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India's just energy transition: Political economy challenges across states and regions☆

Jose Antonio Ordonez [a,b,d,*], Michael Jakob [a], Jan Christoph Steckel [a,c,f], Hauke Ward [a,e]

[a] Mercator Research Institute on Global Commons and Climate Change (MCC Berlin), Torgauer Straße 12–15, 10829, Berlin, Germany
[b] Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Str. 48, 76139, Karlsruhe, Germany
[c] Potsdam Institute for Climate Impact Research (PIK), Telegrafenberg, 14473 Potsdam, Germany
[d] European Commission, Joint Research Centre (JRC), Calle Inca Garcilaso 3, 41092 Seville, Spain
[e] Institute of Environmental Science (CML), Department of Industrial Ecology, Leiden University, Einsteinweg 2, 2333, CC Leiden, the Netherlands
[f] Department Climate- and Development Economics, Brandenburg University of Technology Cottbus-Senftenberg, Erich-Weinert-Straße 1, 03046 Cottbus, Germany

A B S T R A C T

To comply with international climate targets, India will eventually need to phase out coal-fired power plants and substantially increase the use of solar-PV and wind power. Winners and losers of this transformation will not be distributed equally across the country, which potentially holds severe implications for the feasibility of the transformation. In an effort to understand political economy constraints from adversely impacted key societal groups, we discuss how Indian states would be affected in terms of distributional implications for households, industrial competitiveness and employment. We examine the effects of phasing-out of energy subsidies and carbon pricing (USD 40 per ton CO_2) on household incomes. We likewise analyze employment effects of ramping-up renewables and phasing-out of coal-fired power plants. Finally, we assess the impacts of carbon pricing on key industries. Our findings suggest that adverse impacts are strongly concentrated in Eastern, less wealthy, coal- mining states, which would face employment losses with pressure on poor households and energy intensive industries. Employment creation through deployment of renewables would, however, be more dispersed across India's Western and Central states. Complementary policies, such as recycling carbon tax revenues, will be necessary to avoid deepening regional disparities and increase acceptance from adversely impacted regions.

1. Introduction

India's role in global climate change mitigation is paramount. With more than 1.4 billion inhabitants, soon to be the most populous country in the world, it ranks as the third largest emitter of greenhouse gas (GHG) emissions, behind only China and the US. At the same time, around 19% of the population, i.e. 275 million inhabitants, still live below the national poverty line (World Bank, 2022) . India's emissions of 1.7 tonnes CO_2 per capita are about one third of the world average and 10 times lower than those of the USA (Enerdata, 2021).

India's energy sector is largely determined by coal use, which accounted for about 70% of India's total of 2.2 Gt CO_2 energy-related emissions in 2020. In the power sector, coal represented 97% of the total 0.9 Gt of CO_2 emissions (Enerdata, 2021). As an emerging economy with a sustained GDP growth of 7% in the last 10 years, and a growing population, India's electricity demand is projected to more than double in the next two decades (IEA, 2015). Indian CO_2 emissions from energy combustion comprise around 8% of global energy-related emissions and the future development of its electricity sector will substantially challenge the global carbon budget and the ability to remain within a 1.5 °C or 2 °C global warming threshold (IEA, 2021, 2015; Yang and Urpelainen, 2019). To achieve international targets, global coal use without CCS must be phased out by the second half of the century (Luderer et al., 2018; Tong et al., 2019). India's power sector, which has experienced a massive expansion of coal-fired power plants during the last decade, is no exception (Yang and Urpelainen, 2019).

International climate diplomacy has recently shifted attention to the phase-out of the use of coal, *inter alia* prominently highlighted by the Glasgow Declaration (United Nations, 2022). International financial assistance from developed to emerging economies has been mobilized, conditional on agreements to phase out coal use. South Africa, Indonesia and Vietnam have closed Just Energy Transition Agreements, securing 9, 20 and 15 billion USD, respectively, including loans and grants to restrain their coal use. Germany has offered India 10 billion USD to support the achievement of her climate goals (Times of India, 2022). Well positioned to secure larger sums of international finance, further negotiations are underway.

In our broad perspective of an energy transition, phasing out coal use

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* Corresponding author. Mercator Research Institute on Global Commons and Climate Change (MCC Berlin), Torgauer Straße 12–15, 10829, Berlin, Germany.
E-mail address: Jose.ORDONEZ@ec.europa.eu (J.A. Ordonez).

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plays a central role. Emissions from coal represent the largest source of CO_2 emissions in India. They arise predominantly in the power sector, which plays a crucial role for the decarbonization of other sectors via electrification of end-uses, such as industry and transport (Keramidas et al., 2019, 2022). Accordingly, complying with the goals of the Paris Agreement will require an immediate and unprecedentedly rapid reduction in coal use in India, raising questions of social equity and political feasibility of such a transformation (Muttitt et al., 2023; Vinichenko et al., 2023).

In this paper, we aim to shed light on the political challenges to transform India's energy system. We analyze affordability, employment and industrial competitiveness, as important aspects of a just and politically feasible energy transition (Jakob and Steckel, 2022). Given the administrative and socio-economic heterogeneities across India, understanding the geographical distribution of costs and benefits of India's climate and energy policies is crucial to understand the political economy of the energy transition. Costs concentrated on a small group of stakeholders can be expected to spur political resistance, while concerns over disproportional impacts on poor households or rising inequality can also undermine public support for climate policy (Inchauste and Victor, 2017). Devising politically feasible policies for a transition to a low-carbon economy therefore requires a close understanding of how policies would affect different stakeholders (Jakob et al., 2020a).

In view of the prevalent heterogeneity in socio-economic development and fossil fuel dependency across Indian states, policies that exacerbate the gap between poor and affluent states could be contentious or increase the likelihood of inter-state conflicts. India's 2022 energy bill paves the way for the central government to introduce ambitious climate policy (PRS 2022), including national emissions pricing or non-fossil fuel obligations. Understanding the implications of such policies for different states and regions is crucial to the design of a stringent climate policy regime in a politically acceptable way. In this paper we therefore focus on the regional impacts of the energy transition on three key societal groups: households, employees and industries. We develop a qualitative framework that allows us to compare impacts of the energy transition on the aforementioned societal groups, i.e. to assess different dimensions of the just transition. We employ an Input-Output based incidence analysis framework, and link that partial equilibrium approach with state level data for households, industries and employment. Our methodological choice allows us to conduct micro-simulations that consider the geographical dimension of distributional impacts, computing and reporting results consistently at state-level. We focus on identifying the distribution of favorable and disadvantageous conditions of an energy transition across different states.

This paper is organized as follows. Section 2 outlines the relevant literature. Section 3 provides an overview of power generation and in particular the role of coal. Section 4 presents the studied research questions and the methodological approach. Section 5 presents the results from households, employees and industries. Section 6 discusses the results across states in a comparative integrated manner. Section 7 presents conclusions and policy implications.

2. Literature review

In this paper, we analyze the impacts of climate and energy policies across Indian territories. We use one consistent methodical approach that considers distribution across households, effects on employment, and impacts on energy-intensive industries at the regional level.

Recent literature has analyzed the low carbon transition of India's power sector (Vats and Mathur, 2022; Lu et al., 2020; Gulagi et al., 2022; Vishwanathan and Garg, 2020; Chaturvedi, 2021; Rose et al., 2020; Lawrenz et al., 2018). All of these studies see a paramount role for renewable energies to offset coal. These studies provide insights at national level through modelling the heterogeneous endowments of different states and regions with coal and renewables. Gulagi et al. (2022) explore the role of renewables across India's states to transition to a zero-emissions power sector by 2050. The authors observe a heterogeneous expansion of renewables in different states, strongly determined by the distribution of renewable potentials of solar and wind. In the long run, the authors project a strong uptake of solar PV across India's territory. Mohan et al. (2022) examine the cost declines in solar PV and battery storage needed to eliminate coal generation in Karnataka, Gujarat, and Tamil Nadu. The authors finds solar PV capital costs of at least USD 250 per kW, battery storage costs 50% cheaper than current levels will be necessary to displace coal. Michael et al. (2023) evaluate the performance of 16 Indian States across different dimensions of the electricity transition, with Bihar, Uttar Pradesh, and West Bengal scoring on the lower end and Karnataka, Gujarat, Haryana, and Punjab on the higher of the ranking in decarbonising their power sectors.

Numerous previous studies have explored the distributional effects of carbon pricing (see Köppel and Schratzenstaller, 2022; Ohlendorf et al., 2018, Wang et al., 2016, for extensive reviews), which is frequently recommended as an economically efficient instrument to mitigate climate change (High-Level Commission on Carbon Prices, 2017). However, few studies have focussed particularly on India. Combining household expenditures with Input-Output and regression analyses, Grunewald et al. (2012) analyze the drivers of carbon emissions for Indian households between 2005 and 2010, observing that demand for emission-intensive goods and services has increased more than that for lower emission-intensive consumption categories. Focusing on equity effects, Rathore and Bansal (2014) analyze household expenditure data and find carbon taxes in India to be mildly progressive overall, with its progressive nature more pronounced in rural areas. Datta (2010) analyzes the effect of carbon taxing in India by combining Input-Output analysis and household expenditure data. He finds that taxes on transportation and cooking fuels, with the exception of kerosene, are progressive for both the urban and rural sectors. In a similar vein, some studies have examined the implications of electricity subsidy reforms. Based on Input-Output analysis and household expenditure data, households are estimated to suffer real income loses of around 4%–5% if fuel subsidies are eliminated (Anand et al., 2013b). Similarly, energy subsidy removal could lead to a loss of real income by increasing general price levels by 1.4%–3.8%, depending on the oil price (Acharya and Sadath, 2017; Bhattacharyya and Ganguly, 2017). None of these studies, however, provide substantial insight on the regional dimension (e.g. in which states such reforms would be progressive or regressive), as we do in this paper.

Other studies have examined the effect of energy policies on employment. A global review of employment for power sector technologies in the different phases of deployment, such as manufacturing, installation, operation and maintenance, is provided by Cameron and van der Zwaan (2015). The authors show that even though a number of estimates for a range of countries exist, recursive referencing limits this number to just a few original studies. Estimates of renewable energy jobs at a global level are provided by IRENA (2019) and previous reports. For India, however, there are limited assessments on employment figures in the power sector. Pai et al. (2020) investigate the necessary deployment of renewables to compensate for employment losses in coal mining for the largest global coal producing regions and conclude that solar PV could provide this in India. Other studies provide estimates on future employment gains or losses in power development scenarios (GoI, 2015b; Jacobs et al., 2019), but few studies report regional effects.

Finally, a body of literature has examined the prospects of decarbonizing energy intensive industries. For India, some authors have focused on the challenges facing the steel and cement industry in a decarbonized world (Dhar et al., 2020). Some studies have examined the distortionary effect of cross-electricity subsidies for industry and commercial sectors (Chattopadhyay, 2004; Jain and Nandan, 2019), as well as for diesel and gasoline subsidies (Jain, 2018), concluding that untargeted cross subsidies are economically inefficient.

Just a few papers have studied the combined effects of climate policy on income distribution, employment, and industrial competitiveness.

Some authors examine the effect of electricity subsidies on the financial position of utility companies and the public sector (Birner et al., 2011; Dubash, 2007; Dubash and Rajan, 2001a; Lal, 2006; Tongia, 2003). In this context, untargeted energy subsidies have been shown to be inefficient and inequitable, as well as draining funds from other social programs (Anand et al., 2013a; Badiani et al., 2012; David et al., 2015; Pargal and Banerjee, 2014). Our study contributes to this literature by providing a consistent methodological approach to analyze the effects of an Indian energy transition on household consumption, employment and energy-intensive industries. We particularly focus on disparities across sub-national jurisdictions – an issue of substantial policy relevance that has received only very limited attention in recent analyses of India's energy policy.

3. India's power sector and the role of coal

3.1. Power sector overview

As a federal parliamentary democracy, India is subdivided into 29 states and 7 union territories. Energy policy responsibilities are shared between the national government and federal states with different forms of power sector organization, electricity prices and subsidies (Dubash and Rajan, 2001a; Tongia, 2003). While the central government is responsible for coordinating and issuing energy-relevant legislation, states are in charge of implementation. Tariffs remain under the authority of State Electricity Boards (SEBs), which exercise control over the generation, distribution and utilization of electricity within their respective territories. (Dubash and Rajan, 2001a). While reforms towards unbundling SEBs and increasing competition have taken place in recent years, the distribution of electricity remains largely in the hands of state-owned distribution companies (DISCOMs), which represent regional or state-wise monopolies. The financial and technical situation of the approximately 70 DISCOMs within the country is highly precarious, mostly due to the persistent subsidies, which oblige DISCOMs to sell electricity below its generation costs (IEA, 2020, ; Nirula, 2019; Pargal and Banerjee, 2014). States devote considerable shares of their budgets (over 10% in Bihar or Uttarakhand) towards supporting the power sector (Ebinger, 2016; Gulati and Pahuja, 2010; Mayer et al., 2015). Annex B to this paper provides an historical perspective to India's power sector, focusing on the prevalence of subsidies.

In order to increase electricity access and cope with power shortages, in recent years India has invested massively in new power generation capacity. From 2008 to 2018, India's power sector experienced an increase of 140 GW of new coal capacity, expanding the dominant share of coal in the power sector capacities to over 60%. In 2018, India had a total of 227 GW of coal-fired power plants in operation, of which 54 GW were operated by energy-intensive industries to guarantee their own supply, and the remainder by public and private utilities (IEA, 2020). Indeed, captive power plants provide more than 70% of electricity for India's energy intensive industries (steel and metals, non-metallic minerals, chemicals, etc.), and of this, approximately 68% is provided by coal (IEA, 2020). Expanded use of coal from public and private actors has caused a substantial increase in coal-related CO_2 emissions. India still has close to 55 GW of coal-fired power capacity in the pre-construction or construction phase, and currently ranks as the second largest contributor to the global coal power plant pipeline (Global Energy Monitor, 2021). Despite an expansion of renewable energy (RE) electricity capacity of approximately 70 GW in 2020, and the current discussion on expanding the RE target to 500 GW by 2030, India's near term future remains committed to coal (IEA, 2022; 2021; GoI, 2020, 2022b; Spencer et al., 2020; Keramidas et al., 2019; 2022). Table 1 presents an overview of high-level strategies and goals impacting on coal and renewable expansion in India.

Table 1
Existing high-level climate protection strategies in India.

Strategy	Targets
Nationally Determined Contribution 2022 (GoI, 2022)	Emissions-intensity target of 45% below 2005 levels by 2030; 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030; Creation of a carbon sink of 2.5–3 GtCO2e through additional forest and tree cover by 2030.
Long-Term Low-Carbon Development Strategy (MoEFCC, 2022)	Net zero emissions by 2070.
Draft electricity master plan 2022 (GoI, 2022b)	Stipulates coal capacity additions of 26 GW in 2022–2027 and 10 GW in 2027–2032. RE capacity additions of 187 GW in the 2022–2027 and 225 GW in the 2027–2032 period
Renewable energy targets (GoI, 2015b; The Economic Times, 2021)	Target of 175 GW of RE by 2022, from which 100 GW correspond to solar PV and 60 GW wind. Announcement of a 500 GW of RE by 2030 by Prime Minister Modi during COP26 in Glasgow

In its latest Nationally Determined Contribution (NDC) to the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), India pledged to reduce its GHG emission intensity of GDP by 45% below 2005 levels. India's updated NDC also defines the target of reaching a 50% share of non-fossil power generation capacity by 2030 (GoI, 2022, 2022; MoEFCC, 2022). These targets represent an increase in ambition from India's first NDC, aiming at a 33–35% reduction of emission intensity of GDP, and a 40% non-fossil capacity over the same period (GoI, 2015a; MOEFCC, 2021). To achieve its climate protection goals, the country set up an initial target of adding 175 GW of renewable power by 2022, with 100 GW generated by solar PV and 60 GW wind power. While roughly 50% of the capacity envisioned in this target had been deployed by 2022 (c.f. GoI, 2022b), upscaling this target has been recently discussed (GoI, 2020).

During COP26, Prime Minister Naendra Modi announced India's intent to achieve 500 GW of non-fossil capacity by 2030 (The Economic Times, 2021). During COP27, India presented a long-term decarbonization strategy. A reference to the an upgraded absolute capacity target, e.g. the 500 GW RE target, is not included, however, in any high level political document. Following COP27, India legislated the Energy Conservation Bill 2022, amending the 2001 Energy Conservation Act. The new bill enables India's central government to introduce climate policies across different sectors. Most importantly, it paves the way for the introduction of an Emission Trading Scheme, non-fossil fuel obligations to different sectors, as well as standards for buildings and vehicles (PSR Legislative Research, 2022; Chaturvedi and Singh, 2022).

3.2. The role of coal

Fossil fuel endowments and renewable potentials are unevenly distributed across India's states. Coal mines are strongly concentrated in a few central and eastern states, which are home to a large proportion of India's low-income population. Renewable energy potentials are located in more wealthy western states in central and south India (GoI, 2018a). Even though India is a major producer of thermal coal, its production is not sufficient to satisfy domestic demand, with the difference met by coal imports from Australia, Indonesia and South Africa (IEA, 2018). For this reason, India's federal government announced an extraction target of 1 billion tons of coal by 2020, representing an increase of around 730 Mt from 2017 levels (IEA, 2018). Coal-fired power plants consume around 70% of domestic coal production, followed by steel (17%) and cement (4%) (Enerdata, 2021). Domestic coal production is concentrated in state-owned Coal India Limited (CIL), the largest coal producer in the world, which provides around 80% of India's coal (CIL, 2019).

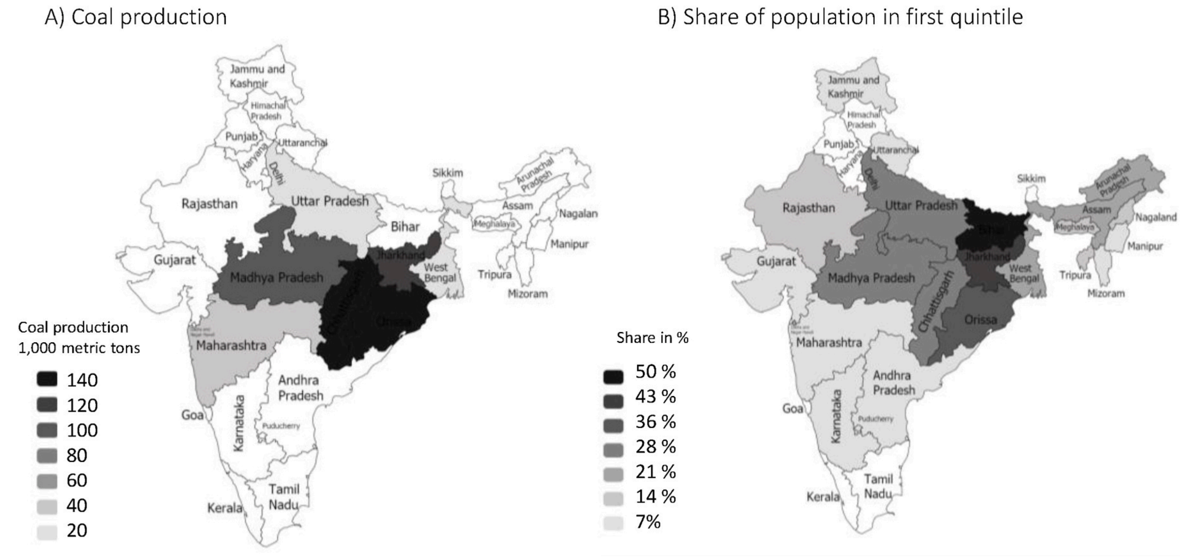

Fig. 1. Distribution of coal production in 2016–2017 (A) and low-income population in 2015–2016 (B) across India's states. Data source: (A) GoI (2018b) and (B) GoI (2017).

Table 2
Societal groups, conflicting policy objectives, and policies and analyses considered in this study.

Societal group	Societal goals	Analysis conduced
Households	• Poverty reduction	• Economy-wide carbon price of USD 40 per ton of CO_2- household impacts.
	• Affordability - sustain low residential electricity prices	• Removal of residential energy subsidies- household impacts.
Industries	• Industrialization and regional economic development • Affordability for industrial competitiveness – sustain low industry electricity prices	• Economy-wide carbon price of USD 40 per ton of CO_2- industry impacts.
Employees	• Sustain employment opportunities • Regional economic development, poverty alleviation	• India's 175 GW RE capacity expansion target- employment impacts. • Phase-out of coal use for power generation - employment impacts.

Coal production is highly geographically concentrated, primarily in six states in the eastern and central region (Fig. 1A). As CIL expects most of its expansion to be in Chhattisgarh, Odisha and Jharkhand, further regional concentration of coal production seems likely (CIL, 2018).

Coal mining is highly relevant for some states, accounting for approximately 10% of total economic output in Jharkhand or Chhattisgarh and between 4% and 2% Madhya Pradesh and Odisha (Spencer et al., 2020). CIL and its subsidiaries directly employ about 300,000 people, of which the majority (84%) are workers (Coal Limited India, 2019). Between 15 and 17 million of additional jobs depend indirectly on coal, particularly in Eastern India (Chandra, 2018b). Eastern states, most importantly Bihar, Jharkhand, Odisha, Chhattisgarh, Uttar and Madhya Pradesh, are also home to a large proportion of India's low-income population (Fig. 1B).

4. Methodological approach

Following Jakob et al. (2020b), who point out the need to address various dimensions of a just transition, we focus our analysis on the effects of an energy transition on households, employees and industries, as important societal groups. Table 2 presents a schematic overview of how the societal goals relevant to each of those groups are accounted for in our analysis.

We study three corresponding sets of questions. First, how would an energy transition affect poverty and inequality across different subnational jurisdictions? Second, in which states would energy-intensive industries be most severely affected by higher electricity prices resulting from a shift to clean power? Third, which federal states would experience the most pronounced adverse employment losses from a coal phase-out, and which ones would benefit most from the expansion of renewable energy? We aim to understand the relative impacts between different states and regions across the aforementioned dimensions, rather than to accurately assess policy impacts on India's energy markets and welfare of consumers.

Rather than analyzing all relevant impacts within a single scenario, we examine three different but consistent stylized simulations (i.e. one for each social group). This allows us to understand the impacts of an energy transition on key societal objectives (see Table 2) more fine-grained than within an integrated scenario (which necessarily requires more aggregation to reduce complexity). We consistently present our results at the state-level to highlight the regional implications of climate policy. Thus we can identify those states where conditions are the most unfavorable towards the dimensions studied, e.g. a combination of potential employment losses, existence of energy intensive industries and strong effects on household income.

For households, we study the incidence of the removal of energy subsidies and carbon taxation. We employ a price of USD 40 per ton of CO_2, which is considered to be the lower bound of values that are consistent with the Paris temperature target of 1.5 °C–2 °C (High-Level Commission on Carbon Prices, 2017). We assume that a carbon price is applied to all energy-related CO_2 emissions. A carbon price can be expected to be major factor to incentivize a transition from coal to renewable energies and can thus be regarded as consistent with the assumed coal phase-out and upscaling of renewables used to assess employment effects. We also examine the effect of a USD 40 carbon price on energy-intensive industries. In terms of employment, we contrast the effects of employment reduction through a phase-out of coal with those of adding 175 GW of renewable capacity, India's short-term renewable energy target.

Following previous literature, we base our analyses for households and industry on a partial-equilibrium, static Input-Output model, a well-established methodology to conduct incidence analysis (Creedy and Sleeman, 2006; Dorband et al., 2019; Feng et al., 2010; Grainger and Kolstad, 2010; Kerkhof et al., 2008; Renner, 2018; Wier et al., 2005). Our Input-Output analysis is based on the EXIOBASE3 database (Stadler et al., 2018).[1] Other common methods to conduct incidence analysis include simple microsimulations, utilizing household or industry expenditure data only, or more complex simulations, based on computable general equilibrium (CGE) models. Each method has strengths and limitations. Simple microsimulations omit economy wide effects, such as the pass-through of carbon-taxation costs across different economic agents. Input-Output analysis allows us to consider these pass-through costs, yet it omits the economic responses of households and industries due to increasing consumer and factor prices. CGE models consider such responses, yet they are sensitive to assumed price elasticities, and can only represent the resulting equilibria after adaptation to a policy change. We therefore consider CGE models to be less suitable to studying political economy implications of energy policy. Dynamic approaches to incidence analysis of energy and climate policy would require integrated energy-economic models with spatial resolution, and heterogenous households. To date, no such model can offer a fine-grained depiction of different types of households and industries at the regional level.

We thus consider our choice of Input-Output based incidence analysis to be appropriate to address our research questions for two important reasons: first, short-term effects have proven to be more important for the political feasibility of energy and climate policies than long-term equilibria; second, we use our results to assess the relative effect on different states, focusing on the regional concentration of impacts, rather than on absolute numbers, so that the relative effects across states can be expected to hold up even for cases in which there is a systematic bias in the absolute estimates.

In the following, we outline our methodological procedure for each dimension. A detailed description and supplementary material is provided as supplementary information.

Households: we use Input-Output analysis to determine carbon footprints resulting from energy use and industrial process emissions generated along the supply chain of final consumption by households. In order to compute the price increase of all goods and services of the economy resulting from the introduction of carbon pricing, we first calculate the relative price increase of primary energy carriers, natural gas, coal and oil and related products, according to their carbon content. We adopt the same approach for industrial process emissions. These exogenous price increases, reflected in vector $\Delta \boldsymbol{p}$, are shifted through economic sectors according to the direct and indirect specific fuel consumption within their Leontief production function, as outlined in equation (1):

$$\text{Carbon tax}: m = (I - A)^{-1}(\Delta p_i {*} a_i + wp_w) \qquad \text{(eq.1)}$$

in which $(\mathrm{I} - \mathrm{A}')^{-1}$ is the Leontief-Inverse, $\boldsymbol{a}$ is the vector of technical coefficients of the use of fossil fuel or industrial process $\boldsymbol{i}$ by all other sectors of the economy, and $\mathbf{m}$ is the resulting price vector, in which each element equals the new relative price of sector $\mathbf{j}$ due to carbon taxation.[2]

In the second step, we combine this sectoral price increase with household expenditure data after Goi (2016) to compute the incremental expenditures for an average household by income quintile and state.[3] We match the sectors $\boldsymbol{j}$ of the input output table to the $\boldsymbol{r}$ items of the Indian household expenditure survey. The resulting total expenditures $\mathbf{e_c}$ of an average household in quintile $\mathbf{c}$ of a given state after carbon taxation result as sum over all consumed items $\boldsymbol{r}$, which have a higher relative price p_r:

$$\text{Household expenditures}: e_c = \sum_r p_{rc} k_{rc} \qquad \text{(eq. 2)}$$

where k represents the vector of all items consumed by an average household in the respective quintile for a given state.

We also consider how energy subsidy removal would affect households through direct price increases for electricity, LPG, and diesel. We proceed analogously to eq. (2), by increasing the price of affected goods according to the state-wise abolition of respective subsidies, when available. Notably, India reformed its untargeted oil-product subsidies by reducing diesel subsidies during the low oil-price environment in 2015, and is targeting LPG subsidies through its direct cash transfer program to low-income households (Jain, 2018). With specific regard to the abolition of the subsidy on oil products, our analysis reflects an *ex-post* counterfactual scenario, aiming to understand the *ceteris paribus* adverse effects on poverty and inequality, as well as its regional distribution among states. We present the incidence of electricity and oil-products subsidy removal and carbon pricing on the poorest household quintile and how the effect differs between the first and fifth quintile, across Indian states. The first income quintile includes the poorest segments of the population. Understanding the incidence on these groups across states is the key to understanding the geographical distribution of adverse effects of carbon pricing and subsidy reform on poverty. Likewise, understanding the difference in effect on the poorest and wealthiest households is the key to understanding the implications for economic inequality across states.

Industries: we combine the sectoral price increase across economic sectors from our Input-Output analysis with data on the state-wise location of industries from the Indian Annual Survey of Industries (GoI, 2010–2018). In order to identify those states most adversely impacted by carbon pricing, we compute the state-wise weighted average price increase $\boldsymbol{y_s}$ of total industrial output, which takes into consideration the share $\boldsymbol{w_j}$ of each industrial sector $\mathbf{j}$ in total industrial output, as well as its corresponding price increase $\mathbf{m}$ as computed in eq (1). We use this measure to identify states $\mathbf{s}$ with a comparably high proportion of energy- and carbon-intensive industries, which would be most impacted by carbon pricing:

$$\text{Industries}: y_s = \sum_j p_{js} {*} w_{js} \qquad \text{(eq.3)}$$

Employment: we base our analysis on official statistics and employment factors (consistently reported in jobs/MW) from available peer-reviewed scientific literature. We use a median value of 0.8 jobs per MW for solar PV and 0.4 jobs per MW for wind power in the installation and operation and maintenance phases, as derived from Cameron and

[1] More information about the underlying Input-Output tables, as well as the source data employed in this analysis is publicly available under https://www.exiobase.eu/.

[2] The component $\mathrm{wP_w}$ in eq. (1) represents the value added coefficient multiplied by its relative price for each sector's Leontief production function, following the Leontief textbook price's model. An in-depth explanation of the model's derivation is found in the supplementary material.

[3] Income quintiles categorize Indian households based on their income level in ascending order in five equal groups, each containing one fifth of households. Quintiles are computed based on micro-data of India's household expenditure survey after GoI (2016), which provides a temporary consistent dataset to the Input-Output tables after Stadler et al. (2018).

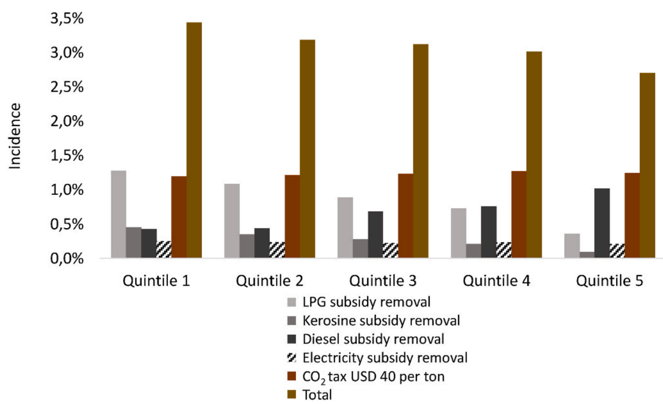

Fig. 2. Incidence in total household expenditures due to subsidy removal and carbon taxation across quintiles on the national level (own elaboration).

van der Zwaan (2015) .[4] In order to identify those states that would gain the most jobs from future renewable power plants, we compute the state-wise distribution of employment creation. We combine employment factors for renewable power plants with the regional distribution of future capacities as stipulated by the Government of India (GoI, 2015b). Likewise, in order to identify those regions suffering job losses through a phase-out of coal, we derive employment figures on coal- and power plants employment by states from official statistics. (CIL, 2018; GoI, 2018b, 2018c, 2010–2018). We put the number of coal mining and coal power plant employees in relation to installed power capacities, and compute an employment factor for coal-fired power plants of 0.22 jobs per MW. This figure changes to 1.6 jobs per MW if mining employment is included. Data on additional employment in other coal-related activities, most importantly (rail) transport, cannot be regionally disentangled. We therefore only provide state-wide figures and estimates of employment at stake in coal mining and coal-fired power plants.

Combined analysis across dimensions: To identify regions for which the combined effects of an energy transition can be expected to be most beneficial or most adverse, we compare the impacts on households, employment and industries across Indian states. Considering the heterogeneity in magnitude and unit of the investigated dimensions (poverty, equity, pressure on energy-intensive industries and employment), we transform impacts to a qualitative scale, determining whether impacts are comparably low, medium or high.

We use terciles, which divide the range of results between the highest and the lowest impacts for each dimension into three equal blocks, to assign a numeric value between 1 (low) and 3 (high).

We then analyze the distribution of relative effects, e.g. those states with comparably high impacts on households, employees and industries. Hence, we contrast states that would derive substantial benefits from an energy transition with those that would lose out in most dimensions, while gaining in only a few.

5. Results

In this section we discuss the effects of a carbon price and subsidy reforms on Indian households, industries and workers from a sub-national perspective.

5.1. Households

At the national level, an energy subsidy reform combined with carbon pricing would have a regressive effect on the distribution of household income. On average, the poorest quintile of Indian households would face a 3.5% impact in their income, while the richest quintile income would, on average, be affected by 2.7% (see Fig. 2). Abolishing LPG and kerosene subsidies would be regressive, dominating the progressive or neutral effects of removing diesel subsidies and introducing carbon prices. Note that these effects reflect an *ex-post* counterfactual scenario, aiming to understand the *ceteris paribus* adverse effect of subsidy abolition on poverty and inequality. The regressive impact of LPG subsidy reform highlights how the subsidy currently benefits low-income groups. In particular, LPG subsidies provide an incentive, other than traditional biomass, for the use of clean cooking facilities. Its immediate health benefits outweigh the negligible share of CO_2 emissions from oil products use in the residential sector (less than 4% of India's total energy emissions stem from the residential sector (James et al., 2020). The results presented do not take into account the fact that revenue recycling schemes can be designed to compensate for the regressive effects of climate polices.

We use the effect on the poorest quintile, as well as the distance between the first and fifth quintile, to compare the results across Indian states (Fig. 3). Fig. 3 (A) focuses on absolute effects on the lowest income quintile in each state. These range from 0.8% to 5%, with most of the states close to the national average of 3.4%. People in Eastern states, where most of the Indian poor are located (see Fig. 1), would in general be affected more strongly given the higher share of energy-related goods in total expenditures. Fig. 3 (B) presents the difference in incidence between the lowest and highest income quintile as a measure of equity effects. A value greater (smaller) than zero implies that relative income losses in the highest quintile is greater (smaller) than those in the first quintile, suggesting a progressive (regressive) effect. Most states show regressive or neutral impacts. A fossil fuel subsidy reform and carbon pricing would be neutral (neither regressive nor progressive) in more affluent north-western or southern States such as Gujarat, Kerala, Tamil Nadu. In contrast, some poorer Eastern states, such as such as Bihar or West Bengal, would face regressive impacts. Combined with the greater impact on low-income households noted above, it seems likely that an energy transition could aggravate pre-existing economic inequality and poverty in these already disadvantaged regions. Even though some Eastern states, such as Odisha, Chhattisgarh or Jharkhand, would face roughly neutral impacts, comparatively large absolute income losses can be expected for households across the entire income spectrum.

To further examine the affected population, Fig. 4 visualizes the equity effects of subsidy removal and carbon pricing against the proportion of population affected. The size of the bubbles corresponds to the share of the state's population belonging to the country's first income quintile. Out of the 10 largest states in India – roughly equivalent to 80% of India's total population – eight states show regressive effects. Only Madhya Pradesh and Karnataka show progressive outcomes. Most of these states are home to a large share of India's population living in the first income quintile, as indicated by the comparably large size of the bubbles. Progressive outcomes for Madhya Pradesh and Karnataka are predominantly driven by diesel subsidy removal.[5]

5.2. Energy-intensive industries

About 40% of India's total CO_2 emissions can be attributed to the industry sector, three quarters of which are emissions related to direct

[4] A discussion on the reliability employment factors and sensitivities by states using the maximum and minimum values for employment factors are provided in the supplementary data annex of this paper. We thereby stick to India's short term, 175 GW RE target, given that the 500 GW RE is not an official target. However, while our aim is to analyze the relative affectedness between states, our results can be interpreted as a proxy for the distribution of employment across states, as upscaling the target will likely have less of an impact on its distribution between states, given India's distribution of RE potentials.

[5] Figure A1 in the Annex breaks down distributional effects by subsidy reform and carbon pricing as shown in Fig. 3 to regions. In most states, removing subsidies for diesel has progressive equity effects, LPG, kerosene subsidies show regressive and electricity neutral effects.

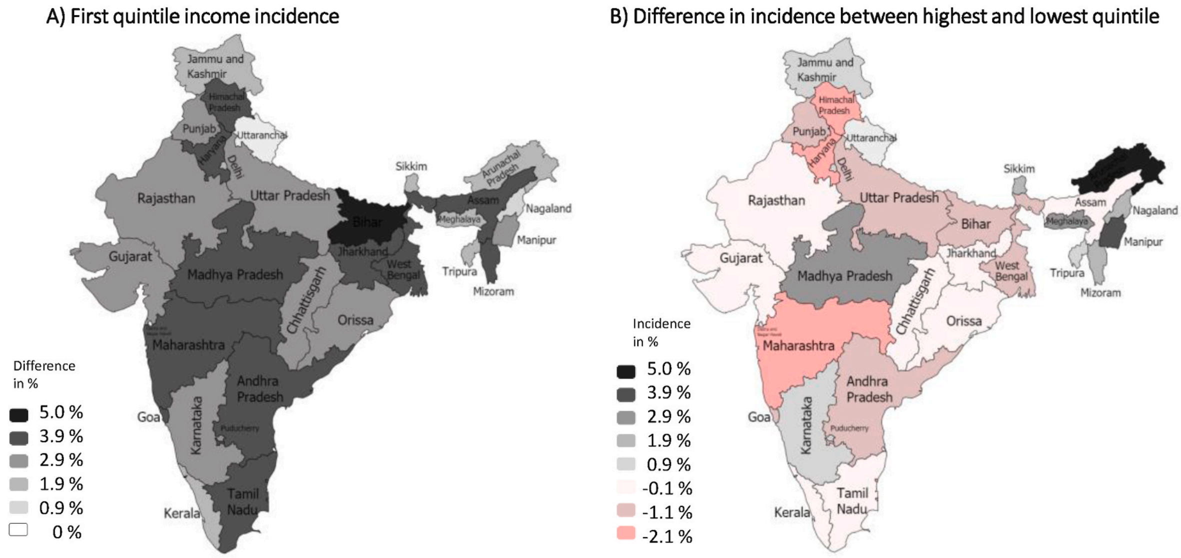

Fig. 3. Impacts on households of abolition of energy subsides and carbon pricing. Incidence towards first quintile (A) and difference in incidence between highest and lowest quintile (B). Red values indicate progressive effects (own elaboration). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

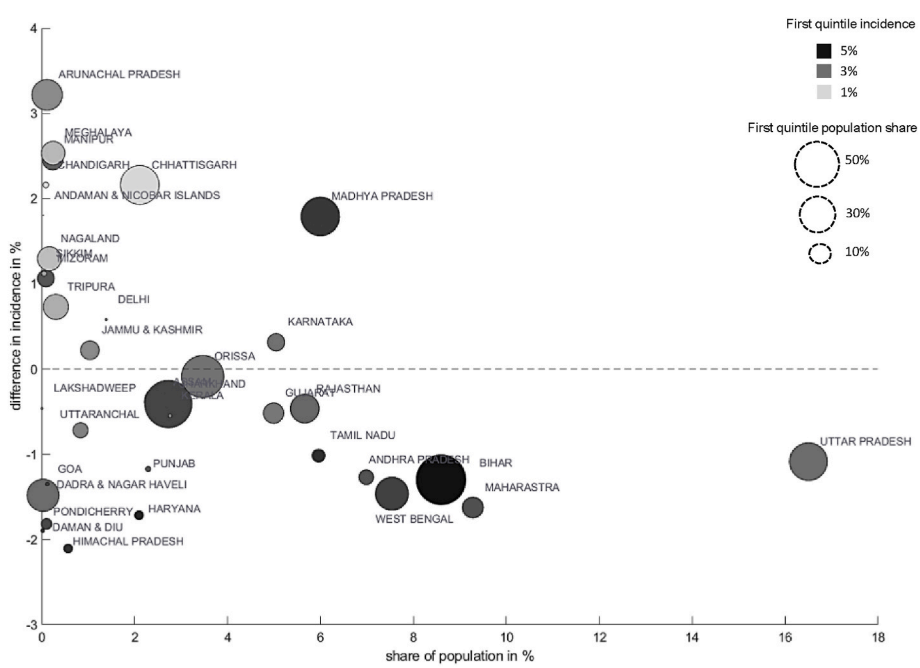

Fig. 4. Difference in incidence of total expenditures between quintile 1 and quintile 5, for energy subsidy removal and a carbon price of 40 USD per ton of CO_2. Negative values correspond to regressive distributional impacts. The size of the bubbles indicates the share of states' population belonging to India's first income quintile. The color indicates the incidence due to subsidy removal and carbon taxation on the first quintile population (own elaboration).

fuel consumption with the remaining quarter relating to industrial processes (Enerdata, 2021). Within the industry sector, CO_2 emissions primarily stem from a few energy-intensive branches: basic and fabricated metals (40%); non-metallic minerals, in particular cement (30%); chemicals (12%); and refining (10%) (Gupta et al., 2019). Most Indian industrial output is located in large industrial clusters in the states of Gujarat, Maharashtra, Tamil Nadu, Karnakata, Andhra and Uttar Pradesh (GoI, 2010–2018). However, states with comparatively lower industrial output, such as Chhattisgarh, Meghalaya, Odisha or Bihar also have a higher proportion of energy-intensive than non-energy-intensive industries in industrial gross production value (see Fig. 5).

With a USD 40 per ton CO_2 price, states with large shares of energy- and carbon-intensive industries experience a greater increase in their weighted average industrial output prices. The price impact depends on the composition of industries. Fig. 6 shows the share of industry in each state's GDP (A), as well as the weighted state-wise price increases of industrial output (B). The eastern states of Chhattisgarh, Odisha and Jharkhand, as well as others such as Gujarat, Tamil Nadu, Himachal Pradesh and Sikkim show a higher proportion of industrial value added on the state's total value added. The largest price hikes are apparent in

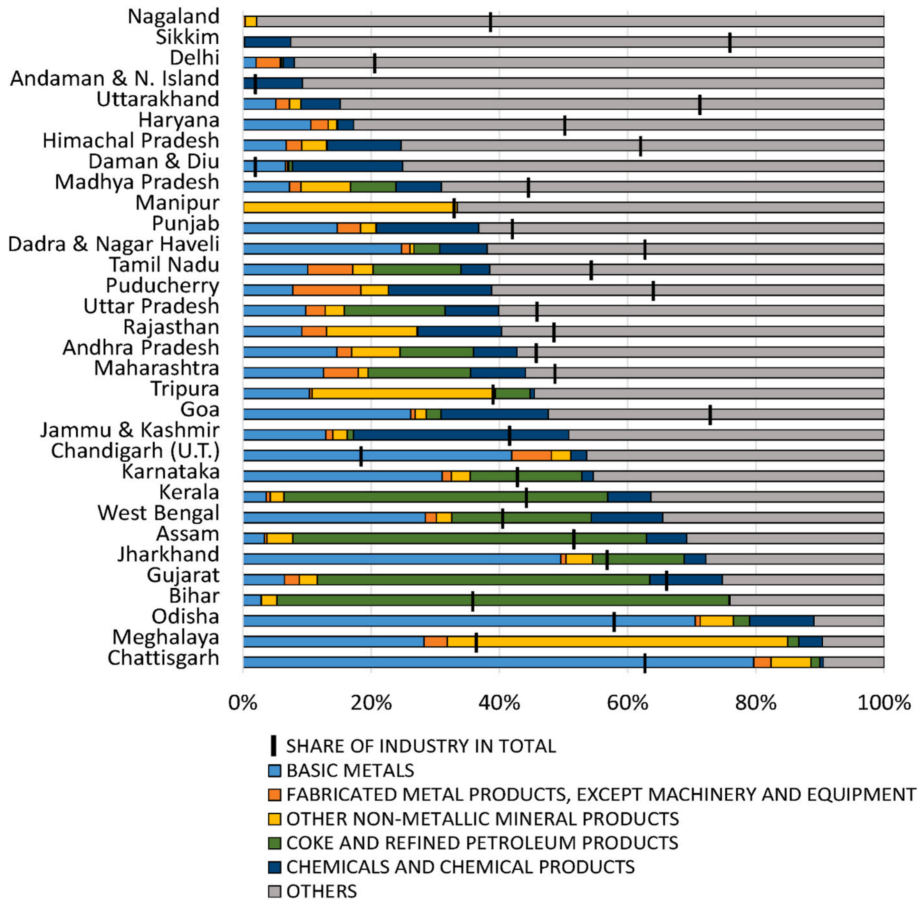

Fig. 5. Share of energy intensive and other industries in industrial gross production. Black markers illustrate the share of industry in State GDP. Data for 2012 after GoI 2012–2018.

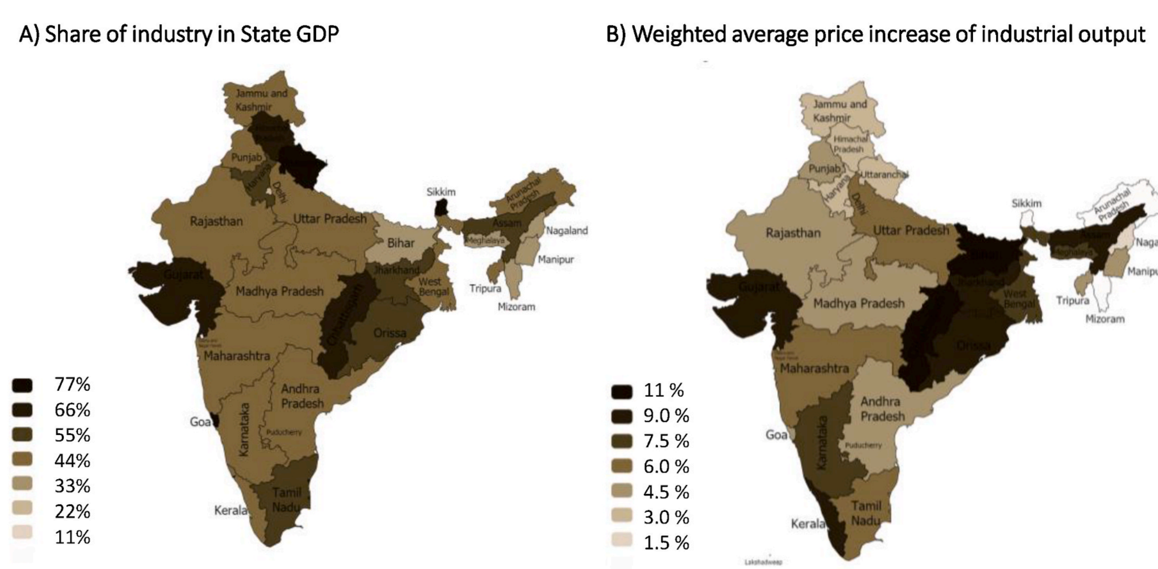

Fig. 6. Share of industry in State GDP (A) and weighted average price increase for industrial output by State due to a USD 40 per ton CO_2 carbon price (B). Data source: (A) GoI, 2018c, (B) own elaboration.

the smaller eastern states of Bihar, Jharkhand, Odisha, and Chhattisgarh, as well as Assam in the Northeast and Gujarat in the West. Northern and Northern States are the least affected. Central and Southern States including Maharashtra, Tamil Nadu, Karnataka, Andhra and Uttar Pradesh, as large industrial clusters, range in between. Thus, the combination of both a high share of energy intensive industries and a high proportion of industrial value added is most pronounced in Eastern states, as well as in Gujarat and some Northern states.

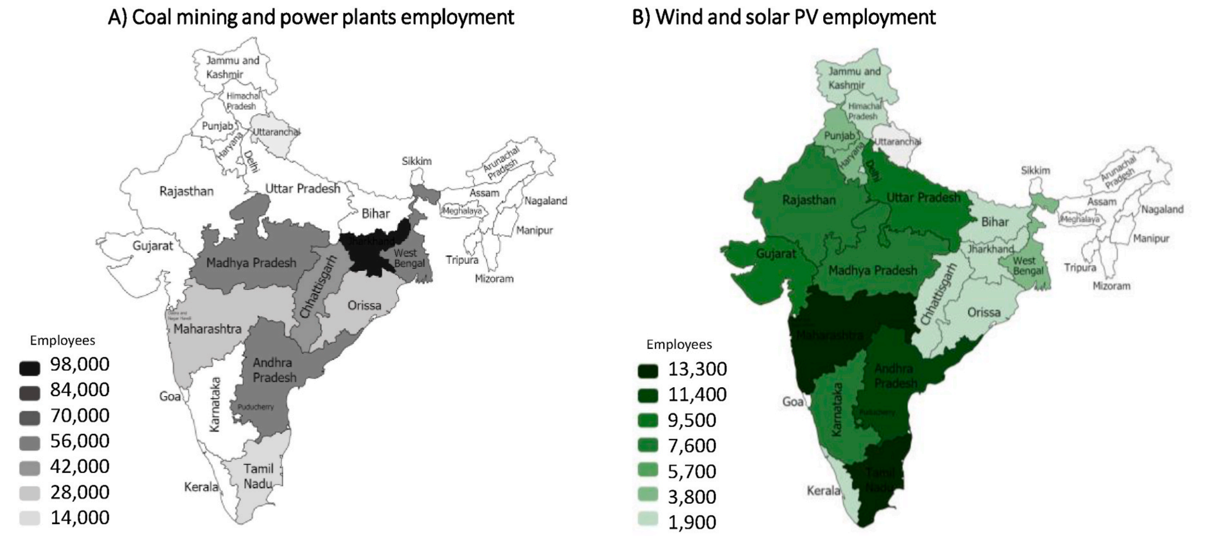

Fig. 7. Employment related to coal in 2014 (A) and potential for job creation by renewable energies (B) across Indian states. Data source: (A) GoI (2015b) and (B) own elaboration.

5.3. Employment

This section first provides an overview of employment related to coal. It then analyzes the potential effect on employment of additional renewable energy sources. Finally, it contrasts potential additional RE jobs with those lost in activities linked to coal at the level of individual states.

5.3.1. Employment linked to coal

Phasing out coal-fired power generation would not only have direct effects, but also indirect impacts along the entire value chain. These are likely to be most pronounced for the employment-intensive coal mining and the transportation sectors, which are among India's most important employers. As of 2018, the coal-fired power sector directly employed approximately 50,000 persons, while the coal mining sector provided about 300,000 jobs. Indirectly, coal mining might provide formal and informal employment to a wider number of people, with estimates varying from 1 to 2.5 million direct and indirect employees (CIL, 2018) (International Labour Organization, 2019; Stadler et al., 2018).

Total employment in coal mining decreased from 400,000 to 300,000 employees between 2008 and 2018, while coal production substantially increased (Tongia and Sehgal, 2019). This implies that total labour productivity in coal mining has nearly doubled. While Odisha provides the second highest share (21%) of total coal production, it has the highest labour productivity (160 employees/kt) and the lowest number of employees (22,000) among Indian states, see Fig. 7 (A). In contrast, West Bengal produces 4% of total output, yet with a labour-intensity of 1800 employees/kt it provides 50,000 jobs in coal mining. The largest number of employees is in Jharkhand (91,000), followed by Telangana (56,000), West Bengal (50,000), Madhya Pradesh (48,000), Maharashtra (27,000) and Odisha (22,000) (GoI, 2018c). Furthermore, Coal India Limited expects most of its expansion in production to be focused in Chhattisgarh, Odisha and Jharkhand, further regionally concentrating coal production (CIL, 2018).

The transportation sector is, next to the coal mining and power plant sector, one of the most important employers in the coal value chain. State-owned Indian Railways is India's, and one of the world's, largest employers, providing roughly 1,300,000 jobs. Considering India's vast territory and the local concentration of coal production in eastern states, the majority (60–70%) of coal supply to power plants must travel considerable distances by railway (GoI, 2019). On average, a ton of coal for thermal power plants must be transported more than 500 km. By weight, more coal is carried by Indian Railways than any other goods (48% of total freight tonnage in 2017) followed by steel (19%) and cement (10%) (GoI, 2019). While it is impossible to disentangle the number of Indian Railways' employees supported by coal transport, it is clear that it is a considerable proportion; 45% of freight earnings derive from coal and the business model, based on passengers underpaying and freight cross-subsidizing passengers, is heavily reliant on coal (Chandra, 2018a; Hindu Business Line, 2018; Kamboj and Tongia, 2018; Montrone et al., 2021; Tongia and Sehgal, 2019; Vishwanathan et al., 2018).

5.3.2. Employment linked to PV and wind

Renewable energies have considerable potential for employment creation. Within its RE target of 175 GW by 2022, India aims to deploy 60 GW of wind power and 100 GW of solar PV.

Following the exact composition of this target by technologies and states as stated in the *Report of the Expert Group on* 175 GW RE *by 2022* (GoI, 2015b), we compute the associated employment creation for construction and operation and maintenance activities. While much uncertainty remains as to the share of local manufacturing of renewable power plants by Indian companies,[6] the installation and O&M employment associated with India's current RE targets are inevitably domestic and would lead to the creation of jobs.

Wind power potentials and future development of capacities are highly concentrated. The state-wise breakdown of India's 60 GW target envisages almost the whole capacity being installed in seven states in the Central West and South West regions: 11.9 GW (20%) in Tamil Nadu; 8.8 GW (15%) in Gujarat; 8.6 GW (14%) in Rajasthan; 8.1 GW (14%) in Andhra Pradesh; 7.6 GW (13%) in Maharashtra; 6.2 GW (10%) in Karnataka; and 6.2 GW (10%) in Madhya Pradesh (GoI, 2015b). Using an employment factor of 0.3 jobs/MW in the O&M stage and 0.1 jobs/MW in the installation phase, the 60 GW of wind capacities would yield about 25,000 direct jobs in total. Solar PV, on the other hand, is more widely distributed across India's territory. Using an employment factor of approximately 0.3 jobs/MW in the O&M sector and 0.5 jobs/MW in

[6] In terms of local manufacturing capacity, most of India's solar PV suppliers are Chinese firms, as Indian manufacturers cannot compete on cost: As of 2018, domestic manufacturers had a market share of 7% IRENA (2016, 2017, 2019). Accordingly, the bulk of solar PV employment will take place in the construction and O&M of power plants. As for wind power, India has an assembling and manufacturing capacity of approximately 10 GW per year, with five companies providing 85% of total production Dwivedi et al. (2016).

the installation phase, 100 GW of solar PV would result in a total of roughly 86,000 direct jobs. Fig. 7 (A) presents the regional distribution of coal-related employment, while Fig. 7B presents the distribution of wind- and solar-related employment across Indian states.

5.3.3. *Employment effects of phasing out coal and expanding RE*

Complying with a 1.5 °C or 2 °C mitigation target would require India to phase out coal in the long term (Luderer et al., 2018; Tong et al., 2019), while at the same time going beyond its current 175 GW RE target to satisfy its growing electricity demand (IEA, 2020). Replacing 1 MW of coal capacity requires the installation of roughly 3–4 times as much solar or wind capacity (Lu et al., 2020), as solar PV and wind power have lower capacity factors (run for less load hours per year). Using the capacity factors and median employment factors reported (0.8 jobs per MW for solar PV and 0.4 jobs per MW for wind vs. those we derive for coal, 1.6 jobs per MW), we conclude that solar PV, in particular, could create employment in the same order of magnitude as that lost in coal. However, the notable geographic mismatch of RE potentials and coal deposits makes it clear that RE-induced employment would not be a substitute for jobs lost in coal-fired electricity producing regions. Considering the 175 GW target only, net coal job losses would surpass RE employment creation. Among the states with the highest net employment losses, 96,000 jobs would be at stake in Jharkhand, followed by Madhya Pradesh with 48,000 jobs and West Bengal 47,700 jobs. Karnataka is among the net winners with 5000 jobs, followed by Gujarat and Punjab each with 3800 jobs, and Rajasthan and Uttar Pradesh each with 3500 jobs. These figures indicate the order of magnitude of the effect on employment and are computed and reported to assess the relative effect on states and regions.

6. Discussion

This section integrates the results presented in the previous section to provide a comprehensive view of which Indian states can be expected to experience the largest gains and losses from an energy system transformation.

An energy transition would generate benefits for some Indian states and losses for others. This poses an important challenge from a political economy perspective; whereas states that would predominantly derive benefits from an energy transition, e.g. in terms of additional employment related to RE have an incentive to support climate policies, those that would adversely suffer are likely to oppose reforms (Inchauste and Victor, 2017). Given the prevalent income inequalities across states, policies that further exacerbate the gap between poor and affluent states could be highly contentious, increasing political polarization, as well as raising the likelihood of inter-state conflicts.

Disadvantageous dimensions for a particular state are regressive impacts on household incomes, a high share of low-income population, and a large proportion of energy-intensive industries and coal employment. In contrast, favorable conditions are employment related to wind and solar-PV development, progressive effects from carbon pricing, and a high proportion of a relatively wealthy population. To analyze impacts in a given state in an integrated manner, we assign each dimension a score from 1 to 3, based on whether the results of the dimension is comparably high (3), medium (2) or low (1), across the range of results in that dimension (see methodology section). Advantageous dimensions

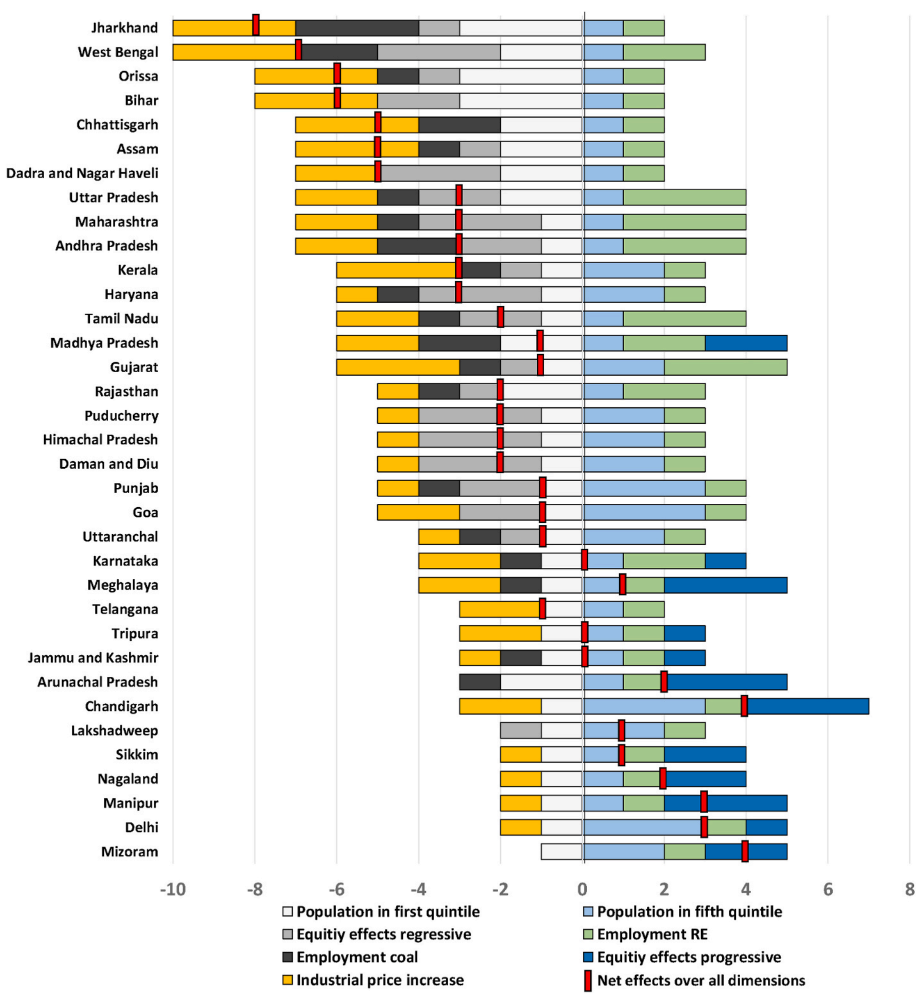

Fig. 8. Qualitative assessment of disadvantageous (negative scale) and favorable (positive scale) conditions as a result of an energy transition across Indian states. Red markers show net effects over all dimensions. Numeric values 1, 2 and 3 correspond to low, medium or high effects, depending on the tercile of impacts in which the respective state is located (own elaboration). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

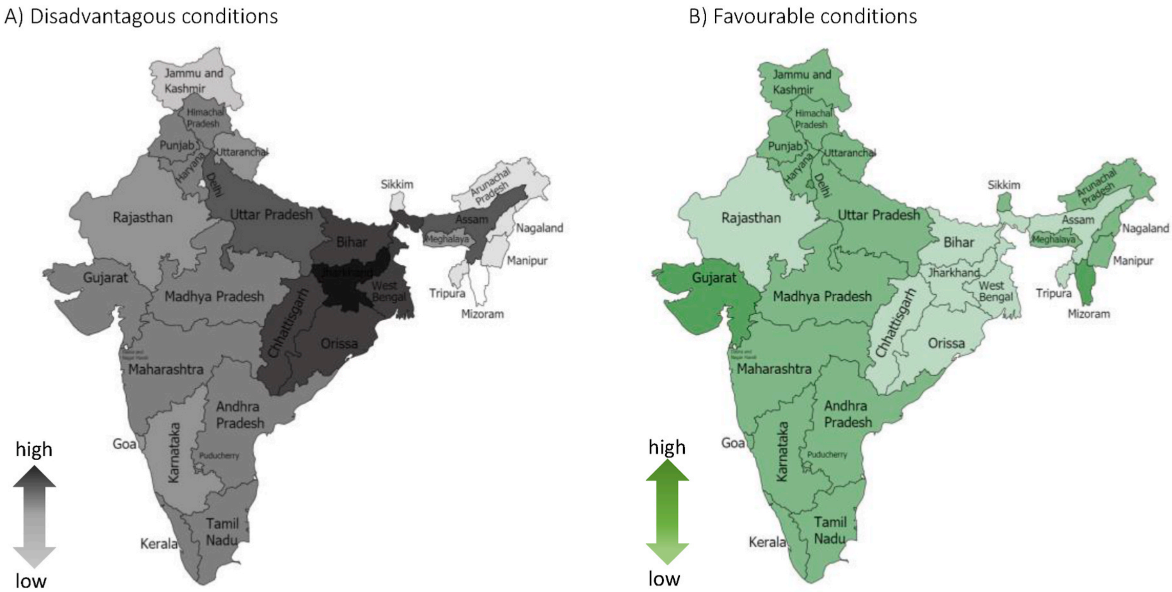

Fig. 9. Geographical distribution of aggregated disadvantageous (A) and favorable (B) conditions as a result of an energy transition across Indian states. (own elaboration).

are shown as positive values, disadvantageous as negative. For example, if a state has high coal employment, high regressive impacts, and a high share of low-income population, it will have a score of −9. Fig. 8 presents an overview of this qualitative assessment of disadvantageous and favorable conditions of an energy transition across Indian states. Figure A2 in the Annex presents the quantitative data used as the basis for this analysis, while the supplementary data annex presents all data in a comprehensive way.

The qualitative assessment of the overlap of favorable and disadvantageous dimensions exposes coal producing states as the most adversely impacted by an energy transition. Coal mining states face most negative scores, with Jharkhand (−10), West Bengal (−10), Odisha (−7) and Bihar (−8) combining most multiple disadvantageous outcomes across different dimensions. Wealthy states score the highest for favorable dimensions, such as Chandigarh (+7) Delhi (+5) or Gujarat (+5).

Net effects differ considerably across states and regions (Fig. 8, red markers). The coal producing Eastern states not only show the most disadvantageous conditions, but also the highest net negative impacts. The rather wealthy, urban Western states would face the highest net advantageous effects, with RE employment creation, progressive equity effects and a wealthy population and low pressure on industries from a carbon price.

Many of the remaining states, such as Gujarat, Karnataka, Tripura, Sikkim, would face both disadvantageous and favorable effects and thus low to middle net negative effects. Prominent examples might be Gujarat or Madhya Pradesh, which might strongly benefit from additional RE employment while at the same time suffer substantial impacts in terms of competitiveness of energy-intensive industries. For these states, it is an open question how costs and benefits towards different societal groups might be weighed against each other and play out in terms of the political support of a Paris compatible transformation.

A regional visualization of the overlap of favorable and disadvantageous dimensions is provided in Fig. 9. While disadvantageous dimensions are strongly concentrated in Eastern states, favorable conditions for an energy transition are less concentrated on specific regions. The mismatch between favorable and disadvantageous conditions creates a substantial challenge for the success of an energy transition. With jurisdiction over the power sector being shared between the federal and state governments, reforms towards climate protection would also have to be carried out by those states suffering the most adverse impacts.

The interpretation of these results needs to bear in mind the limitations of our study. Arguably, the speed at which the energy system is transformed will determine the speed at which adverse impacts materialize. Our static approach cannot provide insights into the temporal dynamic of this transformation, which will differ across states. Furthermore, our study focuses on short-term effects, which have proven to be important determinants of the political feasibility of policies, but omit more long-term adjustments of consumers, workers and industries, which might be heterogeneous across regions. If such adjustments were considered, they would likely reduce the size of the overall effect, but would affect their relative regional distribution only to the extent to which different states have different capabilities to adjust. Finally, our regional analysis cannot account for potential heterogeneities within individual Indian states. Our results should therefore be interpreted as a depiction of relative impacts across different Indian states.

7. Conclusions and policy implications

In this paper, we study the potential distributional effects of an energy transition from the perspective of Indian states. We assess impacts on the distribution of household income, the competitiveness of energy-intensive industries, and employment in coal-related occupations and renewable energy. Our results highlight that states would be very unevenly affected by a climate policy aligned with the targets of the Paris agreement.

An Indian energy transition would risk adversely impacting poverty reduction, employment and regional economic development. We find that the disadvantageous outcomes of an energy transition would be highly concentrated in a few Eastern states, which are home to a high proportion of India's low-income population. These states are among the country's major coal producers and are at the same time relatively dependent on energy-intensive industries. This also holds true in terms of net effects; Eastern states won't benefit from substantial employment creation related to RE sources from current RE expansion plans, which would mostly accrue to Western states. Some Western states are not only richer, but are already less dependent on coal and energy-intensive industries.

A key policy implication is that an integrated perspective of climate protection and other societal goals must be adopted when transforming the energy sector. Safeguarding regional economic futures, providing decent employment opportunities and alleviating adverse impacts for the poorest segments of society will be necessary to mitigate trade-offs between climate protection and other societal development goals, such as poverty and inequality reduction or employment. Compensation schemes funded by carbon pricing revenues and international finance, as well as complementary policies, such as employment schemes and green industrial policies, will be necessary to ensure a just transition in the Indian context.

Carbon revenues could be directed to adversely impacted households to avoid pushing low-income segments of the population into poverty, or widening the gap between rich and poor. Theoretically, this could be done via multiple mechanisms, i.e. via directed or uniform transfers to citizens or households, via tax-reforms or via investments in public services and infrastructure (Franks et al., 2018; Jakob et al., 2015). Yet, whether existing or novel transfer mechanisms can be set up in the Indian context to fully alleviate negative impacts is an open question that requires additional research (see Steckel et al. (2021)). Given the informality of occupations and political sensitivity of energy price variations, the compensation mechanisms should focus on achieving high acceptability and effectively targeting highly adversely impacted societal groups, arguably favoring direct transfers over tax cuts. In India, specifically targeting low-income households could build upon the countries' experience with reforms from in-kind, untargeted LPG subsidies to targeted cash transfers within the DBTL and PaHal cash transfer programs. Despite criticism, these are generally regarded as success stories in reducing unnecessary fiscal burdens while protecting low-income households (Jain et al., 2018; Mittal et al., 2017). Carbon revenues or international finance might also compensate for declining public revenues from coal-related royalties. Directing revenues into infrastructure and public services development might be pivotal to compensate for the provision of healthcare, education and public transport services currently provided by the Indian coal-mining industry via corporate social responsibility programs (Chandra, 2018b). On the other hand, it will remain challenging to compensate for informal occupations (e.g. menial jobs, transportation) and other informal benefits (e.g. non-metered electricity or water provision) with carbon revenue recycling. These benefits might be substantial, particularly in rural areas and for the lowest segments of society.

To support energy transitions, employment schemes comprising early retirement for older employees and relocation for younger ones (Haywood et al., 2021), and industrial policies to target adversely impacted groups (Reitzenstein et al., 2021) have been proposed. Employment schemes could be designed to provide a perspective beyond the phase-out of coal by adopting an integrated perspective, with elements of social policies (employment information and advice services, social insurance and income support during relocation) and labour policies (workforce development by training or industry relocation programs, early retirement programs, etc.). The highly centralized organization of India's coal mining industry as state-owned enterprises might support targeting coal employees in adversely affected coal-regions, as well as designing and implementation of such schemes. A further option is to build more RE power capacities in the most vulnerable states and regions, even if these states may not offer the least-cost potentials for RE generation, in order to create employment to compensate for coal employment losses (Pai et al., 2020). This could be part of the current discussion on a 500 GW RE expansion target. However, the skills required for RE projects might differ from those in coal mining, and a large share of RE employment is created in the construction phase and might not represent long-term employment (Mehrotra, 2022).

CRediT authorship contribution statement

Jose Antonio Ordonez: Conceptualization, Methodology, Data curation, Formal analysis, Visualization, Writing – original draft. **Michael Jakob:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Jan Christoph Steckel:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Hauke Ward:** Methodology, Data curation.

Declaration of competing interest

The authors declare no conflict of interests. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

Data used and presented in this paper is both enclosed to the supplementary data annex and referred to as literature in the references

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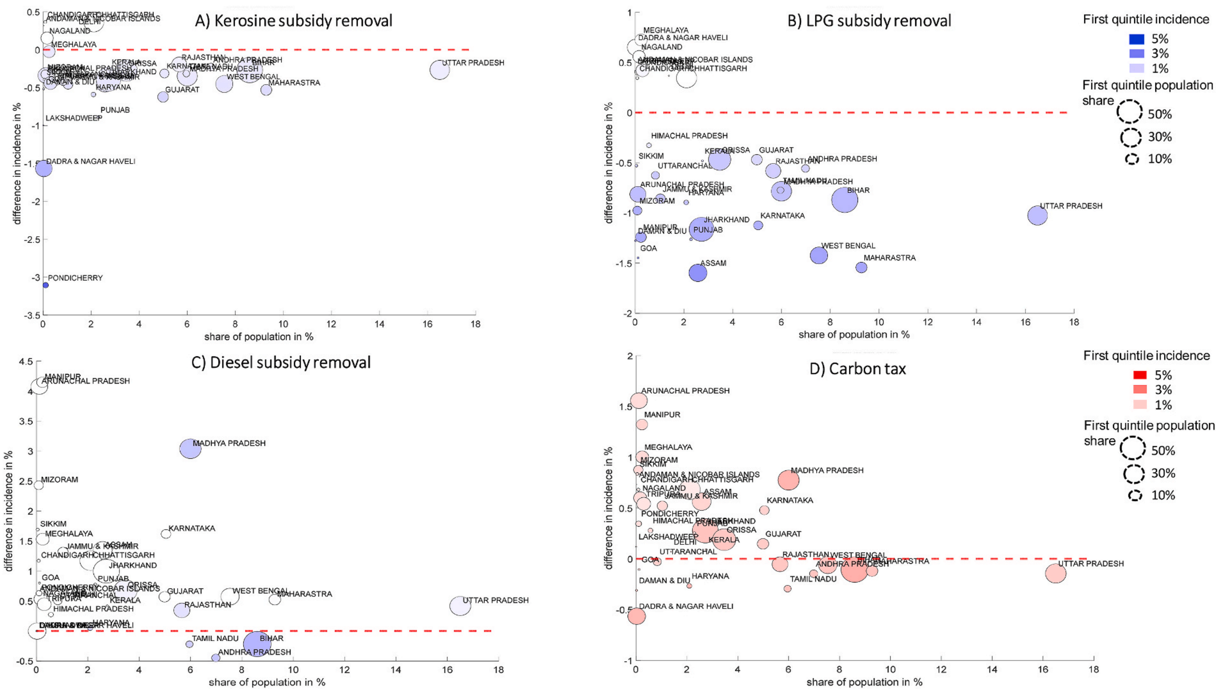
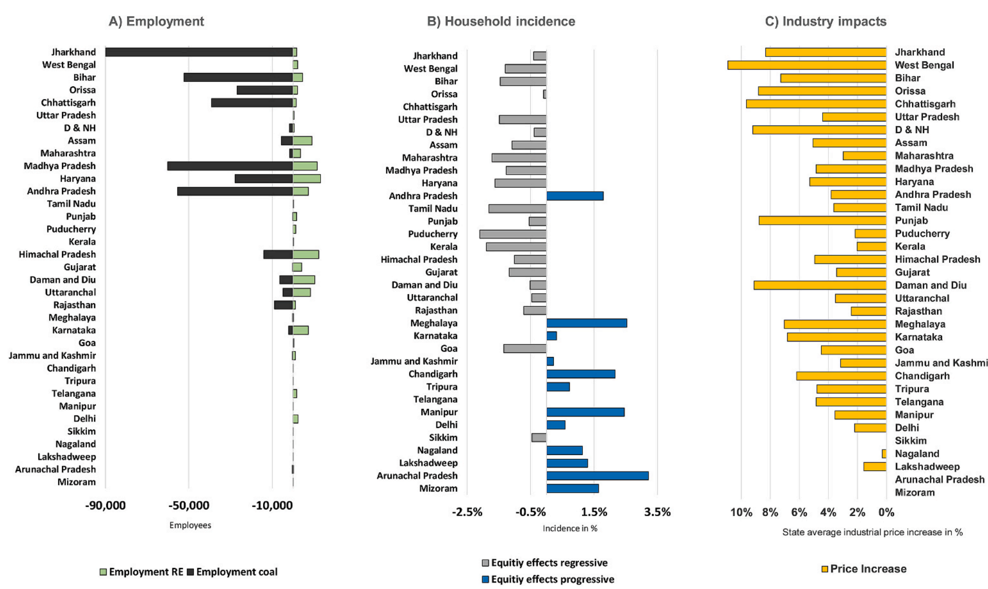
Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2023.113621.

Annex A. Complementary figures on distributional impacts by state



A1. Difference in incidence of total expenditures between quintile 1 and quintile 5, for energy subsidies removal (A, B and C, blue scatter plots) and a carbon price of USD 40 per ton of CO2 (D, red scatter plot). Negative values correspond to regressive distributional impacts. The size of the bubbles indicates the share of states' population belonging to India's first income quintile. The color intensity indicates the incidence on the first quintile households (own elaboration).



A2. Disadvantageous and favorable conditions as a result of an energy transition across Indian states (own elaboration).

Annex B. Power sector governance and the role of states

India's Electricity Supply Act of 1948 put power sector governance largely under state control.[7] The act stipulated that each state should create a State Electricity Board (SEB), exercising control over the generation, distribution and utilization of electricity within their respective territory. While the central government is responsible for coordinating and issuing energy-relevant legislation, states are in charge of implementation, and tariffs remained under the authority of SEBs (Dubash and Rajan, 2001a). In the period now referred to as the Green Revolution, in the late 1970s, states gradually introduced electricity subsides in the residential and agricultural sectors. These subsidies became increasingly relevant for politicians to

[7] This Annex provides a brief historical outline of political economy determinants of the power sector, touching upon the role of states in energy and power sector policy. Exhaustive reviews are provided by Dubash et al. (2018); Ebinger (2016); Dubash (2007); Dubash and Rajan Dubash and Rajan (2001b); Birner et al. (2011); Tongia (2003).

attract the vote of the farming workforce (Badiani et al., 2012). By the 1980s, subsidies became routine political instruments to gain and maintain political support (Badiani et al., 2012; Dubash, 2007). SEBs, politicians and consumers across the country found a common interest in the subsidy regime: politicians appreciated the votes it delivered, customers enjoyed the free power, and SEBs found it provided a means to hide transmission and distribution losses, theft, as well as inefficiencies in revenue collection.

These subsidies had long-term consequences for the electricity sector (Dubash, 2007). Low prices created an increase in demand for residential and agricultural electricity, causing a shortage of electricity. Industrial and commercial users, which cross-subsidize agricultural and residential consumers, invested in private generation, thereby eroding the base of revenues collected by the SEBs and thus triggering a vicious cycle further undermining SEB finances (Tongia, 2003). The situation worsened in the 1990s, and India's government devoted shares of up to one quarter of its total expenditure to electricity subsidies. Major efforts by international donors, most prominently the World Bank, were undertaken to reform the tariff regime, abolish subsidies, and privatize or reform SEBs to reduce political capture. With the goal of improving the economic efficiency and quality of the system, India passed the 2003 Electricity Act, aiming to unbundle vertically integrated SEBs and open up the market to competition. Independent power producers (IPPs) were allowed to enter the market. While the generation sector has seen increased competition, the distribution of electricity remains largely in the hand of state-owned distribution companies (DISCOMs), which represent regional or state-wise monopolies (IEA, 2020).

The financial and technical situation of the approximately 70 DISCOMs within the country remains highly precarious, mostly due to the persistent subsidies, which oblige DISCOMs to sell electricity below its generation costs (IEA, 2020, ; Nirula, 2019; Pargal and Banerjee, 2014). States devote considerable shares (over 10% in Bihar or Uttarakhand) of their public expenditure budgets towards supporting power sector subsidies (Ebinger, 2016; Gulati and Pahuja, 2010; Mayer et al., 2015). In particular, subsidies for electricity use of agricultural and residential consumers are prevalent, which are cross-financed by industrial users. Despite the existence of block tariffs, in the majority of states, households across the entire income distribution are net receivers of subsidies (Mayer et al., 2015).

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