition and summarize the key literature from these fields.

The concept of just transition has historical roots in the labour literature, particularly among those scholars who focused their work on labour environmentalism or green unionism (Rosemberg, 2010; Silverman, 2006, 2008). Such scholarly work focused on topics such as conflicting interests between environmentalists and labour unions, including debates regarding jobs versus the environment in relation to manufacturing and chemical industries. This scholarly work also focused on assessing the conditions under which blue-green alliances are formed (Silverman, 2006, 2008). Much of the academic work is focused on North American cases, with only a handful of studies looking at just transition issues internationally (Silverman, 2008). Moreover, the focus of these studies was not climate action and the resultant impact on fossil fuel workers. Apart from the above explicit focus on just transitions, in the past, scholars focusing on labour economics and markets, labour history, and sociology have focused on rapid production declines or closure, and the impact of such declines or closures on workers and communities. These scholars deployed longitudinal study techniques or case study approaches to assess the impact of closure on workers. It must be noted that the majority of these studies were conducted after the industrial closure occurred and analyzed impacts post-closure.

Some of the key findings of these studies include: 1) single-industry towns were badly impacted (Danson, 2005; Hollywood, 2002; Minchin, 2009; White, 2003); 2) older workers retired or became inactive, younger ones migrated (Beatty & Fothergill, 1996; Danson, 2005; Hollywood, 2002); 3) workers earned less wages in new industries (Brand, 2015; Danson, 2005; Minchin, 2009); and, 4) non-economic personal issues (such as mental health issues) rose (Brand, 2015). Apart from studies related to long-term changes in wages of workers post-closure, scholars in the field of labour economics have in the past also focused on finding relationships between high school enrollment rates and resource boom and bust in resource communities. For example, a study focusing on the “effect of the Appalachian coal boom on high school enrollments” found that a 10% increase in low-skilled workers’ earnings resulted in a decrease of 5–7% in high school enrollment (Black, McKinnish, & Sanders, 2005). However, overall, in this field the educational effects of resource boom and bust remain inconclusive to this day (Marchand & Weber, 2018).

With respect to just transitions in the context of climate change, labour scholars have focused on the jobs vs the environment debate and understanding the role of unions in moving towards a just transition to a green economy (Stevis, 2018; Stevis & Felli, 2014, 2015). A recent study that focused on union strategies and traditions compared different approaches adopted by militant trade unions in the declining coal mining industry in the US and Germany (Abraham, 2017). It concluded that "militant unions with a tradition of neo-corporatism will be best positioned to demand just transitions for their members"(Abraham, 2017). Scholars in this field state that future studies on just transitions should focus on the role of unions nationally in facilitating just transitions (Abraham, 2017) and the role of unions during international climate negotiations in facilitating just transitions (Stevis, 2018; Stevis & Felli, 2014, 2015).

Most scholars studying energy transitions and policy make normative arguments describing the employment challenges faced by fossil fuel communities in the current low-carbon energy transition and argue for the need to deploy just transition policies to help workers and their communities (Healy & Barry, 2017; Johnstone & Hielscher, 2017; Newell & Mulvaney; Cha, 2016). For example, Healy & Barry (2017, 455) argue that to create just transition plans, governments need to "…provide a welfare safety net and adequate compensation for people and communities that have been marginalized or negatively impacted by a low carbon energy transition." Although some empirical studies have been published on the topic, they are mainly focused on OECD countries. For example, a recent study by Olson-Hazboun (2018) examined the perspectives of certain US fossil-fuel dependent communities regarding renewable energy development and found that these communities had negative views of renewable energy development. The study concluded that the main driver behind these negative views was that interviewees perceived renewable energy development as a threat to their local economies (Olson-Hazboun, 2018). A second study based on case study analyses of just transition policies in the US and Germany argues that necessary elements of just transition include "dedicated funding streams, strong public sector role, and partnership with non-governmental organizations and unions" (Cha, 2017).

In the interdisciplinary field of legal geography, scholars argue for a more comprehensive approach to studying just transitions that incorporates climate, energy, and environmental (CEE) justice scholarship, "ultimately promoting fairness and equity throughout the transition away from fossil fuels" (McCauley & Heffron, 2018; Heffron & McCauley, 2018). These scholars state that approaching just transition through a legal lens allows them to grapple with concepts related to justice, while using the lens of geography allows them to focus on where and when injustices in the transition process happen (Heffron & McCauley, 2018). These scholars argue that future work in the area of just transition for a low carbon economy should incorporate CEE justice scholarship, and should explore and promote: (1) distributional justice that deals with distribution of risks and responsibilities; (2) procedural justice that entails long-term engagement with the affected communities; and (3) restorative justice dealing with repairing the harm done to an individual (Heffron & McCauley, 2018). In the case of fossil fuel workers who lose employment due to climate action, they argue that a procedural and restorative lens needs to be adopted and applied for helping workers (Heffron & McCauley, 2018). While these articles make important contributions to the literature, they do not address how their concepts would be applied in a concrete way to real life situations. Apart from the above described work by legal geography scholars on just transition, Weller (2018), using an economic geography lens, examined how policymakers focusing on just transition for coal workers in Latrobe Valley, Australia approached the just transition problem and created related policies. Weller found that policymakers failed to engage with local coal communities, which meant that their approach to crafting policy "…sidelined local interests, misrepresented the issues, exacerbated local disempowerment." Weller (2018) concluded that local opposition to coal transition will not only continue but intensify if future just transition policies fail to incorporate the local perspectives of people impacted by those policies.

Generally, legal scholars have focused on how just transition concepts can be turned into legal principles that are aimed at helping fossil fuel workers and their communities (Doorey, 2015; Eisenberg, 2019). Eisenberg (2019) states that legal scholars should embrace "just transition as an equitable principle of easing the burden decarbonization poses to workers and communities who depend on carbon-heavy industries." Moreover, Doorey (2015) states that climate action and achieving a just transition requires legal scholars from different legal fields such as labour law, environmental law, and regulatory law to expand their areas of expertise and create a new legal frontier that helps mitigate the impact of climate action on fossil fuel workers and their communities. Both Eisenberg (2018) and Doorey (2015) call for future research to focus on understanding the best legal mechanisms for achieving a just transition from a law and policymaking point of view.

Apart from the above work, economists and energy modellers have also conducted studies focusing on assessing whether fossil fuel workers can transition to renewable or clean energy jobs. For example, the existing research on just transition in the field of economics has focused on the livelihood issues of fossil fuel workers and their communities, with a specific focus on costs associated with employment transitions strategies such as retraining workers (Louie & Pearce, 2016). The main emphasis of these studies has been on quantifying costs associated with retraining coal workers in solar photovoltaic related jobs in the US (Louie & Pearce, 2016) and costs associated with providing guaranteed clean energy jobs for all fossil fuel workers in the US (Pollin & Callaci, 2019).

On the other hand, energy modellers (who do not frame their studies as just transitions research) have used either general equilibrium models, macro-econometric models or energy systems models to estimate net job impacts of climate policies. The scholarly work on this topic has led scholars to ask two main questions: (1) what are the overall short-term economy wide job impacts from a climate-policy driven energy transition at regional (Pollitt, Alexandri, Chewpreecha, & Klaassen, 2015) and global levels (Barker, Alexandri, Mercure, Ogawa, & Pollitt, 2016; Mercure et al., 2018)?; and, (2) what are the specific energy sector job impacts of climate policies (Atilgan & Azapagic, 2016; Cameron & Van Der Zwaan, 2015; Çetin & Eĝrican, 2011; Dominish, Briggs, Teske, & Mey, 2019; Fragkos & Paroussos, 2018; Llera, Scarpellini, Aranda, & Zabalza, 2013; Markandya, Arto, González-Eguino, & Román, 2016; Sooriyaarachchi, Tsai, El Khatib, Farid, & Mezher, 2015; Van der Zwaan, Cameron, & Kober, 2013; Wei et al., 2010)? The first uses computable general equilibrium models or macro-econometric models and examines overall shifts in employment in the economy and in broad sectors (e.g. economy wide manufacturing and service) in the short term under scenarios with and without climate policies.

The second type of analysis focuses on the energy sector and uses energy systems models to analyze changes in energy jobs across technologies (e.g. coal versus solar), job types (e.g. coal mining versus solar manufacturing), and regions under various climate policy scenarios.

1.4 Identifying literature gaps

The above review shows several gaps in the just transition literature. First, scholars from different fields have conducted initial work on just transitions and identified various elements of just transitions involving fossil fuel workers and their communities. However, the understanding of elements remains scattered. Thus, there is a need to systematically synthesize the elements and empirical findings emerging from various fields in order to advance overall understanding of just transitions.

Second, the modelling studies that assess whether renewable energy job numbers can offset fossil fuel job numbers under different climate policies have methodological and data limitations. Most studies focus on a small set of OECD countries (Atilgan & Azapagic, 2016; Cameron & Van Der Zwaan, 2015b; Çetin & Eĝrican, 2011; Fragkos & Paroussos, 2018; Llera et al., 2013; Markandya et al., 2016; Sooriyaarachchi et al., 2015; Wei et al., 2010) or rely primarily on empirical datasets from OECD countries to estimate energy job impacts globally (Dominish et al., 2019). Hence, these studies do not capture the large number of jobs in non-OECD countries such as India, Brazil, China, and others, both currently and into the future where energy demand is expected to continue to grow. Those that apply OECD job numbers to non-OECD contexts are not able to capture the very different labor conditions in non-OECD countries that result in differences in job numbers per unit of energy production.

Third, both energy modelling and economics-based studies (that focus on retraining fossil fuel workers for renewable jobs) have ignored the spatial dimension (where jobs might be lost vs gained) of employment transition. Generally, spatial analysis is considered a “blind-spot” in energy transitions studies (Bridge, Bouzarovski, Bradshaw, & Eyre, 2013; Coenen, Benneworth, & Truffer, 2012) and no past study has focused on the spatial dimensions of job transitions.

Finally, most of the empirical just transition literature focuses on OECD countries and the empirical work mainly revolves around fossil fuel workers’ job transitions. These studies ignore other socio-economic implications of fossil fuel industry declines such as loss of fossil fuel industry revenues or social spending.

1.5 Research objectives and methods

In order to fill the gaps in the literature on just transition away from fossil fuels, the main objectives for each of the four core chapters to follow are:

Chapter 2 – Synthesize and conceptualize elements of just transition that scholars in different academic fields identify;

Chapter 3 – Analyze the energy sector employment implications of keeping global warming Well-Below 2°C, globally and in different regions;

Chapter 4 – Assess the feasibility of renewable jobs replacing local coal jobs in top coal producing countries; and,

Chapter 5 – Assess the socio-economic dependency on coal at a local level in India

Table 1.1, below, shows the research objectives, data used, methods and geographical focus for the four core chapters of the dissertation to follow.

Table 1.1 Research objectives, data used, methods applied and geographical focus
The table lays the research objectives, data used, methods and geographical focus for the four core chapters of the dissertation to follow.

Chapter Objective	Research questions	Methods Applied	Data Used	Geographical Focus
Chapter 2: Synthesize and conceptualize elements of just transition that scholars in different academic fields identify	1) What are the frameworks used, methods deployed and geographical focus of scholarly articles that focus on a just transition for fossil fuel workers and their communities? 2) What are the key elements of a just transition for fossil fuel workers and their communities? 3) How are the elements of just transition linked to concepts of justice?	I conducted a systemic review of academic and policy literature that focuses on a just transition for fossil fuel workers and their communities, in order to describe the state of the literature and synthesize elements of just transition that scholars in different academic fields identify. I then used the legal geography 'JUST' framework to characterize each of these elements in terms of: the type of justice they further (distributional, procedural, recognition or restorative justice); the spatial scale; and, the timeframe.	- Academic literature and relevant policy literature	Global
Chapter 3: Analyze the energy sector employment implications of keeping global warming Well-Below 2°C, globally and in	1) How would energy sector employment differ between a world that keeps global warming Well-Below 2°C and a world that continues on current climate policy pathways? 2) How would the landscape of energy sector employment change	I used the novel employment factors dataset and combined it with an integrated assessment model to estimate the impacts of keeping global warming Well-Below 2°C on energy sector employment globally and by region.	- Collected a novel 50-country employment factors dataset collected from primary and secondary sources covering eleven energy technologies and five job types (employment factor refers to the	Global

different regions	under Well-Below 2°C climate scenarios? 3) How do the employment effects vary between regions under Well-Below 2°C climate scenarios?		number of workers employed per unit of electrical & refining capacity or fuel production)	
Chapter 4: Assess the feasibility of renewable jobs replacing local coal jobs in top coal producing countries	1) What is the local solar/wind capacity required in each coal mining area to enable all coal miners to transition to solar/wind jobs? 2) What percentage of coal mining areas in each country and top coal producing states/provinces are suitable for solar and/or wind power generation? 3) What is the scale of solar/wind power deployment required to transition coal miners in areas suitable for solar/wind power?	In this chapter, I focused on coal mining jobs. I mapped the location of coal mines in China, India, the US, and Australia and the accompanying long-term averages for solar and wind power potential in these locations. I then used spatial analysis tools to gauge whether these local coal mining areas are suitable for solar or wind power, and used employment factors to estimate the capacity required to transition all coal miners in these local coal mining areas to solar or wind jobs.	- GIS layers for coal mine locations in China, India, the US, and Australia, - Solar and wind potential shapefiles for these countries - Solar and wind employment factors dataset for the above-mentioned countries	China, India, the US, and Australia
Chapter 5: Assess the socio-economic dependency on coal at a local level in India	1) How can Indian districts' socio-economic dependency on coal be characterized and quantified? 2) How does socio-economic	I first analyzed the primary and secondary literature to conceptualize coal dependency at the Indian district level. I then used various datasets to quantify four key district-level socio-economic indicators of coal	- Collected the following novel datasets at the Indian district (a sub-administrative unit) level: 1) coal mine location and production	India

	dependency on coal vary across districts?	dependency. I then conducted an analysis to identify key coal dependent districts and capture variations among these key coal dependent districts in terms of which indicator they are highly dependent on.	data; 2) coal power plant location and production data; 3) number of pensioners; 4) district mineral fund revenues; 5) coal sector corporate social responsibility (CSR) spending; and, 6) a dataset of coal company employment factors.	

1.6 Rationale for focus on coal, and specific countries

While Chapters 2 and 3 of this dissertation have a global focus that includes all types of fossil fuel workers, Chapter 4 focuses on coal miners in China, India, the US and Australia. Chapter 5 focuses on Indian coal industry workers and their communities.

In order to scope my research, I chose to focus on coal in Chapters 4 & 5 because of the strong global interest in transitioning away from this fossil fuel (Healy & Barry, 2017; Jewell et al., 2019; Johnstone & Hielscher, 2017). The academic and policy focus on coal industry phase-out stems from the fact that coal is not only the most emissions intensive fossil fuel, but also that there are cheaper alternatives. Studies have suggested that countries need to make a rapid shift away from coal in order to achieve global climate targets. In fact, the IPCC Special Report on Global Warming of 1.5 °C suggests that in order to meet the 1.5°C target in all modelled pathways, coal's share in total primary energy supply would need to decrease by 59-78% by 2030 and 73-97% by 2050 (IPCC, 2018). If this decline occurs, it could affect millions of coal workers and their communities, and these workers might face severe hardships (Johnstone & Hielscher, 2017). In fact, coal industry contractions are already underway in PPCA countries and non-PPCA countries such as the US (Grubert, 2020). This makes my research relevant for academics and policymakers alike.

In Chapter 4, I focused on China, India, the US, and Australia as these countries are the world's top coal producers, and collectively represent over 70% of global coal production. Any meaningful coal transition will require phasing out coal in these countries. While I have focused on these four countries, the methodology developed in the Chapter can be applied to any coal or fossil fuel producing region in any country. Moreover, in Chapter 5, I focused on India, as it is a major non-OECD coal dependent country. While some OECD countries have made plans to phase out coal as part of the PPCA, attaining Paris Agreement goals would require emerging economies such as India – the second largest producer and consumer of coal – to reduce their long-term dependency on coal. Currently, nearly 70% of India's electricity is generated using coal. With a population of 1.4 billion and current low levels of per capita energy consumption, India's energy demand is expected to double in the next two decades (International Energy Agency, 2020). Whether India will meet its projected electricity demand using coal or low carbon sources is considered crucial to meeting global climate targets (Tongia, Sehgal, & Kamboj, 2020). While the focus of this Chapter is on the Indian coal sector, the conceptual framework and methodology developed in this Chapter has broad applicability.

Chapter 2: A systematic review of the key elements of a just transition for fossil fuel workers and their communities

As noted in Chapter 1, scholars from different academic fields employ different methods and focus on different aspects of just transition for fossil fuel workers and their communities. These scholars identify various elements of just transition, but the literature remains quite scattered and there is a need to systematically synthesize the academic literature emerging from various fields.

To fill this gap, I ask the following research questions:

1) What are the frameworks used, methods deployed and geographical focus of scholarly articles that focus on a just transition for fossil fuel workers and their communities?

2) What are the key elements of a just transition for fossil fuel workers and their communities?

3) How are the elements of just transition linked to concepts of justice?

To answer these questions, I first conducted a systematic literature review of published peer-reviewed literature on just transitions in order to describe the field and synthesize elements of just transition identified by the authors. Next, I characterized the identified elements based on a framework that emerged from the review in order to enhance the understanding of these elements.

In the next section (2.1) I explain the methodology of this Chapter. In section (2.2) I summarize our results and in final section (2.3) I discuss the implications and limitations of this Chapter.

2.1 Methodology

In the first stage, I systematically searched standard databases and collected relevant articles that adhere to a pre-determined inclusion criteria (Grant & Booth, 2009). I also reviewed some key non-academic reports as they are considered relevant for the topic, given the strong policy relevance of this topic. For non-academic literature, I focused on reports by government commissions and international organizations. I applied inductive coding technique to the final list of articles in order to generate elements or strategies of just transition that scholars identify. In the second stage, I used a just transition framework that emerged from the review to characterize each identified element.

2.1.1 Search strategy for peer-reviewed literature

I searched standard databases such as Google Scholar and Web of Science using various permutations and combinations of words: “just transition,” “just transitions,” “workers,” “coal,” “oil,” “gas,” “fossil fuel workers,” “coal workers,” “oil workers,” “gas workers,” “climate change,” “jobs,” “green jobs,” “communities,” “just transition policy,” “elements,” “principles.” This search was conducted from June to August 2019.

Along with articles generated during my search, I also deployed a snowball technique to identify more articles. To be systematic in my searches, I followed the preferred reporting items for systematic reviews and meta-analysis (PRISMA) flow diagram steps to report the identified literature at various stages of the systematic literature review (see **Figure 2.1** for a generic example). This PRISMA method has been utilized by various past studies (Lee et al., 2017; Lewis & Pattanayak, 2012).

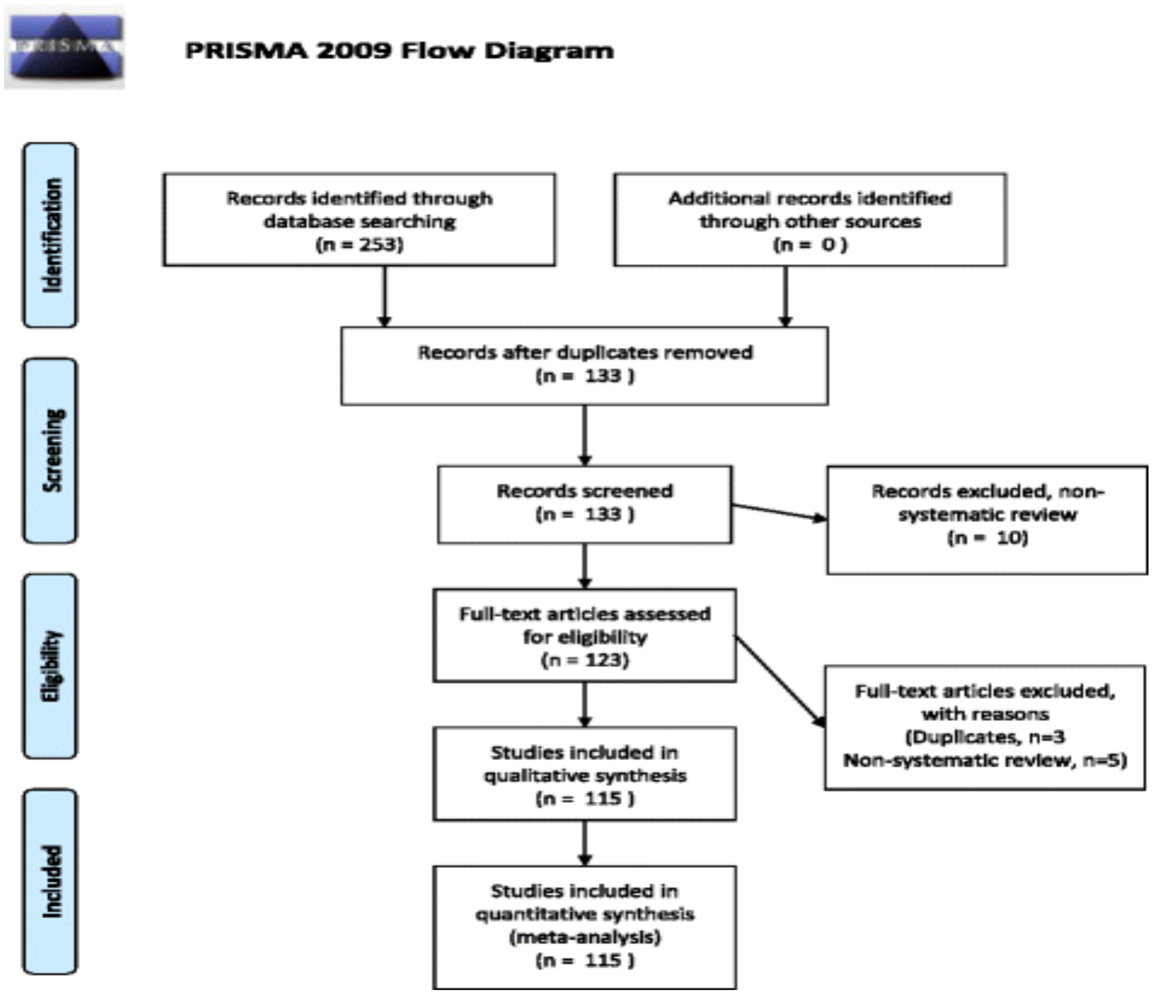


Figure 2.1 Preferred Reporting Items for Systematic Reviews and Meta-analysis flow diagram for searching & extracting data (adapted from (Lee et al., 2017))
PRISMA steps involves identifying and scanning the articles, checking for eligibility and deciding whether the articles should be included in the analysis.

2.1.2 Inclusion criteria & coding of results

After identifying the articles through keyword searches and removing duplicate articles, I applied a pre-decided inclusion criteria (**Table 2.1**) to generate the articles to be included for analysis.

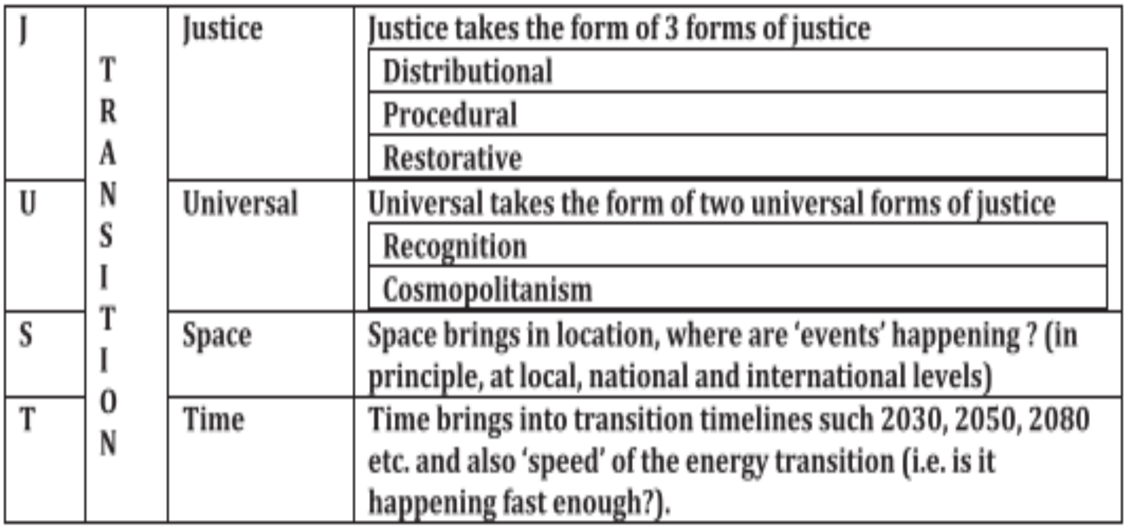
Table 2.1 Inclusion criteria for assessing the articles
The table describes the inclusion criteria chosen for this review.

Item	**Details**	**Reason**
Context	Articles that focus fully or partially on just transitions for fossil fuel workers and their communities in the context of climate change	This context was chosen to answer the research question
Language	English	I limited the scope of our review to articles written in the English language due to my lack of proficiency in other languages
Types of publications	Academic journal articles	I focused on journal articles in line with previous systematic reviews (Lewis & Pattanayak, 2012)
Geographical Focus	Global	To address the issue of publication bias and the fact that fossil fuel industry decline will impact countries in Global South and North alike, I chose to have a global focus
Period	2000 – 2019	This is the period when just transition in the context of climate change was first talked about
Databases	Google Scholar, Web of Science	Past studies have also utilized these databases for conducting systematic reviews (Lewis & Pattanayak, 2012)

After collecting my final list of articles for review based on the above inclusion criteria, I used inductive coding to generate the element themes (Elo et al., 2014; Thomas, 2006). This inductive coding process began by reading articles carefully and creating the list of elements (Elo et al., 2014) and recording relevant text under element. As I read every new article, depending on what emerged from the articles either the relevant content was added to the existing elements or new elements were created. Finally, I went back to the text and elements to re-check the elements to reduce the overlap and redundancy.

2.1.3 Use of framework for characterization of elements

For characterizing the elements, I used Heffron & McCauley's (2018) legal geography 'JUST' framework as this is a comprehensive framework that allows further understanding of elements on the basis of Justice, Universal, Space & Time (**Figure 2.2**). It must be noted that this framework emerged from the review itself (see **Section 2.2.1**)



J	T R A N S I T I O N	Justice	Justice takes the form of 3 forms of justice Distributional Procedural Restorative
U		Universal	Universal takes the form of two universal forms of justice Recognition Cosmopolitanism
S		Space	Space brings in location, where are 'events' happening ? (in principle, at local, national and international levels)
T		Time	Time brings into transition timelines such 2030, 2050, 2080 etc. and also 'speed' of the energy transition (i.e. is it happening fast enough?).

Figure 2.2 Legal Geography 'JUST' framework for the Just Transition (Heffron & McCauley, 2018)
The JUST framework suggests that the justice, universal, spatial and temporal lens are important to consider during the just transition planning process.

Within the Justice and Universal categories, I focused on four forms of justice that are often highlighted in the context of climate, environment and energy studies (Heffron & McCauley, 2018; McCauley & Heffron, 2018; McCauley et al., 2019; Pellegrini-Masini, Pirni, & Maran, 2020):

1. **Distributional justice** concerns the equitable distribution of burdens and benefits of energy and environmental decisions.

2. **Procedural justice** highlights the right to a fair process for different stakeholders to take part equitably in the decision-making process.

3. **Restorative justice (R1)** primarily aims to repair the harm done to individuals, instead of focusing upon punishing the offender.

4**. Recognition justice (R2)** entails recognizing that parts of the society might suffer as a result of energy and environmental decisions and identifying individuals and groups who might be impacted by such decisions.

I did not use cosmopolitan justice[1] as it reinforces the above justice forms but states that the above forms of justice must apply universally to all human beings. From my analysis of elements, it is clear that the elements identified are general and broadly apply to all nations and individuals. For each element, I used the above forms of justice to identify "what justice is needed and/or expected" (Heffron & McCauley, 2018).

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[1] McCauley, Ramasar, Heffron, Sovacool, Mebratu, & Mundaca (2019) "Cosmopolitan justice suggests that principles—such as those from distributive and procedural justice—must apply universally to all human beings in all nations. Cosmopolitan justice acknowledges that all ethnic groups belong to a single community based on a collective morality."

Apart from justice forms, I use spatial and time scales to further characterize the elements. Heffron & McCauley's (2018) framework defines space as where "events" are happening. Here, I grouped each element under national, provincial/state or local level as many articles clearly define the spatial dimensions of these elements at these three levels. Finally, I also grouped each element in terms of timescales—long-term, medium-term and short-term. I defined long-term as a time period of over a decade, medium-term as 3-10 years and short-term 0-2 years.[2]

2.2 Results

In this section, I first describe the results about the state of the literature. Next, I highlight the elements of just transition for fossil fuel workers and their communities that scholars in different academic fields identify and use the legal geography 'JUST' framework to characterize each element in terms of justice forms, space & time (Heffron & McCauley, 2018).

2.2.1 State of the literature

My search yielded 520 articles (**Figure 2.3**). Of these, 515 articles were identified by the database search and 5 others were found via the snowball method. After applying the inclusion criteria, I identified 33 articles for full-text review and analysis. These 33 papers are written by scholars from different academic fields: labour, economics, geography, law, urban studies, energy transitions and policy, and interdisciplinary studies.

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[2] I choose this timeline keeping in mind the PPCA's timelines for phasing out coal-fired electricity generation by 2030 in Organisation for Economic Co-operation and Development (OECD) countries and by 2050 in all countries. Thus, by choosing this timeline, the characterization might be useful for policymakers in countries such as Canada that has decided to phase-out coal by 2030.

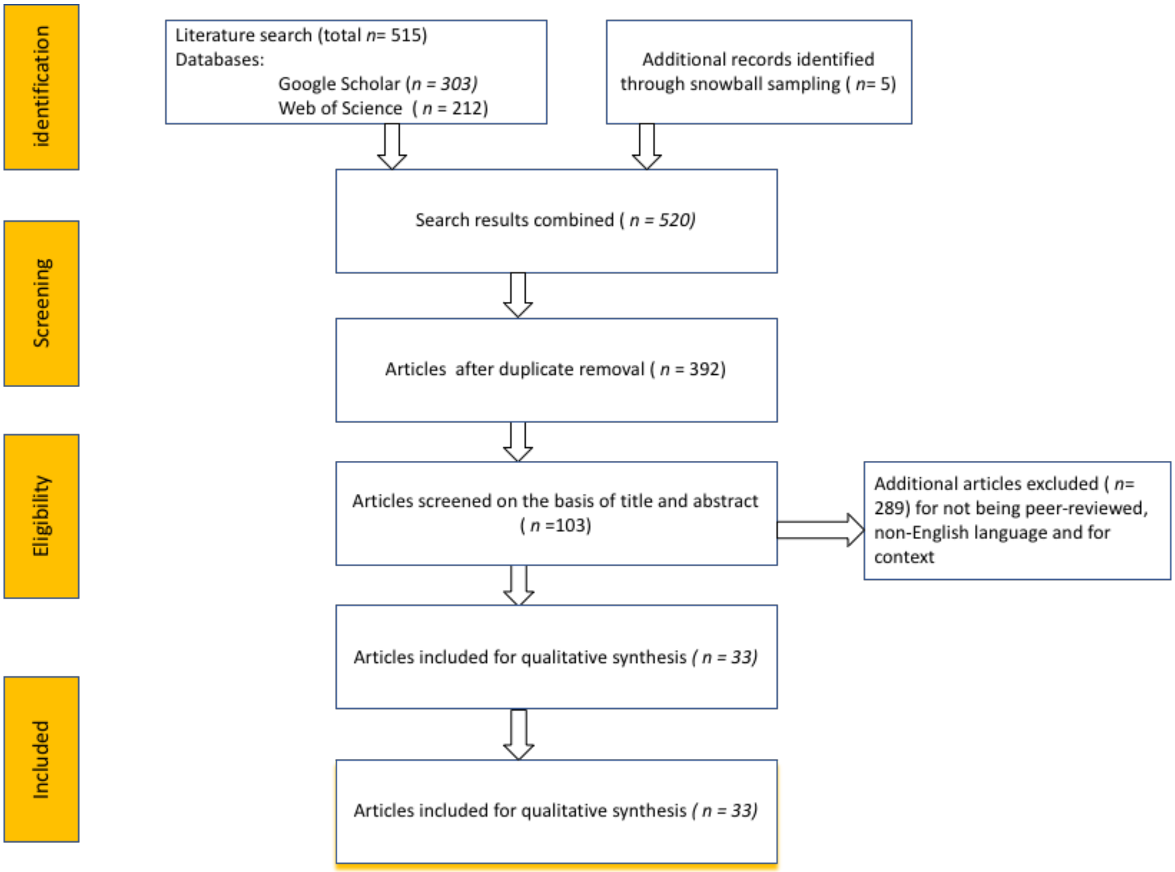

Figure 2.3 Search results reported in the PRISMA flow diagram
The figure shows PRISMA technique used for this analysis. After applying the inclusion criteria, 33 articles were identified for full review.

The number of articles focusing on just transition in the context of climate change has increased since 2015 (**Figure 2.4**). This increased focus on this topic can be possibly attributed to the adoption of just transition as a principle by the United Nations Framework Convention on Climate Change during the 2015 Paris Climate accord (Cha, 2017; Healy & Barry, 2017).

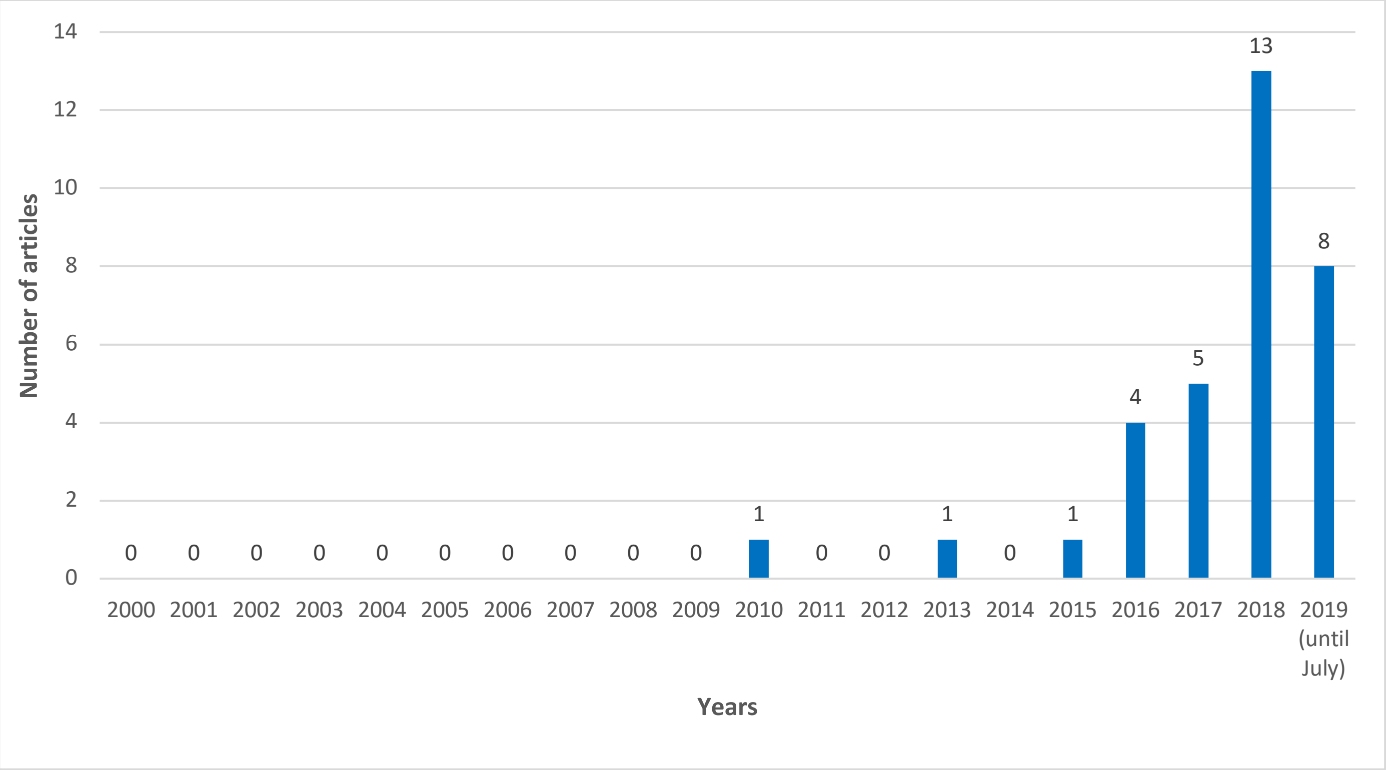

Figure 2.4 Number of articles focused on just transitions for fossil fuel workers & communities per year

The focus on just transition for fossil fuel workers and their communities have been increasing since 2015 after UNFCCC incorporated just transition as part of the Paris climate accord.

Scholars are focusing more on coal workers compared to other fossil fuel workers (**Figure 2.5**). This is not surprising given that coal is already in decline in some OECD countries (Jewell et al., 2019) and coal jobs have become a topic of heated political debate in some of these countries. Coal is arguably more readily substituted within the electricity sector while natural gas has itself been a substitute for coal. The transportation and industrial sectors (e.g. process heat) have less readily available substitutes at the moment. Moreover, the combination of higher emissions per unit energy and lower cost of replacement suggests a greater urgency to replace coal than other fossil fuels. Modelling scenarios in the IPCC special report find that to keep global warming below 1.5°C, the share of coal in total primary energy supply will need to decrease by 59-78% by 2030 and 73-97% by 2050 (IPCC, 2018).

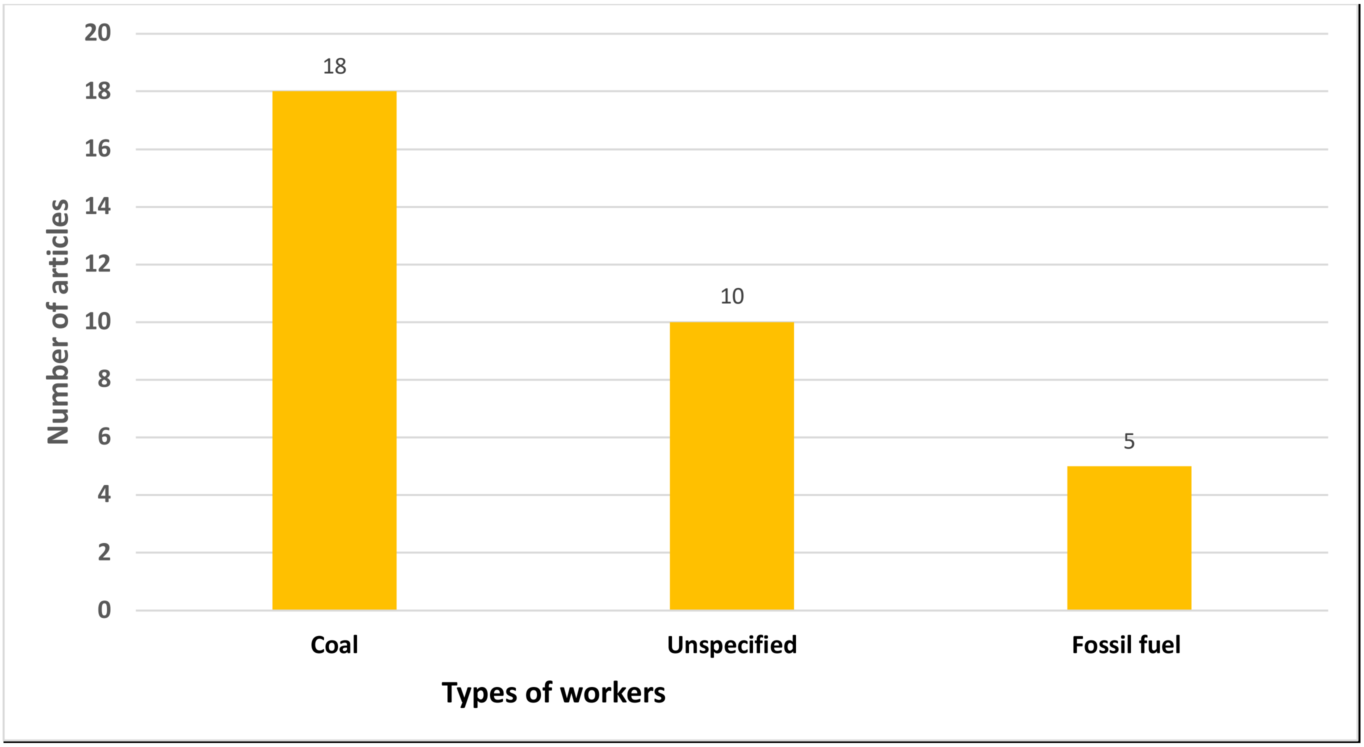

Figure 2.5 Number of articles focused on just transitions per year
More scholars have focused on coal workers than other types of workers.

To date, much of the scholarly focus has been on workers in the US and Australia, while some literature has eschewed regional analysis in favour of a global scope (**Figure 2.6**). I identified one (English language) article each on China (Zhang, Y., & Wang, 2018), Russia (Martus, 2019) and South Africa (Swilling, Musango, & Wakeford, 2016). Remarkably, no article specifically focuses on major coal producers such as India and Indonesia or oil producers such as Saudi Arabia, Iran, Iraq, Brazil, Venezuela, and Nigeria.

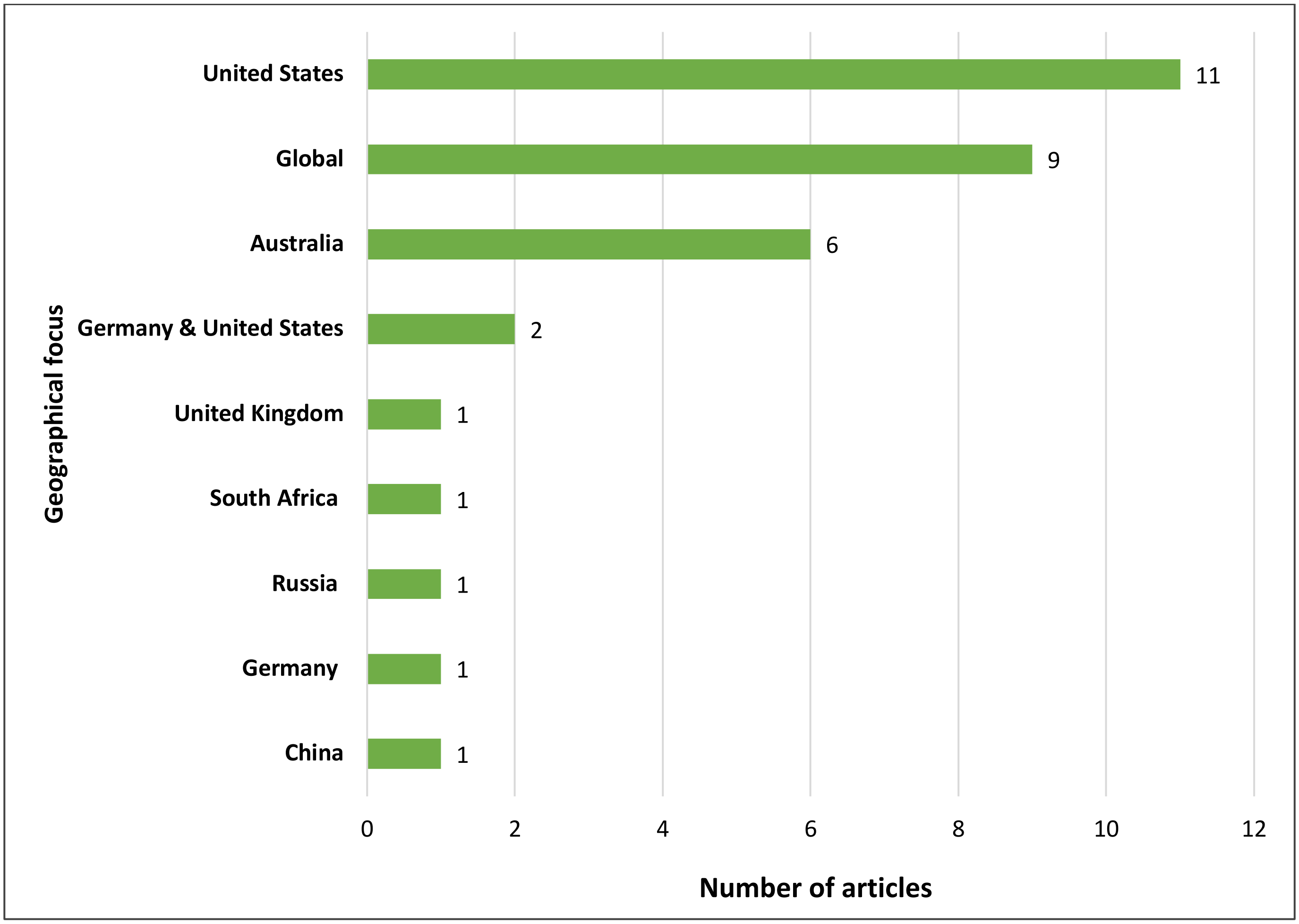

Figure 2.6 Geographical focus of just transition articles
The just transition research articles have so far largely focused on OECD countries.

Out of the 33 articles reviewed here, 5 articles attempted to offer theoretical or conceptual advancements concerning just transition (**Table 2.2).** Pollin & Callaci (2019) is a more policy-focused conceptual framework applicable in the context of the US, while the rest are theoretical. The latter four articles proposed just transition frameworks (Heffron & McCauley, 2018; McCauley & Heffron, 2018) or just transition management frameworks (Goddard & Farrelly, 2018), and one article focused on creating a heuristic scheme defining varieties of just transition (Stevis & Felli, 2015). Fifteen of the 33 articles conduct empirical analysis deploying methods ranging from semi-structured interviews, qualitative document analysis to spatial regression approach using Geographical Information Systems. The remaining articles are normative and/or descriptive in nature and highlight the importance of just transition for furthering energy transitions.

Table 2.2 Description of theoretical/conceptual advancements
The table provides details of the five articles that attempted to offer theoretical or conceptual advancements concerning just transition.

Sources	**Theoretical/conceptual advancement**
Stevis, D., & Felli, R. (2015)	The authors created a heuristic scheme called “varieties of just transition.” Using this scheme, global trade unions’ approaches are broadly divided between “affirmative” and "transformative” forms of just transition
Goddard, G., & Farrelly, M. A. (2018)	The authors explore a new framework called “Just Transition Management”
McCauley, D., & Heffron, R. (2018)	Uniting the Climate, Energy, and Environmental (CEE) justice concepts, the authors created a new just transition analytical framework focusing on: (i) distributive, (ii) procedural and (iii) restorative justice
Heffron, R. J., & McCauley, D. (2018)	The authors provide a legal geography ‘JUST’ framework. This framework entails elements of justice, universal, space & time
Pollin, R., & Callaci, B. (2019)	The authors created an economic policy-focused just transition framework for all fossil fuel workers and their communities in the United States

2.2.2 Results synthesizing just transition elements

Overall, the articles I reviewed collectively identify 17 key elements of just transition. Apart from the elements identified during the review of the academic literature, I also reviewed a few reports published in the non-peer reviewed literature as this is a highly policy relevant topic with growing non-academic literature. I have also included these articles here but have clearly highlighted them. After identifying these 17 elements, based on Heffron & McCauley's (2018) legal geography 'JUST' framework, I classified each element in terms of justice forms, space and time **(Table 2.3).**

Table 2.3 Elements classified according to justice forms, space and time
The table shows 17 key elements of just transitions identified during the review. Please note that in the figure, Distributional justice is represented by D, Procedural justice by P, Restorative justice by R1, and Recognition justice by R2.

Elements identified	Justice forms	Space	Time	Sources
Long-term planning	R2	National & state/provincial level	Long-term	(Snell, 2018), (Snyder, 2018), (Weller, 2019), (Rosemberg, 2010), (Eisenberg, 2019)
The role of unions	P	National & state/provincial & local level	Long-term	(Cha, 2016), (Abraham, 2017), (Stevis & Felli, 2015)
Community engagement	P	Local level	Long-term	(Eisenberg, 2019), (Goddard & Farrelly, 2018), (Rosemberg, 2010), (Snell, 2018), (Weller, 2019)
Local jobs and diversified economies	D, R2	Local level	Long-term	(Carley et al., 2018), (Olson-Hazboun, 2018), (Prinz & Pegels, 2018), (Rosemberg, 2010), (Snell, 2018), (Snyder, 2018), (Lobao, Zhou, Partridge, & Betz, 2016)
Coal as an identity	R2	Local level	Long-term	(Carley et al., 2018), (Bosca & Gillespie, 2018), (Haggerty et al., 2018), (Lewin, 2019)
The gender gap in energy sector jobs	R1, R2	National, state/provincial &	Long-term	(Rosemberg, 2010)

		local governments		
Education/ research institutions	D	National & state/provincial level	Long-term	(Herpich, Brauers, & Oei, 2018), (Witajewski-Baltvilks, 2018)
Worker pensions	R2, D	Local level	Long-term	(Abraham, 2017), (Cha, 2017), (Mayer, 2018), (Pollin & Callaci, 2019)
Just transition principles and the planning, legislative and regulatory processes	D, P, R2,	National, state/provincial & local level	Long-term	(Task force on Just Transition, 2018)
Job quality	R2	National & state/provincial level	Long-term	(Cha, 2016), (Cha, 2017), (Healy & Barry, 2017), (Newell & Mulvaney, 2013), (Rosemberg, 2010)
Job guarantees and compensation	R1	National, state/provincial & local level	Medium-term	(Pollin & Callaci, 2019), (Cha, 2016), (Cha, 2017)
Worker transition service	R2	Local level	Medium-term	(Snell, 2019)
Local infrastructure development	R1, R2	Local level	Medium-term	(Olson-Hazboun, 2018), (Cha, 2017), (Haggerty et al., 2018), (Olson-Hazboun, 2018), (Pollin & Callaci, 2019)
Local government revenue streams	R1, R2	Local level	Medium-term	(Carley, Evans, & Konisky, 2018), (Johnstone & Hielscher, 2017), (Haggerty et al., 2018)
Communication of phase-out plans	P	National & state/provincial & local level	Short-term	(Herpich et al., 2018)
Environmental remediation	R1	Local level	Short-term	(Greenberg, 2018), (Haggerty et al., 2018), (Pollin & Callaci, 2019)
Retraining workers	R2	Local level	Short-term	(Cha, 2017), (Mayer, 2018), (Olson-Hazboun, 2018), (Pollin & Callaci, 2019), (Rosemberg, 2010), (Vona, 2019)

1. Long-term planning

Many scholars emphasized the importance of long-term and strategic planning at the national or state/provincial level as a key to just transition (Snell, 2018; Snyder, 2018; Weller, 2019). Snyder (2018) points out that governments will have to pay for energy transitions—either they would pay now for just transition or pay later when these regions suffer (e.g. for nutrition programs, health care programs, and law enforcement schemes). The first step in long term strategic planning is to identify areas that might be most impacted by decarbonization well before the plans for decarbonization are implemented (Snyder, 2018). Currently, there is a considerable lack of research on areas most vulnerable to decarbonisation and about the social and employment implications of climate policies. This kind of research need to happen even before the just transition policies are created and implemented (Rosemberg, 2010). Next, Weller (2019) argues that targeted efforts would need to be made to ensure that impacted communities are helped through policy interventions. Any long-term planning should also be coordinated between national and provincial/state levels and must consult all stakeholders who might be impacted as a result of transition (Weller, 2019). Eisenberg (2019) states that federal and state governments in several countries might already have some policies in place that may be incorporated as part of the just transition (e.g. employment insurance). It is pertinent to consider these existing policies for planning the new policies.

Overall, the literature highlights the fact that there is a need to identify regions that might be most impacted by decarbonization (recognition justice). Moreover, the literature is also clear about the need for long-term planning and coordination between the national and state/provincial levels.

2. The Role of Unions

Globally, fossil fuel industries have higher rates of unionization compared to other industries (Cha, 2016). One reason is that the majority of fossil fuel production at a global scale is done by state owned companies, who have traditionally encouraged unionization (Natural Resource Governance Institute, 2019). For example, the Indian federal government-owned Coal India Limited (CIL), the world's largest coal mining company, accounts for nearly 85% of coal production in India and has a nearly 100% unionization rate (Pai and Carr-Wilson, 2018). Thus, job losses in the fossil fuel industries might increase tension between unions and pro-environment stakeholders as unions attempt to save the jobs of their members. To make sure that powerful unions don't impede transitions, it is seen as important to have them be part of any just transition plans (Cha, 2016). Several scholars view dialogue with unions as vital for creating just transition plans (Abraham, 2017; Stevis & Felli, 2015) as unions can play an important role in implementing just transition programs and can act as partners in programs such as retraining (Cha, 2016).

Overall, the literature states that policymakers should engage with unions in an equitable manner (procedural justice) in the just transition process. By necessity, the process of engagement needs to be long-term if unions are to be made partners in just transition plans. This needs to happen at different scales—national, state/provincial, and local levels because unions are not a homogenous group operating only at one level. For example, Unifor, Canada's largest union operates throughout the country but has many local branches representing different types of oil sands workers, such as construction workers and trades people among others (Pai and Carr-Wilson, 2018).

3. Community engagement

Several scholars emphasized that dialogue with the local community is key to a successful just transition (Eisenberg, 2019; Goddard & Farrelly, 2018; Rosemberg, 2010; Snell, 2018; Weller, 2019). Olson-Hazboun (2018, p. 372) writes "...marginalized energy communities are likely to continue to align with fossil fuels industries unless they are genuinely engaged in the decision-making and benefit-sharing processes of the low carbon transition." Goddard & Farrelly (2018) argue that not engaging extensively with affected communities usually results in the politicization of energy transition in the name of "jobs vs the environment." Goddard & Farrelly (2018) emphasize that the niche actor networks could be established between workers, communities and niche industries and such networks could be aided by national governments. For example, current niche sectors such as renewable energy companies could form networks with the community members and unions in fossil fuel producing regions to counter the "jobs vs the environment" claims (Goddard & Farrelly, 2018).

Since just transition frameworks or policies apply to local communities including workers, and any meaningful community engagement would require incorporating procedural justice principles. This implies that all relevant stakeholders should get a fair chance to participate in the just transition planning process. Providing evidence in the case of just transition policy making in Victoria, Australia, Weller (2019) states that there is currently a tendency among policymakers to take a top-down approach in making just transition plans and not engage with affected communities. Moreover, the above literature also highlights that the community engagement must be with the affected local community and should be throughout the transition process (long-term).

4. Local jobs & diversified economies

The importance of local jobs and creating a diversified economy was highlighted by many scholars (Carley et al., 2018; Olson-Hazboun, 2018; Prinz & Pegels, 2018; Rosemberg, 2010; Snell, 2018; Snyder, 2018). Creating local jobs and diversified economy may be particularly important for the coal industry as there is historical evidence that when coal mining industries decline, most workers don't migrate when they lose their jobs due to a strong sense of belonging, and the fact that most are older and less skilled (Beatty & Fothergill, 1996; Danson, 2005; Fothergill, 2001). Scholars suggest that local analysis should be conducted and an economic diversification plan should be made based on the outcome (Lobao, Zhou, Partridge, & Betz, 2016). Snyder (2018) highlights the example of the Appalachian Regional Commission in the US that provides business development grants to private enterprises to invest in different industries in the region and help create more diversified employment. Prinz & Pegels (2018) advocates that clean energy jobs should be created in structurally weak regions as these jobs can be a driver of clean energy policies.

The literature highlights the fact that any low carbon transition will result in both job creation and job destruction. Policymakers and other concerned stakeholders operating within a just transition framework will have to both recognize the differential social and economic impacts of having winners and losers of this transition (recognition justice) and develop policies to ensure equitable distribution of burdens and benefits of energy-related decisions (distributional justice). For example, as noted above, coal workers have been less mobile compared to other workers and a just transition approach could recognize their unique situation and seek to create local jobs by diversifying the economy (distributional justice) in terms of post-transition employment. By necessity, this would then require long-term plans as different fossil fuel industries might decline/close down at different times depending on national policies and market conditions.

5. Coal as an Identity

Scholars focusing on coal workers, particularly coal miners, highlight that miners have a strong sense of belonging to the place where they live and work (Carley et al., 2018; Bosca & Gillespie, 2018; Haggerty et al., 2018; Lewin, 2019). Coal is an identity issue in these mining communities, which is amplified by attachment to location, landscape, and personal networks (Carley et al., 2018). In just transition policies and planning, it would be essential to acknowledge people-place attachment of global coal mining communities (GCMC) (Bosca & Gillespie, 2018). Coal communities often use generational identity as a legitimating factor to support the coal industry. For example, Bosca & Gillespie (2018) analyzed written public submissions regarding the development of a coal mining project in Lithgow, New South Wales, Australia and found that coal miners supporting the coal mine development often wrote emotionally about how coal has supported their families for several generations (Bosca & Gillespie, 2018).

Given the fact that coal is also an identity issue for workers and their communities, scholars suggest that just transition plans should acknowledge (recognition justice) this local identity. So far, no study has conveyed how this can be done. However, since this local identity is strongly embedded in coal communities, it might be necessary to recognize this throughout the transition planning process (long-term). While no scholarly work has highlighted the identity issue with respect to other fossil fuel workers such as oil workers, it might also be relevant to other fossil fuel workers.

6. The gender gap in energy sector jobs

Fossil fuel industry jobs have historically been dominated by men, while women have generally been under-represented in these industries. According to the International Renewable Energy Agency (IRENA), the share of women in the oil & gas industry is merely 22% (IRENA, 2019b). A recent study on the closure of gold mines in South Africa found that even though very few women were employed in the formal gold mining sector, the closure of mines made it even more difficult for women to participate in the local workforce as mine closure led to an overall reduction in locally available jobs (Sesele, Marais, van Rooyen, & Cloete, 2020). Although this study was not focused on just transition for fossil fuel workers, it demonstrates the importance of evaluating just transition policies through a gender lens. Without this type of examination, some scholars have voiced concerns that there is a risk woman will not enjoy the fruits of the clean energy transition (Rosemberg, 2010) and just transition policies will only benefit men.

There is very little discussion about this element within academia or in just transition policies, which highlights the need to recognize this historical injustice (recognition justice) and ensure that future just transition work focuses on restoring this gender gap (restorative justice). This kind of gender gap in energy sector employment exist at all levels (national, state/provincial, local) (IRENA, 2019b), thus by necessity it should addressed at all levels. Moreover, given the long historic injustice, (Rosenberg, 2010) states that addressing gender gap in new jobs must be part of a long-term agenda.

7. Education/ research institutions

Herpich, Brauers, & Oei (2018) argue that Governments could encourage the creation of educational and research institutions in fossil fuel regions as they can play an important role in shifting a fossil fuel/ mining region towards a knowledge-based economy. For example, in the 1960s the Ruhr region in Germany (historically a hard coal mining region) did not have a single university. However, the German government supported and financed the creation of several universities. By 2014, the region hosted 22 universities that attracted 250,000 students. "The deployment of the universities enabled a shift from the mining economy towards an economy based on high-value adding sectors (such as the lead markets in the Ruhr area) with increased demand for highly skilled workers and research-based innovation" (Herpich et al., 2018, p. 24). Apart from the universities and research institutions, Witajewski-Baltvilks, Lewandowski, Szpor, Baran, & Antosiewicz (2018) in their report for the *Instytut Badań Strukturalnych* state that education at secondary and tertiary levels must be updated keeping the future labor requirements in mind.

Given the key role educational and research institutions could play in shifting a fossil fuel/ mining region towards a knowledge-based economy, the national & state/provincial level governments could develop policies and provide funding (where feasible) for creating such institutions in areas affected by decarbonization (Herpich et al., 2018). This will ensure equitable distribution of burdens and benefits of energy transitions (distributional Justice). Moreover, creating such institutions would require long-term support from these governments.

8. Worker Pensions

Generally, just transitions work tend to focus on current workers and fail to recognize the large number of pensioners who will be negatively affected as a result of energy transitions away from fossil fuels. In the US, the number of pensioners is almost equal to the number of coal workers

(Pai & Zerriffi, 2018). Many leading coal companies, like Murray Energy, are claiming bankruptcy and putting the pensions of thousands of workers in jeopardy (Randles, 2019).

In India, the current number of coal mining related pensioners (0.5 million) is nearly same as the number of coal miners in the country (Sengupta, 2018). As a result, several scholars advocate for pension protection for forced and naturally retired workers (Abraham, 2017; Cha, 2017; Mayer, 2018; Pollin & Callaci, 2019). Mayer (2018), who studied local policymakers' perspectives on just transition policies in the Mountain West region in the US, found that over 70% of surveyed local government policymakers support pension protection. There is also evidence that this kind of pension protection is hailed by fossil fuel communities in some countries (Abraham, 2017). For example, Abraham (2017) found that a deal between The IG Bergbau, Chemie, Energie (IGBCE) trade union and the German government guaranteeing pension for early retiring coal workers was lauded by the local workers as a good just transition measure (Abraham, 2017).

In many countries, the fossil fuel companies' pay money into a pension fund that supports workers after retirement. In such places, government regulations could ensure that fossil fuel employers honor their pension commitments and, where these companies are in genuine crisis, the federal government may have to consider taking over the obligation for workers' pensions (Pollin & Callaci, 2019). Future work on just transition should assess pensioners (recognition justice) as a key group directly affected by energy transitions in terms of distributional justice. Such work would also have to take into account both the spatial differences between pensioners given differences between fossil fuel regions within a country and the long time-frame of pension protection as any just transition policy in this area would need to be in place until the death of pensioners, and potentially surviving spouses.

9. Just transition principles and the planning, legislative and regulatory processes

Among the ten recommendations of the Task force on Just Transition (2018, p. ix) for Coal Power Workers and Communities in Canada was the need to embed just transition principles in the planning, legislative and regulatory process. While considered important enough by the task force to include in its recommendation list, it is not a topic that has been included in the academic literature on just transition. The task force recommends that the government incorporate "…just transition in federal environmental and labour legislation and regulations, as well as relevant intergovernmental agreements." Integrating just transition into policy, planning and regulation would require consideration of multiple forms of justice. Legislation, policy and regulation will always have differential impacts across affected parties raising questions around equitable distribution of burdens and benefits of energy-related decisions (distributional justice). Correspondingly, those costs and benefits may accrue differently across regions and would raise questions about how particularly vulnerable regions and communities are being recognized (recognition justice). Finally, engagement with communities (procedural justice) on a long-term basis at every level may be necessary for successful implementation.

10. Job Quality

A number of scholars argue that it is important to create "decent" jobs for fossil fuel workers be they in the clean energy or any other industries (Cha, 2016, 2017; Healy & Barry, 2017; Newell & Mulvaney, 2013; Rosemberg, 2010). Decent jobs are generally defined as those that are high-quality, attractive to people who lose employment in traditional industries, and maintain prevailing wage standards and labor agreements (Cha, 2016). Furthermore, Newell & Mulvaney (2013) suggest that the new jobs should be made accessible to people from a variety of backgrounds and skill sets and provide future career progression. Healy & Barry (2017, p. 455) states that mere “job creation is clearly a poor proxy for a just transition—what matters more is the kinds of jobs, how secure they are, how long they last, and related forms of community resilience and innovation in the face of dynamic energy markets.”

Within academia and outside, the main focus has been on transitioning fossil fuel workers to clean energy jobs. Numerous media reports and research by international organisations and scholarly work have highlighted that fossil fuel workers could be transitioned to the growing renewable energy industry jobs (Cardwell, 2017; Louie & Pearce, 2016). Recent studies have also claimed that in the long run renewable energy jobs such as solar and wind jobs could offset fossil fuel industry job losses (ILO, 2018; IRENA, 2018b). However, no study has focused on whether these new renewable jobs or any new jobs are secure or long-term or whether they pay comparable salaries. This kind of analysis is particularly important as historically it has been seen that after any industrial decline/closure, workers who found new jobs earned less and were forced to do part-time jobs (Danson, 2005; Minchin, 2009). In the UK, across industries, for workers who lost employment in old industrial regions, “the route out of non-employment for those without work may well be through insecure, low-paid and dead-end jobs” (Danson, 2005, p. 455).

Thus, understanding the nature of new jobs (renewables or otherwise) at national and state/provincial would be crucial for any just transition plans geared towards transitioning fossil fuel workers (recognition justice). Moreover, in the current energy transition, different kinds of jobs will be created as new climate mitigation technologies are deployed in the future. Hence, understanding the nature of new jobs is considered by scholars a long-term goal.

11. Job guarantees and compensation

Though some scholars highlighted that job guarantees and compensation plans must be created for workers losing employment due to decarbonization (Cha, 2016, 2017), only one scholar provided specifics on a possible plan. For the US, Pollin & Callaci (2019) recommend a 'job guarantee program' that provides guaranteed jobs for all laid-off fossil fuel workers in clean energy industries. Pollin & Callaci (2019) further say that such a program should provide compensation for workers for their loss of salary (restorative justice) for a period of five years (medium-term). During this period, the worker must be guaranteed the same salary and benefits as what they used to get while working in the fossil fuel industry. So, if a worker gets a job in the clean energy industry, the gap in salary and benefits must be covered by the state. Based on the above criteria for 'job guarantee program,' and considering a scenario where fossil fuel industries decline as a result of a 40% decline in US emissions by 2035, Pollin & Callaci (2019) estimate that $200 million per year would be required to compensate all fossil fuel workers who would be laid off during this period. While the example provided is for the US, the details of such a program would be country-specific, as would the assessment of political and economic feasibility.

12. Worker transition service

When industries decline, workers usually need guidance to cope up with the loss of livelihood and for making plans for employment transition (Snell, 2018). Thus, worker transition service centers in fossil fuel regions could provide one-on-one service to all workers in need.

The officers involved in the worker transition service centers could cater to the "needs, challenges, and interests of workers and advocate for them by negotiating with training providers to offer training courses and introducing them to other employment service providers" (Snell, 2018, p. 557). There is evidence that such centers have been successful in some jurisdictions. For example, Snell (2018) states that worker transition service centers were created in Latrobe Valley, a coal region in Victoria, Australia and of the 430 displaced workers who registered at these service centers, nearly 60% were employed again within 6 months.

Each worker transition service would have to identify individuals and groups who might be impacted (recognition justice) and provide assistance to them. These centers would need to be easily accessible to workers, meaning they be local and run for a few years to ensure that all affected worked are helped.

13. Local infrastructure development

Some scholars emphasized the importance of funding local infrastructure development (Cha, 2017; Haggerty et al., 2018; Olson-Hazboun, 2018; Pollin & Callaci, 2019) that might have been so far supported by taxes and revenues from fossil fuel industries. Such funding would have to be based on local contexts as different local regions have different dynamics that makes each regions' needs unique (Eisenberg, 2019). From the literature, it is clear that recognizing local contexts (recognition justice) and restoring local infrastructure (restorative justice) is considered crucial for a just transition. Olson-Hazboun (2018) said that such funding should come from federal or state/provincial governments and must be for a reasonable time period (medium-term).

14. Local government revenue streams

Many fossil fuel regions, especially coal-dependent regions, are dominated by that single sector economically (Carley, Evans, & Konisky, 2018; Johnstone & Hielscher, 2017). In these regions, if coal mines and power plants close, local governments fear losing their largest source of revenue. Thus, transition plans could entail a fiscal strategy to address any loss of revenue (fully or partially) due to fossil fuel industry closures. One way to negate the shortcomings in revenue is by creating a transition revenue and investment strategy that includes "local revenue strategies, state and federal assistance, and a spending strategy linked directly to economic development goals" (Haggerty et al., 2018, p. 77). Haggerty et al. (2018) suggested that since local governments play a significant role in providing a variety of services to rural communities, just transition plans should replace the portion of a local guvernement revenue stream that derived from coal mining and coal power plants.

For replacing and stabilizing local government revenue streams, the recognition and restorative forms of justice are applicable as it is pertinent to first recognize which local government are vulnerable to revenue losses and adopt the right strategies to restore the loss in these revenues. This kind of assessment and implementation may vary across countries and different regions within countries; thus, such strategies would need to be local and locally implementable. Moreover, the funding or support from federal or state/provincial governments needs to consider the fact that stabilizing local government revenues might sometimes take more than short-term intervention especially in cases where fossil fuel industries provide the bulk of a local government's revenues.

15. Communication of phase-out plans

Herpich, Brauers, & Oei (2018, p. 22) recommend that communication about the fossil fuel industry phase-out should be made as early as possible to "ease the disruptiveness of upcoming changes, by helping former coal miners [or fossil fuel industry workers] to stay in the labor market..." As not much has been written about this element, it is not clear what should be the mode of communication or what are the best practices for effective communications for fossil fuel phase-out plans. However, the manner in which phase-out decisions are made and communicated is likely critical to ensuring procedural justice. This would include a fair process for including different stakeholders to take part equitably in the decision-making process even at the idea stage of phase-out. It is also obvious that this kind of engagement about fossil fuel phase-out needs to happen at all levels in the short-term.

16. Environmental remediation

Fossil fuel extraction often negatively impacts landscapes and waterbodies, with potential effects on both human health and ecosystems. Remediation of those landscapes and systems can be seen as a form of restorative justice. The required remediation would be specific to each local site, such as specific coal mining areas, and could be expected to take a couple of years (Pai & Carr-Wilson, 2018). Three scholars suggested that decommissioning of fossil fuel infrastructure and environmental remediation in fossil fuel areas could provide several benefits (Greenberg, 2018; Haggerty et al., 2018; Pollin & Callaci, 2019). In the short-term, decommissioning fossil fuel infrastructure or reclaiming old coal mining sites would provide economic opportunities in the form of investments and job creation (Haggerty et al., 2018; Pollin & Callaci, 2019). Later, remediation would help create access to recreational activities that can help combat negative economic consequences of legacy contamination (Haggerty et al., 2018). Greenberg (2018) recommends that a fund be created for environmental remediation and priority for remediation jobs could go to former miners and local community members in the area.

17. Retraining workers

Many scholars emphasized the importance of retraining (Cha, 2017; Mayer, 2018; Olson-Hazboun, 2018; Pollin & Callaci, 2019; Rosemberg, 2010; Vona, 2019) and one scholar who studied local policymakers' perspectives on just transition policies in the Mountain West region in the US found that nearly four-fifths of local government policymakers surveyed expressed support for retraining (Mayer, 2018). Pollin & Callaci (2019) claim that while some jobs in the clean energy industry are similar to jobs in the fossil fuel industry, others are different and retraining fossil fuel workers and preparing them for jobs in the clean energy industry is a critical element of a just transition. The authors calculated that $65 million per year would be required in the US to retrain all laid-off fossil fuel workers to clean energy jobs. This assumes the fossil fuel industry declines as a result of a 40% decline in the US emissions by 2035.

Recognition justice would require that retraining programs aimed at helping fossil fuel workers appropriately identify the workers affected by energy transitions, the skills they possess, and the skills required for them to be working in clean energy industries or other industries. Moreover, as suggested by some scholars, workers would need to be provided easy access to such short-term skill-specific programs.

2.3 Discussion and conclusion

Scholars in academic fields such as labor, economics, geography, law, energy transitions and policy have sought to identify and explain different elements (or strategies) of a just transition for fossil fuel workers and communities. While individually these studies make important contributions, no systematic review has been conducted in the past synthesizing all these just transition elements. Using a systematic search and review strategy, I analyzed 33 articles that focus on just transition for fossil fuel workers and their communities in the context of climate change. In addition, I also analyzed key reports by national commissions on just transition and reports by select think tanks.

My review points to three main findings. First, the field is still new, and most studies focus on a few industrialized countries (although some have a global focus) and on coal workers. Given the fact that millions work in the fossil fuel industries in countries such as India, China, Brazil and Middle-Eastern countries (all major fossil fuel producers), future just transition work must focus on expanding the geographic scope to better understand similarities and differences in the transition process. Moreover, so far, just transition studies have largely focused on coal workers. That is partly justified given the carbon footprint of coal, but future studies could focus on enhancing the field and understanding of just transition by focusing on oil and gas workers and comparing across fossil fuels and across fossil fuel-intensive sectors. In addition to differences in industry structure, workers in other sectors may have different attributes than coal workers in terms of their working conditions, skill sets, salary structure, and mobility. Thus, depending on these attributes and the needs of workers, the just transition plans might look very different. Future work could also pay attention to lessens that can also be learnt from other non-fossil fuel sectors also experiencing transition.

Second, I found that the literature so far contains both quantitative and qualitative studies, as well as theoretical studies, but is largely normative and/or descriptive. Future research could focus on contributing to the empirical literature including conducting more qualitative and quantitative studies of just transition options, and by creating actionable just transition frameworks for various jurisdictions.

Third, my review collectively generated 17 key elements of just transition, which range from the requirement of long-term planning to importance of retraining. In this review, I explain these elements further by using Heffron & McCauley's (2018) legal geography 'JUST' framework to characterize each of these elements based on justice forms, spatial and time scales. For justice forms, for each element I identify "what justice is needed and/or expected." Moreover, I also characterized each element on the basis of spatial scales (national, provincial/state and/or local level) and time (long-term, medium-term and short-term). By characterizing each element, I show that for designing various just transition strategies policymakers should pay attention to different justice forms. These elements also vary spatially suggesting the involvement of different stakeholders at different levels of government in the transition process. Moreover, given the timelines of interventions (long-term to short-term) involved, my findings emphasize the need to undertake holistic planning to meet the goals of just transition.

Our first two major findings highlight major gaps in the literature and points to areas where future research is required. Moreover, by identifying just transition elements and characterizing each element on the basis of justice forms, space & time, I also contribute to the scholarly understanding of the emerging field of just transitions for fossil fuel workers and their communities. Specifically, by characterizing these elements, I make a first attempt to further scholarly and policy focused understanding of each of these elements and showing how theoretical concepts (such as justice forms) need be used while designing specifics of just transition plans involving each identified element.

Furthermore, these elements can also provide policymakers insights into where to target their efforts in creating just transition strategies. However, it must be noted that the elements highlighted in this paper are not an exhaustive list and many of these elements are poorly defined in the literature. For example, many scholars identify retraining workers as critically important for helping fossil fuel workers transition to new jobs. However, the articles about this element are either descriptive or have focused on costs associated with retraining fossil fuel workers to jobs in clean energy industries. So far, no study has focused on the kinds of skills required for working in clean energy industries or, for that matter, whether emerging jobs in a given economy are more likely to be found in non-energy industries. Future studies could focus on identifying how to make retraining programs more effective and in line with new job requirements whether in clean energy or other industries. Future work could also focus on assessing whether existing institutions currently running retraining programs are equipped to provide desired retraining for new kinds of jobs.

Overall, future work in this area needs to provide more evidence and clarity on each of these just transition elements. There is also a need for greater realism in future scholarly work, particularly focusing on remote fossil fuel-based communities where creation of equally well-paid jobs on a similar scale may prove challenging. Lastly, while many scholars are examining just transition strategies, none of the scientific articles so far has systematically incorporated the views of fossil fuel workers such as coal workers and their communities into the key features and elements of a just transition. This is a major gap and remains an area of future research.

For the political support of energy transitions required to meet the global climate targets, scholars believe that implementation of just transition strategies for fossil fuel workers and their communities could be important. Others argue that there is an ethical obligation to provide for the well-being of fossil fuel workers and their communities as the world transitions to low carbon sources. This Chapter identifies elements that are considered vital to just transition strategies, but scholars, citizens, and policymakers need to critically assess and implement these elements to ameliorate opposition from fossil fuel workers and their communities to the much-need low carbon transitions.

Chapter 3: Analyzing the energy sector employment implications of keeping global warming well below 2°C

Most studies that focus on understanding specific energy sector job impacts of climate policies focus on a small set of OECD countries (Atilgan & Azapagic, 2016; Cameron & Van Der Zwaan, 2015; Çetin & Eĝrican, 2011; Fragkos & Paroussos, 2018; Llera et al., 2013; Markandya et al., 2016; Sooriyaarachchi et al., 2015; Wei et al., 2010) or rely on datasets from OECD countries to estimate energy job impacts globally (Dominish et al., 2019). As noted in Chapter 1, these OECD only studies are not able to capture employment impacts in non-OECD countries such as India, Brazil, China, and others, which contribute a large number of energy jobs. The only global analysis on this topic applies OECD job datasets to non-OECD contexts. Thus, it is not able to capture the very different labor conditions in non-OECD countries that result in differences in job numbers per unit of energy production. Overall, the global and regional energy sector employment impacts of climate policies require overcoming methodological and data limitations.

In order to address the above limitations, I asked the following research questions:

1) How would energy sector employment differ between a world that keeps global warming Well-Below 2°C and a world that continues on current climate policy pathways?

2) How would the landscape of energy sector employment change under Well-Below 2°C climate scenarios?

3) How do the employment effects vary between regions under Well-Below 2°C climate scenarios?

To answer these questions, I built a novel 50 country global jobs dataset and used an integrated assessment model (IAM) to investigate the impact of the global climate targets of Well-Below 2°C (WB2C) on energy sector employment by energy technologies, job types and regions. Specifically, I focus on quantifying the impact of energy system changes on "direct jobs", or jobs that relate to core activities involved in energy supply chains.

In the next section (3.1) I explain the methods. In section (3.2) I summarize the results, and in the final section (3.3) I discuss the implications and limitations of my study.

3.1 Methodology

I first collected a comprehensive global dataset of employment factors (i.e. how many workers are employed per unit of electrical or refining capacity or fuel production) for nearly 50 countries spanning eleven energy technologies and five job types (**see data collection section 3.1.1 for more details**). I then applied the employment factors dataset to the outputs of the World Induced Technical Change Hybrid (WITCH) integrated assessment model to project future energy jobs under both a WB2C and a Reference scenario (**See 3.1.2 for scenario details**). Here, WB2C refers to 66% probability of meeting 1.5 °C climate target.

3.1.1 Data collection

I used a supply chain mapping approach to determine the equivalent core activities for each of the energy sectors **(see Appendix A1 for supply chain mapping)**. Focusing on the most significant direct jobs for every energy technology, I collected "employment factors" data or how many workers are employed per unit of energy for each energy sector and job type.

In order to collect the employment factors dataset, I used two approaches (**Figure 3.1**). First, I collected country specific employment factors data published in the academic literature, government reports and reports by well-known international organizations or consultancies.

Second, if the data was not already available in the form of employment factors, I collected the most up-to-date number of jobs for different energy technologies disaggregated into job types in different countries and then divided these job numbers by the respective energy capacity and/or fuel produced associated with that country/energy sector/job type.

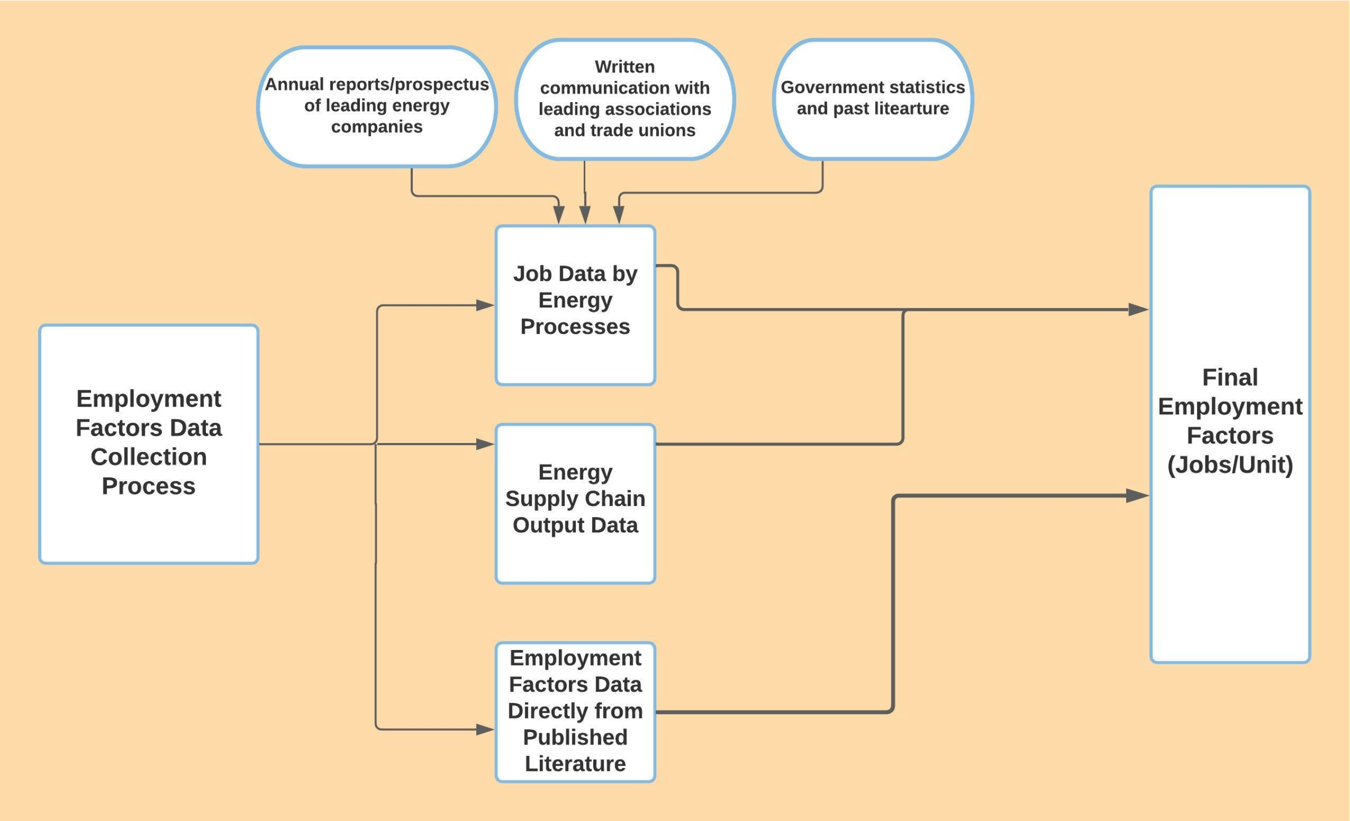

Figure 3.1 Data collection flow diagram
Flow diagram shows the employment factors data collection process.

For the second approach, in addition to collating current job numbers published in the academic literature and reports, I drew on: 1) annual reports, sustainability reports, prospectus documents and official websites of leading oil & gas companies like Saudi Aramco (Saudi Arabia), Gazprom (Russia), Sinopec (China), Kuwait National Petroleum Company (Kuwait), PetroVietnam (Vietnam), Pemex (Mexico) or from leading coal companies such as Coal India (India), Eskom (South Africa), SUEK Ltd (Russia) among others; 2) written communications with trade associations like the World Nuclear Association and trade unions like the Federation of Oil Unions (Iraq) and Central de los Trabajadores y Trabajadoras (Brazil); and 3) official national statistics, such as Statistics Norway (Norway) and Ministry of Petroleum & Natural Gas (India).

As an example, for coal mining in India, I collected data on the current number of jobs in Coal India Limited (India's monopoly coal mining company), and then collected coal production data for that year. I then divided the jobs data with production data to generate employment factors for coal mining in India in the form of jobs/million tonne of coal produced. I used this second approach to collect the majority of employment factors data in fossil fuel industries, nuclear, and a large portion of data for renewables (**Dataset link:** https://bit.ly/3cDIxtJ).

Table 3.1, below, shows the energy technologies and the job types included in this analysis. It must be noted that I was not able to collect data for fossil fuel industry and nuclear industry equipment manufacturing jobs due to the lack of availability of datasets. I reviewed the literature, wrote to country level industry associations and unions but I was not successful in gathering this data. This is a limitation of this Chapter that needs to be addressed in future work on this topic. However, applying a previous OECD average employment factors for manufacturing jobs from the above mentioned global study (Dominish et al., 2019), I find that manufacturing jobs constitute a small share of total jobs in these technologies. They range from 0.05% (for nuclear) to 3% (for natural gas) of total jobs for those technologies. Thus, this is not likely to be a major source of error or uncertainty in the estimates.

Table 3.1 Energy technologies and job types included in the analysis
The table shows 11 energy technologies and 5 job types included in our analysis.

Energy Technologies (right) & job types (below)	**Coal**	**Gas**	**Oil**	**Nuclear**	**Hydro power**	**Solar PV**	**Solar CSP**	**Bio fuels**	**Wind onshore**	**Wind offshore**	**Solid biomass**
Construction & Installation	X	X	X	X	X	X	X	-	X	X	X
Manufacturing	-	-	-	-	X	X	X	X	X	X	X
O&M	X	X	X	X	X	X	X	-	X	X	X
Fuel production	X	X	X	X	-	-	-	X	-	-	-
Refining	-	-	X	-	-	-	-	X	-	-	-

In the dataset, I compiled employment factors data on coal production in jobs/million tonnes produced; uranium production in jobs/peta joule; oil & gas exploration & production in jobs/thousand barrels of oil equivalent produced; biofuel production in jobs/million liters produced; oil refining in jobs/thousand barrels per day capacity; and power plant operations and maintenance jobs in jobs/GW capacity. In line with past studies, for construction & installation and manufacturing jobs, I collected employment factors data in "job years"/GW instead of jobs/GW, as these are temporary jobs typically occurring at the beginning of the project development (Cameron & Van Der Zwaan, 2015; Rutovitz, Dominish, & Downes, 2015; Wei et al., 2010). Here, "job years" represent the number of workers multiplied by the number of years they work. Then, I converted job years/GW data into jobs/GW. I did this by dividing job years/GW data by the number of years required for construction of a power plant – the construction period typically varies between 1 and 10 years for different energy technologies (Rutovitz et al., 2015) (**see Appendix A2 for energy technology wise construction years**)**.** For example, a typical onshore wind power plant requires 2 years for construction. Thus, I divided the onshore wind power plant employment factor (job years/ GW) by 2 to get jobs/GW data for a particular year. The dataset for fuels is further divided into hard coal and lignite while oil and gas is divided into conventional and unconventional**.**

3.1.2 Scenario design using WITCH model and key assumptions

The Reference scenario assumes that countries follow their current Nationally Determined Contributions (NDC) targets until 2030 and then assumes that the current NDCs continue in terms of relative stringency (i.e. same policies) through 2050. For creating the WB2C pathways, the model uses the globally estimated peak carbon budget (742 GtCO2 for the period 2011-2100) (Rogelj, Forster, Kriegler, Smith, & Séférian, 2019), for creating scenarios to meet the WB2C target.

To ensure the robustness of the results, I explored both Reference & WB2C scenarios using the standard Shared Socioeconomic Pathways (SSP) storylines (Riahi et al., 2017), which are designed to explore a wide range of socio-economic and technological assumptions relevant for climate change policy and have been widely used for similar *"What-if analyses"* (Rogelj et al., 2018). Here, I present the main results for a SSP2 or "middle -of-the road" pathway, where socio-economic trends and technological change follow historical trends. I also test the results under a fossil-rich world (SSP3), where climate change mitigation becomes a larger challenge and under a sustainable world (SSP1), rich in green technologies.

Finally, in all six pathways I incorporated labour productivity improvements by assuming that the employment factors in non-OECD countries converge linearly towards the mean in the OECD regions by 2050. I did this because previous work has shown that non-OECD countries currently have more jobs per unit of energy because these countries have more labour-intensive practices, but in the future, there may be improvements in labor productivity (Dominish et al., 2019). **Figure 3.2** below presents the primary energy mix for each of the scenarios and **Figure 3.3** shows global CO2 emissions across all scenarios and policies.

In order to calculate future renewable energy manufacturing jobs, I assigned these jobs to a "Global Pool" instead of individual countries/regions. Fundamentally, there is nothing physically tying these jobs to a particular geography in the same way that coal mining has to happen where coal deposits are located. There is some argument to be made that countries with current manufacturing capacity would be at an advantage for having future manufacturing (and jobs) occur there. However, I cannot make any strong assumptions about what proportion of future manufacturing jobs would happen in the same countries of today.

Historical evidence shows that for manufacturing sectors the first mover advantage is not supreme, particularly in the face of large industry expansion. Data on Solar PV shows that whereas Chinese firms only entered the market in 2000, that is, 20 years after first movers, Chinese firms now account for over half of all manufacturing (Binz, Tang, & Huenteler, 2017). This shift happened in only ten years. Thus, in the face of a massive expansion of renewables, the development of manufacturing capacity is not a foregone conclusion and new entrants have the potential to compete with today's manufacturers with smart industrial policies.

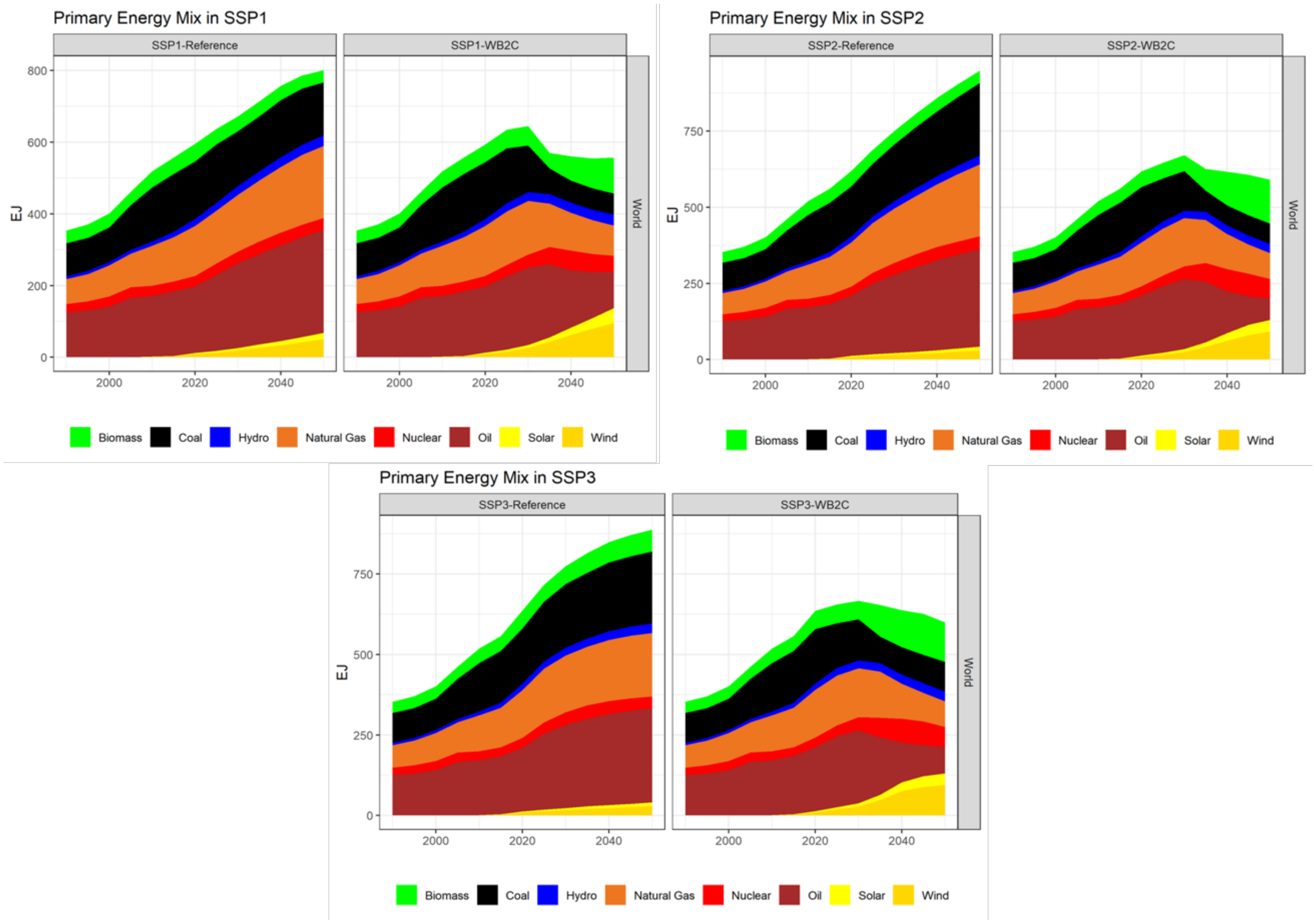

Figure 3.2 Primary energy mix for WB2C & Reference scenarios
The figure shows primary energy mix from 2020 to 2050 under both WB2C and Reference scenarios and their pathways under shared socio-economic pathways (SSP). The model assumes that a growing fraction of emissions from future fossil fuel use will be offset by negative emission technologies and carbon capture.

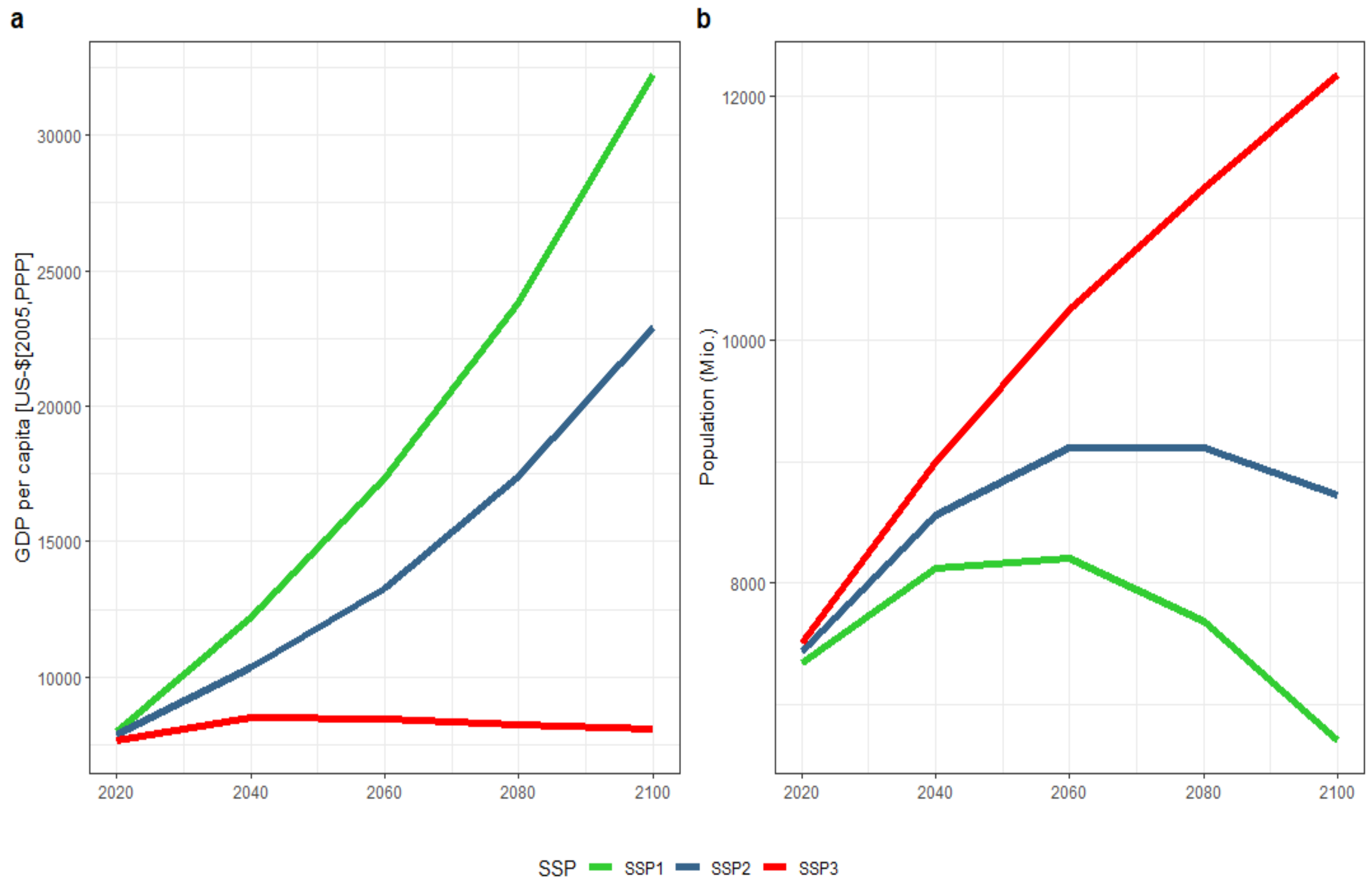

Figure 3.3 Baseline GDP and population drivers across shared socio-economic pathways
The figure shows projections for GDP per capita and population growth across SSP1, SSP2 and SSP3.

3.1.3 The WITCH model

The WITCH model is an IAM developed and maintained at the RFF-CMCC European Institute on Economics and the Environment and is designed to assess climate change mitigation and adaptation policies (Bosetti, Carraro, Galeotti, Massetti, & Tavoni, 2006; Emmerling et al., 2016). It is a global dynamic model that integrates into a unified framework the most important drivers of climate change and an inter-temporal optimal growth model captures the long-term economic growth dynamics. In the model, a compact representation of the energy sector is fully integrated (hard linked) with the rest of the economy so that energy investments and resources are chosen optimally, together with the other macroeconomic variables.

The WITCH model represents the world in a set of a varying number of macro regions – for this Chapter, 17 representative regions were used (**see Appendix A3 for WITCH region details**); for each, it generates the optimal mitigation strategy for the long-term (from 2005 to 2100) as a response to a carbon price compatible with external constraints on emissions.

3.1.4 Combining scenario outputs and calculating jobs

In order to calculate current jobs and future jobs, I converted the employment factors dataset denoted by $e = 1..E$ for energy technologies and $j = 1..J$ for job types to jobs per common unit of energy or power capacity ($\frac{jobs}{PJ}$ or $\frac{jobs}{GW}$) denoted $jobint_{ej}$. Then, I used energy-related output quantities from the WITCH model to compute the total current jobs numbers.

Here, the WITCH model's energy-related outputs are denoted as: yearly installments I_EN_e in GW; total installed capacity K_EN_e, in GW; fuel extraction Q_OUT_e, in PJ; and, total primary energy supply Q_PES_e, in PJ.

The total number of direct energy jobs is then simply computed for the base year as:

$$\boldsymbol{TotalJobs} = \sum_{e} \boldsymbol{jobint_{e,j} \cdot I\_EN_e} + \sum_{e} \boldsymbol{jobint_{e,j} \cdot I\_EN_e} + \sum_{e} \boldsymbol{jobint_{e,j} \cdot K\_EN_e} + \sum_{e} \boldsymbol{jobint_{e,j} \cdot Q\_OUT_e} + \sum_{e} \boldsymbol{jobint_{e,j} \cdot Q\_PES_e}.$$

To compute Future $TotalJobs$, the above formula was applied to the scenario pathways generated by the WITCH model in all 17 regions according to energy quantities produced by the model in each of these regions. It must be noted that the employment factor dataset contains only one value per technology and job type for each country. Therefore, I conducted an uncertainty analysis. For each of the 17 macro regions in the WITCH model, I used the minimum and maximum values for each country, technology, and job type. By combining these ranges with the ranges across SSP scenarios I account for the uncertainty of our results.

Here, I present the results for the central estimate SSP2 and report the uncertainty ranges in brackets. The results for the other SSPs and their uncertainty ranges can be seen in figures in the results.

3.2 Results

3.2.1 Keeping well below 2°C may increase global energy jobs

In the year 2020, approximately 18 million people were directly employed in the energy sector: 12.3 million people in fossil fuel industries, 4.5 million in renewable energy industries, and 0.8 million in the nuclear industry. Out of the 12.3 million people employed in fossil fuel industries, nearly 9.5 million are employed in fossil fuel extraction sectors (coal mining and oil & gas extraction).

Under the projected Reference scenario, I find that by 2050 energy sector jobs might grow to 21 million [17 – 26] and under a WB2C target to 26 million [23 – 30] jobs. In the WB2C scenarios, fossil fuel jobs might decline considerably from 12.3 million today to 3 million [2.5 – 5.0] (**Figure 3.4**).

The modelling results also show that this decline is concentrated in the extraction of fossil fuels (coal mining, oil, and gas production & exploration), which account for around 80% of the job losses. However, these job losses might be compensated globally by large gains in renewable energy jobs – growing from 4.5 million jobs today to 22 million [14 – 25] in 2050, with over 85% of these gains in the solar and wind industry. These jobs would span manufacturing, operations and maintenance (O&M) and construction jobs.

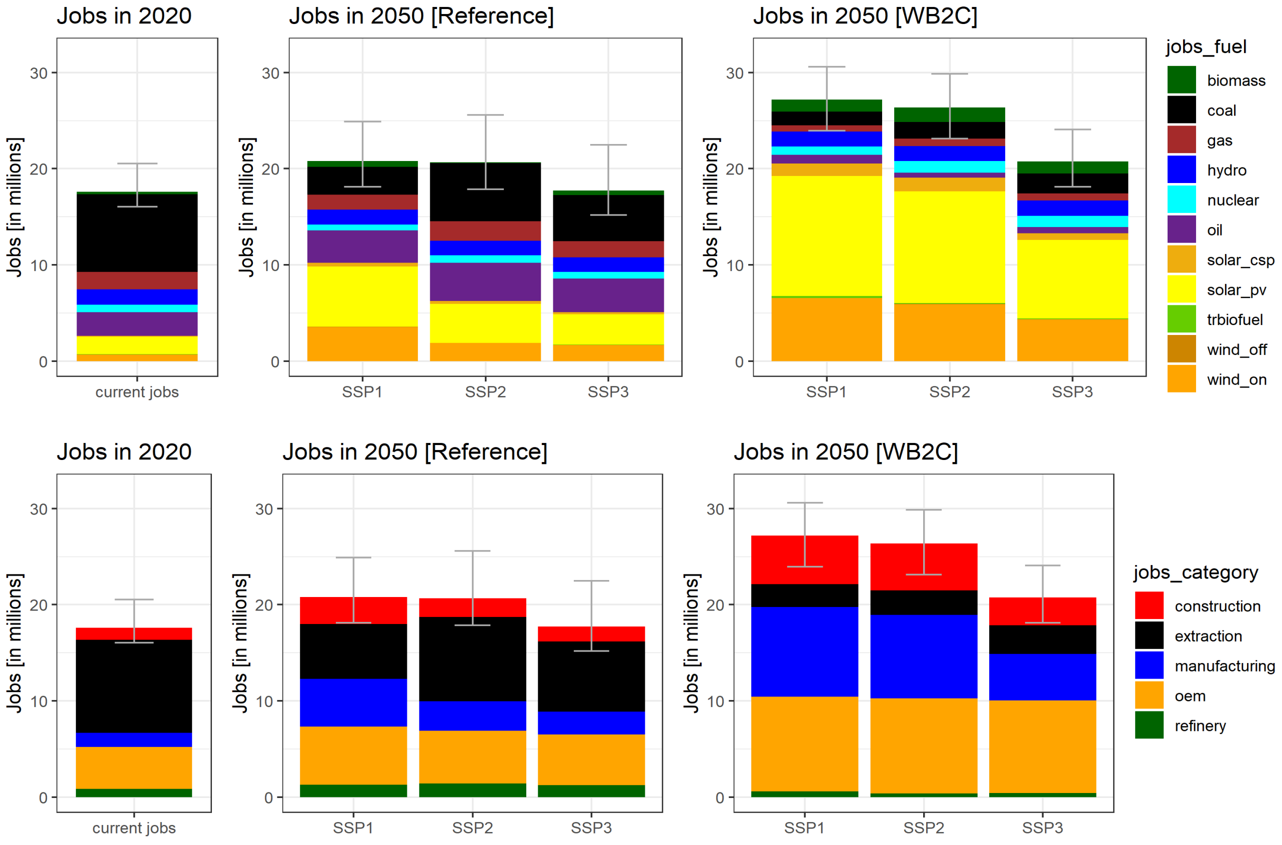

Figure 3.4 Current jobs and jobs in 2050 by energy source and type under different scenarios
The figure shows the changes in energy sector jobs by energy technology and type between 2020 and 2050 under both Reference and WB2C scenarios. Below, SSP1 represents "Sustainability", SSP2 represents "Middle of the Road" and SSP3 represents "Regional Rivalry." Whiskers indicate the uncertainty range based on the minimum and maximum of jobs intensities across countries in each region. In the figure, csp refers to concentrated solar power and pv refers to photovoltaic.

The total energy sector jobs are in fact higher in the WB2C scenario than both today and in the Reference scenario from 2025 onwards **(Figure 3.5)**. However, the increase in jobs in the WB2C scenario levels off over time.

In the WB2C scenario, there is the more rapid shift to low-carbon technologies that are more job-intensive, which leads to an increase and spike in jobs, particularly during the expansion of renewable energy capacity (mainly in construction and manufacturing jobs). At some point, however, due to technological progress and reduction in the transition speed, jobs slowly start to decline.

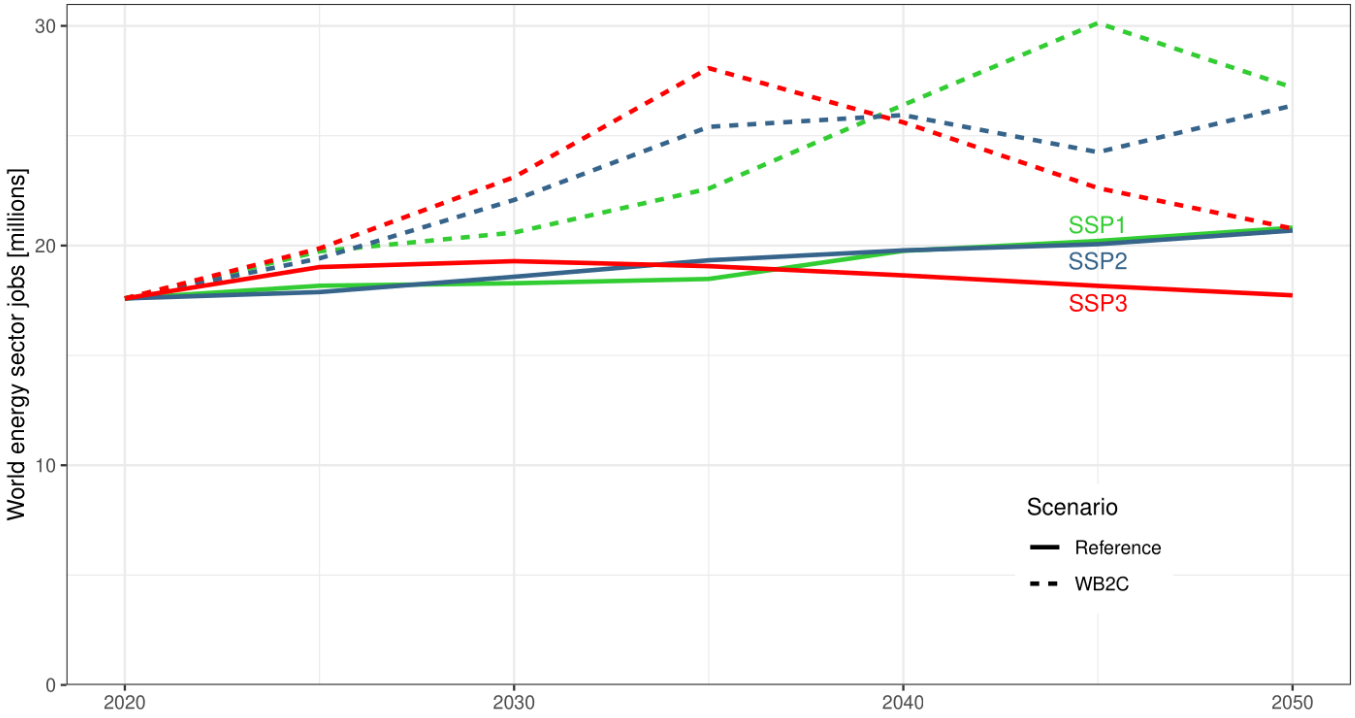

Figure 3.5 Evolution of energy jobs at the world level in the Reference and WB2C scenarios until 2050
The figure shows the changes in the energy sector over time from 2020 to 2050 under both reference (solid) and WB2C (dashed) scenarios. The shared socio-economic pathways (SSP) are depicted with different colors – SSP1 (green), SSP2 (red) and SSP3(blue).

3.2.2 Growth of manufacturing jobs in solar and wind

A large portion (8.7 million [4.0 – 9.5] in 2050) or 38 % of the expansion of renewable energy jobs in 2050 to meet the WB2C climate targets would be in the manufacturing of solar and wind. This trend captures the shift in the landscape of energy sector jobs between "old" energy technologies (coal, oil & gas), where jobs are linked to extraction, versus “new” energy technologies (solar & wind), where the bulk of the jobs are likely to occur in manufacturing. I find that the growth of these manufacturing jobs in the global pool is observed in the Reference scenario. However, after 2030, there are consistently at least 2 million more global pool jobs in the WB2C scenario than the Reference scenario (**Figure 3.6**).

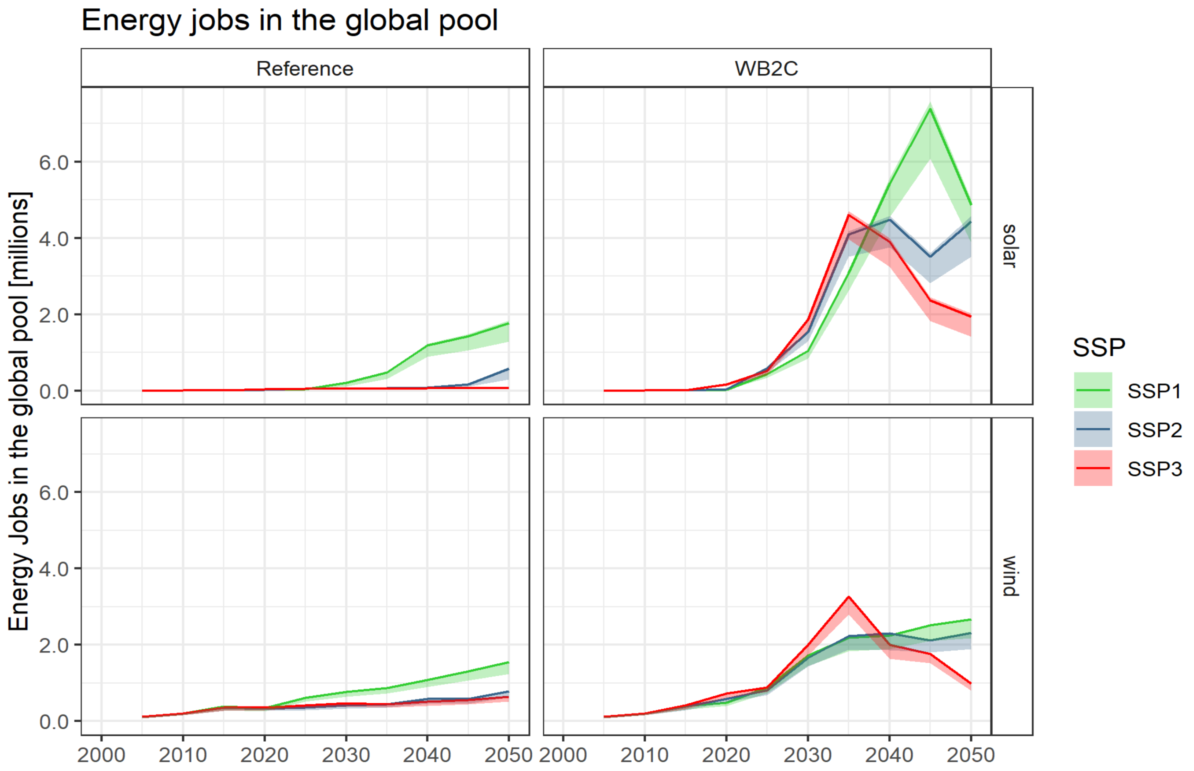

Figure 3.6 Manufacturing jobs over time in solar and wind industries represented as a global pool
Solar and wind manufacturing jobs are nearly always higher in the WB2C scenario compared to the Reference scenario. Shaded areas indicate the uncertainty range.

3.2.3 Regional employment gains and losses

The development of energy jobs varies greatly between regions. This can be seen in **Figure 3.7**, which shows the percentage change in jobs between 2020 and 2050 for the Reference (Panel A) and WB2C scenarios (Panel B). Most regions show job increases in the Reference scenario compared to today except for moderate job losses in India (under some SSPs), and the notable exception of China with job losses of up to 39%. Comparing Panel B to Panel A shows the effect within regions of the climate policy (Reference vs WB2C) (**Figure 3.7)**.

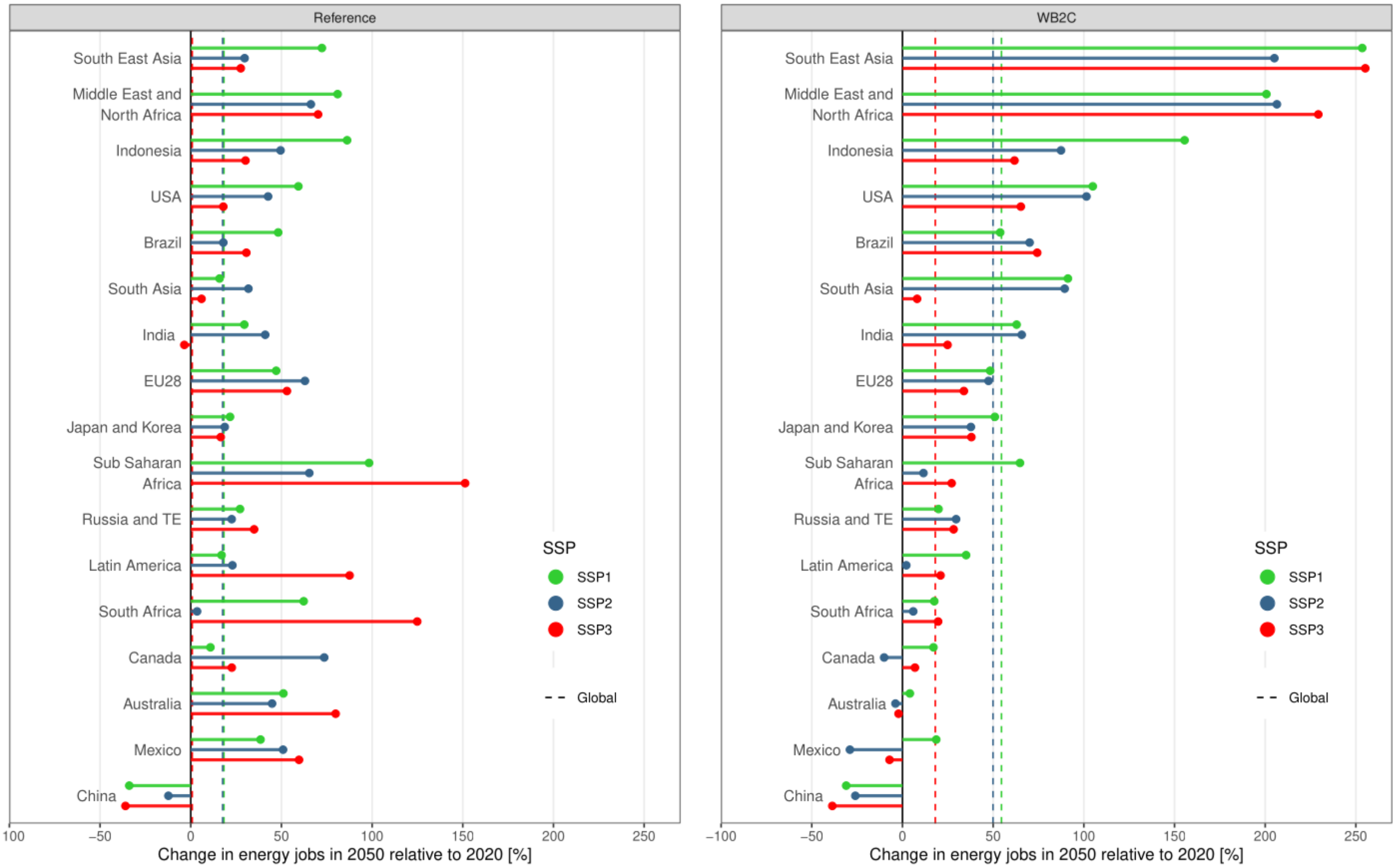

Figure 3.7 Regional changes in energy jobs from 2020 to 2050 for the Reference and the WB2C scenarios

Values are expressed in percentage change. Socio-economic projections (SSP) are depicted with different colors. The global change in energy jobs is denoted by the dashed lines. Regions are ordered by the mean changes across SSPs in the Reference scenario.

Some fossil fuel exporting regions such as Mexico, Australia, Canada (except for SSP1), South Africa (except for SSP2), and Sub-Saharan Africa (constituting oil exporters such as Nigeria and Angola) would see those job gains disappear with a strong climate policy (i.e in the WB2C scenario). Most of the current energy sector jobs in these exporting countries are in the extraction sector, either in oil and gas exploration and production or the coal mining sector. As the demand for fossil fuels falls in the WB2C scenario, these exporting countries would lose employment in their extraction sectors, which is not compensated by an increase in renewable energy jobs. However, it should be noted that regions such as Sub-Saharan Africa have a relatively small number of energy sector jobs, such that even small differences between the Reference and WB2C scenarios (a difference of around 15000 jobs in 2050) can result in high percentage differences in jobs.

In regions such as the European Union, Russia and TE, and Latin America there would be overall job increases in both the WB2C and Reference scenarios compared to today, but the percentage increase depends on the SSPs led pathways these regions follow.

Many other regions (South East Asia, Middle East and North Africa, Indonesia, the US, Brazil, South Asia, India, and Japan and Korea), show an even higher percentage increase in jobs in the energy sector under a stringent climate policy (i.e. the WB2C scenario). Among these, the emerging economies of South East Asia, Indonesia, Brazil, South Asia and India currently have a large number of jobs in the fossil fuel sector with relatively higher job intensities than the Middle East and North Africa and the US. In the WB2C scenario, while their fossil fuel jobs decrease, the increase in energy demand and massive deployment of renewables leads to an overall rise in jobs. Japan and Korea, which currently rely on imports of all fossil fuels, would transition to low carbon sources under the WB2C scenario creating a slight increase in overall jobs compared to today.

In absolute terms, the Middle East and North Africa, and the US might gain over a million jobs in 2050 in the WB2C scenario compared to today, while other regions show more modest gains

(**Table 3.2**). In the case of these two regions, future job losses are in their relatively low job intensity (meaning fewer people are employed) fossil fuel sectors. However, these regions also have high renewable energy potential (with higher job intensities in the renewable energy sector) resulting in higher job numbers in the future overall.

It must be noted that the precise outcomes for any of these regions over time and as their energy sectors shift with policy are a complex mix of changes in job intensity, energy demand, and differing impacts of economic drivers associated with the three SSPs. Each SSP pathway has a clear influence on regional job numbers. For example, for India, South East Asia and Canada in WB2C scenario, the SSP1 (or sustainability) pathway leads to more jobs compared to SSP2 (middle of the road) and SSP3 (fossil-rich) pathways. The policy impact can also be quite different for some SSPs compared than others even within a region. In some cases (e.g. Mexico, Canada) even turning job gains into job losses (e.g. SSP2 for Canada and SSP2 and SSP3 for Mexico). Sub-Saharan Africa is another example where the addition of climate policy has less impact on SSP1 results as compared to the impact on SSP3. This has implications for how climate policies might be seen from a jobs perspective in these different regions that is dependent upon global patterns and trends in economics, demographics and policy.

Table 3.2 Region wise net job impacts in the WB2C scenario under SSP2
The table shows the difference in jobs in 2050 minus 2020 under the WB2C scenario under SSP2. Most regions gain jobs compared to today except for China, Mexico, Canada and Australia.

Job Gains (JG) in WB2C scenario under SSP2	**Regions**
JG > 1 million	US, Middle East and North Africa
100,000 < JG <1 million	Europe, India, South East Asia, Russia & TE, Japan and Korea, Indonesia, Brazil
0 < JG < 100,000	Latin America, Sub Saharan Africa, South Asia, South Africa
JG <0	China, Mexico, Canada, Australia

One key finding is that under both the Reference and WB2C scenarios, China would have lower energy sector jobs in 2050 compared to today, due to the loss of jobs in the coal mining sector. Generally, those regions facing job losses (such as fossil fuel exporters) or only modest job gains **(Figure 3.7)** can compete for the between 3 and 8 million expected manufacturing jobs in future upscaled installation of solar and wind, which are allocated in the global pool**.** China and other major renewable energy equipment manufacturing countries have a head start over other countries, which puts them at an advantage to attract these jobs.

3.3 Discussion and conclusion

This Chapter builds on previous studies that focus on climate policies' impact on energy jobs in a small set of OECD countries or use OECD data to examine global energy job impacts from climate policies. I created a novel dataset of job intensities in 50 countries including major non-OECD countries such as China, India, Russia, and Brazil, among others, and applied these job intensities to outputs from the WITCH integrated assessment model under Reference and WB2C scenarios.

My results point to three main findings. First, currently the majority of fossil fuel jobs are in the coal mining and oil and gas extraction sectors. This is an important finding as it indicates that extraction sectors are where governments need to focus their efforts in order to create just transition policies.

Second, my results show that globally, the energy sector will see a net increase in jobs compared to today, if countries ramp up their NDCs to meet WB2C climate targets. Moreover, while the majority of fossil fuel jobs could be lost as these sectors decline, regionally these jobs could be offset by gains in renewable energy jobs in most regions but not all.

While the biggest job gains might happen in the Middle East and North Africa and the US, other fossil fuel exporting countries and China might lose jobs under ambitious climate policy scenarios. These jobs losses might be deeply contested politically as typically fossil fuel jobs are regionally concentrated within a country and is generally good paying jobs. For example, in Canada, oil extraction jobs are concentrated in the province of Alberta where the current Conservative government supports the continuation of the fossil fuel industry in the name of protecting jobs.

Third, there would be a large expansion of renewable manufacturing jobs that could lead to competition among countries to attract and expand solar and wind industries. This is a critical finding as current fossil fuel dependent countries with substantial fossil fuel extraction jobs who face job losses in sectors like coal mining or others could promote the domestic renewable energy equipment manufacturing sector to create a large number of domestic jobs. Countries like

India are already rolling out policies in this direction with the intention to create local jobs (Press Information Bureau, 2020). However, given the capital market conditions and low industrialization rates in many African countries and other low-income countries, it may not be easy for these countries to attract investments for promoting a renewable energy equipment manufacturing sector. In this way, climate and energy policy may become even further bound up with larger questions around development and industrialization policy at both the national and international level.

These results will further scholarly understanding of the employment-related trade-offs, challenges, and opportunities associated with low carbon transitions. However, projections of job gains and losses are based on modelled pathways that rely on assumptions about technology cost, investments, and shared socioeconomic pathways, among others. Therefore, these results help illuminate trends but do not predict exact future job numbers. Moreover, the model this analysis employs, along with other IAMs, is not able to capture and fully forecast the complex socio-political issues that shape real-world climate and energy policies, such as the development of social movements and shifting political decisions. For example, the model makes projections based on countries adopting high levels of carbon price, whose political acceptability remains low in many fossil fuel-based economies.

Scholars conducting studies on employment transition under different climate and energy policy scenarios could use my dataset and/or methodology to conduct similar assessments. For example, the influential IPCC reports that rely on modelling outputs and the research groups that extensively rely on IAMs to ask “What if” questions could utilize my dataset and create a range of scenarios for conducting similar employment assessments at a national, regional and global level. Beyond modelling jobs, my employment factors dataset can be used for spatial analysis to calculate the average number of jobs in a particular project. For example, it can be used to estimate how many people are involved in coal mining in a particular local area.

From a policy point of view, improving the scientific understanding of the extent to which total renewable jobs could offset the total employment losses from contractions in fossil fuel industries in different regions could enable strategic and long-term policy interventions for achieving ambitious climate policies. Beyond the utility of knowing the absolute number of jobs lost versus gained, the results of this Chapter will help policymakers identify which job types (for example, extraction or refining jobs) within fossil fuel industries are likely to be more impacted than others and identify which renewable energy jobs might help offset those jobs.

While this Chapter makes several contributions, it has some limitations. First, it does not focus on the quality of jobs lost in fossil fuel industries versus gained in renewable industries. Second, the dataset created in this Chapter only captures direct jobs, and not indirect and induced jobs. Lastly, the Chapter does not explain whether new renewable energy jobs can be created in areas where fossil fuel workers live and work at a spatial scale smaller than the country. These are all opportunities for future work.

Chapter 4: Assessing the feasibility of renewable jobs replacing local coal mining jobs

This Chapter builds on previous Chapter and other scholarly work that focuses on assessing renewable energy jobs as an option for fossil fuel workers. The results of Chapter 3 shows that renewable energy jobs can offset job losses in the fossil fuel industries in many regions; and some US focused studies have shown that a relatively minor investment is required for retraining fossil fuel workers in renewable jobs (Louie & Pearce, 2016; Pollin & Callaci, 2019). However, past work has not assessed the renewable energy jobs potential in 'local' fossil fuel or coal mining areas.

This is a major gap as creating local jobs for coal mining industry workers is considered crucial as coal miners do not migrate when they lose their employment (Beatty, Fothergill, & Powell, 2007; Danson, 2005; Gore & Hollywood, 2009; Hollywood, 2002). Past studies, in the academic fields of labor economics and geography, focusing on the decline of coal mining has shown that unlike other professional workers who migrate to find new jobs when they are laid off, most coal miners become 'inactive' when they lose their jobs. This is due to a strong connection to their local community, and the fact that most are older and less skilled (Beatty, Fothergill, & Powell, 2007; Danson, 2005; Gore & Hollywood, 2009; Hollywood, 2002). At the same time, research has found that some younger coal miners migrate within the region when they lose their jobs (Hollywood 2002, Danson 2005, Gore and Hollywood 2009). Thus, if renewable energy jobs are to be considered an employment option for coal miners, it is important to understand renewable energy jobs' potential in local coal mining areas. To fill this knowledge gap, in this Chapter, I asked the following research questions:

1) What is the local solar/wind capacity required in each coal mining area to enable all coal miners to transition to solar/wind jobs?

2) What percentage of coal mining areas in each country and top coal producing states/provinces are suitable for solar and/or wind power generation?

3) What is the scale of solar/wind power deployment required to transition coal miners in areas suitable for solar/wind power?

It must be noted that among renewable energy jobs, in order to scope my research, I specifically focused on solar and wind jobs because they represent the majority of renewable energy jobs currently and in the future (**See Chapter 3**). While I focus on solar and wind jobs, I fully recognize that coal miners can transition to other RE production jobs or jobs in completely different industries. In fact, one of the contributions of this Chapter is that it describes and applies a novel spatial methodology that can be used to conduct similar assessments regarding coal miner transition to other renewable energy jobs such as geothermal or bioenergy, or jobs in completely different sectors.

To answer these above questions, I collected several secondary datasets to conduct a spatially explicit resource suitability analysis for understanding whether 'local' renewable energy jobs can be created for coal miners in China, India, the US & Australia. I also investigated the local renewable energy capacity required to be built in local coal mining areas to enable all coal miners in these areas to transition to solar or wind jobs. Moreover, by using the results from the resource suitability analysis and specifically focusing on coal mining areas suitable for renewable power, I calculated the total national solar/wind capacity required to transition all coal miners living in suitable areas to solar or wind jobs.

In addition, I also conducted a regional techno-economic resource suitability analysis to assess whether there are suitable solar and wind power resources in the major coal-producing states/provinces within our case study countries. This is in line with the past research discussed above, which suggests that some younger coal miners migrate for work within their region.

In the next section (4.1) I explain the methodology. In section (4.2) I summarize our results and in final section (4.3) I discuss the implications and limitations of my study.

4.1 Methodology

In this Chapter, I focused on China, India, the US and Australia. These are the top coal-producing countries and account for over 70% of global coal production (Enerdata, 2019) **(Table 4.1).** With renewable jobs, I focus on utility-scale solar and/or wind power projects and related jobs. The jobs in these projects can be divided into manufacturing jobs, which can be located anywhere, and deployment jobs such as operations and maintenance (O&M) jobs that can be located in specific areas (e.g. coal mining areas). Deployment jobs are directly influenced by the distribution of solar or wind resources. There are also some similarities worth noting between the nature and skill requirements of solar and wind deployment jobs on the one hand and coal mining jobs on the other. Solar and wind power includes permanent (O&M) jobs (IRENA, 2018a), similar to the permanent nature of coal mining jobs (Pai and Carr-Wilson 2018). Additionally, although more country specific evidence is required, at least for the US, scholars Louie and Pearce (2016) state that all coal miners can transition to PV jobs either directly or with some retraining.

Specifically, I assessed the techno-economic resource suitability for creating utility-scale solar and/or wind power projects in coal mining areas and in top coal mining provinces/states in the four focus countries. I did this by assessing a key parameter for setting up solar and/or wind projects—availability of suitable solar and wind power resources in the area (Clifton, Hodge, Draxl, Badger, & Habte, 2017; Mahtta, Joshi, & Jindal, 2014), which is a key requirement identified for developers/companies or governments to start a solar or wind power project (Clifton et al., 2017; Mahtta et al., 2014). I also calculated the average number of coal miners working in each coal mining area by country and using country-specific employment factors, or how many workers are employed per GW of installed for solar and wind power projects, I calculated the local solar and wind capacity required to transition all coal miners living in these areas to solar or wind jobs.

Table 4.1 Coal production, reserves, miners and major coal-producing regions for China, India, US, and Australia

*Together, these countries account for 70% of global annual coal production. Within each country we also focused on the top coal-producing provinces/ states, responsible for over 85% of each country's coal production. Source: [a] (Enerdata, 2019)***;** *[b] (British Petroleum, 2018)***;** *[c] (Bureau of Labor Statistics, 2018; Minerals Council of Australia, 2018; Ministry of Coal, 2017; Song, Niu, & Xiao, 2017)***;** *[d] (Bai et al., 2018; Energy Information Administration, 2017; Maslyuk & Dharmaratna, 2013; Ministry of Coal, 2016)*

Country	**Coal production (million tonnes)[a]** (Enerdata, 2018)	**Coal reserves (million tonnes)[b]**	**Coal miners (thousands)[c]**	**Provinces/ states covered in this paper**	**% of national production covered[d]**
China	3,349	138,819	6,110	Shanxi, Inner Mongolia, Shaanxi, Anhui, Heilongjiang, Xinjiang, Shandong, Henan, Guizhou	90%
India	717	97,728	485	Chhattisgarh, Jharkhand, Orissa, Madhya Pradesh, Telangana	85%
USA	701	250,916	52	Wyoming, West Virginia, Pennsylvania, Illinois, Kentucky, Texas, Montana, Indiana, North Dakota	90%
Australia	478	144,818	50	New South Wales, Queensland, Victoria	99%

4.1.1 Possibility of creating solar and wind power plants in coal mining regions

I used Geographical Information System (GIS) tools to create four composite maps (one for each country) that include coal mine/field locations and long-term averages of solar and wind power resources. I used these maps to show (1) the percentage of total local coal mining areas in each country that are suitable for solar and/or wind power generation; and, (2) the percentage of areas in key coal-producing provinces/states suitable for solar or wind power generation.

To calculate (1), I first defined areas where coal mining is concentrated today and the surrounding areas where coal miners live. I operationalized this parameter as the radius within 50 km of a specific coal mine. For sensitivity analysis of this parameter, apart from the 50 km radius, I also conducted a similar analysis using a 20 km radius, and a similar analysis using the mine point itself. There was negligible change in results (less than 5.21% for any country) (**see Appendix B1 for more on methods and sensitivity analysis**).

Next, I calculated the average solar and/or wind power potential of this 50 km coal mining area based on measures of technical feasibility (**see section 4.1.2 below**) for solar and wind power generation. I then used resource suitability limits for solar and wind power resources to calculate the percentage of local coal mining areas within a country and province/state suitable for utility-scale solar and/or wind power generation. For calculating (2), I focused on the top coal-producing provinces/states and used the same resource suitability cut-offs for the percentage calculation.

4.1.2 Defining resource suitability

To measure the resource suitability, I used the average long-term Global Horizontal Irradiance (GHI) data for solar power generation (Clifton et al, 2017; He & Kammen, 2016; Mahtta et al.,

2014) and the average wind speed at a hub-height of 80 m for wind power generation (Archer, 2005; Archer & Jacobson, 2003; Hallgren, Gunturu, & Schlosser, 2014; Holt & Wang, 2012; McElroy, Lu, Nielsen, & Wang, 2009; Wang, Ullrich, & Millstein, 2018) in line with previous studies. For utility-scale solar and wind power plants to be feasible, the long-term average GHI must be ≥ 4 kWh/m2/day (Mahtta et al., 2014) and the long-term average wind speed must be ≥ 6.9 m/s respectively (Archer, 2005; Archer & Jacobson, 2003, 2007; Yu, Zhong, Bian, & Heilman, 2016). I used these as lower limits in this analysis.

To verify my approach, I calculated what percentage of current utility-scale solar installations in our focus countries are located in areas with average GHI values ≥ 4 kWh/m2/day and found that between 82% and 100% are located in such areas **(see Appendix B1 for more on methods)**. For wind, I do not have comparable data so I could not conduct such analysis, but many previous studies have utilized standard wind speed classes (1- 7) **(see Appendix B1 for more on methods)** and used the limit of 6.9 m/s (Class 3 wind speed) to calculate feasible wind power potential (Archer and Jacobson, 2005; Archer and Jacobson, 2003, 2007; Yu et al 2016)

4.1.3 Assessing solar/wind capacity required to transition coal miners

To estimate the local solar or wind capacity required to transition all coal miners to solar and wind jobs, I first calculated the average number of coal miners working in each coal mining area by country. Next, using this average, and the data on country-specific 'employment factors,' or how many workers are employed per GW of installed capacity (Jobs/GW) for O&M jobs for solar and wind power projects, I calculated the local solar and wind capacity (in GW) required to transition all coal miners living in these areas to solar or wind jobs. Here, I focused on O&M jobs as they are typically long-term permanent jobs similar to coal mining jobs.

Further, using the results from the local resource suitability analysis and focusing only on coal mining areas suitable for solar or wind power, I calculated the national aggregate renewable energy capacity required to transition all coal miners just in those suitable areas to local solar or wind jobs. I then compared this required national capacity to current deployment of solar and wind in all four countries (IRENA, 2019).

4.1.4 Data collection

For solar power potential, I utilized the latest GHI data—from the Global Solar Atlas, owned by the World Bank Group (2016) and provided by Solargis—to create the maps that provide average GHI value for the period from "1994, 1999, or 2007 (depending on the geographical region) to 2015". For wind potential, we used Vaisala's Global Wind datasets for 5km onshore wind speed at 80 m hub-height that provide average wind speed calculated over a 10 year period (IRENA, 2018c).

I used shapefiles for coal mine locations from country-specific sources: for China, I used the US Geological Survey (USGS) dataset (Trippi, Belkin, Dai, Tewalt, & Chou, 2014); for the US, I used the US Energy Information Administration (2018) dataset; for Australia, I used the Geoscience Australia's (2015) dataset. For India, since coal mine datasets was not available, I used the USGS's coalfields dataset (Trippi & Tewalt, 2011) and highlighted the key coalfields where large-scale coal mining is currently happening. I conducted the analysis using the coalfields dataset and operationalized the 50 km radius concept for India. This did not affect our results (**see Appendix B1 for more on methods**).

I also collected the latest country-specific employment factors (Jobs/GW) data to calculate the required solar or wind capacity locally and nationally **(Table 4.2)**. I collected this employment factors data from academic literature, consultancy reports, and reports by international organisations. However, the solar power employment factors for China and the US were not available. I calculated the employment factors for these countries by collecting the actual O&M jobs data from IRENA (2018) and the US Solar foundation (2018) respectively, and then dividing it by total capacity for the same year (IRENA, 2019a).

Table 4.2 Employment factors for solar and wind technologies in different countries
Employment factors below refers to operations and maintenance jobs per GW installed capacity of solar or wind power. Source: [a] *(Cai, Wang, Chen, & Wang, 2011; IRENA, 2018b; Kuldeep, Koti, Dutt, Bishnoi, & Dalal, 2019; The Solar Foundation, 2020),* [b] *(Cai et al., 2011; Clean Energy Council, 2014; Kuldeep et al., 2019; Wei et al., 2010)*

Countries	**Solar employment factors (Jobs/GWe)**[a]	**Wind employment factors (Jobs/GWe)**[b]
China	497	378
India	500	500
USA	225	400
Australia	130	100

4.2 Results

4.2.1 Majority of China's coal mining areas have limited suitability for solar power but even less for wind

China, the world's biggest coal-producer accounts for 45% of the global coal production (Enerdata, 2019) employing 6 million coal miners (Song et al., 2017). The coal production in China is concentrated in nine key coal-producing provinces (**Table 4.1**).

In China 5.73 GWe of solar capacity would need to be installed in each coal mining area to transition all coal miners in these areas to solar jobs. However, my GIS analysis shows that only

29% of the coal mining areas in China are suitable for solar power generation, with heterogeneity between provinces ranging from 88% in Inner Mongolia to no suitable areas in some provinces (**Table 4.3**). For about 1.8 million coal miners working in the coal mining areas that are suitable for solar power, an additional 3565 GWe of capacity would need to be deployed, roughly twenty times the current 175 GWe capacity

In terms of wind power, 7.54 GWe wind capacity would need to be installed in each coal mining area to transition coal miners to wind jobs. However, my analysis shows that only 5% of coal mining areas in the country are suitable for wind power generation with Inner Mongolia having 32% of its coal mining areas suitable for wind and all other key coal provinces less than 5% (**Figure 4.1).** For 0.3 million coal miners who work in coal mines in areas that are suitable for wind power, the national capacity required is 808 GWe**.** This is roughly four times the current national wind capacity of 180 GWe. I find that only 5% of the coal mining areas are suitable for both solar and wind power, mainly in Inner Mongolia.

At the provincial level, I find that suitability for solar power generation ranges from 70% of provincial areas to less than 10%. My analysis for wind power shows that less than 30% of the land area in all provinces is suitable for wind power (**Table 4.3**).

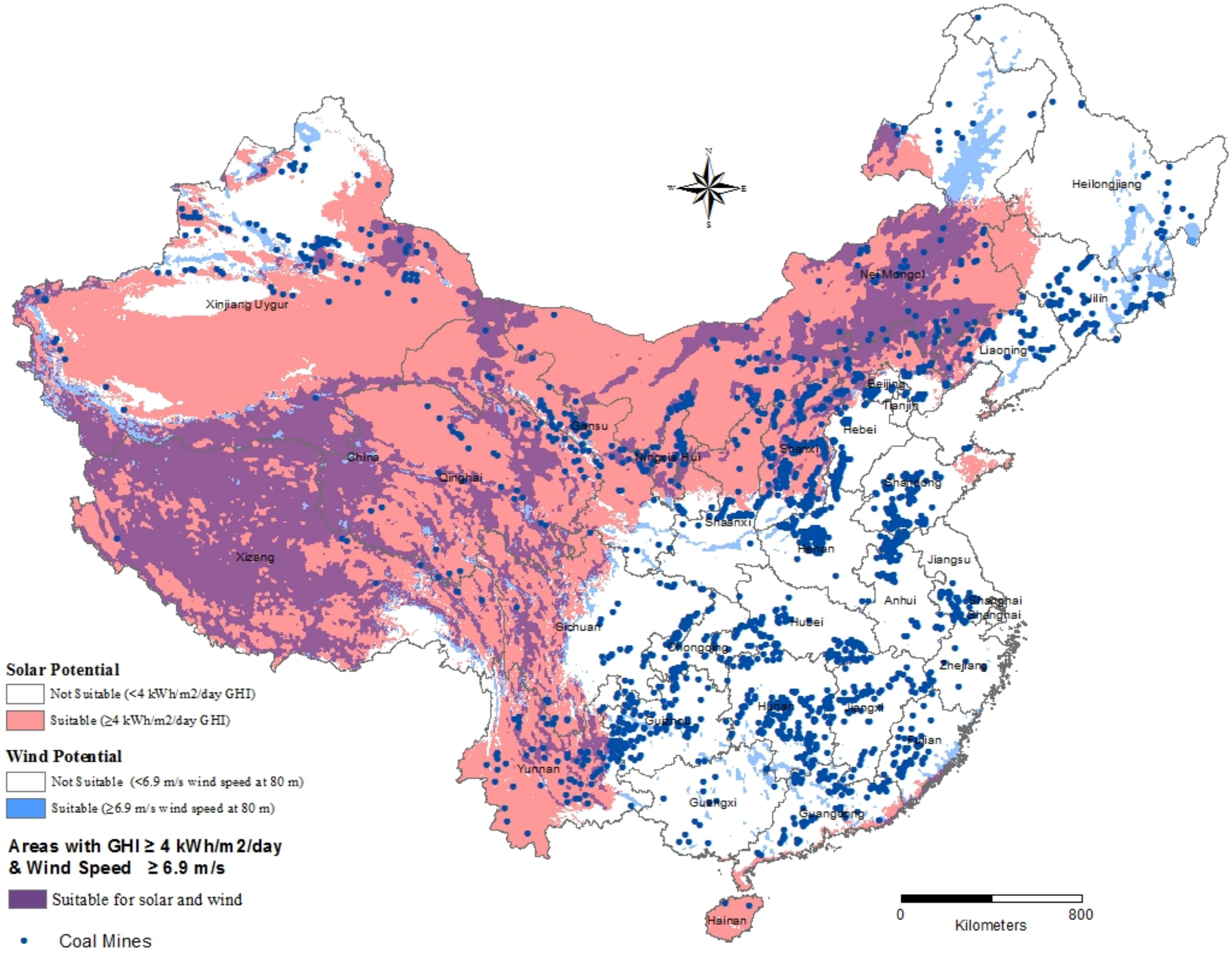

Figure 4.1 Solar and/or wind potential, and coal mines in China
The coal mining areas with average GHI value greater than or equal to 4 kWh/m2/day (Mahtta et al., 2014) and wind speed at 80 m greater than or equal to 6.9 m/s (Archer & Jacobson, 2003, 2007; Yu et al., 2016) are considered suitable for solar and wind power generation respectively. The blue points represent locations of coal mines. The map shows areas suitable for only solar power, only wind power, and both for solar and wind power. Large number of coal mines in Eastern and South-Central China are located in places not suitable for either solar and/or wind power.

Table 4.3 Percentage of coal mining areas, and percentage of areas within provinces/states suitable for solar or wind power generation

Coal mining areas here means an area with a 50 km radius around the point location of a coal mine. For suitable solar and wind power, average GHI value should be greater than or equal to 4 kWh/m2/day (Mahtta et al., 2014) and wind speed at 80 m should be greater than or equal to 6.9 m/s (Archer & Jacobson, 2003, 2007; Yu et al., 2016) respectively. The first three columns show the percentage of total coal mining areas suitable for solar and/or wind. The last two columns show the percentage of total areas within the province/state suitable for solar or wind power.

	Percentage of coal mining areas suitable for…			**Percentage of major coal-producing province/state areas suitable for…**	
	solar power	wind power	solar **and** wind power	solar power	wind power
China	**29%**	**5%**	**5%**	**N/A**	**N/A**
Shanxi	87%	1%	1%	81%	17%
Inner Mongolia	88%	32%	31%	78%	28%
Shaanxi	18%	0%	0%	38%	4%
Anhui	0%	0%	0%	0%	0%
Heilongjiang	0%	5%	0%	2%	5%
Xinjiang	58%	5%	5%	70%	18%
Shandong	0%	0%	0%	9%	0%
Henan	0%	0%	0%	0%	1%

Guizhou	0%	0%	0%	1%	3%
India	**99%**	**1%**	**1%**	**N/A**	**N/A**
Chhattisgarh	100%	0%	0%	100%	0%
Jharkhand	100%	0%	0%	100%	0%
Orissa	100%	0%	0%	100%	0%
Madhya Pradesh	100%	0%	0%	100%	0%
Telangana	100%	0%	0%	100%	0%
USA	**62%**	**7%**	**2%**	**N/A**	**N/A**
Wyoming	100%	69%	69%	98%	47%
West Virginia	60%	2%	0%	41%	13%
Pennsylvania	0%	14%	0%	15%	8%
Illinois	100%	0%	0%	87%	1%
Kentucky	100%	0%	0%	100%	0%
Texas	100%	0%	0%	100%	34%
Montana	83%	0%	0%	66%	24%
Indiana	100%	0%	0%	80%	1%
North Dakota	0%	100%	0%	12%	86%
Australia		**4%**	**2%**		

	96%			**N/A**	**N/A**
New South Wales	100%	0%	0%	100%	4%
Queensland	100%	0%	0%	100%	2%
Victoria	40%	40%	40%	89%	17%

Table 4.4 Solar capacity required to transition all coal miners working in mines suitable for solar power to solar jobs

The table shows that except for the US, each coal mining area would require several GWs of solar power capacity locally to enable all coal miners in these areas to transition to solar jobs. Source: [a] (IRENA, 2019a)

Countries	**Average coal mining jobs per mine**	**Number of mines suitable for solar power**	**Number of workers in mines suitable for solar power**	**Local solar capacity required in each coal mining area to replace coal mining jobs (GWe)**	**National solar capacity required to replace coal mining jobs in suitable solar areas (GWe)**	**Current solar installed capacity (2018) (GWe)** [a]
China	2852	621	1771387	5.73	3565	175
India	984	488	480081	1.96	960	27
USA	73	440	32225	0.32	143	50
Australia	435	110	47826	3.34	369	10

Table 4.5 Wind capacity required to transition all coal miners working in mines suitable for wind power to wind jobs

The table shows that except for the US, each coal mining area would require several GWs of wind power capacity locally to enable all coal miners in these areas to transition to wind jobs. Source: [a] *(IRENA, 2019a).*

	Average coal mining jobs per mine	**Number of mines suitable for wind power**	**Number of workers in mines suitable for wind power**	**Local wind capacity required in each coal mining area to replace coal mining jobs (GWe)**	**National wind capacity required to replace coal mining jobs in suitable wind areas (GWe)**	**Current wind installed capacity (2018) (GWe)** [a]
China	2852	107	305500	7.54	808	180
India	984	5	4850	1.96	10	35
USA	73	50	3640	0.18	9	94
Australia	435	5	2000	4.35	20	6

4.2.2 Nearly all coal mining areas in India are suitable for solar power but not for wind power

In India, nearly 0.5 million coal miners (Ministry of Coal, 2020b) produce over 700 MT of coal annually (Enerdata, 2019). Coal production in India is concentrated in five key states (**Table 4.1**).

In India, 1.96 GWe of solar power capacity would need to be installed in each local coal mining area to transition all coal miners to local solar jobs. My analysis shows that in India, nearly all the local coal mining areas are suitable for solar power generation including in the key coal-producing states (**Table 4.1)**. For about 0.5 million coal miners working in these coal mining areas suitable for solar power, India would require an additional 960 GWe of capacity.

This would mean increasing the current capacity by nearly 37 times (from today’s capacity of 27 GWe). To replace local coal mining jobs with wind jobs, India would need to install 1.96 GWe of wind power capacity in each coal mining area. However, I find that almost no coal mining areas in India and its key coal-producing states are suitable for wind power generation. For the small number of coal miners working in these coal mining areas suitable for wind power (4850) to transition to local wind jobs, the cumulative national capacity required is 10 GWe.

Figure 4.2 shows solar and/or wind power potential in India along with locations of coalfields, particularly highlighting the coalfields in the key coal-producing Indian states.

Furthermore, there are negligible (less than 1%) coal mining areas that are suitable for both solar and wind.

At the regional level, all key coal-producting states are suitable for solar power generation, however, no areas in the key coal-producing states are suitable for wind-power generation.

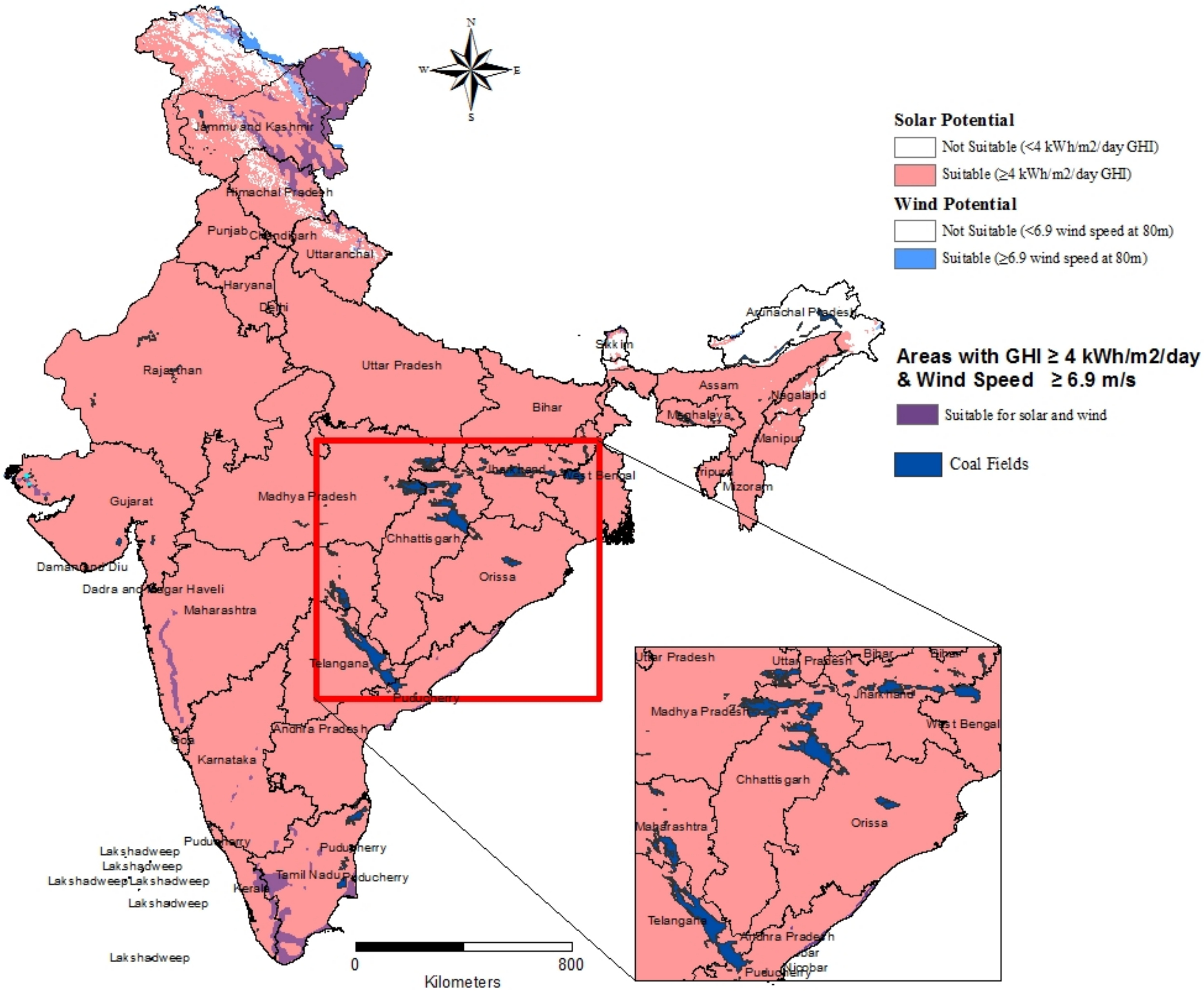

Figure 4.2 Solar and/or wind potential, and coalfields in India

*The coal mining areas with average GHI value greater than or equal to 4 kWh/m2/day ((*Mahtta et al., 2014)*) and wind speed at 80 m greater than or equal to 6.9 m/s are considered suitable for solar and wind power generation (Archer & Jacobson, 2003, 2007; Yu et al., 2016) respectively. The blue points represent locations of coalfields in India. The map shows areas suitable for only solar power, only wind power, and both solar and wind power. The map shows nearly all coalfields (including all key coalfields in Eastern and Central parts) in India are located in areas suitable for solar power generation. On the other hand, all major coalfields in Eastern and Central India are located in areas not suitable for wind power generation.*

4.2.3 Majority of coal mining areas in the US are suitable for solar power but not for wind power

The US boasts similar coal production to India and employs 52,000 coal miners (Bureau of Labor Statistics, 2018). Coal production is concentrated in nine states (**Table 1.1**) (**Figure 4.3**). Overall, in the US, 0.32 GWe of solar capacity would need to be installed in each coal mining area to transition all coal miners in those areas to solar jobs. My analysis shows that around 62% of the local coal mining areas in the US are suitable for solar power generation – in some states over 80% of coal mining areas are suitable for solar power and in others no coal mining areas are suitable for solar power generation **(Table 4.3)**. For the 32,000 mine workers who work in coal mining areas suitable for solar power to get local solar jobs, the US would require 143 GWe of cumulative capacity, roughly three times the current national solar capacity **(**
Table 4.4).

In terms of wind power, 0.18 GWe of wind capacity would need to be installed in each coal mining area to transition all coal miners to wind jobs. However, only 7% of coal mining areas in the US are suitable for wind power generation. The suitable areas for wind power generation are concentrated in North Dakota where all the coal-mining areas are suitable for wind power and in Wyoming where 70% of coal mining areas have wind power suitability **(Table 4.3)**.

Transitioning the small number of coal miners (3600) who work in areas suitable for wind power to local wind jobs would require increasing the national wind power capacity by 9 GWe**.**

Moreover, I find that less than 2% of the coal mining areas in the US are suitable for both solar and wind power mostly concentrated in Wyoming.

At the state level, there is heterogeneity between states in terms of solar power suitability – ranging from over 80% in Wyoming, Texas, Illinois, Indiana, and Kentucky to less than 15% in

Pennsylvania and North Dakota. In terms of state-wide wind suitability, North Dakota has large areas (86%) suitable for wind power generation and the rest of the states are under 50%.

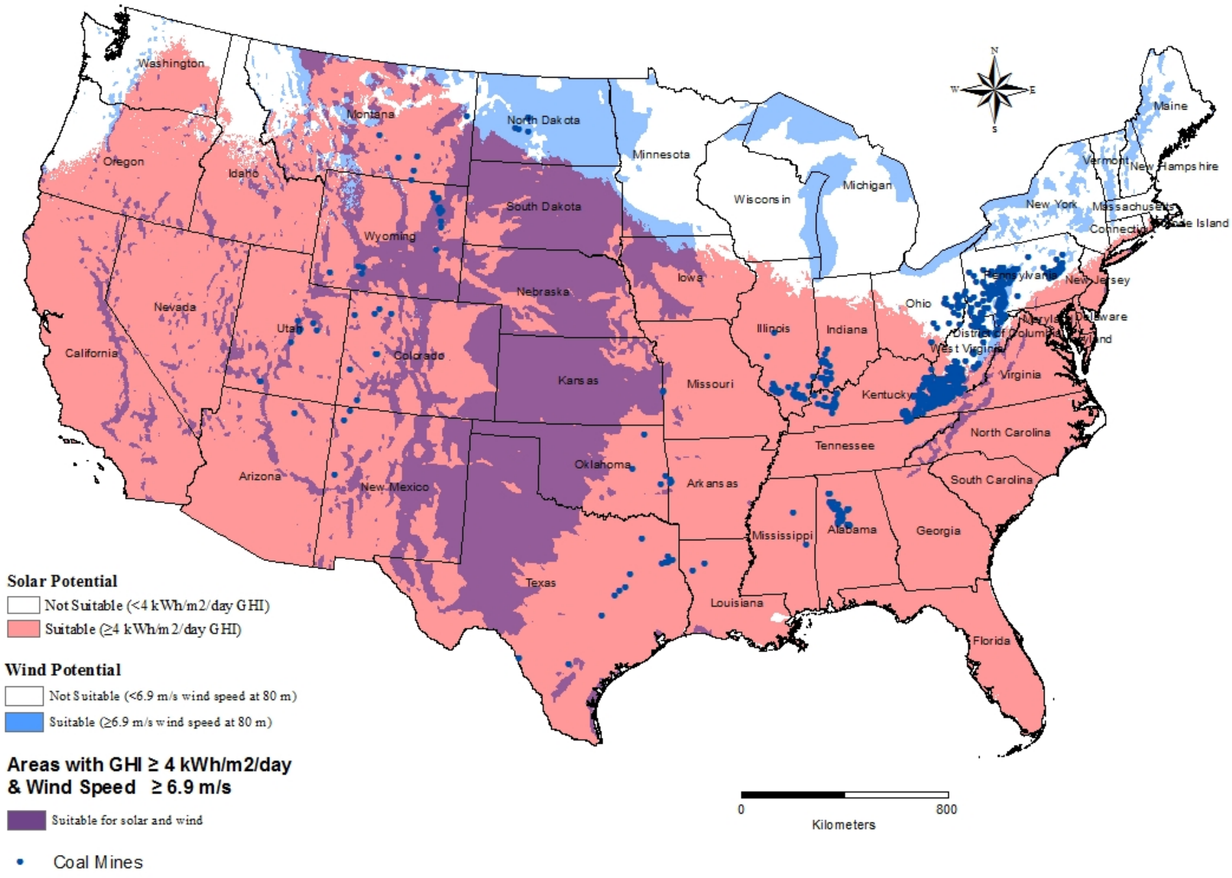

Figure 4.3 Solar and/or wind potential, and coal mines in the US

The coal mining areas with average GHI value greater than or equal to 4 kWh/m2/day (Mahtta et al., 2014) and wind speed at 80 m greater than or equal to 6.9 m/s are considered suitable for solar and wind power generation (Archer & Jacobson, 2003, 2007; Yu et al., 2016) respectively. The blue points represent locations for coal mines. The map shows areas suitable for only solar power, only wind power, and both for solar and wind power. Except coal mines in parts of the Eastern US and North Dakota, most other coal mines are located in suitable solar power generation areas. The majority of coal mines in the US are located in places not suitable for wind power generation. Wyoming State is the only state with several coal mines located in areas suitable for both solar and wind power generation.

4.2.4 Nearly all coal mining areas in Australia are suitable for solar power but not for wind power

Australia produces close to 500 MT of coal annually and employs 50,000 miners (Enerdata, 2018; Minerals Council of Australia, 2018). Coal production is concentrated in three states **(Table 4.1).**

In Australia, 3.34 GWe of solar capacity would need to be installed in each coal mining area to transition its coal miners to solar jobs. Here, I find that close to 96% of the coal mining areas are suitable for solar power generation. All coal mining areas in NSW and Queensland, and 40% in Victoria are suitable for solar power generation **(Table 4.3)**. For transitioning coal miners working in these suitable coal mining areas, Australia would require 369 GWe of national capacity, roughly 37 times the current 10 GWe capacity**.**

In terms of wind, 4.35 GWe wind capacity would need to be installed in each coal mining area to transition its coal miners to wind jobs. However, only 4% of coal mining areas in Australia are suitable for wind power generation – none in Queensland and NSW and just 40% in Victoria. For the 2000 coal miners who work in coal mining areas suitable for wind power to transition to wind jobs locally, the cumulative capacity required is 20 GWe.

Overall, my analysis shows that only 2% of coal mining areas in Australia are suitable for both solar and wind power**.**

At the state level, all of NSW and Queensland and the majority of Victoria (89%) is suitable for solar power generation. In terms of wind power, less than 4% of the area in all three states is suitable for wind power generation.

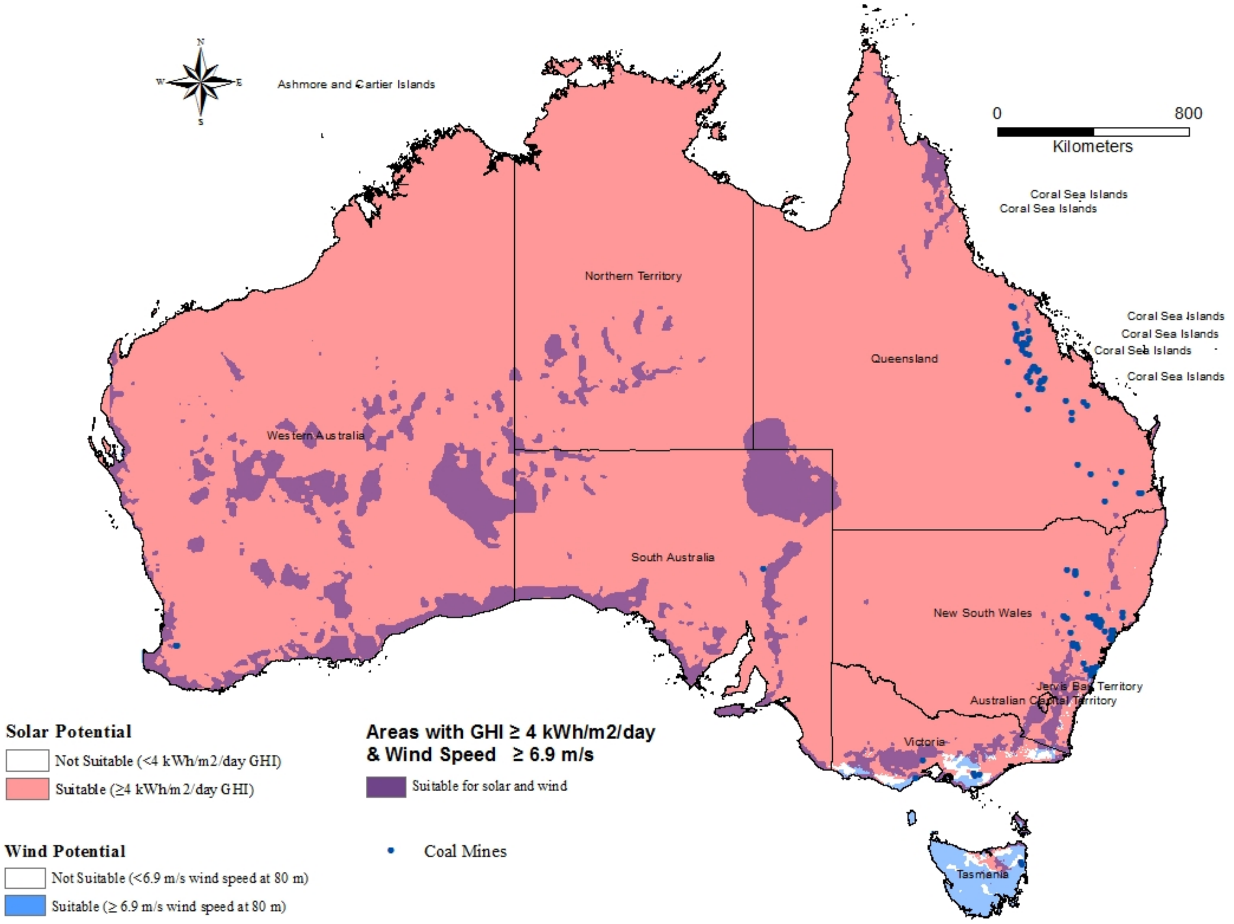

Figure 4.4 Solar and/or wind potential, and coal mines in Australia

The coal mining areas with average GHI value greater than or equal to 4 kWh/m2/day (Mahtta et al., 2014) and wind speed at 80 m greater than or equal to 6.9 m/s are considered suitable for solar and wind power generation (Archer & Jacobson, 2003, 2007; Yu et al., 2016) respectively. The blue points represent locations of coal mines. The map shows areas suitable for only solar power, only wind power, and both for solar and wind power. Except for some mines in Tasmania and in Victoria, all other coal mines are located in suitable solar resource potential areas. On the other hand, coal mines in Queensland and NSW are located in places not suitable for wind power generation. In the whole country, only two coal mines in Victoria are located in areas suitable both solar and wind power.

4.3 Discussion & conclusion

Prior studies on job options for coal miners have either focused on issues like retraining (Louie & Pearce, 2016; Pollin & Callaci, 2018) or comparing the number of fossil fuel or coal jobs with projections for future RE jobs. While these studies make important contributions to the literature, they do not explore whether RE jobs can be created locally for coal miners. This is an important question since past studies have shown that out-of-work coal miners typically do not migrate for work.

Based on this historical understanding, I focused on evaluating the local solar and wind capacity required in each coal mining area to enable all coal miners to transition to solar or wind jobs, and assessed the techno-economic resource suitability of creating local solar and/or wind power projects (and their related jobs) in key coal-producing countries. I also assessed the scale of renewable energy deployment required to help coal miners' transition to local solar or wind jobs.

My results also show that except for the US, each coal mining area would require several GWs of solar or wind power capacity locally to enable all coal miners in these areas to transition to solar or wind jobs. Furthermore, my GIS analysis shows that deploying solar and wind power may not be techno-economically feasible in all coal mining areas due to low suitability of the resource. From my analysis it is clear that while solar has greater techno-economic resource suitability than wind for replacing local coal mining jobs, this suitability doesn't exist in all coal mining areas. In China, only 29% of the coal mining areas have suitable solar power resources. However, in India and Australia nearly all coal mining areas are suitable for solar power, while around 62% of the coal mining areas in the US are suitable for solar power. Moreover, the wind power suitability in coal mining areas is low in all four countries at less than 7% of coal mining areas having suitable resources. Additionally, less than 5% of coal mining areas are suitable for both solar and wind power generation. Even at the provincial/state level, my analysis shows that solar has more resource potential than wind to replace coal mining jobs.

Yet, even for solar, countries would need to substantially increase their current installed solar capacity (from 3 times in the US to 37 times in India), to transition only those coal miners who live in suitable solar areas to solar jobs. The scale of deployment of renewable energy required raises serious questions about the viability of a transition path that depends solely on local renewable energy jobs for coal miners. This is true at both the local level where several GWe of installed capacity would be required per coal mining area and in aggregate where several times national capacity would be required just for absorbing mining jobs in areas suitable for renewable energy deployment. Such large-scale installations in local coal mining areas may not be easy even in those local coal mining areas that are suitable for solar or wind power as they may not be the places where it makes most economic sense for installing solar or wind power plants. Politically, it might be difficult for local mining areas to attract solar and wind industries, as some local politicians and their allies may support the continuation of the coal sector and oppose renewable development. For example, in India, some local politicians and their allies financially benefit from coal mining contracts (Chandra, 2018) and thus are likely to continue to support the coal industry. This means, in practical terms, not all coal miners may be able to transition to solar or wind jobs locally even in areas with suitable resources.

Policy makers, other stakeholders, and analysts concerned about transitioning coal mining workers should, therefore, consider expanding the scope of their options beyond renewable energy jobs. Policy interventions considering employment in other sectors could build on the methodology developed in this paper to assess the suitability of other industries such as tourism.

By conducting this spatial analysis, this Chapter makes a significant conceptual contribution to the emerging just transitions literature focusing on fossil fuel workers' livelihood issues. Since spatial analysis is considered a “blind-spot” in energy transitions studies (Bridge, Bouzarovski, Bradshaw, & Eyre, 2013; Coenen, Benneworth, & Truffer, 2012), this Chapter also contributes methodologically by explicitly considering the spatial distribution of coal production vs solar/wind potential.

While, this Chapter contributes conceptually and methodologically to thinking about employment transitions in a spatial sense, it has a few limitations that are avenues for future work on this topic. First, I did not conduct a skills transferability analysis between coal mining jobs and renewable energy jobs, which are an opportunity for further research. Second, I did not account for detailed local land-use planning and policy assessments, which would influence the distribution of solar or wind power projects in each of these coal mining areas. Third, I also did not calculate the number of declining coal mining jobs vs number of potential solar/wind jobs in different coal mining areas, given that job intensity in each coal mining area will vary due to factors such as labor and capital productivity, therefore, such analysis is best suitable for a few selected coal mining areas. Future research can use my results to select specific coal mining areas suitable for solar or wind power to conduct more detailed local analyses.

If the world is serious about meeting the global climate targets, it is indispensable that politically powerful coal mining interests do not block coal phase-outs. One innovative way would be to provide coal miners with alternate jobs. Overall, my findings provide policymakers, industry and non-profit organizations who are already invested in retraining coal miners for solar and wind jobs insight on where to target their efforts. However, I also show that while solar jobs could be the answer in some coal mining areas, policymakers would need to focus on a variety of industries including both renewables and non-renewables to help coal miners make an employment transition locally.

Chapter 5: Assessing the socio-economic dependency on coal at a local level in India

Chapter 2 concludes that just transitions research is primarily focused on OECD countries and recommends that future just transition work needs to expand its geographic scope and focus on emerging coal dependent economies. This chapter seeks to implement that recommendation by examining just transition within the context of one of the major coal producing and consuming country outside the OECD, namely India.

In India, work on coal transitions has largely focused on techno-economic analyses (Malik et al., 2020; Shrimali, 2020; Tongia et al., 2020). These technology-focused studies typically analyze least cost or cost-effective ways to achieve coal transitions and are largely centered around proposals to shut down a few inefficient coal-fired power plants as they are either older or expensive (Fernandes & Sharma, 2020; Shrimali, 2020). While these analyses show that shutting down these coal-fired power plants can lead to cost savings in terms of electricity costs, they do not examine the socio-economic impacts or just transition implications of coal power plant closures on coal workers, their communities, and the region.

During the last five decades, the Indian federal government and some state governments have expanded coal mining and power development through government-owned enterprises, in order to meet growing energy needs and achieve social and economic development (Chandra, 2018; Pai & Carr-Wilson, 2018). This has meant that certain regions in India with coal mining or coal power plants now depend on the jobs, local government revenues, and social spending that coal companies provide (Chandra, 2018; Pai & Carr-Wilson, 2018; Tongia et al., 2020).

While some studies on the Indian coal sector briefly mention the number of direct jobs and federal government revenues the coal sector contributes at a national scale (Athawale, Joshi, & Bharvirkar, 2019; Tongia et al., 2020), no study has focused on and quantified the scale of socio-economic dependence on coal at the regional or district level. Each Indian state is divided into several districts, which vary in geographic size and total population. This type of district-level analysis is important because the degree to which and way in which each district is dependent on coal may vary due to differences in coal production, power plant capacity and other reasons.

Understanding the spatial variance of socio-economic dependence on coal is a key first step to creating just transition plans for such areas (Bridge, Bouzarovski, Bradshaw, & Eyre, 2013; Coenen, Benneworth, & Truffer, 2012; Snyder, 2018).

A key reason that this district level analysis has not been performed in India is the lack of publicly available datasets (Rai, Tongia, Shrimali, & Abhyankar, 2017). For example, to quantify district level socio-economic dependency on coal mining, the first crucial data requirement is to identify the locations of coal mines and their current production for different districts in India. However, even this basic dataset was not available. In comparison, government agencies in OECD countries such as the US make such geospatial coal mining datasets publicly available (U.S. Energy Information Administration, 2018). Scholars have acknowledged the fact that energy research in India faces this data availability problem: “Lack of robust datasets has been a stumbling block for serious research and analysis on energy in India, evidenced, for instance, by limited data-driven analysis in top journals” (Rai et al., 2017).

In this Chapter, I conduct the first just transition research on India focused on district level metrics and fill several data gaps. I do this by asking the following research questions:

1) How can Indian districts' socio-economic dependency on coal be characterized and quantified?

2) How does socio-economic dependency on coal vary across districts?

To answer these research questions, I first analyzed the primary and secondary literature to conceptualize how Indian districts are dependent on coal for its social and economic needs. I then collected several novel datasets to quantify district-level socio-economic indicators of coal dependency. I then conducted an analysis to identify key coal dependent districts and capture variations among these key coal dependent districts in terms of which indicator they are highly dependent on.

In the next section (5.2), I explain the structure of the Indian coal sector and its socio-economic inputs to the Indian economy and conceptualize coal dependency in India. In section (5.3), I define the scope of this study and explain the methodology for conducting district level assessment. In section (5.4) I discuss the results. In section (5.5), I discuss these results in the context of existing literature and explain the policy implications and limitations of this study.

5.1 India's coal landscape

This section describes the structure of the Indian coal sector and its socio-economic inputs to the Indian economy. The description below is drawn from the latest annual reports of the Federal coal ministry (Ministry of Coal, 2020b) and leading government-owned coal companies Coal India Limited (CIL) (Coal India Limited, 2020) and NTPC Ltd (NTPC, 2020), and past literature on this topic (Chandra, 2018; Fernandes & Sharma, 2020; Kamboj & Tongia, 2018; Lahiri-Dutt, 2014; Pai & Carr-Wilson, 2018; Tongia et al., 2020). I also consulted with two CIL officials and two NTPC officials, as well as one Indian Revenue Service (IRS) official[1].

India's coal sector is dominated by multiple federal government and state government-owned enterprises that are involved in both coal mining and coal power generation. Indian Railways, another federal-government owned entity, transports nearly 60% of produced coal (Kamboj & Tongia, 2018). Below, I discuss the structure of the Indian coal mining and power sectors in further detail and describe their overall socio-economic contributions. The conceptualization of coal's socio-economic contribution at the district level (which is the focus of this Chapter) emerges from this description (**See 5.2.1**).

5.1.1 Socio-economic contribution of the coal mining sector at the national level

In 2018-2019, CIL, Singareni Collieries Company Limited (SCCL), and Neyveli Lignite Corporation (NLC), the three largest government-owned coal mining companies, produced 93% of the total coal produced in India (Ministry of Coal, 2020b). The federal government owned CIL, the largest coal mining company in India (and the world), alone produced around 610 Million Tonnes (MT) (81%) of the total 765 MT coal produced in the country. CIL operates through its eight fully-owned subsidiaries and its operations are spread over 9 Indian states, concentrated in eastern and central India (Coal India Limited, 2020). After CIL, SCCL is the second most prominent government-owned coal mining company. SCCL is a joint venture between the federal government and the state government of Telangana in southern India. It produces coal exclusively in the state of Telangana. The third most prominent company is NLC,

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[1] I have also drawn on my decade-long experience researching the coal industry in India, visiting numerous coal mines and power plants and interacting with coal industry officials.

which produces coal in Tamil Nadu and Rajasthan (NLC, 2020). The remaining 7% of the total coal was produced by a small number of other government owned companies and private coal companies (Ministry of Coal, 2020b).

All coal mining companies pay taxes and royalties to the federal government as outlined in (**Figure 5.1)**. Regionally, in at least nine Indian states, the coal mining industry pays considerable taxes and royalties to state and district governments (Chandra, 2018; Pai & Carr-Wilson, 2018). For example, in 2019 alone CIL paid approximately Rs 50,000 crores (approx. 7 billion US$) (Coal India Limited, 2020) in total taxes and royalties to federal, state and district governments. For comparison, this is nearly 3% of total federal governments' revenue collection or the total yearly budget allocation for Mahatma Gandhi National Rural Employment Guarantee Scheme (India's largest social security scheme), which guarantees 100 days of work to all rural households (Ministry of Rural Development, 2020). Royalties paid at the district level are direct contributions to the district mineral funds (DMF), which are funds that district governments use to pay for local projects focused on improving health outcomes, education, and enhancing rural development.

In addition to contributions in the form of taxes and royalties, government-owned coal mining companies carry out social spending in coal regions by building houses for their employees, funding local infrastructure projects, and constructing and running schools and hospitals (Chandra, 2018; Pai & Carr-Wilson, 2018). Much of this is done through federal government mandated Corporate Social Responsibility (CSR) spending and discretionary welfare funds. For CSR, federal legislation governing Indian companies requires all companies to spend 2% of their net profits on local development projects in areas where they operate (Ministry of Corporate

Affairs, 2020). In addition to CSR spending, companies such as CIL also spend additional discretionary money on employee welfare by providing employees and their families with free housing and medical services (Coal India Limited, 2020). For example, CIL provides free medical services to its employees, their families, and others living in coal bearing areas (Chandra, 2018) through "69 fully equipped hospitals with 4366 beds, 361 dispensaries, 542 ambulances and 1070 doctors including specialists" (Coal India Limited, 2020).

The coal mining sector also provides direct, indirect, and induced jobs. For the most part, overall job numbers are poorly quantified in the existing literature. Some specific direct job numbers are available for CIL. According to CIL's most recent annual report, CIL directly employs 270,000 people (Coal India Limited, 2020). The number of indirect jobs (such as people working for contractors who repair coal mining equipment) and induced jobs (involving people working in local retail industries in coal towns such as in tea shops or grocery stores) is not quantified, although these jobs are common in all coal producing regions (Chandra, 2018; Pai & Carr-Wilson, 2018). There is also a large, unquantified informal sector. In most coal bearing states in India, local villagers extract or scavenge coal to use it as domestic fuel, or sell it at the market to others for domestic or industrial use. These individuals are referred to as informal workers (or sometimes, "illegal" workers) and are prevalent in coal-bearing areas (Lahiri-Dutt, 2014). One scholar estimates that although informal workers produce a fraction of the total coal in India per year (an estimated 15 MT), the informal sector generates a larger number of jobs than total employment in the formal coal mining industry (Lahiri-Dutt, 2014).

In addition, there are nearly half a million coal mining industry pensioners in India, whose pensions depend on the continuation of the coal mining industry. The coal mining industry pension fund is run by Coal Mines Provident Fund Organization (CMPFO, 2020), a government organization that collects equal contributions from coal mining companies and workers, then pays pensions to coal mine workers after their retirement. In practise, the money from existing workers and coal companies is paid out to current retired workers, meaning any coal contraction will have consequences for coal industry pensioners (CMPFO, 2020).

The Indian railway sector is also heavily dependent on coal transport, which contributes nearly 50% of its total freight revenues (Kamboj & Tongia, 2018). Indian Railway's business model is based on overcharging coal mining companies for freight then subsidizing passenger fares. Subsidizing passenger tariffs for railway transport is a politically salient issue, as Indian Railways sees over 8 billion passenger trips each year (Kamboj & Tongia, 2018).

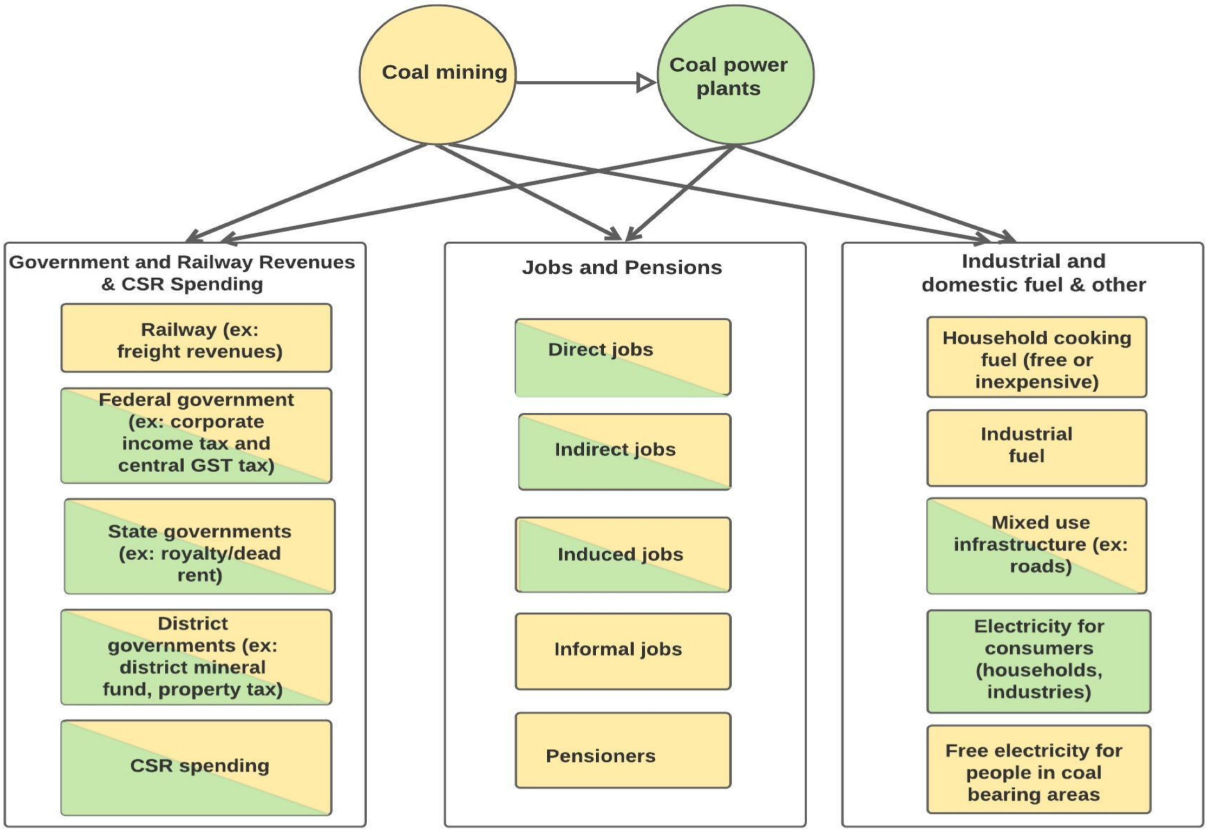


Figure 5.1 Coal sector socio-economic contribution

The coal mining and coal power sectors contribute direct revenues to all levels of government and railways. The coal sector also engages in CSR spending and provides jobs and pensions to people. Coal is also a source of cheap (or in some cases free) fuel for households and industry and is a source of other benefits. The colour yellow, below, indicates coal mining's socio-economic contribution; green indicates coal power plants' socio-economic contribution; and half green, half yellow indicates contributions made by both coal mining and coal power plants.

5.1.2 Socio-economic contribution of the coal power sector at the national level

Nearly 55% of India's coal-fired power plants are owned and operated by federal government companies such as NTPC Ltd (NTPC, 2020) or state government owned companies (CEA, 2020). Making up the remaining 45%, private companies play a larger role in the coal power generation sector as compared to coal mining.

In terms of socio-economic contribution, the coal power sector contributes to federal, state and district-level taxes and spends on CSR in local areas (**Figure 5.1**). However, this sector does not contribute to the DMF directly, although companies pay other district taxes. Similar to the coal mining industry, the numbers of direct, indirect and induced jobs in the coal power industry are not quantified.

5.2 Methodology

For this study, I collected six novel datasets in order to quantify four key socio-economic indicators of coal dependency at the district level. I then conducted an analysis to identify top coal dependent districts in India.

Here, I first describe the different categories of coal dependence at a district level based on the analysis in **section 5.1** and define the scope of the paper. Next, I describe the indicators used in this study, describe the data collection process, and describe the methodology used for analysis.

5.2.1 District level socio-economic dependency & study scope

Coal companies' socio-economic contributions at a district level can be grouped into four categories: jobs and pensions (people related); 2) district revenues (local government related); 3) welfare spending (community welfare related); and 4) industrial and domestic fuel and other (**Figure 5.2**). In this study, I focus on categories 1-3. I do not focus on the fourth category as many types of activity in this category are context-specific, irregular, ad-hoc, and informal. For example, coal companies sometimes provide free electricity to people living in coal bearing areas as an informal way to build their 'social contract' with local communities (Chandra, 2018). While important, quantifying category 4 indicators will require tailored, local-level analyses using methods such as surveys, which is beyond the scope of this Chapter.

Within categories 1-3, I quantify four key socio-economic indicators at the district level: the number of jobs in the coal mining and coal power sector (direct and indirect), the number of coal industry pensioners, total yearly DMF contributions, and total yearly CSR spending. I was not able to quantify induced or informal jobs, other district level rents and taxes, or discretionary welfare funds due to lack of available and reliable data. This is a limitation of this Chapter as including data on these indicators might influence the overall results. For example, some districts may have a large number of informal jobs or collect significant district taxes and rents.

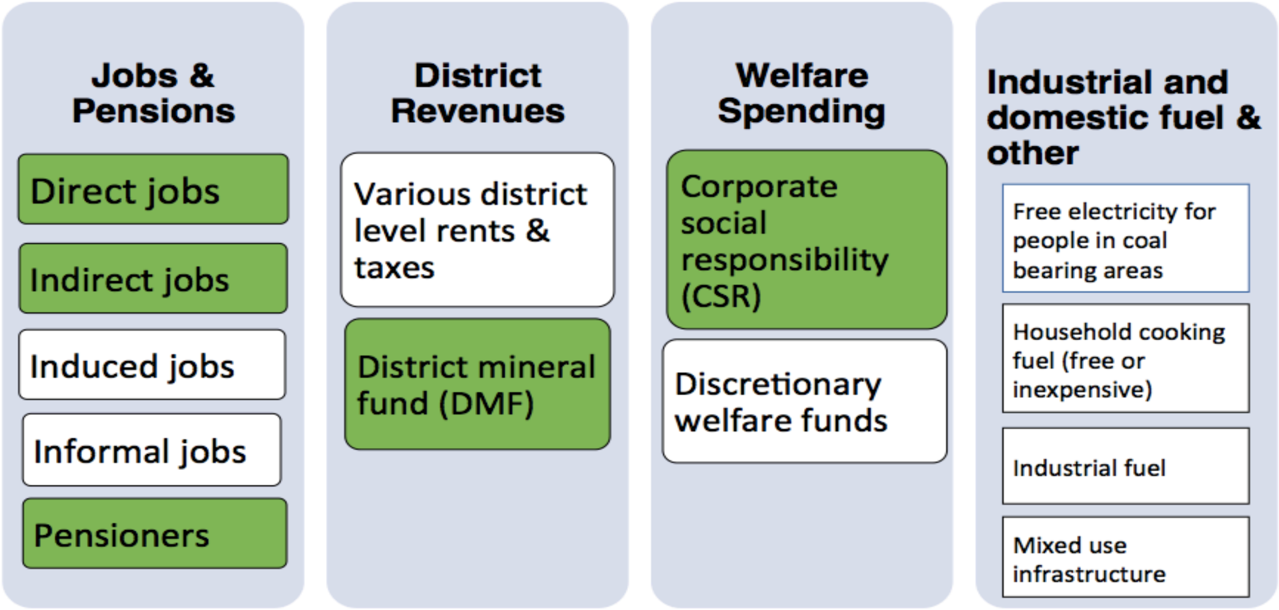


Figure 5.2 Socio-economic contribution of the coal sector at the district level

For all coal dependent districts, I quantify direct and indirect jobs, pensioners, DMF contributions and CSR spending. These are highlighted in green. Variables in white have not been quantified for this study.

5.2.2 Data collection and quantifying indicators

I collected six novel datasets in order to quantify four indicators—the number of jobs in the coal mining and coal power sector (direct and indirect), the number of coal industry pensioners, total yearly DMF contributions, and total yearly CSR spending. These datasets are: 1) Indian coal mine location and production dataset; 2) Coal company wise employment factors dataset; 3) Coal power plant location and installed capacity dataset; 4) District wise coal pensioners dataset; 5) District mineral fund dataset; and, 6) District wise CSR spending dataset. Below, I describe each indicator and its input dataset.

5.2.2.1 District level coal jobs

Coal mining jobs

To calculate direct coal mining jobs**,** I first collected an "Indian coal mine location and production" dataset showing the geographic location and coal production for all 459 operational Indian coal mines. Next, I created an "employment factor" dataset. I collected data on employment and production for CIL and its subsidiaries (representing 80% of coal production in India), and used these data to calculate employment factors for these companies (i.e. the number of jobs per million tonne production) (**Figure 5.3**). Finally, I applied the appropriate employment factors to each mine to estimate the number of direct jobs per mine, aggregating this information to determine direct jobs at the district level. This type of employment factor approach to energy sector job quantification has been used extensively in past scholarly work (Cameron & Van Der Zwaan, 2015; Pai et al., 2020; Wei et al., 2010).

I collected the "Indian coal mine location and production" dataset by filing applications under India's federal *Right to Information Act, 2005* with CIL (& its subsidiary companies), SCCL, NLC, and the Coal Controller Organization (India's coal sector regulator). The *Right to Information Act, 2005* is India's federal freedom of information legislation. Overall, this dataset includes information on each of the 459 operational coal mines in India with the following details: 1) name of the mine; 2) name of the district in which the mine is located; 3) coal production for 2019-2020; 4) mine owner; and, 5) type of mine (OC or UG). The dataset also includes geocoordinates for each mine **(Dataset link: https://doi.org/10.7910/DVN/TDEK8O).** The "employment factors" dataset for CIL and its subsidiaries is disaggregated by type of mining (Open cast or Underground) along with a weighted average for the company as a whole (**Figure 5.3**). I used the latest Joint Bi-partite Committee of Coal Industry (JBCCI) (Ministry of Coal, 2020a) report to generate this dataset. It must be noted that CIL subsidiaries either mine coal directly or through contractors. I created the employment factors dataset using CIL subsidiaries' direct production and employment numbers. Due to lack of employment numbers for CIL contractors, I assumed that contractor-run mines have the same employment factors as that of the CIL subsidiary that hires the contractor. For example, for CIL subsidiary Eastern Coalfields Limited (ECL), I assumed that all the ECL mines have the same employment factor whether they are run by the ECL or its contractors. I note that the impact of this assumption is mitigated by the fact that the contractor run mines are always located in the same district as the directly operated mines and in most cases right next to mines run by CIL subsidiaries. Both CIL subsidiaries and their contractors operate mines that have similar mine geology, local conditions and use a local workforce (Chandra, 2018; Pai & Carr-Wilson, 2018). However, I recognize that this is a limitation of our study. Future work can collect detailed datasets on employment factors for contractor run mines for each coal company and then use our mines dataset to improve the jobs quantification.

For non-CIL mines (nearly 20% of production), I used CIL country-wide employment factors for OC & UG mines. I made this assumption because of lack of availability of employment factors data for non-CIL mines—a limitation that can be addressed in future analyses by collecting employment factors data for these coal companies. There are a small number of mines (about

4%) operated by 3 CIL subsidiaries that are considered mixed mines where coal production is happening using both OC & UG methods. For these mines, I used the weighted average employment factor for the subsidiary that owns the mine.

To calculate indirect jobs, I used the following indirect job multiplier for coal mining provided by the Ministry of Coal under a *Right to Information Act, 2005* request: for every direct coal-mining job there are three indirect jobs in related auxiliary support industries.

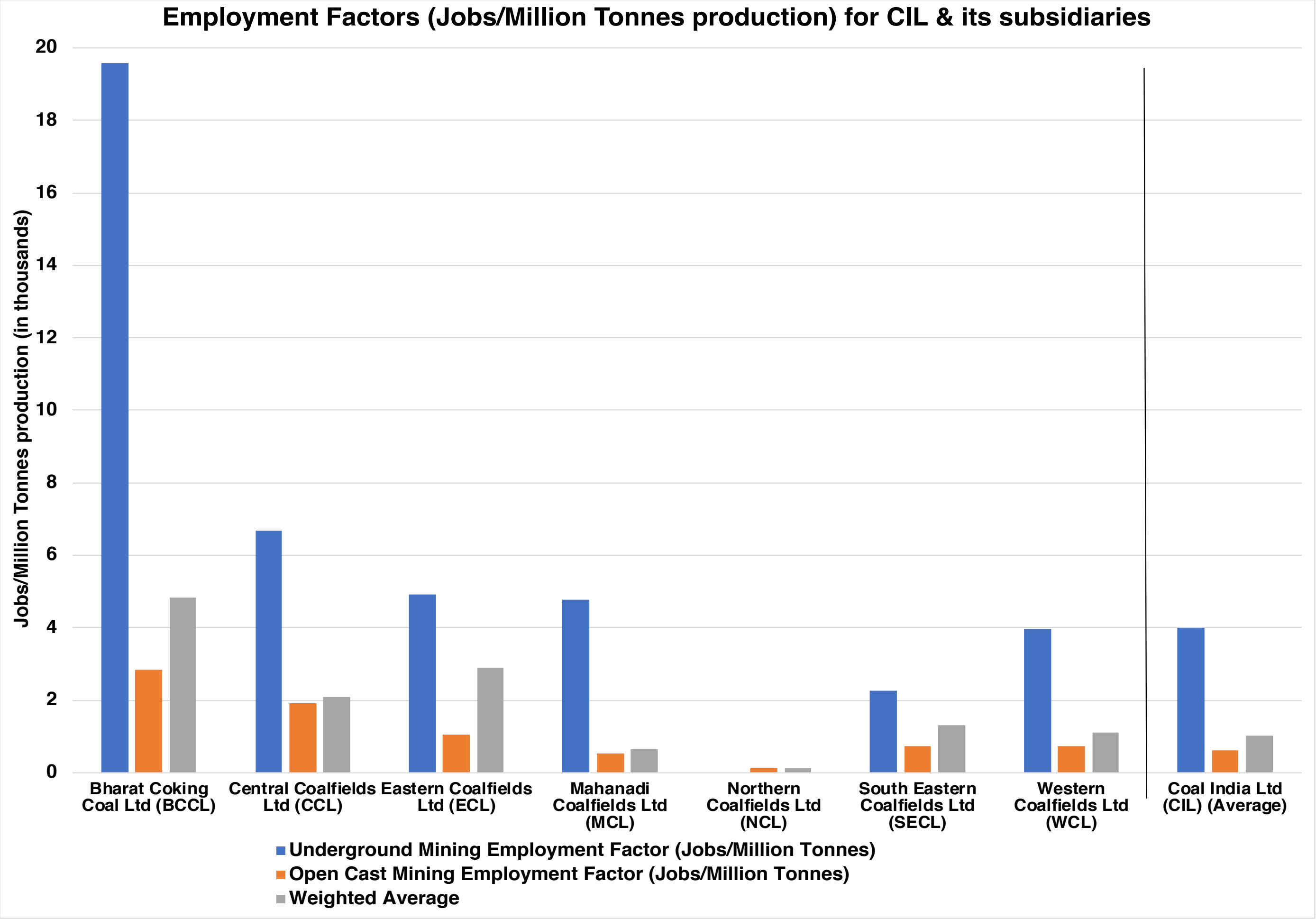


Figure 5.3 Employment factors for CIL and its subsidiaries

The employment factors vary greatly between subsidiaries and vary with the type of coal mining. Underground mining is much more labour intensive than opencast mining across subsidiaries.

Coal Power Plant Jobs

To calculate direct jobs in coal power plants, I used Global Energy Monitor's (2020) latest dataset, which provides detailed information on coal power plants in India, including their location and installed capacity. I used Council on Energy, Environment and Water (Kuldeep et al., 2019)'s employment factor data for Indian coal power plants. Finally, I used Eco Care consultancy's direct to indirect jobs multiplier based on socio-economic survey for Indian coal power plants: for every direct coal power plant job in India there are 3.5 indirect jobs in coal transport, manufacturing, and ancillary industries (Eco Care, 2010).

5.2.2.2 Pensioners

I collected a dataset on district level coal pensioners from the Coal Mines Provident Fund Employees Congress, the official union of the CMPFO organisation.

5.2.2.3 District mineral fund

I created a dataset of district level DMF contributions based on data obtained through *Right to Information Act, 2005* requests filed with CIL, SCCL, NLC and Ministry of Coal.

5.2.2.4 CSR spending

I created a dataset of district level coal mining company CSR spending based on data obtained through *Right to Information Act, 2005* requests filed with CIL, SCCL, NLC and other government-owned coal mining companies.

I created a dataset of district level coal power company CSR spending based on data obtained through *Right to Information Act, 2005* requests filed with NTPC and other government-owned coal power companies. I also incorporated data on private coal power company CSR spending, which I obtained by reviewing the latest annual reports of Tata Steel, Adani Power and other private companies. It must be noted that I only incorporated private company CSR data for companies whose main activity is coal power production. For example, if a company's core business is steel or cement production but owns a small power plant to support its core business activity, I did not incorporate this company's CSR data as it was not possible to disaggregate the CSR data from the annual report.

5.2.3 Determination of top coal dependent districts

After computing district level jobs (direct and indirect) in the coal mining and coal power sector, and collecting datasets for the number of coal industry pensioners, total yearly DMF contributions, and total yearly CSR spending, I normalized these indicators (district level coal jobs per capita, district level pensioners per capita, district level DMF per capita and district level CSR per capita) using district level population data (Office of the Registrar General & Census Commissioner, 2011). I did this to facilitate the comparison of indicator values between districts. After normalizing each indicator, I created a table of coal dependent districts that fall within the top 10% of each of the four indictors: district level coal jobs per capita; district level pensioners per capita; district level DMF per capita; and, district level CSR per capita. This table shows which districts are highly dependent on one or more indicators (i.e. in the top 10% for the indicator). I focused on the coal dependent districts that fall within the top 10% of each of the four indicators in order to identify key coal dependent districts that policymakers may wish to focus on when engaging with just transition planning in India. Moreover, this kind of analysis is also able to capture variations among the top districts in terms of which indicator they are highly dependent on.

5.3 Results

This study's results show that there are 284 districts in India that have some form of coal dependency – they are home to coal workers or pensioners, or collect DMF revenues, and/or have benefitted from CSR spending. There are 51 districts where coal mining occurs, and in 2019-2020, nearly 770 MT of coal was produced collectively in these districts. India also has almost 230 GWs of thermal power plant capacity spread across 140 districts (Global Energy Minotor, 2020) (**Figure 5.4 &**

Figure 5.5).

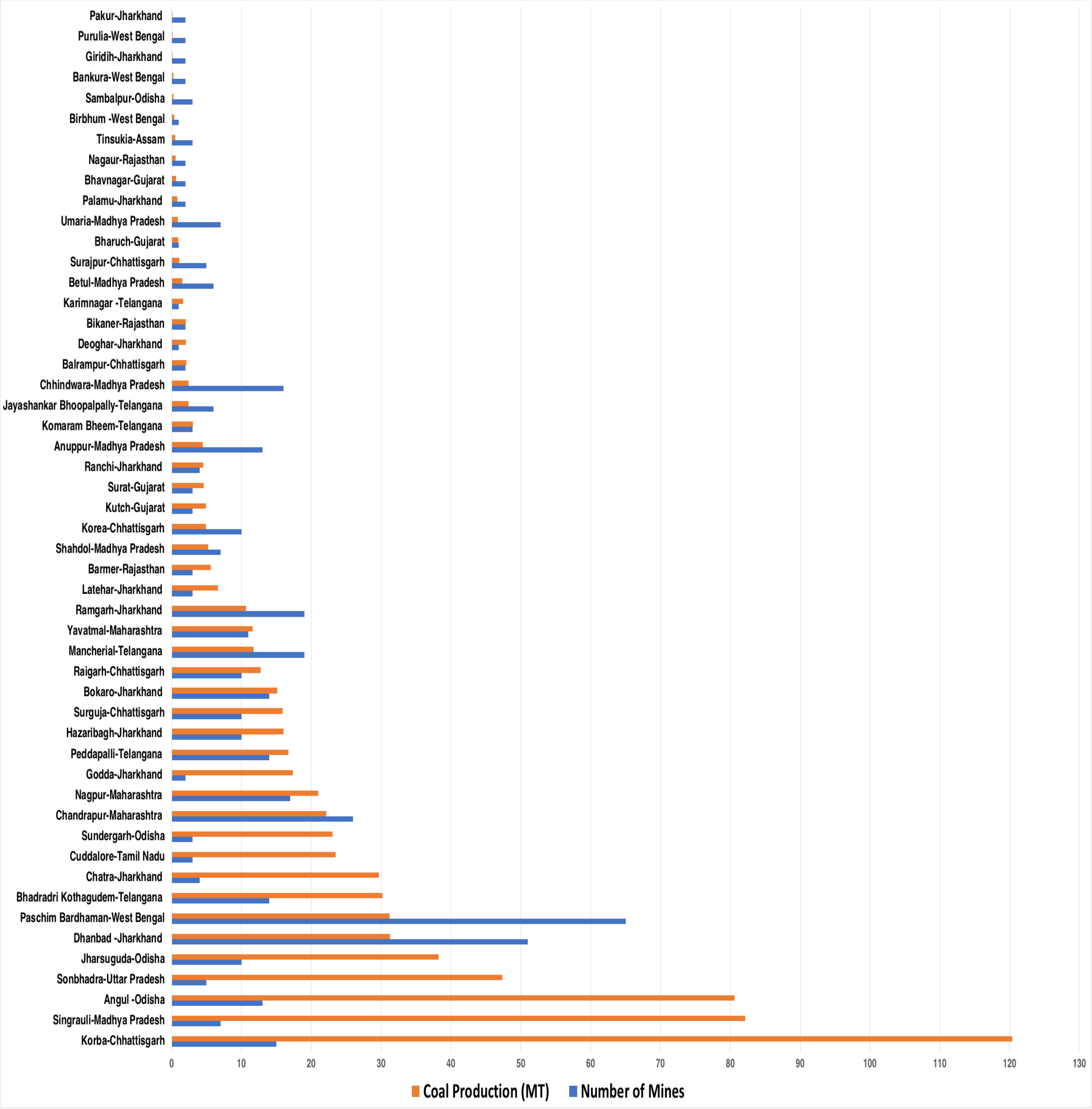
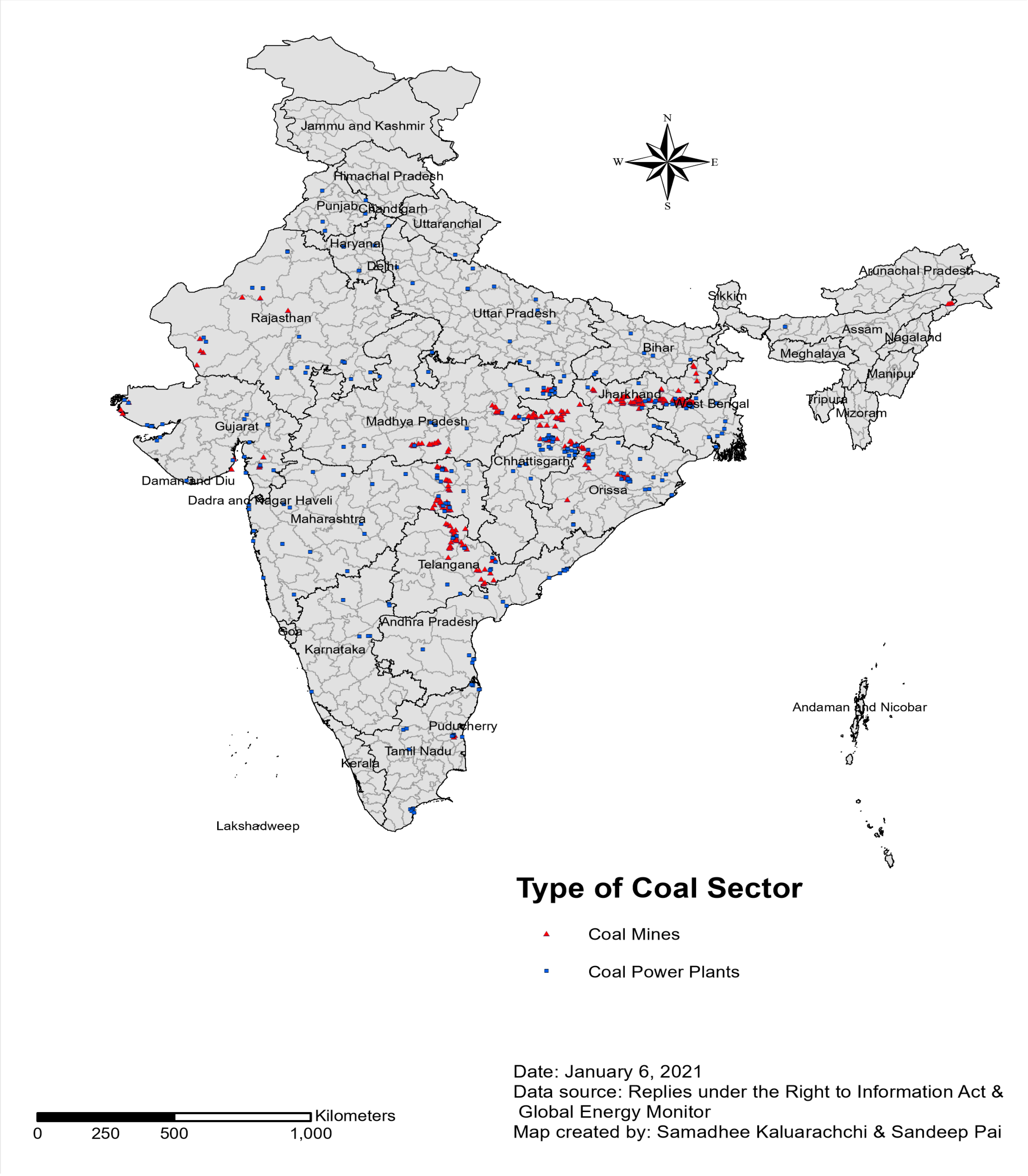


Figure 5.4 District level coal production and number of mines

This graph shows the large variation in the number of coal mines per district and coal production. It covers 51 coal producing districts in 13 states.



Date: January 6, 2021
Data source: Replies under the Right to Information Act & Global Energy Monitor
Map created by: Samadhee Kaluarachchi & Sandeep Pai

Figure 5.5 Coal mines and coal power plants by district
The map shows the location of all coal mines and coal power plants in India with district and state boundaries.

This study estimates that 3.6 million people are either directly or indirectly employed in the coal mining and power sectors in 159 districts in India. Nearly 80% of these coal jobs are linked to coal mining sector located in 51 districts. The rest 20% coal jobs are linked to the power plant jobs, which are located in 141 districts (some of which are also included in the coal mining district number above). This is an important finding as it shows that the coal mining sector's socio-economic contribution in terms of jobs is much higher than the power sector but that it is more concentrated in a smaller number of districts.

Moreover, there are nearly half a million coal industry pensioners in India living in 199 districts. This study also finds that the coal industry collectively contributed Rs 3346 crore (480 million US$) towards district mineral funds in 52 districts in India. In the year 2019-2020, coal mining and power companies also spent Rs 1011 crores (144 million US$) as CSR spending in sectors such as health, education and infrastructure development. Of the total Rs 1011 crores (144 million US$) spent by coal companies as CSR spending, around Rs 680 crore (97 million US$) was spent by companies in 90 districts. The remaining Rs 330 crore (47 million US$) was spent on national and statewide projects that were not tied to any particular district.

A key finding of this paper is that there is large variation among these 284 districts in terms of both the scale of coal dependency and the type of coal dependency – i.e. whether a district is predominantly dependent on jobs, pensioners, DMF, CSR or a combination of one or more of these indicators.

I first present the results showing district level jobs, pensioners, DMF contributions, and CSR spending. Next, I outline the results on top coal dependent districts.

5.3.1 Coal jobs

Out of the 159 districts where coal jobs exist, there are 7 districts with over 100,000 direct and indirect coal mining and coal power plant jobs. Moreover, 43 districts (including the 7 mentioned above) have over 10,000 jobs (**Figure 5.6**). Eighty-three districts have between 10,000 and 1000 jobs. The remaining 33 districts have less than 1000 jobs. Overall, there is a large variation among districts in terms of the number of jobs **(all district results - https://bit.ly/3dqZdUD)**. In terms of districts, Dhanbad (Jharkhand) is home to the largest number of coal workers at nearly 0.5 million, the majority of whom are employed in the coal mining sector. Parbhani (Maharashtra) and Kendujhar (Odisha) have the smallest number of coal jobs at only 83 jobs each.

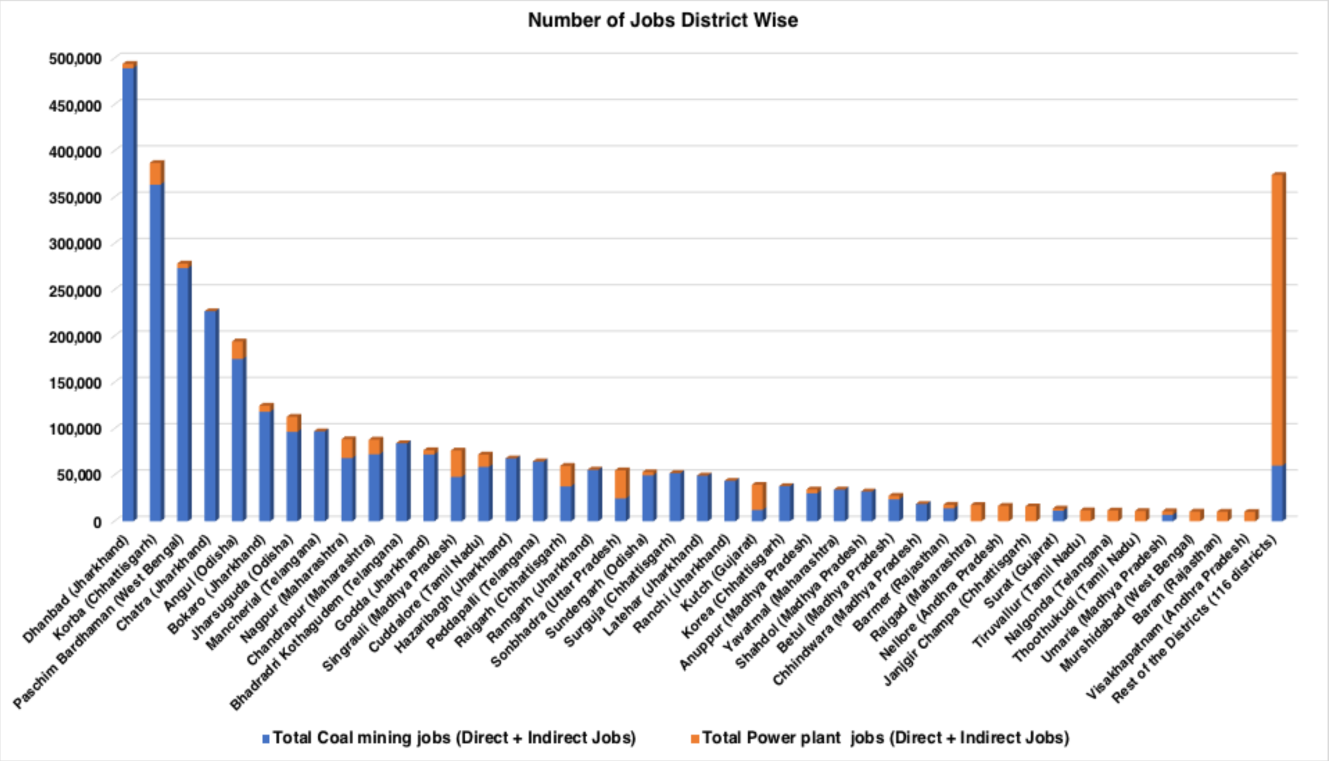


Figure 5.6 Districts with over 10,000 coal jobs

In total, 43 districts have over 10,000 jobs. Most of the jobs are in the coal mining sector. Dhanbad, Korba and Paschim Bardhaman have the highest number of coal jobs.

5.3.2 Coal pensioners

The results show 0.52 million coal pensioners collectively live in 199 districts. However, the majority of these pensioners live in 24 districts that have over 5,000 pensioners each (**Figure 5.7)**. Among these 24 districts, 11 districts have over 10,000 pensioners. Of these 11 districts, Dhanbad (Jharkhand) and Paschim Bardhaman (West Bengal) stand out with over 50,000 pensioners each living in these districts. These two districts are home to CIL's oldest subsidiaries Bharat Coking Coal Ltd and Eastern Coalfields Ltd, which were formed in the 1970s when the coal mining industry was nationalized in India. After nationalization, CIL inherited a large numbers of workers from existing private coal mining companies that it took over (Chandra, 2018). Over time, these workers retired and remained in these two districts. On the other end of the spectrum, there are 65 districts with less than 100 pensioners each **(All district results - https://bit.ly/3dqZdUD)**.

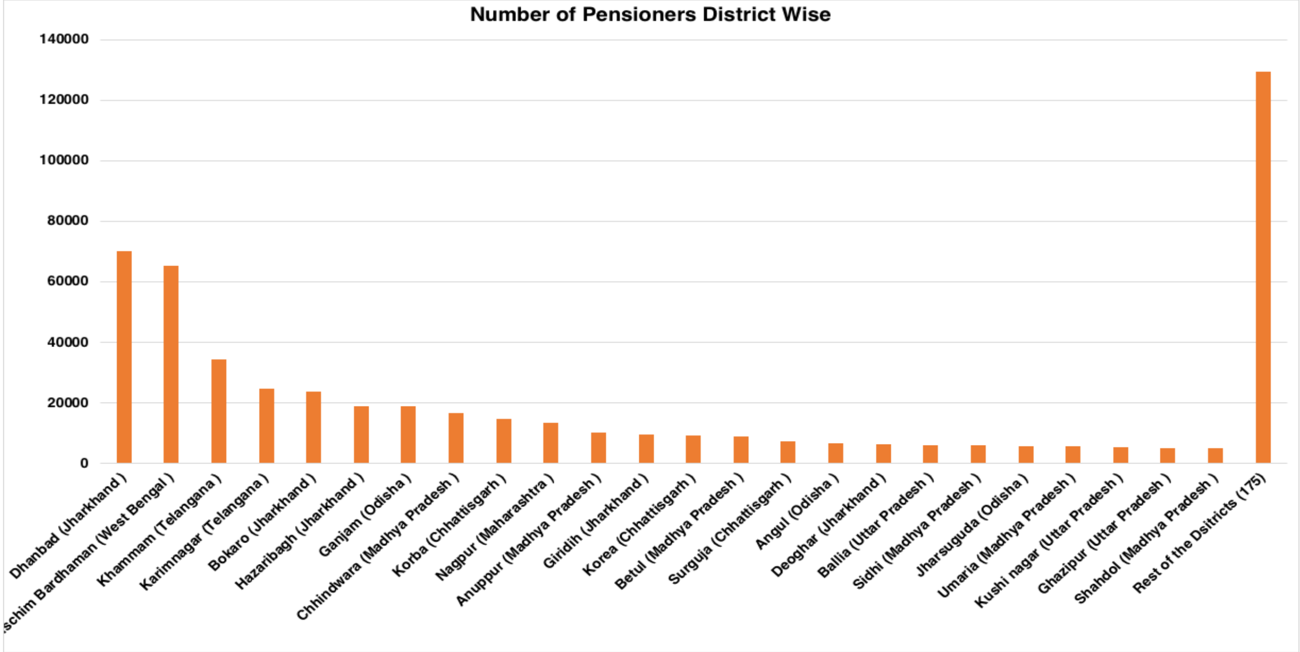


Figure 5.7 Districts with over 5000 pensioners

This graph shows 24 districts that have over 5,000 coal pensioners

5.3.3 District mineral fund

I find that 20 of the 52 districts that collected coal sector DMF contributions, collected over Rs 50 crores (approx. 7 million US$) per year. Korba district in Chhattisgarh, which is also the district that produces the most coal, tops the chart in terms of DMF collection and Singrauli district in Madhya Pradesh is a close second – on average, these districts collect over Rs 400 crores (over 60 million US$) per year (**Figure 5.8**). There are 20 districts that collect between Rs 5 – 50 crore (between 0.70 - 7 million US$). The bottom 12 districts collect an average of less than Rs 5 crores (0.70 million US$) per year **(all district results - https://bit.ly/3dqZdUD**).

Each district charges a DMF amount to coal companies based on the federal government rules. The DMF rules suggest that for coal mines that were operational before January 2015, district governments should charge DMF at 30% of the royalty paid to the state government. However, if the mines became operational after January 2015, the rate is 10% of the royalty paid to the state government (Hohl, Sison, Stastny, & Zamil, 2018). The royalty itself is calculated based on price of coal – usually higher quality coal results in a higher price. Therefore, if we compare two districts that produce the same amount of coal, if the first district produces good quality coal or has older mines than the second district, then the former district will collect more royalty. These rules have resulted in variations in terms of DMF amounts that coal producing districts collect.

In terms of utilization of DMF funds, the Indian federal government has mandated that 60% of DMF contributions collected by each district should be applied in 'high priority areas' including health care, education, skill development, and sanitation (Hohl et al., 2018). The remaining 40% of the funds must be used for physical infrastructure development, irrigation, energy and watershed development, and for measures that enhance environmental quality in mining districts (Hohl et al., 2018).

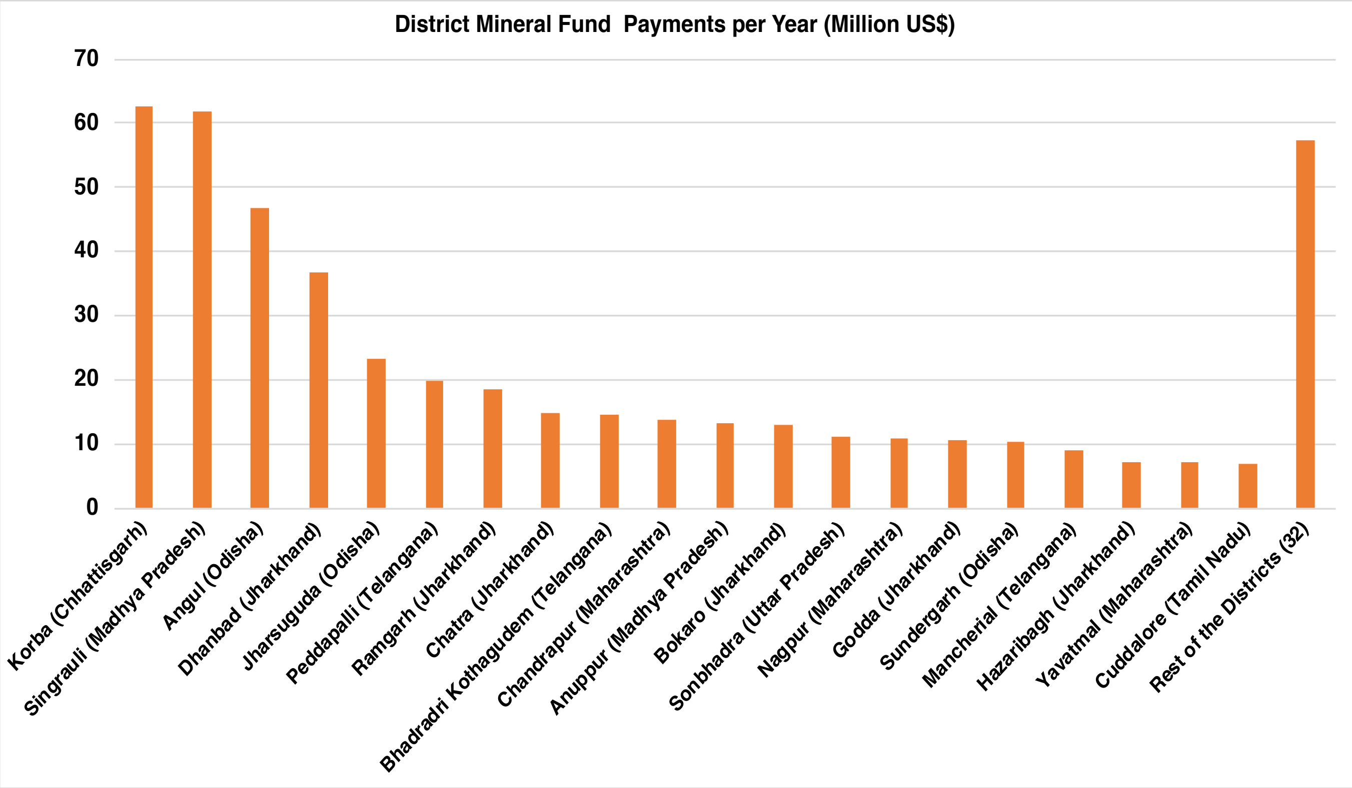


Figure 5.8 District mineral fund payments for top 20 districts

This figure shows DMF contributions (in US$) for the 20 districts that collect the highest annual DMF contributions.

5.3.4 Corporate social responsibility spending

Of the total Rs 1011 crore (144 million US$) spent by coal companies for CSR programs, Rs 660 (97 million USD$) was spent by companies in 90 districts. In 23 districts, coal companies spent over Rs 7 crores (1 million USD$) in 2019-2020 (**Figure 5.9**). In Angul district (Odisha), the district with the highest level of CSR spending, Rs 131 crore (approx. 18 million US$) was spent in 2019-2020. In contrast, in Dumka and Jamtara districts (Jharkhand), the districts with the lowest levels of CSR spending, less than Rs 1.1 lakh (1500 US$) was spent in 2019-2020 **(all district results - https://bit.ly/3dqZdUD**).

Each coal company has an independent CSR committee made up of high-ranking officers of the company. This CSR committee decides where and how to spend money each year. Most coal companies spend the CSR money in local areas around their operations (Coal India Limited, 2020; Ministry of Coal, 2020b; NLC, 2020) but this is not always the case. Overall, in the year 2019-2020, India's largest coal power company, NTPC, claims in its annual report that the company spent 2/3 of their CSR funds (28 million out of 44 million US$) in four key areas — "eradicating hunger and poverty, health care and sanitation, education and skill development, and rural development."

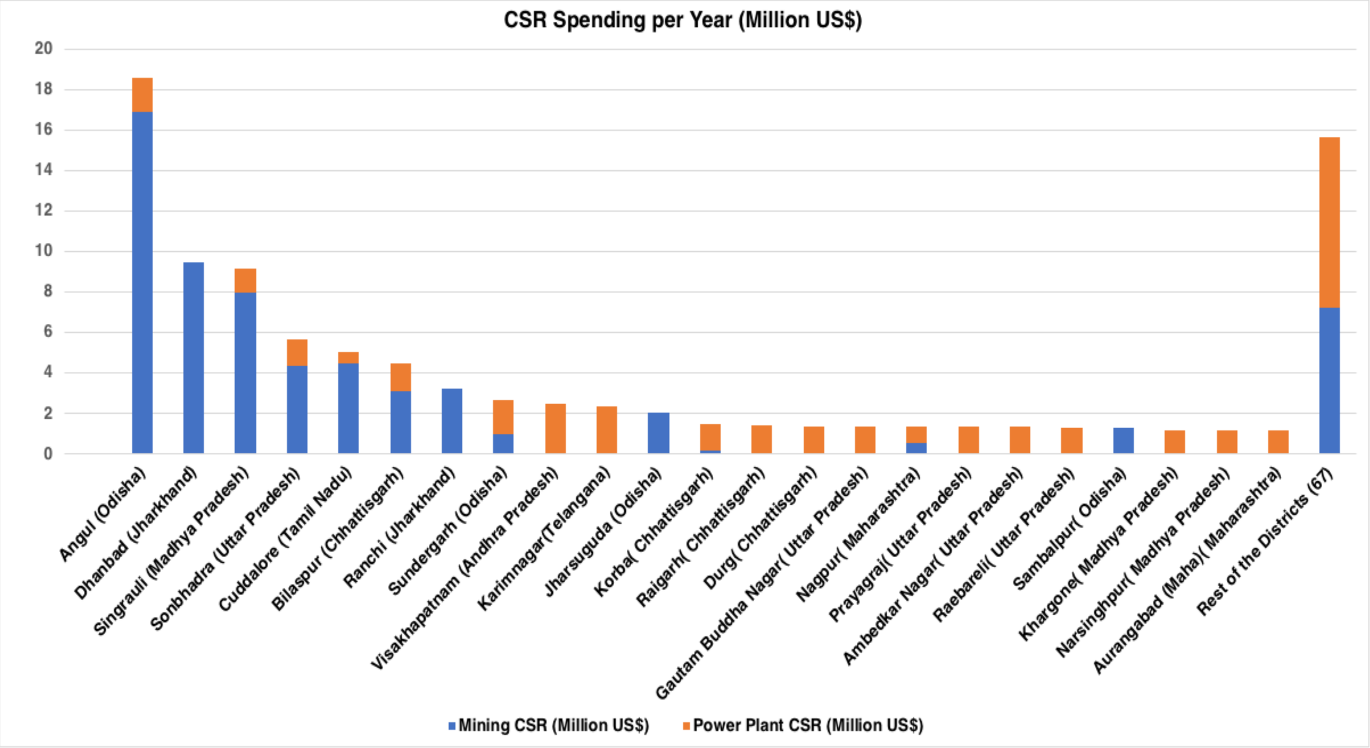


Figure 5.9 Districts with over 1 million US$ in CSR spending

This figure shows DMF contributions (in US$) for the 19 districts that collect the highest annual DMF contributions

5.3.5 Analysis of top coal dependent districts

Out of the 284 coal dependent districts in India, 33 fall within the top 10% of one or more indicators: district level coal jobs per capita; district level pensioners per capita; district level DMF per capita; and, and district level CSR per capita (**Table 5.1**) (**see Appendix C1 for full results of 284 districts**). As shown in **Figure 5.10**, for the remaining districts, most have low dependency and are skewed towards low indicator values. Therefore, the 33 key coal dependent districts are the areas where policymakers could focus their just transition planning efforts.

Of the 33 districts that fall within the top 10% for one or more indicator, 9 are in the state of Jharkhand, 7 in the state of Madhya Pradesh, 5 each in the states of Telangana and Odisha, 4 in the state of Chhattisgarh, and 1 each in the states of Uttar Pradesh, Tamil Nadu, and West Bengal.

Among the 33 districts, Jharsuguda and Angul districts in Odisha are the only two districts that show high dependency for all four indicators. There are 3 districts that have high dependency on three out of four indicators, although the exact indicators that these districts are dependent on varies: Korba (Chhattisgarh) has high jobs, pensioners and DMF dependency; Dhanbad (Jharkhand) has high jobs, pensioners, and CSR dependency; and, Singrauli has high jobs, DMF and CSR dependency.

Next, there are 7 districts that have high dependency on two out of four indicators. The districts of Annupur (Madhya Pradesh), Korea (Chhattisgarh), Bokaro (Jharkhand), and Paschim Bardhaman (West Bengal) have high dependence on jobs and pensioners. Peddapalli (Telangana) and Ramgarh (Jharkhand) has high jobs and DMF dependency. Karimnagar (Telangana) has high pensioner and CSR dependency.

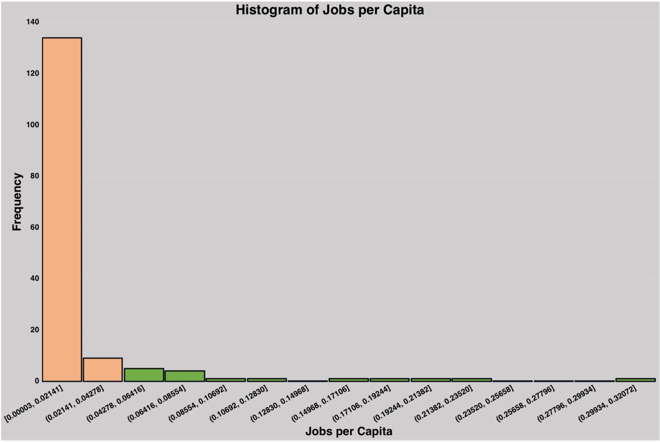
The remaining 21 (out of 33) districts are highly dependent on only one indicator, however the specific indicator varies among districts.

Overall, the results show that the top districts for one indicator may not always be the top districts for other indicators. Some districts are more heavily dependent on jobs, while others have large numbers of pensioners or depend more on DMF contributions or CSR spending. This is particularly interesting as it indicates that just transition interventions in these top 33 coal dependent districts must be tailored to the different types of dependency and the related transition supports needed.

Table 5.1 The 33 top coal dependent districts
This table shows the 33 districts that fall within the top 10% of districts for coal jobs, coal pensioners, DMF collection, or CSR spending. Green cells show high jobs dependency, yellow high pensioners dependency, orange high DMF dependency, and blue high CSR dependency. The white cells indicate values that do not fall within the top 10% for a specific indicator.

State Name	District Name	Jobs Normalized	Pensioners Normalized	DMF Normalized	CSR Normalized
Odisha	Jharsuguda	0.194720099	0.010234597	3.99181E-05	3.4737E-06
Odisha	Angul	0.152406596	0.005191467	3.67968E-05	1.4459E-05
Chhattisgarh	Korba	0.320715725	0.012316018	5.17864E-05	1.2375E-06
Jharkhand	Dhanbad	0.183983566	0.026187871	1.36518E-05	3.488E-06
Madhya Pradesh	Singrauli	0.064835059	0	5.24227E-05	7.6846E-06
Madhya Pradesh	Anuppur	0.045864313	0.0139582	1.75346E-05	1.593E-07
Chhattisgarh	Korea	0.057681984	0.013977481	8.16309E-06	2.6283E-08
Jharkhand	Bokaro	0.060527902	0.011553922	6.27252E-06	1.5445E-07
West Bengal	Paschim Bardhaman	0.096548527	0.022708638	1.86147E-07	2.6941E-07
Telangana	Peddapalli	0.081343093	0	2.47846E-05	6.0847E-09
Jharkhand	Ramgarh	0.058714333	0.000295963	1.9464E-05	5.8749E-07
Telangana	Karimnagar	0.009392857	0.02453687	2.86094E-06	2.3247E-06
Jharkhand	Chatra	0.217438148	0.00191392	1.41771E-05	9.0143E-07

Telangana	Mancherial	0.120392526	0	1.13105E-05	5.9964E-09
Telangana	Bhadradri Kothagudem	0.07879752	0	1.36431E-05	4.5259E-09
Jharkhand	Latehar	0.067904602	0.000584612	1.21247E-06	3.4972E-08
Jharkhand	Godda	0.058410918	0.001086368	8.04007E-06	3.3362E-07
Madhya Pradesh	Umaria	0.016757512	0.00876608	4.34706E-06	9.7711E-09
Telangana	Khammam	0.004863949	0.024544836	1.75794E-06	3.4526E-09
Jharkhand	Hazaribagh	0.03913079	0.010958233	4.13261E-06	3.3384E-08
Madhya Pradesh	Chhindwara	0.008925684	0.008078254	1.55191E-06	7.8057E-08
Madhya Pradesh	Betul	0.01749855	0.005670443	1.21785E-06	1.8716E-08
Odisha	Ganjam	0	0.005355861	0	0
Madhya Pradesh	Sidhi	0.005974204	0.005290883	0	0
Madhya Pradesh	Shahdol	0.030225943	0.004702349	3.85043E-06	0
Jharkhand	Deoghar	0.005710176	0.004270569	1.72777E-06	5.7395E-08
Jharkhand	Giridih	0.000406563	0.003979188	2.62428E-07	1.295E-08
Chhattisgarh	Surguja	0.022070032	0.003173035	1.24072E-06	4.4494E-09
Uttar Pradesh	Sonbhadra	0.029523467	0.000107379	5.91311E-06	3.0066E-06
Odisha	Sundergarh	0.025311764	0.000123242	4.86855E-06	1.2489E-06
Tamil Nadu	Cuddalore	0.027645325	0	2.67588E-06	1.9274E-06
Chhattisgarh	Bilaspur	0.026658308	0	0	4.9367E-07
Odisha	Sambalpur	0.005081258	0.00051388	7.82635E-08	1.2401E-06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Frequency
0
20
40
60
80
100
120
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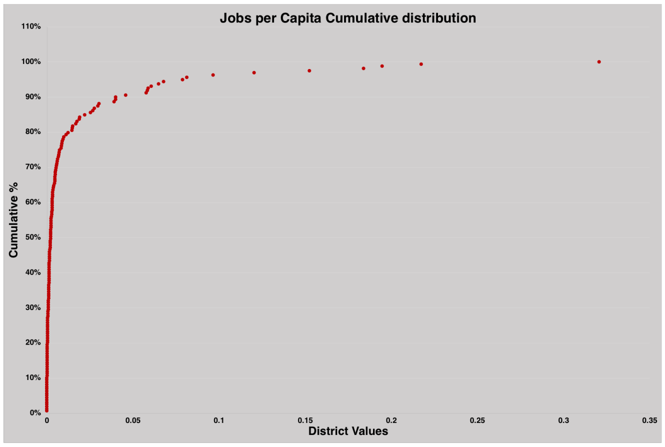
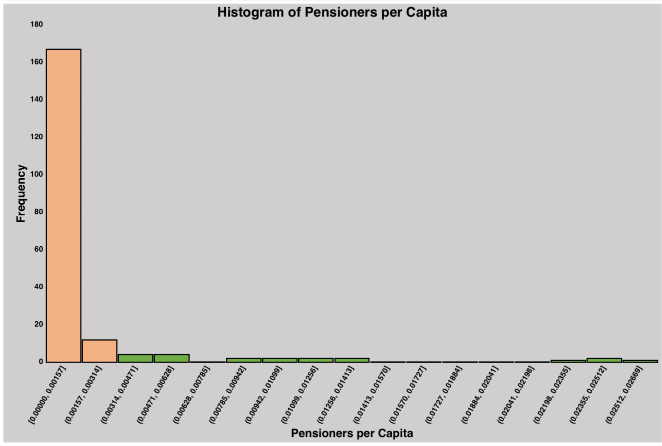
Jobs per Capita


Jobs per Capita Cumulative distribution
Cumulative %
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
110%
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
District Values


Histogram of Pensioners per Capita
Frequency
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20
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60
80
100
120
140
160
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(0.00314, 0.00471]
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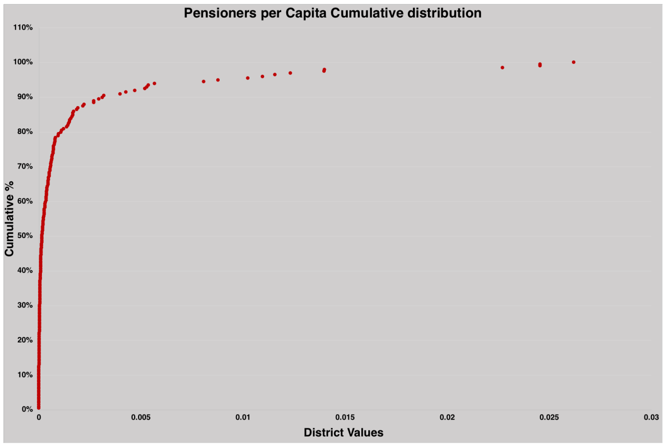
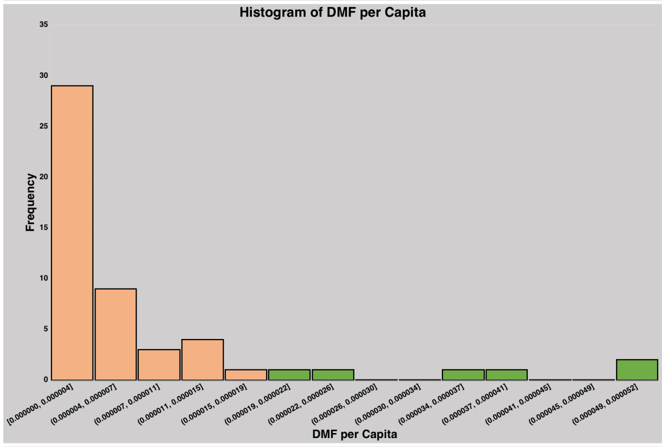
Pensioners per Capita


Pensioners per Capita Cumulative distribution
Cumulative %
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
110%
0
0.005
0.01
0.015
0.02
0.025
0.03
District Values


Histogram of DMF per Capita
Frequency
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10
15
20
25
30
35
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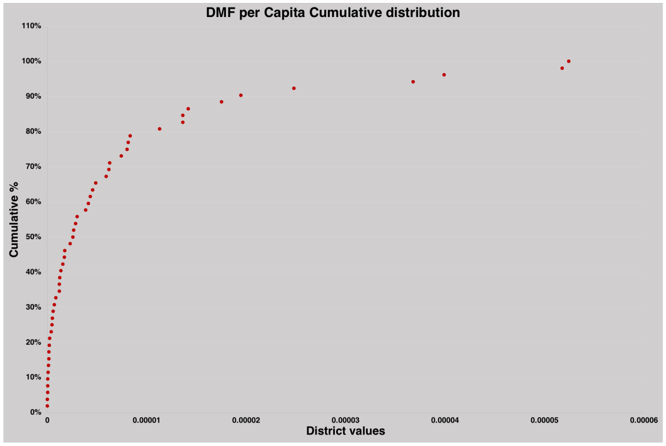
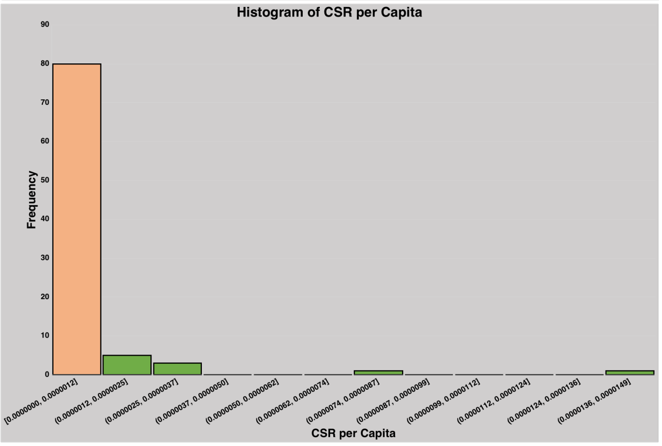
DMF per Capita


DMF per Capita Cumulative distribution
Cumulative %
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
110%
0
0.00001
0.00002
0.00003
0.00004
0.00005
0.00006
District values


Histogram of CSR per Capita
Frequency
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10
20
30
40
50
60
70
80
90
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(0.0000136, 0.0000149]
CSR per Capita

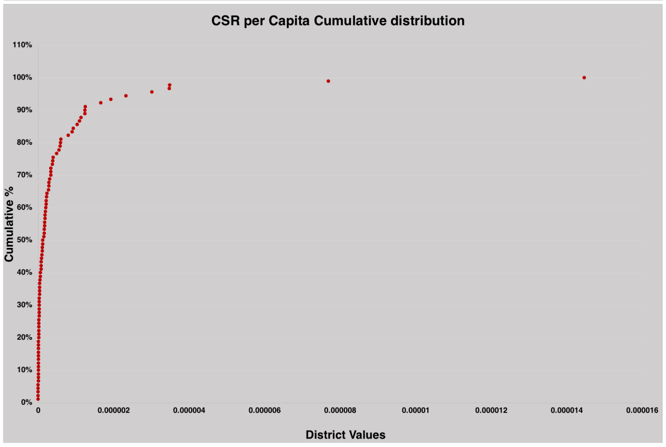
CSR per Capita Cumulative distribution
Cumulative %
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
110%
0
0.000002
0.000004
0.000006
0.000008
0.00001
0.000012
0.000014
0.000016
District Values

Figure 5.10 Histogram and cumulative distribution plots

The figure shows histogram and cumulative distribution plots for four indicators: district level coal jobs per capita; district level pensioners per capita; district level DMF per capita; and, district level CSR per capita. In the histograms, the green bars represent indicator values that fall within the top 10% for the indicator, while light orange represents indicator values that fall within the remaining 90%. For all four indicators, the data shows that there is a small number of districts that have high indicator values, with variation amongst these values. However, the majority of districts have low dependency and are clustered around the same low indicator values.

5.4 Discussion and conclusion

India is the second largest global producer and consumer of coal and its coal trajectory is crucial to meeting global climate targets (Tongia et al., 2020). However, there is a knowledge gap regarding the socio-economic dimensions of coal transitions – in India, and around the world. Existing work on coal transitions has largely focused on least cost techno-economic analyses (Malik et al., 2020; Shrimali, 2020; Tongia et al., 2020). As shown in Chapter 2, research to date on the socio-economic or just transition aspects of coal transitions is largely focused on OECD countries, with little exploration of this topic in emerging economies such as India. However, the literature acknowledges that it is important to understand the socio-economic dimensions of coal transitions in order to create just transition plans for coal dependent communities that will facilitate justice in transition and help mitigate potential political resistance these communities may raise against such low carbon policies.

Filling this knowledge gap requires good data. However, as scholars have highlighted, energy research in India also faces a data availability problem (Rai et al., 2017). Even basic datasets like the location of coal mines and their coal production are not publicly available. This has been a key factor impeding the quantification of socio-economic dependency on coal in the Indian context.

This Chapter contributes to filling these knowledge and data gaps. This is the first study that quantifies Indian districts' socio-economic dependency on coal. Here, I first identified four key categories for district-level coal dependency, based on my analysis of the latest annual reports of the Federal coal ministry and large government-owned companies, a literature review, and interviews with coal company officials. Next, I focused on three out of the four categories, and collected six novel datasets in order to quantify four key district-level socio-economic indicators of coal dependency — direct and indirect jobs, number of pensioners, DMF contributions, and coal sector CSR spending. I collected these datasets through a combination of 32 *Right to Information, 2005* requests, analysis of company annual reports, and collection of data directly from a major union. I also used the GEM dataset (Global Energy Minotor, 2020) for Indian coal power plants for this analysis. After quantifying the values for the above four indicators, I normalized their values and conducted an analysis to identify key coal dependent districts and capture variations among these key coal dependent districts in terms of which indicator they are highly dependent on.

This study finds that there are 284 districts that have some form of coal dependency – in the form of direct and indirect coal mine or power plant jobs, coal pensioners, DMF contributions, and/or CSR spending. I find that Dhanbad district (Jharkhand) has the highest number of coal jobs and pensioners, Korba district (Chhattisgarh) collects the highest DMF contributions, and Angul district (Odisha) sees the highest CSR spending by coal companies. Moreover, out of the 284 coal dependent districts in India, 33 districts fall within the top 10% of one or more indicators. However, the specific indicator for which these districts are highly dependent on the coal sector varies greatly among these districts.

Apart from difference in district population, the variations in types of dependency are a result of various factors. Coal mining is concentrated in 51 districts but provides 80% of all coal jobs. On the other hand, the power plants are spread around 140 districts but represents only 20% of all jobs. Thus, coal mining districts are most dependent on jobs, especially those that are home to labor intensive underground mines. Moreover, while some coal pensioners stay back after retirement in districts they worked, others migrate to nearby urban districts or other parts of the country resulting in variation among districts for this indicator. Moreover, the districts governments collect DMF funds based on the price of coal and the age of coal mine, which means that districts with similar coal production numbers end up collecting different amounts of DMF funds. Finally, the CSR amount to be spent in districts is determined by each coal companies' CSR committee – yet again resulting in variation among districts as companies are not limited to spending in a given district.

This Chapter contributes to the just transition literature in several ways. It is the first study on the socio-economic dimensions of coal transition in India, a major coal-dependent country, which helps broaden the existing just transition literature beyond OECD countries. Amidst a just transition literature that focuses primarily on job transition, this study also makes a conceptual contribution by identifying other key socio-economic indicators of coal dependence, including pensioners, local government revenues, and CSR spending. The methodology developed in this chapter (quantifying indicators and identifying top coal dependent districts) could be applied in other countries to understand variance in socio-economic coal dependency at the regional level. Moreover, the results—which show large variation in the degree and type of socio-economic coal dependency between districts — highlight the need for scholars to conduct detailed studies focusing on sub-national fossil fuel dependent jurisdictions. It also shows that scholars need to be focus beyond jobs as key to just transition and be mindful of different types of transition supports that will be needed and where.

Finally, the novel datasets collected for this paper will be useful for scholars who are researching the spatial dimensions of coal transitions in India both from a techno-economic and socio-economic point of view. I also anticipate that a number of scholars will be interested in using the datasets, such as the Indian coal mine location and production dataset, to identify specific districts to focus on for more detailed local socio-economic analysis. Some of the future applications of the datasets include: 1) examining spatial variance in local air pollution and health outcomes near coal mines and coal power plants; and, 2) case selection for further district-level qualitative and quantitative studies regarding socio-economic dependency on coal.

Beyond contributions to the literature, this study will be useful for all levels of government in India and other stakeholders such as trade unions when engaging with planning coal-related just transition. For example, it sheds light on specific districts that government may wish to focus their efforts and limited resources on in order to create effective just transition plans. It also shows how government companies like CIL and NTPC are deeply embedded in the current social, economic and political landscape of local coal regions in the country. Given these deep ties, these companies could help facilitate just transition for these regions by diversifying their business model to create opportunities in non-fossil fuel sectors. In fact, both CIL and NTPC has already made explicit plans to diversify their businesses by pledging investments in renewable energy, solar wafer manufacturing and aluminum smelting.

While this study makes several contributions to the literature, it has a few limitations. It focuses on coal dependency at the district level, however there may be other state-level dependencies that could compound the risks highlighted in this paper. For example, if a state government in India loses coal royalties and this revenue is not replaced by other sources, overall cuts in state spending may impact coal dependent districts as well. This might be more severe in states like Jharkhand where multiple districts are heavily coal dependent and the state government itself relies on coal royalties. Moreover, while this paper focuses on dependency, there may be district or state level resilience factors (such as diversified economies, planned investments, or others) that help mitigate some of these dependencies. Future research can build on this paper and incorporate these ideas.

Chapter 6: Conclusion

Just transitions research that focuses on fossil fuel workers and their communities to date is largely normative and descriptive. It has broadly focuses on conceptualizing just transitions (Heffron & McCauley, 2018; McCauley & Heffron, 2018; Newell & Mulvaney, 2013) and defining the role and views of different stakeholders in the just transition planning process (Abraham, 2017; Carley et al., 2018; Cha, 2016, 2017; Olson-Hazboun, 2018). The limited empirical literature largely focuses on exploring renewable energy jobs as an option for fossil fuel workers (Cameron & Van Der Zwaan, 2015; Eisenberg, 2019; Louie & Pearce, 2016; Pollin & Callaci, 2019; Van der Zwaan et al., 2013; Wei et al., 2010). Moreover, even the empirical literature that focuses on job transition ignores the spatial dimensions of employment transitions – where jobs will be lost or gained within a country – and has methodological and data gaps.

In this dissertation, I contributed to the just transition literature conceptually by explaining the key components of just transition and defining its scale and scope. I also conducted three empirical studies, for which I developed new methodologies, collected novel datasets, and applied those methodologies to come up with important insights in the field. Specifically, in my core Chapters (2-5), I conducted a systematic review of the just transition literature, assessed whether renewable energy jobs can replace fossil fuel job losses both spatially and temporally, and spatially analyzed the socio-economic dependency of coal at a local level in India. Below, I provide a summary of the key findings of each core chapter, explain the academic and policy contributions and limitations of my dissertation, and propose avenues for future research.

6.1 Summary of key findings

In Chapter 2, I conducted a systematic review of academic and select policy literature to comprehensively synthesize key elements of just transition for fossil fuel workers and their communities. Next, I conceptualized the identified elements using Heffron & McCauley's (2018) legal geography 'JUST' framework. The literature collectively identifies 17 key elements of a just transition which range from the need for long-term planning to the importance of retraining. These elements vary in terms of the type of justice forms they further, spatial scales, and timeframe. The review found that the field is new and most of the global just transition literature focuses on a few industrialized countries and on coal workers. Moreover, many of the articles are normative or descriptive, although there has been some empirical work. This Chapter concludes that just transition research requires a focus on several key elements of just transition, which reflect the spatial, temporal and justice dimensions of transition.

In Chapter 3, I collected a novel 50 country dataset of employment factors (the number of workers employed per unit of electrical and refining capacity or fuel production) consisting of 11 energy technologies and 5 job types. I then used the outputs of the WITCH integrated assessment model to investigate the impact that meeting the Well-Below 2 Degrees C (WB2C) global climate target could have on global and regional energy sector employment. The results of this chapter show that meeting this climate target could result in more direct energy sector jobs than today – both globally and in many regions. However, some fossil fuel exporting countries and China may have fewer energy jobs than today. The results show that "old" energy technology jobs (predominantly coal, oil, and gas extraction jobs) will decline, while "new" energy technology jobs (predominantly solar and wind manufacturing jobs) will increase. This is an important finding as current fossil fuel dependent countries with substantial fossil fuel extraction jobs could take advance action to promote the domestic renewable energy manufacturing sector in their country to help mitigate domestic job losses associated with meeting the global climate targets. This Chapter concludes that although meeting climate targets might create more energy sector jobs at a global scale and in many regions, this is not true everywhere and many trade-offs, challenges, and opportunities exist within the necessary employment transition.

Chapter 4 focuses on the coal mining industry in China, India, the US, and Australia, which represent 70% of global coal production. I conducted a spatial analysis using secondary data sources to gauge whether there are suitable solar and wind power resources in these countries' coal mining areas in order to install solar/wind plants and create related jobs. I also investigated the scale of renewables deployment required to facilitate an employment transition for coal miners in areas suitable for solar/wind power. The results show that with the exception of the US, several GWs of solar or wind capacity would be required in each local coal mining area to transition all coal miners to solar/wind jobs. Moreover, while solar has more resource suitability than wind in coal mining areas, suitable solar resources are not available everywhere. Over 95% of coal mining areas in both India and Australia have sufficient solar resources to realize this transition. However, in China, the country with the largest coal mining workforce, only 29% of coal mining areas are suitable for solar power. In all four countries, less than 7% of coal mining areas have suitable wind resources. Further, all countries would have to scale-up their current solar capacity significantly to transition coal miners who work in areas suitable for solar development. This Chapter concludes that it may not be technically feasible to create local solar or wind jobs in all coal mining areas, therefore, not all coal miners may be able to transition to solar or wind jobs locally.

Chapter 5 examines variation in Indian districts' socio-economic dependency on the coal industry. I first conceptualized India's socio-economic dependency on coal. Next, I collected several large novel datasets to quantify the scale of current socio-economic dependency on coal at the district (a sub-administrative unit) level in India, and provide a comparative assessment of district-level coal dependency. I find that the coal industry contributes to districts in many ways, by providing jobs, supporting pensioners, spending on CSR, and contributing to district mineral funds. Overall, this Chapter finds that 284 districts (out of 736 districts in India) have some form of coal dependency, with large variation in both the scale of coal dependency and the type of coal dependency – i.e. whether a district is predominantly dependent on jobs, pensioners, district mineral fund revenues, CSR spending, or a combination of one or more of these indicators. Moreover, 33 out of 284 districts in India are the top coal dependent districts in the country. However, the specific indicator for which these districts are highly dependent on the coal sector varies greatly among these districts. This Chapter concludes that creating just transition plans for Indian districts will require understanding and accounting for variation in the type and degree of districts' socio-economic dependency on the coal industry.

6.2 Academic contributions

My dissertation makes three broad contributions to the academic literature on just transition. First, it shows that just transition will involve planning for various tangible and intangible aspects of dependencies associated with the fossil fuel industry. In Chapter 2, I show that beyond jobs, there are several tangible issues (i.e. local revenues, pensions) and intangible issues (i.e. identity) that are essential aspects of just transition. I further make the case in Chapter 5 that certain tangible dependencies (such as local tax revenues) are sometimes more pertinent than jobs in some local contexts.

Second, I show the importance of understanding the nuanced and complex spatial dimensions of just transition. As my chapters show, just transition interventions will require different considerations in different countries of the world, and even regions within a country. In Chapter 3, I find that job losses and gains as a result of meeting climate targets vary across countries around the world. Under stringent climate policy scenarios, China and other fossil fuel exporting economies such as Mexico, Canada and Australia may lose jobs compared to today. However, other countries or regions such as the US, Middle East and North Africa, and India among others will gain jobs. Moreover, Chapter 4 shows that even in countries such as the US or India, which could benefit from implementing climate policies that see more renewable energy jobs created than jobs lost in the fossil fuel sector, it may not be possible to create renewable energy jobs locally for fossil fuel workers such as coal miners. Beyond jobs, Chapter 5 shows that other just transition considerations such as local dependency on tax revenues or social spending also vary from region to region within a country.

Third, with regards to fossil fuel jobs, I add specificity to the types of fossil fuel jobs that might require more attention than others in a transition. Some of my dissertation chapters provide evidence that the extraction sector currently provides more jobs than other parts of the fossil fuel supply chain and is most vulnerable to decarbonization. For example, Chapter 3 shows that currently, the global coal and oil & gas extraction sectors collectively constitute nearly 80% of total fossil fuel jobs. This evidence is further built on in Chapter 5, where I show that in India, the coal mining sector accounts for just over 80% of total coal jobs in the country.

In addition to these broad contributions, my individual Chapters contribute to the just transition literature conceptually and methodologically, and provide novel datasets for the field.

The literature synthesis in Chapter 2 advances scholarly understanding of just transition by bringing together concepts of just transition from different academic fields. This will be useful as no previous study has collated the disparate but related just transition elements identified by scholars in different academic fields. This synthesis work also paves the way for development of new conceptual frameworks, and will serve as a stepping-stone for development of additional just transition studies as it links literatures from different academic fields such as energy transitions, energy policy, geography, law, labour, and economics. To the best of my knowledge, this is the first attempt to show how theoretical concepts (such as justice forms) should be used in designing the specifics of just transition plans.

For Chapter 3 of my dissertation, I used an IAM for employment assessment and created a 50-country dataset. This new approach – using an IAM for employment assessment – and the new dataset will be useful for scholars who wish to conduct further IAM based analysis regarding energy sector jobs. For example, the influential IPCC reports and research groups that work on "What if" questions using different IAMs could utilize my dataset to conduct similar employment assessments at regional and global levels.

The spatial methodology that I created and applied in Chapter 4 will have wide applicability in just transitions research. For example, scholars can use my methodology to assess whether fossil fuel workers can transition to other types of local renewable energy jobs such as geothermal or bioenergy, or jobs in completely different sectors.

Amidst a just transition literature that focuses primarily on job transition, Chapter 5 contributes conceptually by identifying other key socio-economic indicators of coal dependency such as local government revenues, worker pensions, and CSR spending. The methodology developed in this Chapter (quantifying indicators and identifying top coal dependent districts) could be applied in other countries to understand variance in socio-economic fossil fuel dependency at the regional level. Moreover, the novel datasets collected for this Chapter will be useful for scholars who are researching the spatial dimensions of coal transitions in India both from a techno-economic and socio-economic point of view. I also anticipate that a number of scholars will be interested in using the datasets, such as the Indian coal mine location and production dataset, to identify specific districts to focus on for more detailed local socio-economic analysis.

6.3 Policy implications and recommendations

Many governments and international organizations are formulating just transitions strategies to help fossil fuel workers and their communities navigate such a transition. Moreover, debates regarding just transition are increasingly playing out in the news and social media, either on their own or in relation to fossil fuel phase-outs.

This work contributes to policy action and policy discourse regarding just transitions in the following four ways. First, my dissertation shows that policy makers need to think about just transitions in a more holistic way that incorporates spatial, temporal, and justice aspects of transition. Beyond jobs, policy makers also need to focus on economic, social, regional, demographic, and other aspects of just transition.

Second, many governmental and intergovernmental Just Transition Taskforces are trying to synthesize knowledge regarding just transitions. These groups can draw on the conceptual and empirical findings of my dissertation. In fact, the elements of the systematic review, the global employment factors dataset, and the India-specific datasets have already been used in various national and international organization reports.

Third, my dissertation shows that renewable energy jobs may not always be a local option for fossil fuel workers. This finding will contribute to the ongoing policy dialogue and media discourse regarding whether renewable energy jobs are a feasible option for fossil fuel workers.

Finally, the novel datasets collected for this dissertation will be tremendously useful for many advocacy groups and international organisations that advocate for bolder climate action. For example, different fossil fuel companies and governments justify fossil fuel projects or their expansion as they help create local jobs. The employment factors dataset in Chapter 4 can help organizations check these claims.

More broadly, based on the findings of the different Chapters of my dissertation, I recommend that fossil fuel dependent nations through their research councils and other research institutes undertake extensive studies to understand the risk and opportunities of fossil fuel transitions for workers and their communities. Socio-economic dependency on fossil fuels and the risks associated with transition will vary across countries. Therefore, it is important that future research unpacks the various layers of socio-economic dependency on fossil fuels. Chapter 5 of my dissertation can be helpful in thinking about relevant categories of socio-economic dependency to study, beyond jobs. After developing a baseline understanding of the type and scale of socio-economic dependency, countries can use this baseline data to run modelling scenarios, to understand the future risk transition may pose for workers and communities.

At the same time, future studies should also evaluate resilience opportunities, such as opportunities associated with fossil fuel dependent countries diversifying their economies. This can be done by mapping sectors that have the maximum potential for growth within a country, then exploring how countries can create industrial policies to promote these sectors. Beyond renewable energy production and manufacturing, studies should also explore the potential of other sectors such as agriculture and tourism. It would also be helpful for researchers to conduct qualitative and survey-based studies that collect diversification ideas from communities themselves. These field-based studies could also help further understanding of non-tangible dimensions of fossil fuel dependency such as community identity.

The above-mentioned studies would require quality data. To facilitate this, fossil fuel dependent countries should task a particular ministry or secretariat with compiling data related to various aspects of energy transition. For example, this could include data regarding the location of fossil fuel infrastructure, local government revenues linked to fossil fuels, and data regarding the location and fossil fuel consumption of dependent industries, which could assist countries to understand the risk associated with transition.

6.4 Study limitations, areas of future research

In this section, I discuss some of the broader limitations of my dissertation and propose future research efforts in the field of just transition.

First, while I conducted multiple quantitative studies, I did not conduct any study that assesses the views of fossil fuel workers and their communities. I originally planned to conduct a qualitative study as part of this dissertation, which would assess fossil fuel workers' views regarding just transition. However, this was not possible due to the COVID-19 pandemic.

Chapter 2 shows that there is a need to systematically obtain and incorporate the views of fossil fuel workers and their communities regarding what a just transition should entail. Without obtaining and incorporating the views of fossil fuel workers and their communities regarding just transition, there is a possibility that key aspects of just transition in the climate change context might be ignored. This is a limitation that needs to be addressed in future work. For example, scholars could conduct qualitative interviews and focus group discussions to understand and incorporate views of fossil fuel workers and their communities.

Second, I focused only on renewable energy jobs as an alternate option for fossil fuel workers. However, future research should conduct more assessments of fossil fuel dependent regions to assess the suitability of non-renewable energy jobs in local areas.

Third, although my research examined just transition issues related to direct and indirect fossil fuel industry workers, I was not able to capture just transition issues related to induced and informal workers. Future work should be done to enhance understanding of just transition issues related to induced and informal workers, including developing methodologies and collecting datasets to estimate related jobs numbers. In particular, in many non-OECD countries like India, there are large numbers of informal coal industry workers. This remains an understudied area and requires deeper exploration in the future.

Finally, barring Chapter 2, my dissertation did not focus on important social and justice issues associated with just transition such as gender, labor demographics, and identity. It would be desirable for future research on just transitions to examine these important issues.

6.5 Concluding remarks

This dissertation shows that just transition is not only a jobs problem. It requires a holistic understanding of different social, economic, demographic, and other issues. Just transition also requires a spatial, geographic lens. What is required for a just transition may vary at the regional level within a country; different regions may have different just transition considerations. Renewable energy jobs may or may not be suitable replacements for fossil fuel jobs; future work could assess the suitability of other industries for job replacement.

Scholars believe that implementing just transition strategies for fossil fuel workers and their communities may help increase the general acceptability of climate policies among fossil fuel dependent communities. Others argue there is an ethical obligation to provide for the well-being of fossil fuel workers and their communities as the world transitions to low carbon sources of energy. To the best of my knowledge, my dissertation is the first to focus on just transition. It helps advance the state of knowledge in this field regarding what a just transition must include, and how governments and policymakers should approach planning such a transition.

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Appendices

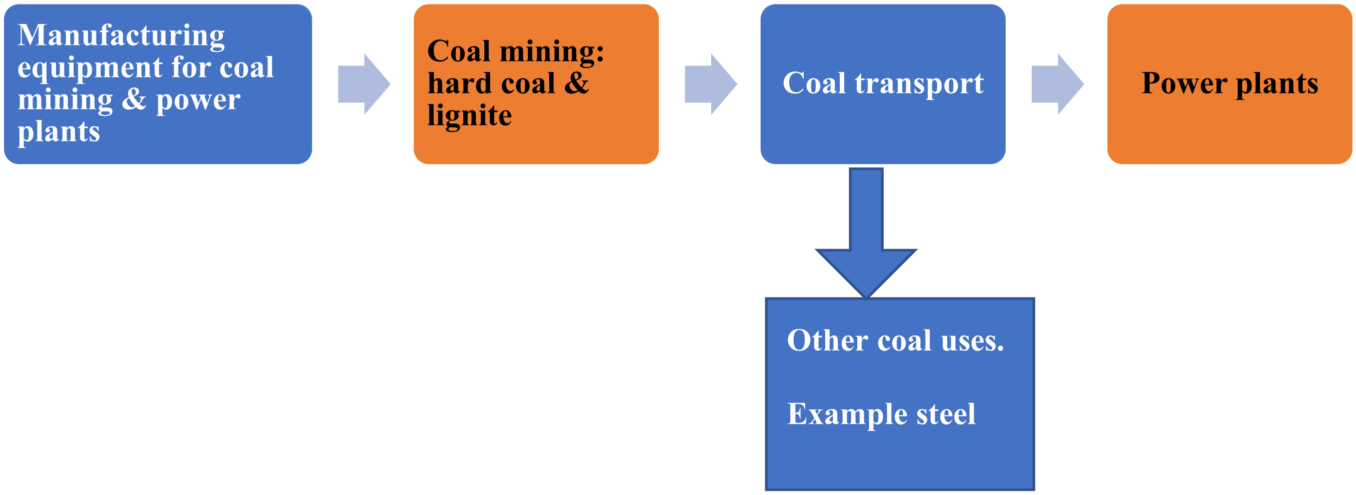
Appendix A Chapter 3 Analyzing the energy sector employment implications of keeping global warming Well Below 2°C

A.1 System boundaries

In this Chapter, I adopted a supply chain approach on each energy technology. Below I describe the supply chain for each energy technology and highlight the processes for which I collected employment factors data (represented in orange).

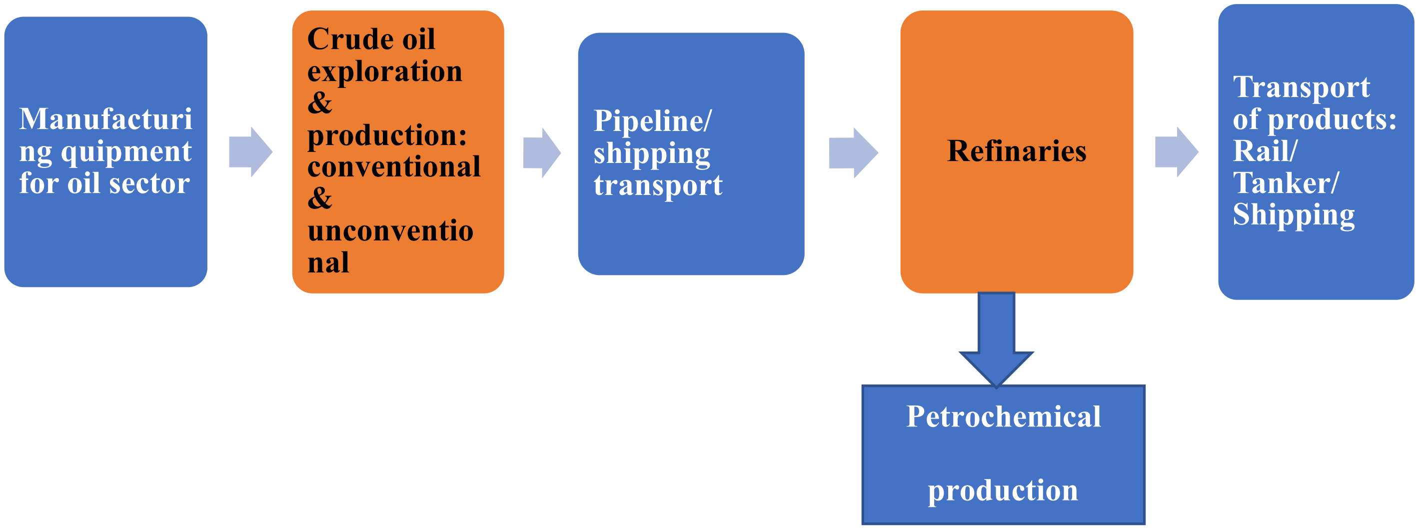
Coal

- Coal mining - jobs/ Million Tonnes (produced)
- Coal power plants (O&M) - jobs/ GW (installed capacity)
- Coal power plants (construction) - job years/ GW (new installation)



Oil

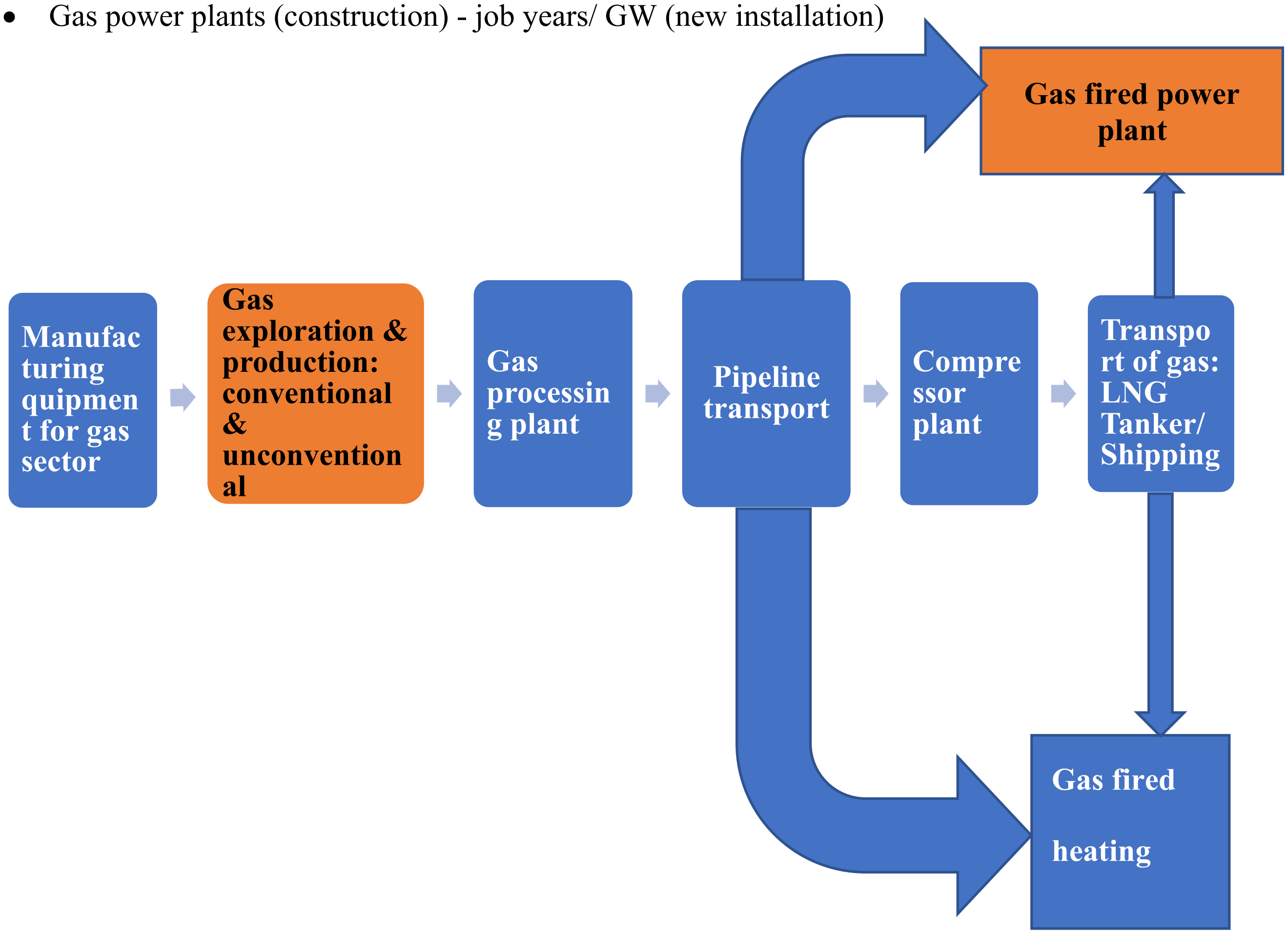
- Crude oil exploration & production - jobs/ thousand tonnes of oil equivalent (produced)
- Refineries (O&M) - jobs/ thousand barrels per day (capacity)



Gas

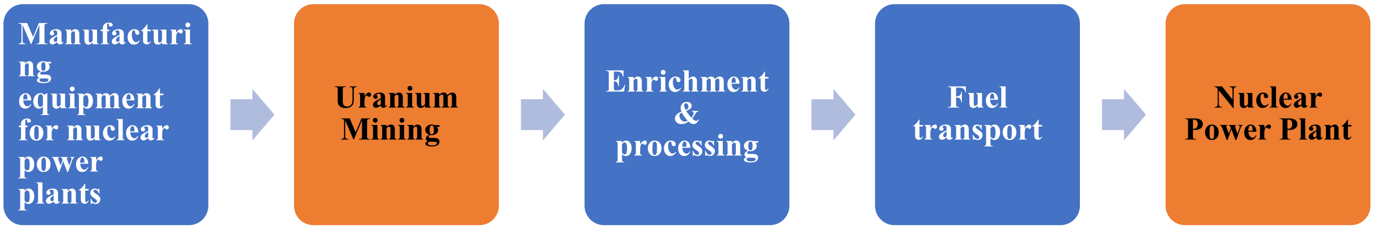
- Gas exploration & production - jobs/ thousand tonnes of oil equivalent (produced)
- Gas power plants (O&M) - jobs/ GW (installed capacity)

- Gas power plants (construction) - job years/ GW (new installation)



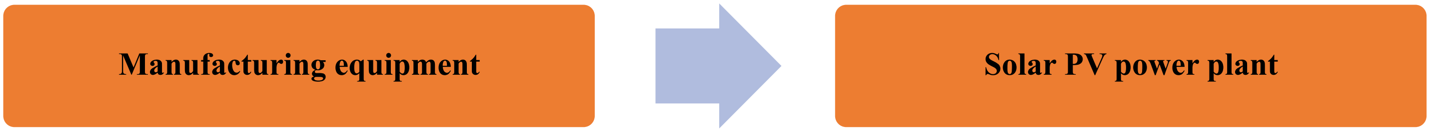
Nuclear

- Uranium mining - jobs/ Peta Joule
- Nuclear power plants (O&M) - jobs/ GW (installed capacity)
- Nuclear power plants (construction) - job years/ GW (new installation)



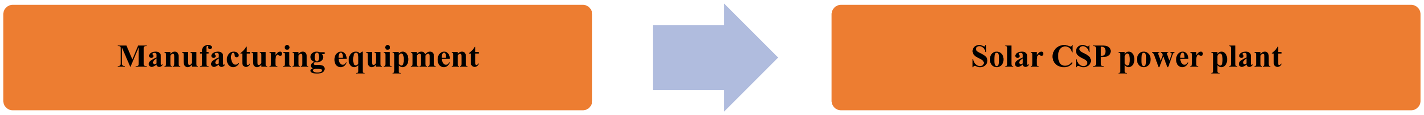
Solar PV

- Solar PV power plants (O&M) - jobs/ GW (installed capacity)
- Solar PV power plants (construction) - job years/ GW (new installation)
- Solar PV (manufacturing) - job years/ GW



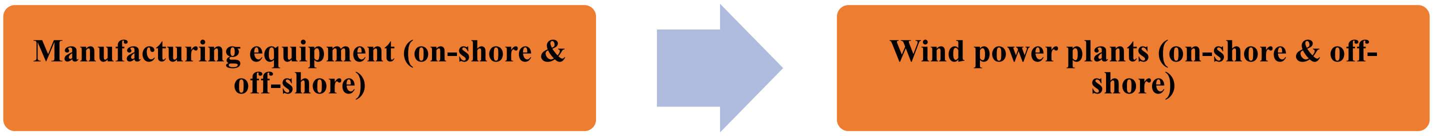
Concentrated Solar Power (CSP)

- Solar CSP power plants (O&M) - jobs/ GW (installed capacity)
- Solar CSP power plants (construction) - job years/ GW (new installation)
- Solar CSP (manufacturing) - job years/ GW



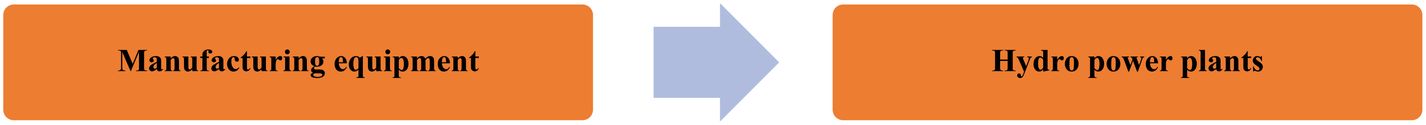
Wind (on-shore & off-shore)

- Wind power plants (O&M) - jobs/ GW (installed capacity)
- Wind power plants (construction) - job years/ GW (new installation)
- Wind (manufacturing) - job years/ GW



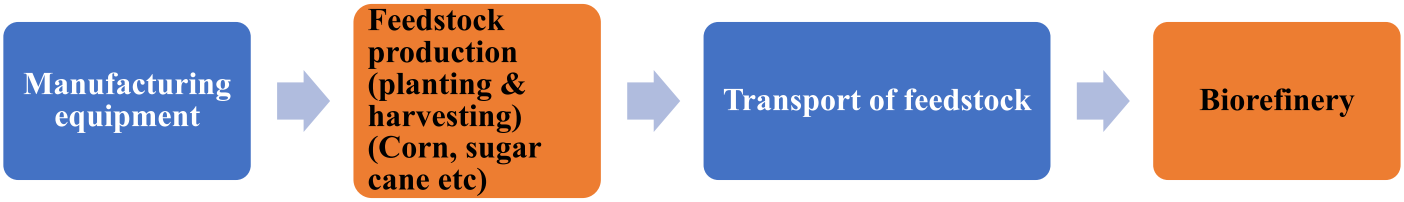
Hydro (small & large)

- Hydro power plants (O&M) - jobs/ GW (installed capacity)
- Hydro power plants (construction) - job years/ GW (new installation)
- Hydro (manufacturing) - job years/ GW



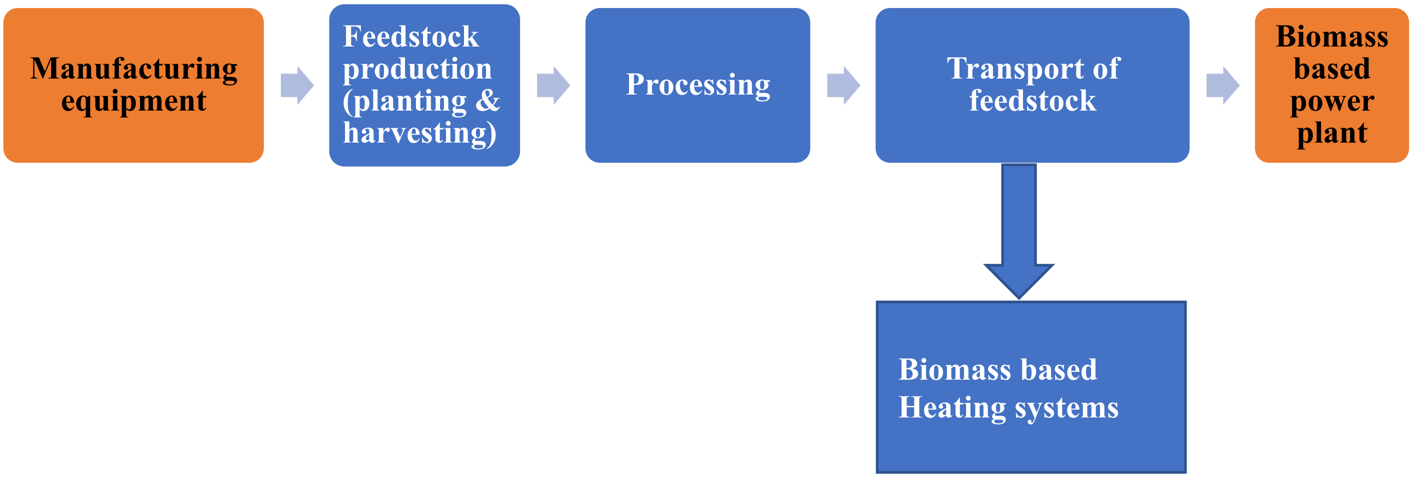
Liquid Biofuels

- Biofuel production – jobs/ Million Liters



Solid Biofuels

- Biomass power plants (O&M) - jobs/ GW (installed capacity)
- Biomass power plants (construction) - job years/ GW (new installation)
- Biomass (manufacturing) - job years/ GW

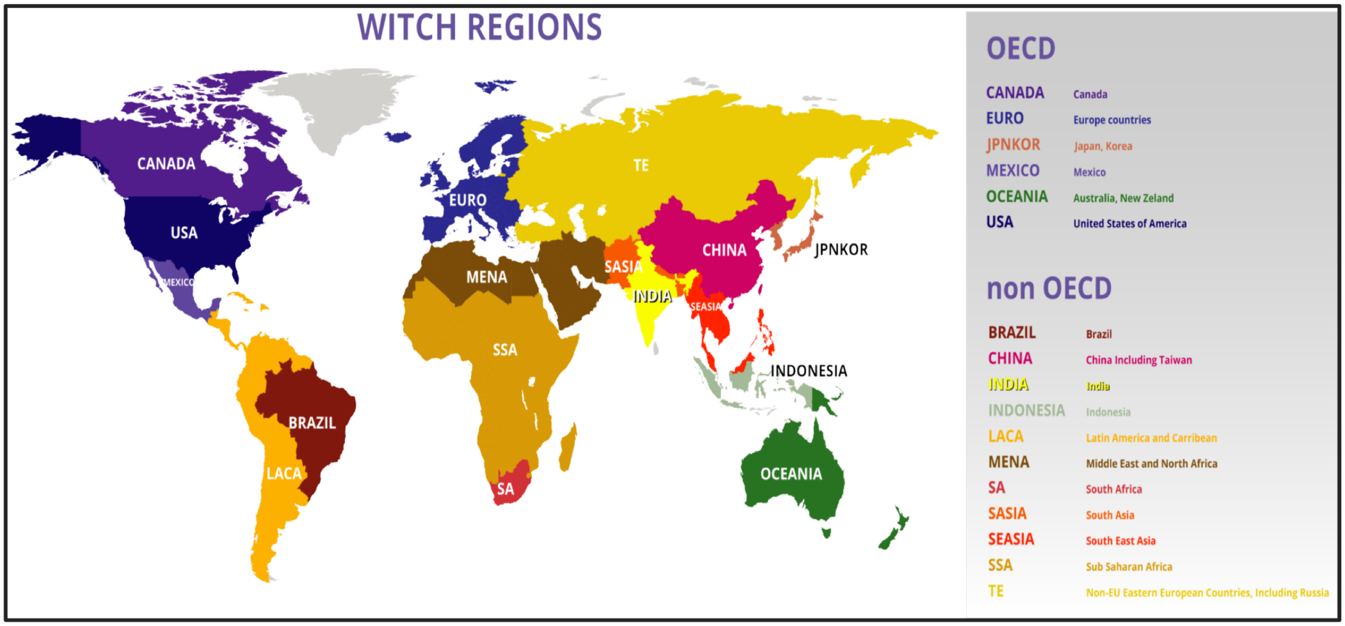


A.2 Energy technology wise construction & manufacturing years

Energy Technologies	**Construction & Manufacturing years**
Coal	5
Gas	2
Nuclear	10
Solid Biomass	2
Hydro (large & small)	2
Wind onshore	2
Wind offshore	4
Solar (PV & CSP)	1
Geothermal	2

Source: (Rutoviz et al, 2015)

A.3 World induced technical change hybrid (WITCH) regions



Appendix B Chapter 4 Assessing the feasibility of renewable jobs replacing local coal mining jobs

B.1 More on methods

This study was designed to quantify (1) the percentage of coal mining areas in top coal mining countries—China, India, the US and Australia— that are suitable for solar and/or wind power generation; (2) the percentage of provinces/states areas in key coal mining provinces/states suitable for solar or wind power generation.

I used geographic information system (GIS) tools to create the maps and analyze datasets used in the maps for quantifying the above. I created four different composite maps (placed in the main paper), one each for a particular country, plus eight additional maps, two for each country (**See Figure 1- 8, for the eight additional maps**). The four composite maps included country maps with existing coal mine/field locations, and solar and wind power resource potential. The eight additional maps included either solar or wind potential, coal mine/field locations, and either solar or wind power plants.

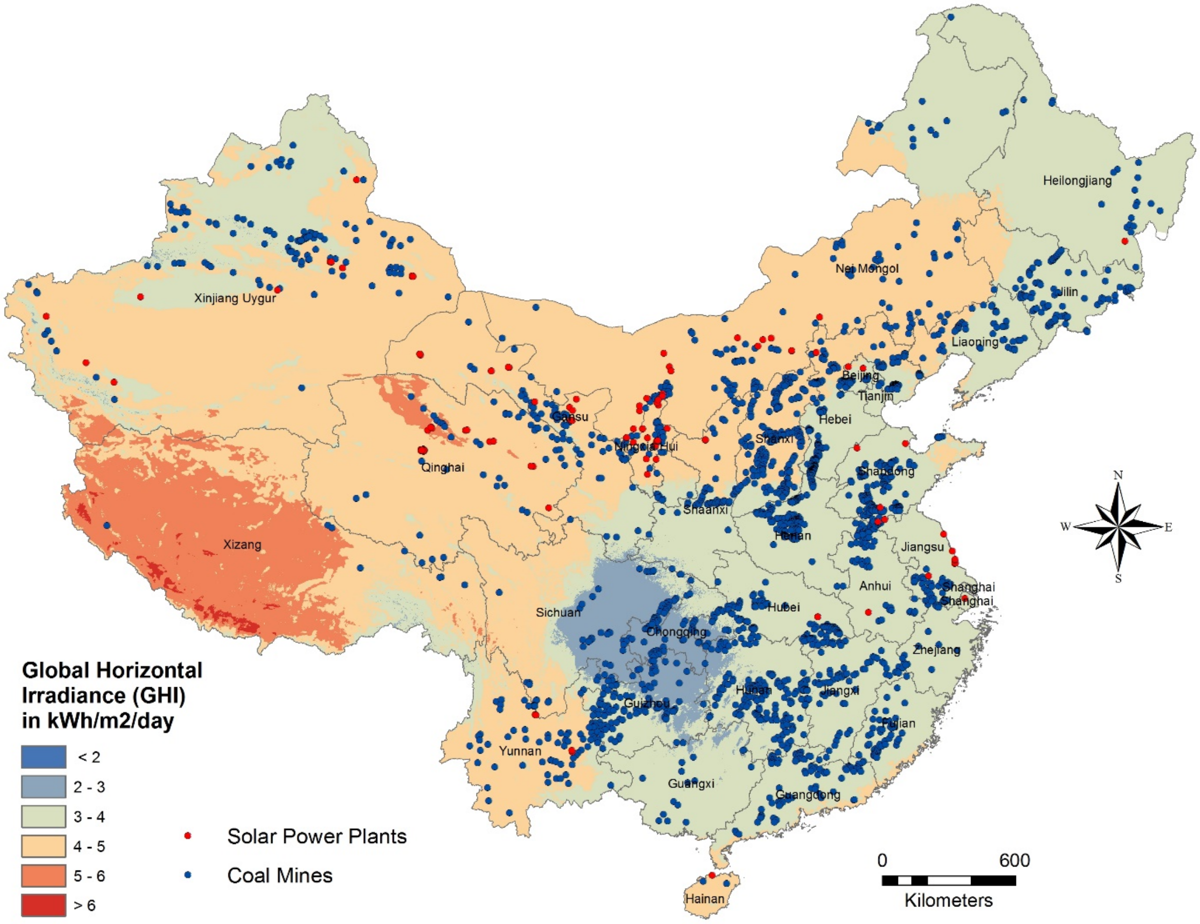


Figure 1 **Solar Potential, Coal Mines & Solar Power Plants in China**
Global Horizontal Irradiance greater than or equal to 4 kWh/m2/day is considered suitable for solar power projects. The blue points represent locations of coal mines, and red points represent locations of solar power plants in China. The map shows that Northern, and Western provinces in China have the best solar resources, while a large number of coal mines in Eastern and South-Central China are located in places not suitable for solar power generation.

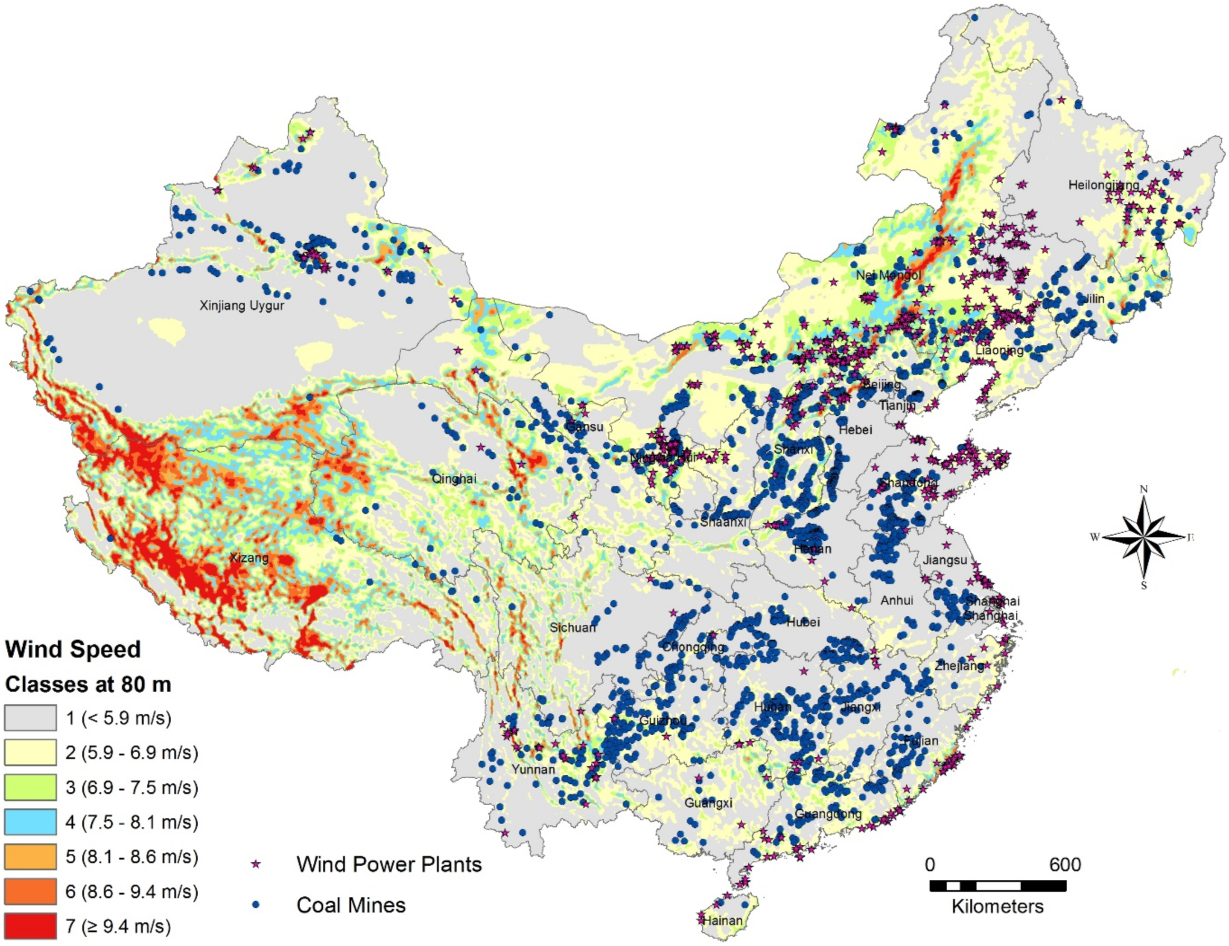


Figure 2 Wind Potential, Coal Mines & Wind Power Plants in China

Wind Speed Class of 3 and above are considered suitable for wind power plants. The blue points represent locations of coal mines, and red star points represent locations of wind power plants in China. The map shows that Northern, and South-Western provinces in China have the best wind resources, while a large number of coal mines in Eastern and South-Central China are located in places not suitable for wind power generation. It must be noted that within the provinces there are places with suitable wind resources.

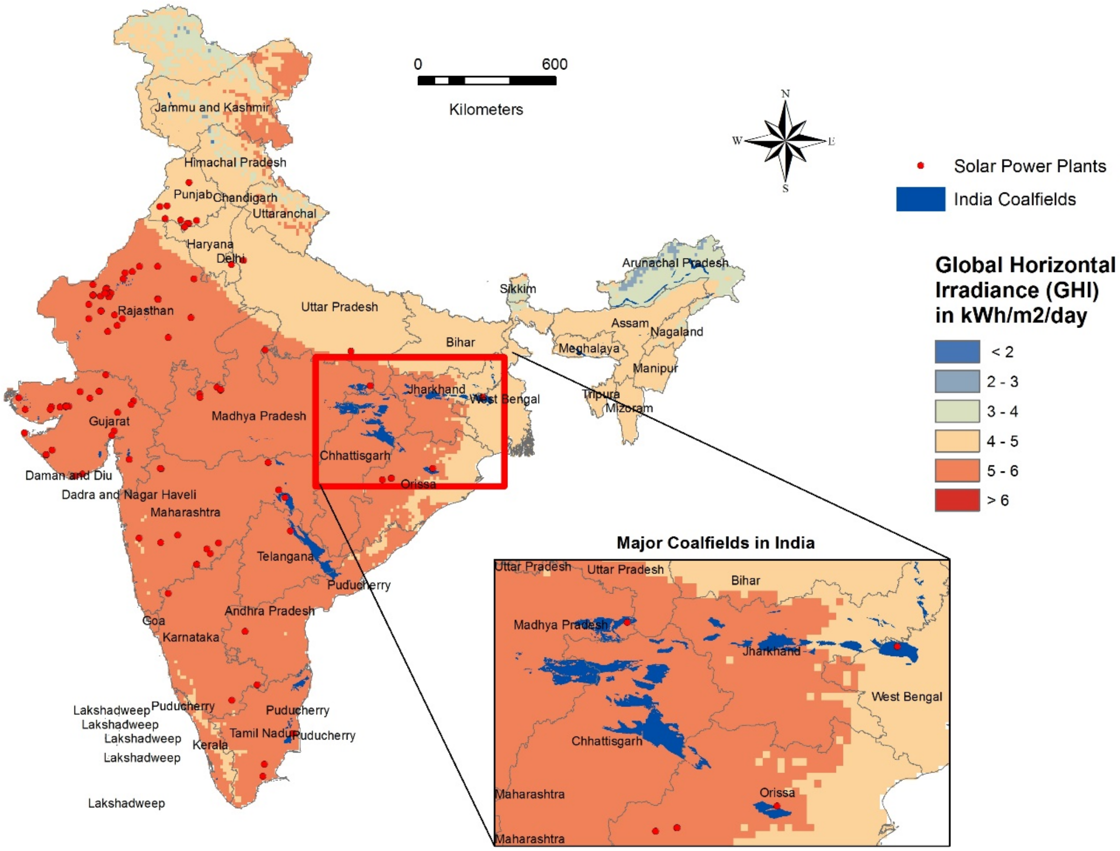


Figure 3 Solar Potential, Coalfields & Solar Power Plants in India
Global Horizontal Irradiance of greater than or equal to 4 kWh/m2/day is considered suitable for solar power projects. The areas in blue represent locations of coalfields in India, and red points represent locations of solar power plants in India. The map shows that all major coalfields in Eastern and Central India are in areas suitable for solar power generation.

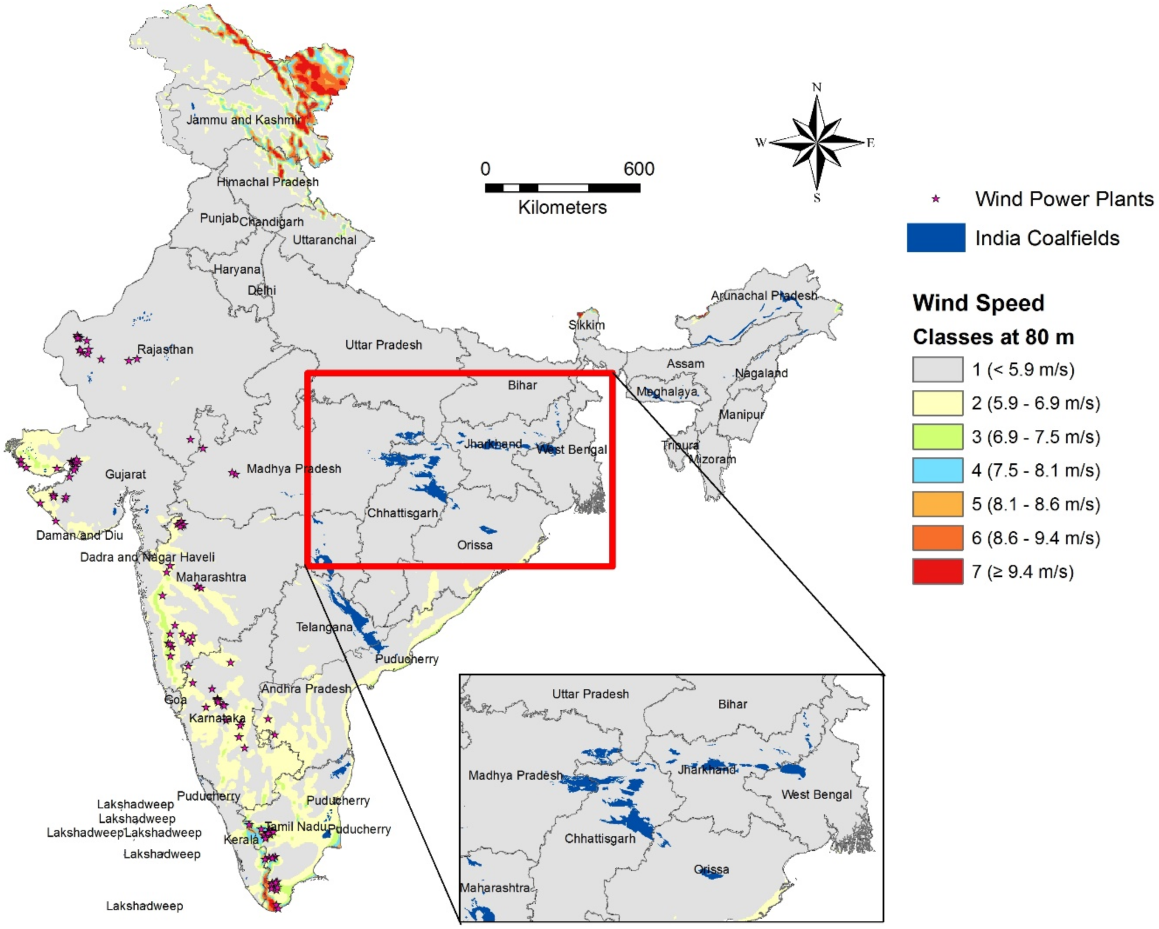


Figure 4 Wind Potential, Coalfields, & Wind Power Plants in India
Wind Speed Class of 3 and above are considered suitable for wind power plants. The areas in blue represent locations of coalfields in India, and red star points represent locations of wind power plants in India. The map shows that all major coalfields in Eastern and Central India are located in areas that are not suitable for wind power generation.

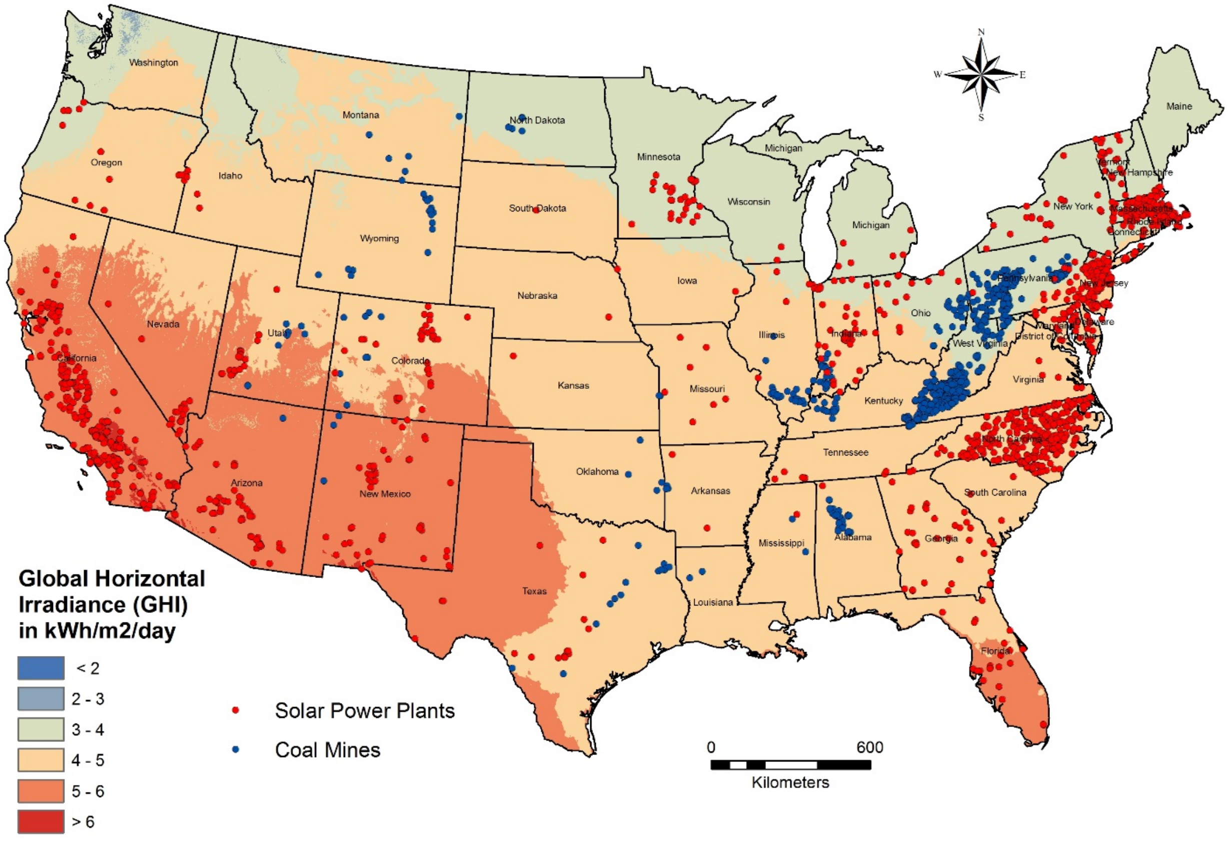


Figure 5 Solar Potential, Coal Mines & Solar Power Plants in the US

Global Horizontal Irradiance of greater than or equal to 4 kWh/m2/day is considered suitable for solar power projects. The blue points represent locations of coal mines, and red points represent locations of solar power plants in the US. The map shows that large parts of US are suitable for solar power generation. Except some mines in parts of Eastern US and North Dakota, most other coal mining areas are suitable for solar power generation.

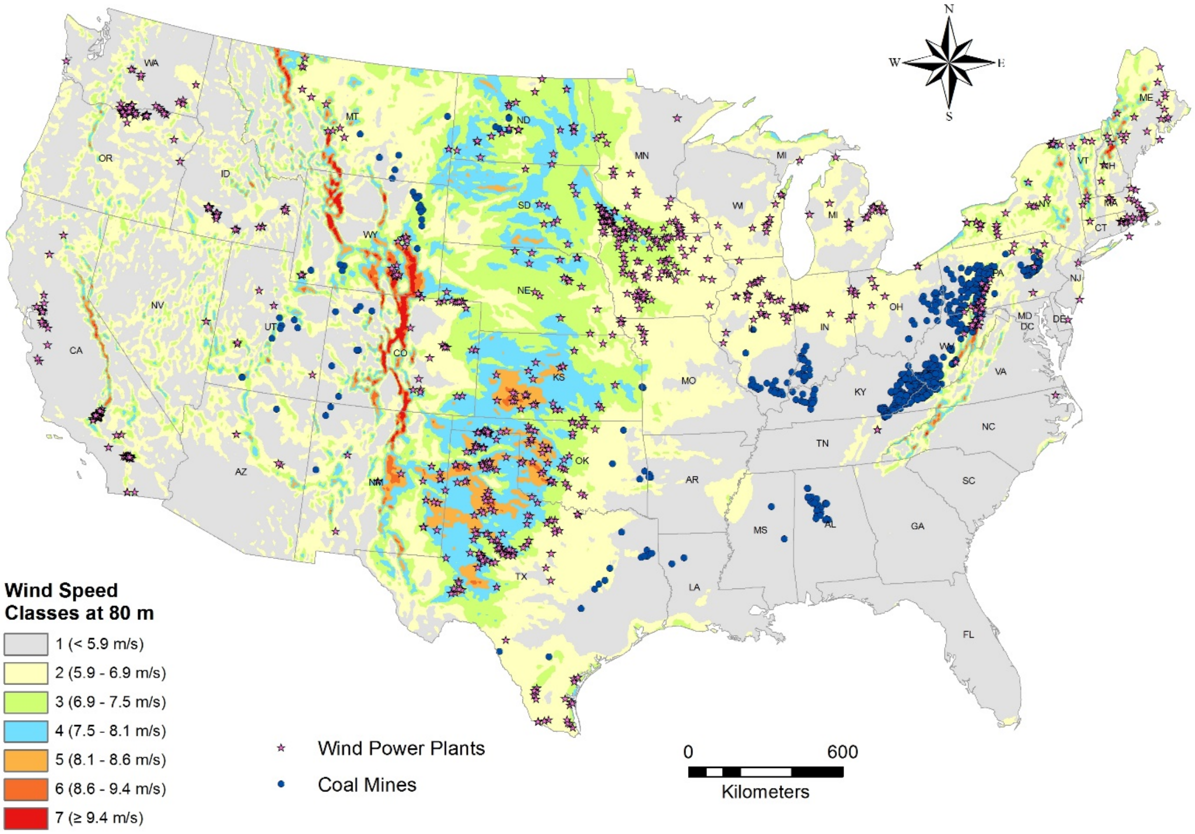


Figure 6 Wind Potential, Coal Mines, & Wind Power Plants in the US
Wind Speed Class of 3 and above are considered suitable for wind power plants. The blue points represent locations of coal mines, and red star points represent locations of wind power plants in the US. The map shows that middle part of US from North Dakota and Montana in the north to Texas in the south, several states have suitable wind resources for wind power generation. A large number of coal mines in Eastern and Central US are located in places not suitable for wind power generation. It must be noted that within the states there are places with suitable wind resources.

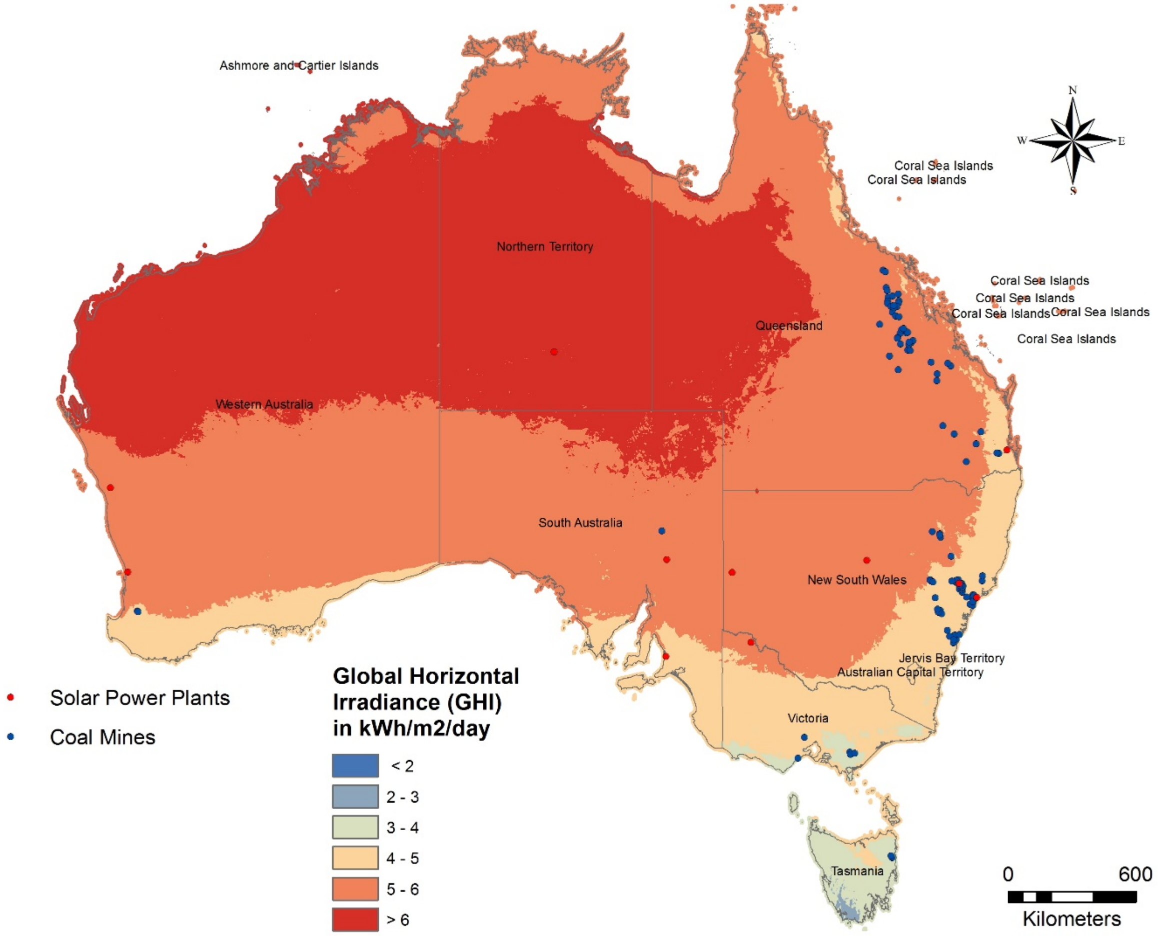


Figure 7 Solar Potential, Coal Mines & Solar Power Plants in Australia
Global Horizontal Irradiance of greater than or equal to 4 kWh/m2/day is considered suitable for solar power projects. The blue points represent locations of coal mines, and red points represent locations of solar power plants in Australia. The map shows that except parts of Victoria, and Tasmania, the entire country of Australia is suitable for solar power generation. Except for mines in Tasmania and some mines in Victoria, all other coal mines are located in optimal solar resource potential areas.

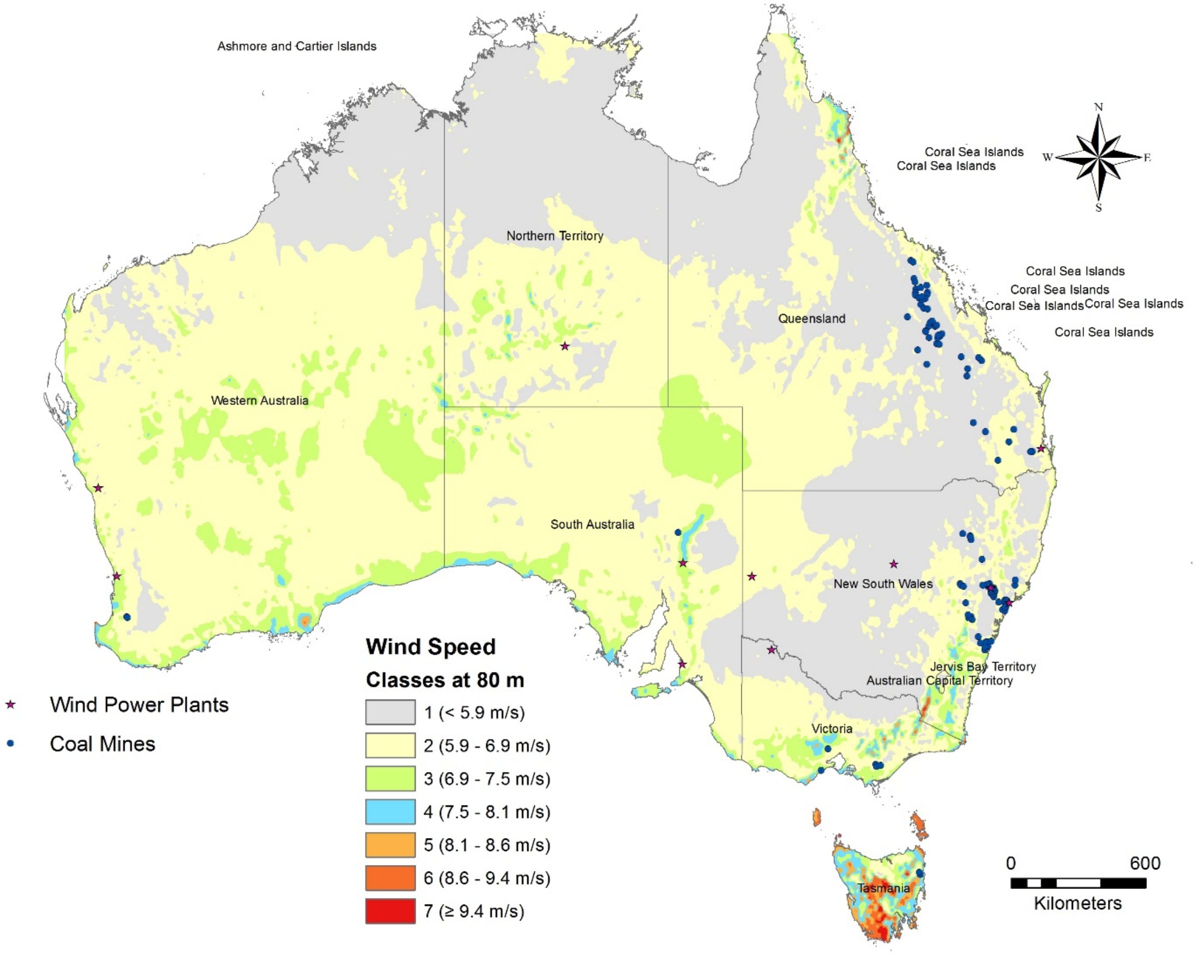


Figure 8 Wind Potential, Coal Mines, & Wind Power Plants in Australia
Wind Speed Class of 3 and above are considered suitable for wind power plants. The blue points represent locations of coal mines, and red star points represent locations of wind power plants in Australia. Coal mines in Queensland and New South Wales are located in places not suitable for wind power generation. It must be noted that within the states there are places with suitable wind resources.

- **Solar Potential Cut-offs**

I utilized Global Horizontal Irradiance (GHI) datasets for each country to map the spatial distribution of solar power resource potential. GHI is the total solar radiation that falls on a horizontal surface, and its average data measured over a large period of time is most commonly used for understanding the feasibility of solar power generation (Clifton et al., 2017; He &

Kammen, 2016; Mahtta et al., 2014; Ohtake et al., 2015). In this paper, I focused only on GHI as it is a fixed factor for an area as opposed to other factors such as land availability. Past studies have highlighted the fact that the greater the GHI value, the better the area is for setting up and running a solar power plant (Merrouni, Elalaoui, Mezrhab, Mezrhab, & Ghennioui, 2018; Anwarzai & Nagasaka, 2017; Clifton et al., 2017; He & Kammen, 2016; Niblick & Landis, 2016; Prasad, Taylor, & Kay, 2017). A utility-scale solar power plant will only be feasible if the average GHI value (for a long time period) of a site is greater than or equal to 4 kWh/m2/day (Mahtta et al., 2014). To check the validity of this hypothesis, I calculated the average GHI of the location of the existing utility-scale solar power plants. I found that all power plants in India and Australia, and over 80% of solar power plants in US and China are currently located in areas with GHI values greater than or equal to 4 kWh/m2/day (**See Table 1**). Thus, in line with previous research, this paper also considered areas greater than or equal to 4 kWh/m2/day GHI value as suitable for solar power generation (Mahtta et al., 2014).

Table 1: Existing solar plant locations in different GHI (in kWh/m2/day) range of values
All current solar power plants in India and Australia, and over 82% of solar power plants in the US and China are located in areas with GHI values greater than or equal to 4 kWh/m2/day

Countries	**GHI< 1**	**1 ≥ GHI < 2**	**2 ≥ GHI < 3**	**3 ≥ GHI < 4**	**4 ≥ GHI < 5**	**5 ≥ GHI < 6**	**GHI ≥ 6**
China	0%	0%	0%	14%	83%	3%	0%
India	0%	0%	0%	0%	13%	87%	0%
USA	0%	0%	0%	18%	47%	33%	2%
Australia	0%	0%	0%	0%	37%	54%	9%

The GHI data might have an error of 4-8% for a particular location depending on the region (The World Bank Group, 2016). Since the analysis done in this paper is for an area of 50 km radius, provincial and country level, I can largely ignore this error as the analysis entails a very large area.

- **Wind Potential Cut-offs**

The wind speed at hub-height 80 m has been extensively used by scholars to spatially analyze the suitability of wind power resources to produce globally, country-wide and within regions (Archer, 2005; Archer & Jacobson, 2003; Hallgren, Gunturu, & Schlosser, 2014; Holt & Wang, 2012; McElroy, Lu, Nielsen, & Wang, 2009; Wang, Ullrich, & Millstein, 2018). In line with prior studies, I also used datasets of wind speed at 80 m hub-height to create wind power potential maps. Wind potential is then divided into wind power classes (Class 1 -7) (Archer, 2005; Archer & Jacobson, 2003, 2007; Li, Zhong, Bian, & Heilman, 2010). Areas that fall under Class 1 (wind speed below 5.9 m/s) and Class 2 (wind speed between 5.9 – 6.9 m/s) are considered as unsuitable and marginal respectively for wind power generation **(Table 2).** On the other hand, according to the literature, wind speed Class 3 or higher (wind speed ≥ 6.9 m/s) are considered suitable for wind power generation (Archer, 2005; Li et al., 2010; Yu, Zhong, Bian, & Heilman, 2016). In this study, I only assessed the onshore wind power potential since all coal mining areas are located inland and thus leaving out the offshore wind potential has no impact on the analysis. I did not assess the location of wind power plants and their wind speed because: 1) I did not have adequate datasets for existing wind power plants especially in India and Australia, therefore any assessment will be incomplete; 2) the supplementary maps for wind (for each country) show that wind power resources vary a lot more than solar resources and are very location sensitive.

Table 2: Wind Speed Class at 80m
Wind class 3 and above are considered suitable for wind power generation (Archer, 2005; Archer & Jacobson, 2003, 2007).

Class	Wind Speed at 80m (m/s)	Suitability for Wind Power
1	**V < 5.9**	**Unsuitable**
2	**5.9 ≤ v < 6.9**	**Marginal**
3	6.9 ≤ v < 7.5	Suitable
4	6.9 ≤ v < 8.1	Suitable
5	6.9 ≤ v < 8.6	Suitable
6	6.9 ≤ v < 9.4	Suitable
7	v ≥ 9.4	Suitable

- **Solar/Wind Power Plants**

In order to plot the solar and wind power plants in the eight supplementary maps, I used the "The Global Power Plant Database," an open-source dataset that covers grid-scale (1 Mega Watt and greater) electricity generating facilities (Global Energy Observatory, Google, KTH Royal Institute of Technology in Stockholm, Enipedia, 2018). This dataset was last updated in June 2018, and it contains 28,500 operating power plants from 164 countries representing around 80% of the world's power capacity (Global Energy Observatory, Google, KTH Royal Institute of Technology in Stockholm, Enipedia, 2018). This dataset is suitable for our paper, as I analyzed utility-scale solar and wind power plants in our case study countries. The downloaded dataset was clipped in ArcGIS to generate solar and wind power plant datasets for each of my case study countries.

- **Local Coal Mining Level Analysis**

Once the maps were created using the ArcGIS software, I applied several SQL queries to find out the percentage of coal mining areas that are suitable for solar power generation (average GHI value of 4 kWh/m2/day or higher), and wind power generation (average wind speed at 80m greater than or equal to 6.9 m/s). First, I created a coal mine buffer area of 50 km radius around each mine point, in each case study country and calculated the average GHI and average wind speed for each of these coal mine buffer area **(see Figure 9, for mine buffer area example)**.

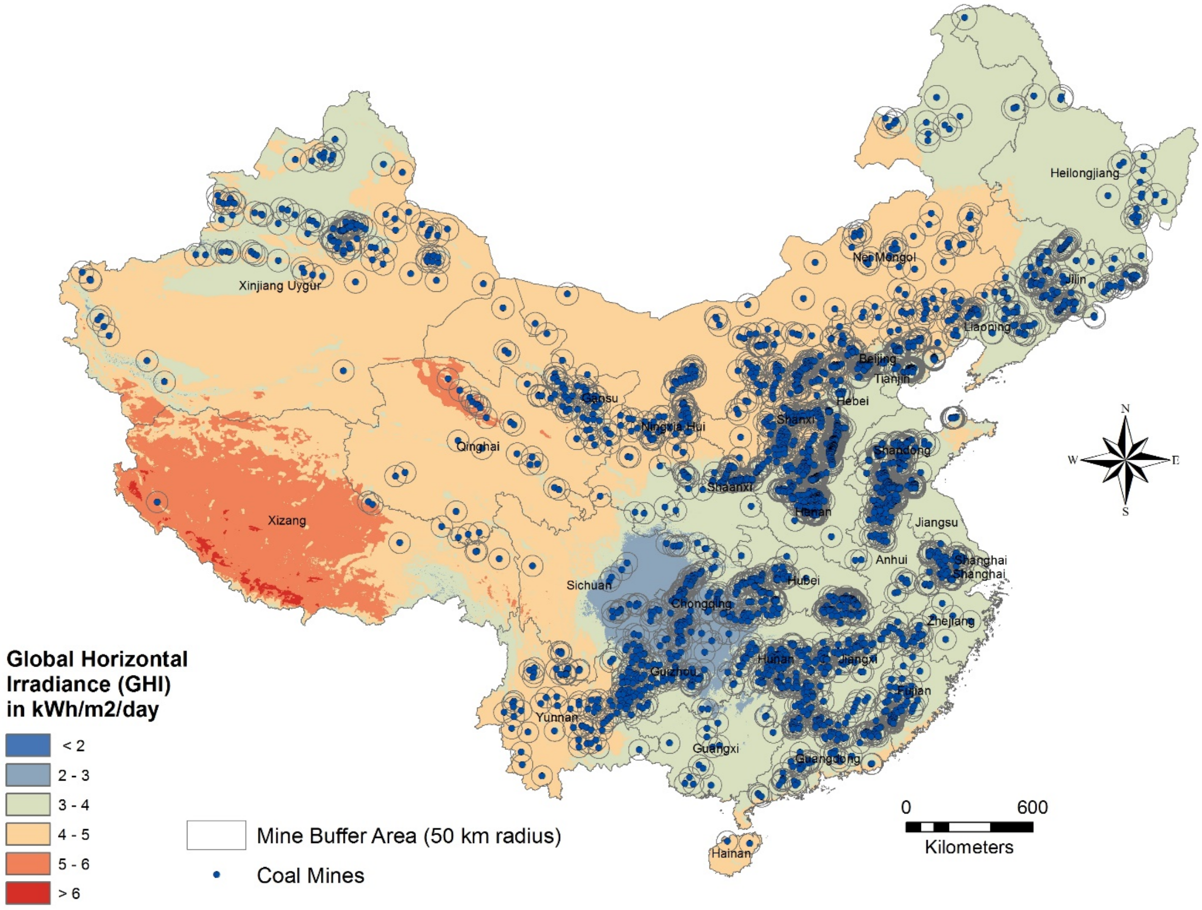


Figure 9: Solar Potential, Coal Mines & Coal Mine Buffer area of 50 km radius in China
Global Horizontal Irradiance of greater than or equal to 4 kWh/m2/day is considered suitable for solar power projects. The blue points represent locations of coal mines, and circles represent coal mine buffer area of 50 km radius for each mine point.

Next, I employed the geospatial modelling environment tool (an open source software) in ArcGIS to calculate the percentage of coal mine buffer areas (at country level and provincial/state level) that have average buffer area GHI value greater than or equal to 4 kWh/m2/day, and average buffer area wind speed value greater than or equal to 6.9 m/s (average wind speed at 80m greater than or equal to 6.9 m/s).

I conducted a similar analysis with a mine buffer area of a 20 km radius and the mine point itself and compared the outcome of this analysis with my results. Performing this sensitivity analysis was important for checking the validity of our results. In all countries, the mine buffer areas (of 50 km radius), mine buffer areas (of 20 km radius) and the mine points are in the same GHI range or Wind Class, with a few exceptions. The GHI range and wind classes are represented in the legends (**represented in Figure 1-9 maps)** For example, in China, 8.91% of mine points and 5.16% of mine buffer areas (with 50 km radius) have average Wind Speed greater than or equal to 6.9 m/s. A closer look at all the maps also shows that most of the mines points and their surrounding areas in the maps clearly fall in one wind speed or GHI range. Overall, there was an insignificant change of maximum 5.21%, when overall percentages of mine buffer areas (of 50 km radius), mine buffer areas (of 20 km radius) and mine points with suitable solar power generation or wind power generation were compared for each country **(Figure 10 & Figure 11)**

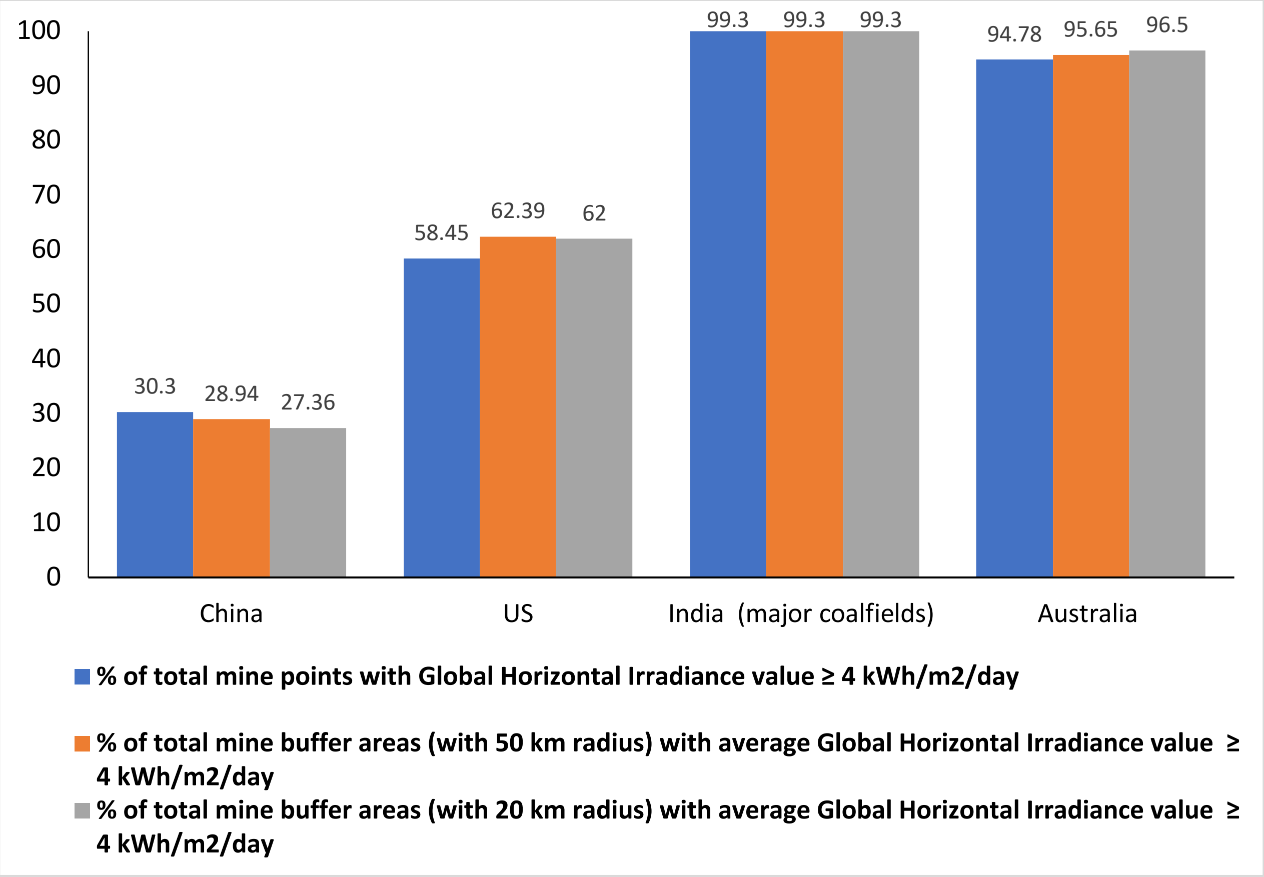


Figure 10: percentage of mine points, mine buffer areas (with 50 km radius), and mine buffer areas (with 20 km radius) with an average Global Horizontal Irradiance value ≥ 4 kWh/m2/day

The comparison shows that the difference between % of mine points, mine buffer areas (with 50 km radius), and mine buffer areas (with 20 km radius) having an average Global Horizontal Irradiance ≥ 4 kWh/m2/day is a maximum for 3.94% for any country.

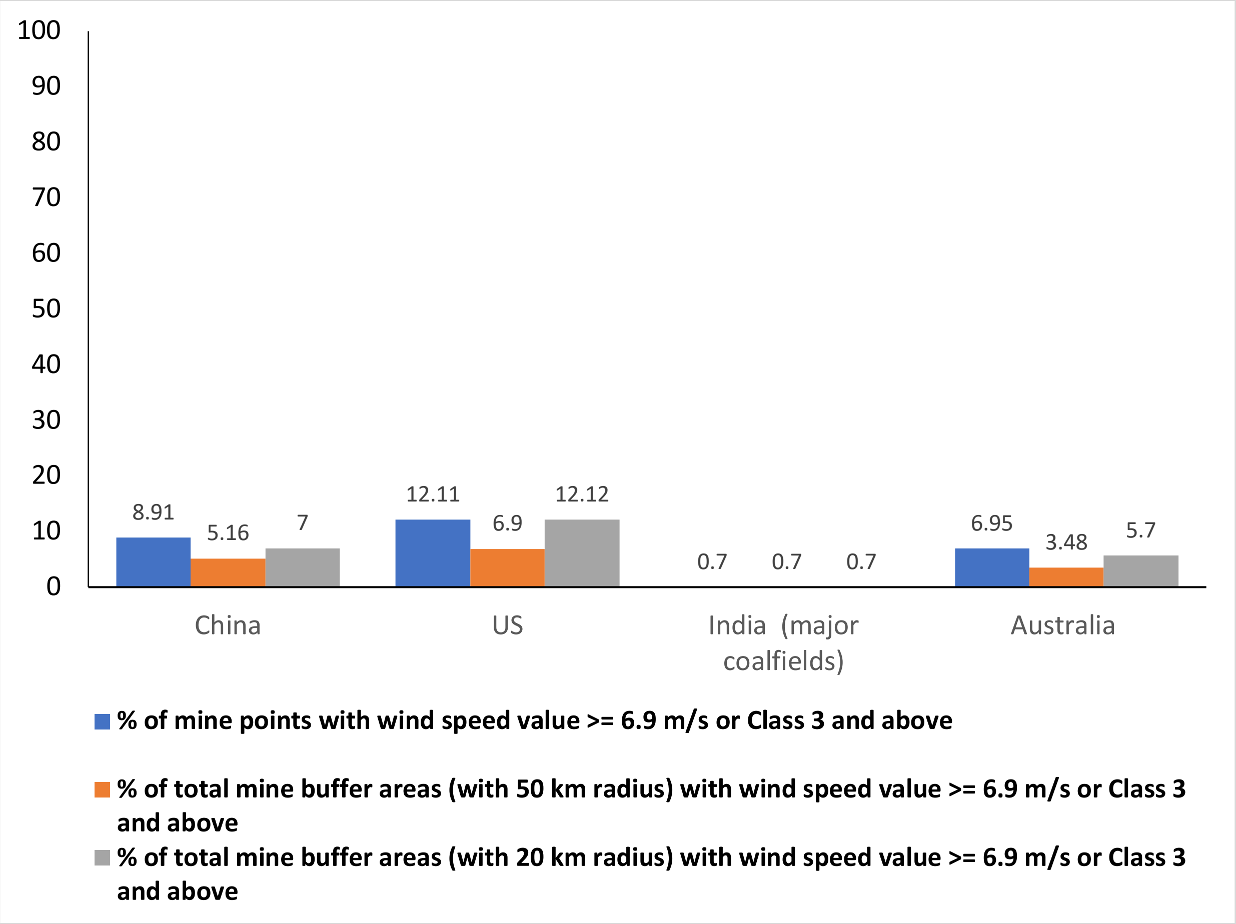


Figure 11: percentage of mine points, mine buffer areas (with 50 km radius), and mine buffer areas (with 20 km radius) with an average wind speed ≥ 6.9 m/s or class 3 and above
The comparison shows that the difference between % of mine points, mine buffer areas (with 50 km radius), and mine buffer areas (with 20 km radius) having an average wind speed ≥ 6.9 m/s or class 3 and above is a maximum of 5.22 % for any country.

I did not carry out either 50 km, 20 km or mine point radius level analysis for India because the datasets for mine point locations were not available. However, this did not affect our results as India’s solar resources are continuous and suitable, and the suitable wind resources just don’t fall within the state boundaries of coalfield areas. All the coalfield areas in top coal-producing states are located in suitable solar power generation areas, and no coalfield areas in top coal-producing states are suitable for wind power generation.

Appendix C Chapter 5 Assessing the socio-economic dependency on coal at a local level in India

C.1 Full results

The table below shows full results for all 284 districts.

Table 1: 284 Coal dependent districts
This table shows the coal dependency for all 284 districts. The values in the cell are normalized indicators—jobs per capita, pensioners per capita, DMF per capita and CSR per capita. The table also shows the 33 districts that fall within the top 10% of districts for coal jobs, coal pensioners, DMF collection, or CSR spending. Green cells show high jobs dependency, yellow high pensioners dependency, orange high DMF dependency, and blue high CSR dependency. The white cells indicate values that do not fall within the top 10% for a specific indicator. The table is arranged in the decreasing order of job dependency.

State Name	District Name	Jobs Normalized	Pensioners Normalized	DMF Normalized	CSR Normalized
Chhattisgarh	Korba	0.320715725	0.012316018	5.17864E-05	1.23747E-06
Jharkhand	Chatra	0.217438148	0.00191392	1.41771E-05	9.01427E-07
Odisha	Jharsuguda	0.194720099	0.010234597	3.99181E-05	3.47373E-06
Jharkhand	Dhanbad	0.183983566	0.026187871	1.36518E-05	3.48796E-06
Odisha	Angul	0.152406596	0.005191467	3.67968E-05	1.44588E-05
Telangana	Mancherial	0.120392526	0	1.13105E-05	5.99642E-09
West Bengal	Paschim Bardhaman	0.096548527	0.022708638	1.86147E-07	2.69412E-07
Telangana	Peddapalli	0.081343093	0	2.47846E-05	6.08467E-09
Telangana	Bhadradri Kothagudem	0.07879752	0	1.36431E-05	4.52587E-09
Jharkhand	Latehar	0.067904602	0.000584612	1.21247E-06	3.49722E-08
Madhya Pradesh	Singrauli	0.064835059	0	5.24227E-05	7.68461E-06
Jharkhand	Bokaro	0.060527902	0.011553922	6.27252E-06	1.54451E-07
Jharkhand	Ramgarh	0.058714333	0.000295963	1.9464E-05	5.8749E-07
Jharkhand	Godda	0.058410918	0.001086368	8.04007E-06	3.33621E-07
Chhattisgarh	Korea	0.057681984	0.013977481	8.16309E-06	2.62825E-08
Madhya Pradesh	Anuppur	0.045864313	0.0139582	1.75346E-05	1.59295E-07
Chhattisgarh	Raigarh	0.04005241	0.001561596	4.5702E-06	9.30851E-07

Maharashtra	Chandrapur	0.040023391	0.00215578	6.19941E-06	3.3361E-07
Jharkhand	Hazaribagh	0.03913079	0.010958233	4.13261E-06	3.33838E-08
Madhya Pradesh	Shahdol	0.030225943	0.004702349	3.85043E-06	0
Uttar Pradesh	Sonbhadra	0.029523467	0.000107379	5.91311E-06	3.00662E-06
Tamil Nadu	Cuddalore	0.027645325	0	2.67588E-06	1.92741E-06
Chhattisgarh	Bilaspur	0.026658308	0	0	4.93672E-07
Chhattisgarh	Bijapur	0.026658308	0	0	4.93672E-07
Odisha	Sundergarh	0.025311764	0.000123242	4.86855E-06	1.24886E-06
Chhattisgarh	Surguja	0.022070032	0.003173035	1.24072E-06	4.44937E-09
Maharashtra	Nagpur	0.019033612	0.00292743	2.31656E-06	2.83483E-07
Gujarat	Kutch	0.018813862	0	5.81312E-07	1.69415E-07
Madhya Pradesh	Betul	0.01749855	0.005670443	1.21785E-06	1.87157E-08
Madhya Pradesh	Umaria	0.016757512	0.00876608	4.34706E-06	9.77111E-09
Jharkhand	Ranchi	0.014994113	0.001655656	7.28955E-07	1.09894E-06
Telangana	Komaram Bheem	0.014694021	0	8.35963E-06	9.38197E-09
Telangana	Jayashankar Bhoopalpally	0.014500577	0	7.45748E-06	1.16117E-08
Maharashtra	Yavatmal	0.012362919	0.000667665	2.58271E-06	1.79523E-08
Chhattisgarh	Surajpur	0.011165678	0	2.99502E-06	2.04151E-07
Chhattisgarh	Janjgir Champa	0.009957356	0.002688758	0	0
Telangana	Karimnagar	0.009392857	0.02453687	2.86094E-06	2.32472E-06
Madhya Pradesh	Chhindwara	0.008925684	0.008078254	1.55191E-06	7.80574E-08
Chhattisgarh	Balrampur	0.008715111	0	1.36839E-06	8.04938E-08
Rajasthan	Baran	0.008439467	0	0	0
Haryana	Jhajjar	0.008341672	0	0	0
Punjab	Mansa	0.007292358	0	0	0
Maharashtra	Gondia	0.007074065	4.08315E-05	0	0
Rajasthan	Barmer	0.006833584	0	4.95206E-07	0
Maharashtra	Raigad	0.006667489	1.13887E-06	0	0
Tamil Nadu	Thoothukudi	0.006314793	0	0	0
Madhya	Sidhi	0.005974204	0.005290883	0	0

Pradesh					
Jharkhand	Deoghar	0.005710176	0.004270569	1.72777E-06	5.73953E-08
Andhra Pradesh	Nellore	0.005610432	5.05718E-06	0	0
Madhya Pradesh	Khandwa	0.005453334	0	0	0
Odisha	Sambalpur	0.005081258	0.00051388	7.82635E-08	1.24011E-06
Karnataka	Raichur	0.004931235	0	0	0
Telangana	Khammam	0.004863949	0.024544836	1.75794E-06	3.45262E-09
Telangana	Adilabad	0.004798497	0.001114289	0	0
Andhra Pradesh	Visakhapatnam	0.004743555	4.25432E-05	0	1.13885E-06
Uttar Pradesh	Lalitpur	0.004595069	0	0	0
Andhra Pradesh	Kadapa	0.004393079	0	0	0
Jharkhand	Koderma	0.003958065	0.000642226	0	0
Gujarat	Tapi	0.003899336	0	0	0
Punjab	Rupnagar	0.00347839	4.08982E-05	0	0
Odisha	Dhenkanal	0.003432011	0.000264082	0	0
Telangana	Nalgonda	0.003347905	2.29305E-06	0	0
Andhra Pradesh	Krishna	0.003245181	8.51345E-05	0	0
Karnataka	Bellary	0.003230792	0	0	0
Haryana	Panipat	0.003198508	0	0	0
Tamil Nadu	Tiruvallur	0.003168501	0	0	7.51052E-10
Uttar Pradesh	Gautam Buddha Nagar	0.003130667	0	0	8.00866E-07
Rajasthan	Sri Ganganagar	0.003110197	0	0	0
Karnataka	Udupi	0.002889513	0	0	5.8694E-08
Gujarat	Kheda	0.002798162	0	0	0
Rajasthan	Bikaner	0.002601404	0	1.9674E-07	0
Madhya Pradesh	Narsinghpur	0.002542922	0	0	1.03732E-06
West Bengal	Purulia	0.002451829	0.001673313	2.86678E-10	2.16361E-07
West Bengal	Bankura	0.002449631	0.000757922	3.76014E-08	0
Rajasthan	Jhalawar	0.002410836	0	0	0
Assam	Kokrajhar	0.002396741	0	0	3.78744E-07
Gujarat	Surat	0.002257139	0	1.87393E-07	1.20862E-07
Gujarat	Jamnagar	0.002231127	0	0	0
Rajasthan	Kota	0.002188354	0	0	0
Bihar	Bhagalpur	0.002183809	0.000328531	0	1.75129E-07

Telangana	Warangal Rural	0.002166903	0	0	0
Maharashtra	Ratnagiri	0.002106412	0	0	0
Punjab	Patiala	0.002093701	0	0	0
Madhya Pradesh	Khargone	0.001997922	0	0	6.04683E-07
Haryana	Hisar	0.001950765	0	0	0
Punjab	Bathinda	0.001878396	0	0	0
Jharkhand	East Singhbhum	0.001655894	0.000300864	0	2.35952E-07
Gujarat	Bharuch	0.001649773	0	1.46588E-07	0
Uttar Pradesh	Jhansi	0.00161708	0	0	0
Bihar	Aurangabad	0.001573183	0.00136374	0	2.09443E-07
West Bengal	Murshidabad	0.001476603	7.12294E-05	0	7.67282E-08
Telangana	Warangal Urban	0.001423424	0.000501901	0	0
Haryana	Yamunanagar	0.001400917	0	0	0
West Bengal	Purba Medinipur	0.001368578	0	0	3.41217E-09
Punjab	Tarn Taran	0.00136733	0	0	0
Maharashtra	Amravati	0.001325021	2.76966E-06	0	0
Uttar Pradesh	Ambedkar Nagar	0.001302396	4.62907E-05	0	5.48116E-07
Uttar Pradesh	Raebareli	0.001290317	6.75366E-06	0	3.82316E-07
Uttar Pradesh	Prayagraj	0.001256804	0.000347811	0	2.20731E-07
Gujarat	Gandhinagar	0.00124257	0	0	0
Madhya Pradesh	Seoni	0.001233385	9.13619E-05	0	0
Uttar Pradesh	Shahjahanpur	0.001216399	0	0	0
Tamil Nadu	Salem	0.001196836	2.87187E-07	0	0
West Bengal	Birbhum	0.001135891	0.000605299	2.05459E-08	2.01502E-08
Chhattisgarh	Raipur	0.001114433	0.000376734	0	0
Jharkhand	Palamu	0.001113334	0.001636193	3.84954E-07	0
Maharashtra	Nashik	0.001049108	0	0	0
Gujarat	Bhavnagar	0.001022419	0	5.22989E-08	0
Assam	Tinsukia	0.000980534	0.000958636	8.78842E-07	2.97621E-08
Maharashtra	Solapur	0.0008667	0	0	1.03758E-07
Maharashtra	Beed	0.000822518	0	0	0
Maharashtra	Jalgaon	0.000810973	0	0	0
Maharashtra	Akola	0.000781463	0	0	3.14901E-08
Bihar	Begusarai	0.000687148	0.000143745	0	1.79092E-07
Bihar	Patna	0.000641264	0.000545863	0	9.11198E-08
Madhya Pradesh	Sagar	0.000595974	0.000145472	0	0

Chhattisgarh	Durg	0.000474779	0.000140556	0	3.99731E-07
Uttar Pradesh	Aligarh	0.000470346	0	0	0
Rajasthan	Nagaur	0.000439067	0	4.02933E-08	0
Odisha	Jajpur	0.000434437	5.69179E-05	0	0
Rajasthan	Chittorgarh	0.000429563	0	0	0
Odisha	Rayagada	0.000424703	0	0	0
Odisha	Jagatsinghpur	0.000423889	3.69403E-05	0	0
Jharkhand	Giridih	0.000406563	0.003979188	2.62428E-07	1.29496E-08
Odisha	Cuttack	0.00039752	6.13457E-05	0	0
Rajasthan	Rajsamand	0.000392185	0	0	0
Bihar	Muzaffarpur	0.000360202	0.000138094	0	1.10809E-07
Rajasthan	Ajmer	0.000329262	0	0	0
Gujarat	Anand	0.00029803	0	0	0
Jharkhand	Pakur	0.000279869	0.000448679	5.22733E-07	5.8306E-07
West Bengal	South 24 Parganas	0.000260507	0.000202157	0	0
Maharashtra	Mumbai Suburban	0.000227237	0	0	3.78841E-08
Tamil Nadu	Ramanathapuram	0.000209465	1.69937E-05	0	0
Maharashtra	Dhule	0.000207352	0	0	0
Odisha	Bhadrak	0.000188205	0	0	0
Gujarat	Ahmedabad	0.000178803	0	0	1.18571E-07
West Bengal	Purba Bardhaman	0.000175886	0.000387548	0	0
West Bengal	Hooghly	0.00016951	0.000218693	0	8.80209E-10
Odisha	Kalahandi	0.000161808	2.60009E-05	0	0
Maharashtra	Thane	0.000135853	4.97281E-06	0	0
Uttarakhand	Nainital	0.000127702	0	0	0
Uttar Pradesh	Pilibhit	0.000125627	0	0	0
Tamil Nadu	Karur	0.00010653	0	0	0
Gujarat	Junagadh	9.30158E-05	0	0	0
West Bengal	Kolkata	8.51125E-05	0.00063202	0	1.99507E-08
Uttar Pradesh	Etah	8.11505E-05	0	0	0
Tamil Nadu	Erode	7.55414E-05	4.441E-07	0	0
Uttar Pradesh	Gonda	7.43029E-05	0	0	0
Rajasthan	Udaipur	7.39143E-05	0	0	0
West Bengal	North 24 Parganas	6.79735E-05	0	0	2.7651E-09
Uttar Pradesh	Lakhimpur Kheri	6.34505E-05	0	0	0
Uttar Pradesh	Kanpur Nagar	6.18824E-05	2.3356E-05	0	0

Odisha	Kendujhar	4.72046E-05	1.27655E-05	0	0
Andhra Pradesh	West Godavari	4.69183E-05	3.20963E-05	0	0
Maharashtra	Parbhani	4.63214E-05	0	0	0
Uttar Pradesh	Mirzapur	4.31443E-05	0.000163799	0	0
Andhra Pradesh	East Godavari	3.66084E-05	3.11432E-05	0	0
Maharashtra	Pune	2.7059E-05	1.50593E-05	0	3.7593E-08
Maharashtra	Kolhapur	2.63313E-05	0	0	0
Jharkhand	West Singhbhum	0	6.66981E-05	0	0
Bihar	West Champaran	0	0.000244724	0	0
Andhra Pradesh	Vizianagaram	0	0.00011025	0	0
Tamil Nadu	Vellore	0	2.03235E-06	0	0
Uttar Pradesh	Varanasi	0	0.000360636	0	4.80864E-08
Bihar	Vaishali	0	0.000143061	0	0
Gujarat	Vadodara	0	0	0	2.18455E-08
Uttar Pradesh	Unnao	0	5.79082E-05	0	0
Madhya Pradesh	Ujjain	0	5.03306E-07	0	0
Tamil Nadu	Tiruchirappalli	0	1.46935E-06	0	0
Kerala	Thrissur	0	3.2039E-07	0	0
Bihar	Supaul	0	3.58893E-05	0	0
Uttar Pradesh	Sultanpur	0	9.16485E-05	0	0
Andhra Pradesh	Srikakulam	0	0.000462742	0	0
Delhi	South Delhi	0	0	0	1.27807E-08
Bihar	Siwan	0	0.000446785	0	0
Bihar	Sitamarhi	0	6.22157E-05	0	0
Jharkhand	Simdega	0	8.83955E-05	0	0
Uttar Pradesh	Siddharthnagar	0	4.9623E-05	0	0
Bihar	Sheikhpura	0	0.002223647	0	0
Jharkhand	Seraikela Kharsawan	0	9.1075E-05	0	3.32828E-07
Madhya Pradesh	Satna	0	0.00011934	0	1.58282E-07
Bihar	Saran	0	0.000631601	0	0
Uttar Pradesh	Sant Kabir Nagar	0	0.000453596	0	0
Bihar	Samastipur	0	0.000232778	0	0
Jharkhand	Sahebganj	0	0.00011038	0	0
Bihar	Saharsa	0	0.000137321	0	0

Bihar	Rohtas	0	0.000263183	0	0
Madhya Pradesh	Rewa	0	0.000254534	0	0
Madhya Pradesh	Raisen	0	2.55333E-05	0	0
Bihar	Purnia	0	1.22526E-06	0	0
Odisha	Puri	0	1.35395E-05	0	0
Puducherry	Puducherry	0	8.41849E-06	0	0
Rajasthan	Pratapgarh	0	0.000725934	0	0
Andhra Pradesh	Prakasam	0	2.91545E-05	0	0
West Bengal	Paschim Medinipur	0	4.92098E-05	0	0
Delhi	New Delhi	0	0.001711219	0	0
Odisha	Nayagarh	0	9.14011E-05	0	0
Bihar	Nawada	0	0.000697566	0	0
Chhattisgarh	Narayanpur	0	0	0	1.95251E-07
Bihar	Nalanda	0	0.000209546	0	0
West Bengal	Nadia	0	5.28292E-05	0	0
Karnataka	Mysore	0	2.66567E-06	0	0
Uttar Pradesh	Muzaffarnagar	0	1.93073E-06	0	0
Bihar	Munger	0	0.000543953	0	0
Odisha	Mayurbhanj	0	5.19895E-05	0	0
Uttar Pradesh	Mau	0	0.001209446	0	0
Odisha	Malkangiri	0	2.93546E-05	0	0
West Bengal	Malda	0	1.65461E-05	0	0
Uttar Pradesh	Maharajganj	0	0.000767683	0	0
Tamil Nadu	Madurai	0	3.94964E-06	0	0
Bihar	Madhubani	0	8.69104E-05	0	0
Bihar	Madhepura	0	4.59595E-05	0	0
Uttar Pradesh	Lucknow	0	1.52511E-06	0	0
Jharkhand	Lohardaga	0	0.000186232	0	0
Bihar	Lakhisarai	0	0.001463665	0	0
Uttar Pradesh	Kushi nagar	0	0.001505943	0	0
Odisha	Koraput	0	5.79858E-06	0	0
Kerala	Kollam	0	3.79453E-07	0	0
Jharkhand	Khunti	0	1.31607E-05	0	0
Odisha	Khordha	0	0.000157216	0	3.67895E-08
Bihar	Khagaria	0	0.00037795	0	0
Odisha	Kendrapara	0	5.34588E-05	0	0

Madhya Pradesh	Katni	0	0.000160212	0	0
Kerala	Kasaragod	0	2.29467E-06	0	0
Punjab	Kapurthala	0	3.68022E-05	0	0
Kerala	Kannur	0	0	0	2.91985E-08
Bihar	Kaimur	0	0.000256397	0	0
Rajasthan	Jhunjhunu	0	1.77816E-05	0	0
Bihar	Jehanabad	0	0.000580283	0	0
Uttar Pradesh	Jaunpur	0	0.000304837	0	0
Bihar	Jamui	0	0.002686314	0	0
Jharkhand	Jamtara	0	0.003109822	0	1.76982E-09
Rajasthan	Jaipur	0	1.38843E-05	0	0
Madhya Pradesh	Jabalpur	0	0.000194455	0	0
Madhya Pradesh	Indore	0	2.38045E-05	0	0
Telangana	Hyderabad	0	4.74305E-05	0	0
West Bengal	Howrah	0	8.1649E-05	0	0
Maharashtra	Hingoli	0	0	0	1.4864E-08
Haryana	Gurugram	0	9.9047E-06	0	0
Andhra Pradesh	Guntur	0	5.20279E-05	0	0
Jharkhand	Gumla	0	0.000100467	0	0
Uttar Pradesh	Gorakhpur	0	0.000725079	0	0
Bihar	Gopalganj	0	0.000365338	0	0
Uttar Pradesh	Ghazipur	0	0.001423375	0	0
Uttar Pradesh	Ghaziabad	0	1.068E-06	0	0
Bihar	Gaya	0	0.000710249	0	0
Jharkhand	Garhwa	0	0.000501972	0	0
Odisha	Ganjam	0	0.005355861	0	0
Odisha	Gajapati	0	0.000413626	0	0
Haryana	Faridabad	0	2.59707E-05	0	0
Kerala	Ernakulam	0	2.46772E-05	0	0
Meghalaya	East Khasi Hills	0	0	0	1.14858E-07
Bihar	East Champaran	0	5.84386E-05	0	0
Jharkhand	Dumka	0	0.000376104	0	1.05945E-10
Madhya Pradesh	Dindori	0	6.52923E-05	0	0
Assam	Dibrugarh	0	2.41266E-05	0	0
Karnataka	Dharwad	0	0	0	2.84241E-07
Madhya	Dewas	0	6.39503E-07	0	0

Pradesh					
Uttar Pradesh	Deoria	0	0.000798788	0	0
Uttarakhand	Dehradun	0	5.89381E-07	0	2.43992E-08
West Bengal	Darjeeling	0	3.79029E-05	0	0
Bihar	Darbhanga	0	0.000404329	0	0
West Bengal	Dakshin Dinajpur	0	1.55106E-05	0	0
Tamil Nadu	Coimbatore	0	2.89181E-07	0	0
Andhra Pradesh	Chittoor	0	9.56938E-05	0	0
Tamil Nadu	Chennai	0	2.49638E-05	0	0
Uttar Pradesh	Chandauli	0	0.000699524	0	0
Bihar	Buxar	0	0.000935329	0	0
Maharashtra	Buldhana	0	1.08265E-05	0	0
Madhya Pradesh	Bhopal	0	0.000184306	0	5.90453E-09
Bihar	Bhojpur	0	0.000788372	0	0
Madhya Pradesh	Bhind	0	4.28654E-05	0	0
Uttar Pradesh	Basti	0	9.21093E-05	0	0
Bihar	Banka	0	0.000572548	0	0
Karnataka	Bangalore Urban	0	2.23457E-05	0	0
Uttar Pradesh	Ballia	0	0.001846116	0	0
Odisha	Balasore	0	0.000214722	0	0
Madhya Pradesh	Balaghat	0	3.1733E-05	0	0
Karnataka	Bagalkot	0	0	0	1.85209E-07
Uttar Pradesh	Azamgarh	0	0.00047075	0	0
Maharashtra	Aurangabad	0	0	0	3.06002E-07
Bihar	Arwal	0	0.000809026	0	0
Bihar	Araria	0	3.91241E-06	0	0
Punjab	Amritsar	0	4.81801E-06	0	0