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# When decarbonization meets development: The sectoral feasibility of greenhouse gas mitigation in India



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## ABSTRACT

In the run-up to the 2015 Paris climate talks, the Indian government announced ambitious climate mitigation goals as part of its INDC (Intended Nationally Determined Contributions). Whether India can meet these targets is a critical question with implications for the success of the Paris climate agreement.

We assess India's potential for emissions mitigation through a sectoral lens, focusing on eight dominant sectors – namely electricity production, agriculture, road transport, buildings, and four disaggregated industry subsectors (steel, cement, petrochemicals, and fertilizers).

We argue that whether emissions mitigation is favorable from a structural perspective is a function of two main factors: (1) political/organizational feasibility and (2) techno-economic feasibility. Political/organizational feasibility in turn is assessed through two additional factors, market concentration and government concentration. Our central intuition is that fragmented markets and/or fragmented government structures pose barriers for collective action.

Road transport represents the most favorable sector for emissions mitigation followed by petrochemicals. Cement and fertilizers are already at or near the global efficiency frontier. Three sectors – electricity, agriculture, and steel – represent hard cases on both dimensions of feasibility. Buildings possess strong techno-economic feasibility but challenging political/organizational feasibility.

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## 1. Introduction

India's role in the 2015 Paris climate talks was central. With China having already reached a bilateral climate accord with the United States, attention focused on India's ambitions and its concerns about climate finance and the division of responsibility for limiting greenhouse gases. The *New York Times* proclaimed India's prime minister, "Narendra Modi Could Make or Break Obama's Climate Legacy" [1]. But with more than 240 million Indians lacking electricity, Modi argued his country needed carbon space to grow and the primary responsibility for mitigation still lay with the developed world [2].<sup>1</sup>

The Paris agreement enshrined a process based on bottom-up commitments by all countries for emissions mitigation, so-called Nationally Determined Contributions (NDCs). The agreement also

includes a review process that will assess progress and periodically "ratchet" up collective ambition to avoid dangerous climate change [3]. Though climate change requires, as Goldthau notes, a multi-scale response [4], this turn to pledge and review nonetheless puts the emphasis of implementation of the Paris agreement on state-level action.

By 2014, India was the 4th largest emitter of greenhouse gases – responsible for 7% of global emissions [5]. However, India's growth potential is more salient to the future trajectory of global emissions. At current rates of growth and existing policies, India's carbon dioxide emissions are projected to triple between 2013 and 2040, with emissions exceeding the United States by about 2035.<sup>2</sup> Some increase is unavoidable. As India's leadership noted, the country's per capita emissions are a fraction of developed countries. Thus, extending energy access to hundreds of millions will increase India's emissions regardless. Still, more aggressive climate mitiga-

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<sup>2</sup> India's carbon dioxide emissions in 2013 were 1880 MT and were projected under current policies to increase to 6067 MT in 2040 ([7], pp. 598, 637–638).

tion could reduce India's future emissions by 57% in 2040 compared to the baseline.<sup>3</sup>

In the lead up to Paris, the Indian government announced ambitious climate mitigation goals, including a reduction in emissions intensity by 33–35% below 2005 levels by 2030 and an increase in the non-fossil share of the country's electricity to 40% by 2030 [6]. While non-fossil energy currently accounts for about 30% of the country's electricity, India will increase its electricity generation by about 170% by 2030 under current policies ([7], p. 639). This would imply upwards of a quadrupling in non-fossil energy by 2030 [8].

Our analysis of India's ability to mitigate its greenhouse gas emissions seeks to correct several lacunae in leading energy journals. As Benjamin Sovacool noted in this journal's launch, political scientists historically have constituted a small proportion of authors, inter-disciplinary teams have been rare, and few articles have covered the developing world. Engineering and economic models have been favored over social science, with field research infrequently deployed. As a consequence, important substantive questions about the political economy of energy systems and governance have not been adequately explored, including what political systems facilitate rapid energy transitions [9,10], what forms of governance produce optimal energy policies [9], and how to reconcile climate change with energy access and energy security [11]. This piece on India draws on insights from political science and other social sciences, employs elite interviews and other qualitative methodologies, and features an inter-disciplinary international research team. We explore the implementation challenges of decarbonization, of mitigating greenhouse gases, as India develops.

Whether India and other major economies can meet their greenhouse gas emissions targets is a critical question with implications for the success of the Paris climate agreement. Studies that look at mitigation feasibility such as those by McKinsey & Company tend to focus narrowly on technical and economic feasibility, largely leaving questions of political economy aside [12,13]. Another way to approach the implementation potential for emissions mitigation in India is through a sectoral political economy lens, focusing on the major sources of emissions in each area of the economy (such as electricity, agriculture, road transport, and direct emissions from industry). Previous sectoral approaches to climate change have largely emphasized whether a transnational sectoral response is viable [14]. Though we are interested in transnational sectoral cooperation, our objective is to assess the scope for emissions reductions in a single country with a method that is generalizable to other major economies that are significant contributors of greenhouse gases.

We argue that whether emissions mitigation is favorable from a structural perspective is a function of two main factors: (1) *political/organizational feasibility* and (2) *techno-economic feasibility*. Different sectors possess different conjunctions of the two. Some possess favorable combinations of both dimensions, others face mixed possibilities, and still others face unfavorable combinations. Our central intuition is that fragmented markets or government structures pose barriers for collective action, while concentrated structures *may* aid such action. We review eight dominant sectors, namely electricity production, agriculture, road transport, buildings, and four disaggregated industry subsectors (steel, cement, petrochemicals, and fertilizers). From the vantage point of our methodology, road transport represents the most favorable sector for emissions mitigation followed by petrochemicals. Three sectors – electricity, agriculture, and to a lesser extent steel – represent harder cases on both dimensions of feasibility. Buildings possess strong technical potential but challenging political/organizational

feasibility. Cement and fertilizers in India are already near the global technical frontier.

Our sector-based political economy approach to emissions mitigation is applicable beyond India. By looking at the countries that are large sources of emissions and the relative feasibility of emissions reductions in the most important sectors of their economies, we can appreciate the implementation challenges of the Paris agreement and how national and international actors might overcome them. To say that some sectors face structural barriers to emissions mitigation is not to say that these forces are immutable, merely to acknowledge that structures are sticky, that they may endure over the medium-run of a decade or more. Addressing underlying structural impediments may take time and vigorous agency.

We unpack this argument in three sections. The first lays out our conceptual framework. In the second, we apply this approach to each sector. We conclude with policy implications and areas for further research. This article is based on a review of sectoral data and about 30 field interviews in India (for detailed methods, see Appendices 1 and 20 in Supplementary material for an anonymized list of interviewees).

## 2. Conceptualizing the scope for emissions reductions

How can we understand the prospects for emissions mitigation in India? We identify two dimensions of feasibility from a structural perspective, one political/organizational and the other technical/economic. By feasibility, we mean possible actions to significantly reduce GHG emissions or avoid future emissions growth in a sector. Both dimensions vary from high to low feasibility.

The first dimension emphasizes whether structural features of the market and the government in that sector are conducive for emissions mitigation. Our central intuition is that either the market or government benefits from a concentrated structure to facilitate collective action and mitigation. Our conceptualization of structure, especially on the government side, includes political and institutional factors. We deliberately leave aside actors' preferences and focus on structural constraints and enablers of change. This is not because we think actor preferences are unimportant – this is far from the case – but because a structural measure can be assessed more completely and accurately in our framework than intent or will. These depend on political leadership and can change quickly depending on the status of the economy or the increased political salience of new issues in the co-benefits arena such as air pollution.

In our second dimension, we code the technical/economic prospects for emissions mitigation based on how far the sector is from its efficiency frontier and the cost of abatement measures. Sectors that are near their efficiency frontier have limited room for improvement. Even sectors with technical scope for emissions reductions may require costly investments that make mitigation challenging.

While a simplification, dichotomizing these two dimensions yields the following matrix (see Fig. 1). In the bottom left quadrant, Cell A, are hard cases for emissions mitigation, characterized by low feasibility on both dimensions. In the upper right, Cell C, both dimensions of feasibility are high. These are most favorable sectors for emissions mitigation. The other two cells are mixed cases, where one favorable attribute is offset by an unfavorable one. The upper left, Cell B, possesses low political/organizational feasibility but high techno-economic feasibility. Cell D possesses high political/organizational feasibility but low-techno economic feasibility, either because it is already at its efficiency frontier or because abatement measures are costly.

<sup>3</sup> The IEA estimates India's emissions in the 450 scenario for 2040 to be 2632 MT ([7], p. 639).

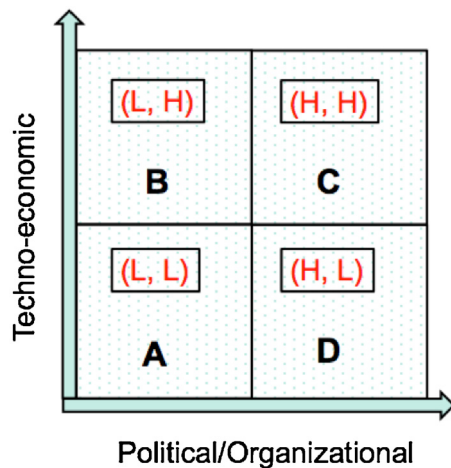


Fig. 1. Overall Assessment of Mitigation Feasibility.

### 2.1. Political/organizational feasibility

Our primary contribution is on the political/organizational side. We assess this dimension based on two underlying sub-dimensions, namely *market concentration* and *government concentration*. It is important to note that in our usage of the term, “concentration” does not necessarily equate to “power”, but rather is simply the inverse of the degree of fragmentation. For example, a concentrated market structure could still be relatively weak if the power of government in that sector is higher than that of the market.

#### 2.1.1. Market concentration

We first assess the degree of market concentration. Concentrated sources of emissions provide nodes or focal points where large emissions reductions may be possible. Within individual sectors, there is great variation in the number of actors responsible for emissions, with some sectors (such as agriculture) and sources of emissions (such as from traditional fuel sources, namely low efficiency cookstoves) generally quite diffuse and difficult to organize.<sup>4</sup> Other sectors/sources of emissions such as steel and automobiles may have smaller numbers of producers, even if there are many end users.

In assessing market concentration, in addition to the number of actors, we evaluate whether the sector is characterized by a small or large number of product lines that contribute to emissions. We also assess whether the market is nationally integrated or divided into regional markets. For both, more product lines and a fragmented national market make collective action more challenging.

We take the viewpoint that sectors that possess more market concentration are potentially more feasible for emissions mitigation from a collective action perspective ([15], [84], p. 521). In our view, the transaction costs of regulating many small sources of emissions are high. In their assessment of international sectoral possibilities for climate mitigation, the World Resources Institute concluded that limited numbers of actors are easier to coordinate ([14], p. 22). Similarly, Todd Sandler argued that small numbers of producers made it easier to tackle the ozone problem ([16], pp. 217–218).

If a handful of firms are largely responsible for emissions in a sector, changes in their behavior will radiate throughout the market much more quickly. For example, five companies dominate the Indian air conditioner market; their efforts to reduce the use

of hydrofluorocarbons (HFCs), potent climate forcers, will affect nearly the entire market [17]. However, when many firms generate emissions in a sector, change by a few of them will have minimal impact. Moreover, where millions of actors are spread over a wide geographic area, the state’s ability to impose regulations is challenging. As Ken Oye writes: “As the number of players increases, transactions and information costs rise” ([18], p. 19). It is also difficult, though not impossible for groups with large numbers of actors to organize ([19], p. 783, [20], p. 39). In his classic work, Mancur Olson argued that because the benefits of collective action for individuals in large groups are small, large groups suffer from sub-optimal collective action and free-riding behavior [15]. To the extent that emissions mitigation involves some adjustment costs, sectors with fewer actors will also have greater profit margins than more competitive sectors and can more readily absorb the transition costs.

This is not to say concentrated markets always or mostly facilitate change toward emissions mitigation. We recognize that market concentration can also translate into an ability to resist change, especially if concentration is also accompanied by political power. As Dale Murphy argues, “concentrated markets facilitate collective action and the ability to shape regulations” ([21], p. 14). Indeed, in theories of regulatory capture and rent-seeking, existing rules often preserve incumbents’ privileges and insulate them from competitors [22]. For example, incumbents such as fossil fuels producers have opposed action that would reduce emissions and subject them to competition from renewables.

However, structurally, it may be easier to realize large-scale emissions mitigation in concentrated markets. States can mute market opposition by offering private benefits such as grandfathered emissions permits [16]. In the face of incumbent intransigence, powerful states can also shift their support to new market entrants. Indeed, as Murphy and others argue, in many instances, incumbent firms may favor regulation to raise the barriers to market entry to competitors. This can lead to so-called “Baptist and bootlegger” coalitions of environmentalists and business interests ([21], p. 16, [23]). Self-regulation can also play a role, if incumbents can see a future for themselves in the transition to a low-carbon economy (and face international or domestic market pressure to do so), either by making their operations more efficient or re-constituting themselves. Further, concentrated markets with large established brand players are subject to reputational/naming-and-shaming costs on the one hand and benefits on the other. They, given supranormal profits provided by less competitive markets, can also more readily afford the adjustment costs of climate mitigation. The shaming potential is much less of a factor in the case of a fragmented market, due to the relative anonymity of the myriad small players.

#### 2.1.2. Government concentration

We assess the number of separate levels or actors that influence policy in a sector, either as a function of constitutional power or political/historical practice. Sectors in which the central government shares rule-making authority with states/provinces or local governments or are primarily a state or local responsibility are more fragmented and increase the collective action costs of mitigation.

Our logic is informed by veto players theory which argues that systems with more players are prone to policy inertia. With more players, the ability to reach a common position becomes more difficult, unless the actors have homogenous preferences [24]. Principal-agent theory also is relevant. If multiple principals (i.e. government actors) control a policy, then unless they share preferences, agents (i.e. market actors) have slack to pursue their own agenda [25].

As part of the government concentration assessment, we also ask whether government credibly can offer or withhold incentives

<sup>4</sup> This approach is informed by [86].

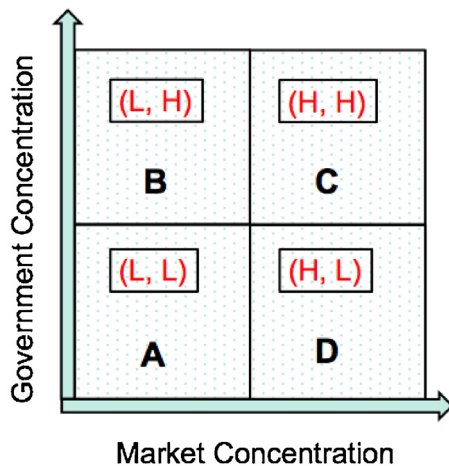


Fig. 2. Political/Organizational Feasibility.

to market actors to mitigate emissions, either through regulation or access to credit, subsidies, land, or fuel linkages for electric power.<sup>5</sup> Some sectors are strongly influenced by powerful political/voting constituencies; such factors are included where appropriate in our assessment. We code whether there is high or low concentration for both market and government. That yields a nested  $2 \times 2$  matrix through which we make an ultimate judgment of political/organizational feasibility (see Fig. 2).

For this sub-matrix, the coding is nuanced. Recalling our general rule is to code concentration as creating more favorable decision nodes for action, cases in Cell A (lower left) are least favorable with fragmented government and markets. Cell B contains cases of low market and high government concentration. These are more favorable cases than cell A – favorable from a government perspective but the market is challenging to organize with many producers, product lines or segmented markets. We code such cases more favorably when the government clearly possesses “asymmetric agency” *vis a vis* market actors in terms of a demonstrated ability to impose and enforce regulations and penalties ([26], p. 84). Cell D are cases of market concentration, which is favorable for emissions reduction, but government fragmentation. Provided market actors are responsible for a large share of emissions, we code these cases as high political/organizational feasibility if the sector is lightly regulated such that the relative balance of power favors market actors. However, this combination can also lead to opposition if market actors’ preferences are opposed to mitigation. Market actors are not always inclined to oppose emissions mitigation, particularly if they face international or domestic reputational pressure to green their operations and/of if new rules redound to their benefit [27]. We have seen nascent efforts to do that in beef, palm, soy and other sectors. Cell C contains cases of high market and high government concentration, which structurally creates two concentrated nodes. Recalling that concentration is not necessarily identical to power, the coding in such a situation depends on the relative power of each – it is possible to have a concentrated but weak node. The result however could potentially be a deadlock if the power balance is relatively equal and the government and private sectors have a long history of antagonism. We code such cases as favorable if the power balance favors one side or the other or if there is no history of the two being at odds.

Our theory does not privilege a particular model of regulation. We do not presume (nor preclude) that regulation comes about

through negotiated outcomes between the government and interest groups. As Shafer argues, the structures of different economic sectors may shape what regulatory arrangements are possible. In his view, states that have a few big firms tend to develop institutions that are organized around them with close ties between state agencies, management, and labor. Where there are many small firms, the state can have more autonomy to regulate them ([28], pp. 12–13). However, his argument presumes a degree of national-level state capacity to impose policies that may be difficult to realize if governance is fragmented. Moreover, in more complex economies, regulatory arrangements may vary across sectors.

Where government action is fragmented among national, state, and local authorities, we submit this poses a barrier to collective action. Likewise, fragmented market structures require emissions mitigation across an entire country and the collective efforts of many different actors, each of which is responsible for a small share of emissions. Where governments themselves are also fragmented, their ability to regulate many private actors is challenging. Where government structures are concentrated but markets are fragmented, powerful state actors with asymmetric agency can overcome these constraints. Where both government and market structures are concentrated, more corporatist arrangements may be unavoidable to achieve successful mitigation since concentrated market structures may confer political power. Where markets are concentrated and governments structures are fragmented, self-regulation by market actors may potentially be the only vehicle for mitigation at the national level, though sub-national units may be able to impose or negotiate solutions.

## 2.2. Techno-economic feasibility

Beyond political/organizational feasibility, we also code techno-economic feasibility, based on two sub-dimensions, namely how far the sector is from its efficiency frontier (technological feasibility) and the costliness of abatement efforts (economic feasibility).

### 2.2.1. Technological feasibility and the efficiency frontier

Some sectors in India are near their efficiency frontier in terms of energy efficiency and use of available technology. This makes further improvements difficult. For technological feasibility, our indicator is an assessment of the gap between the so-called Best Available Technology (BAT) and what the sector in India uses. BAT is defined as the latest available, state-of-the-art technologies and processes within a sector. These are not notional technological improvements that are theoretically possible or for which prototypes exist but the most efficient processes that are already commercially available and being adopted by market leaders. While BAT can and does change with technological innovation, the current technological frontier of commercially available technology poses a short- to medium-run benchmark for comparison, corresponding approximately to the commitment period defined in Paris (until about 2030). Given the hazards of accurate forecasting of technological change, we take a more cautious approach of using only the BAT frontier as it is currently established.

### 2.2.2. Costs of abatement

Even in sectors where further efficiencies are possible, the cost of improvements may be prohibitive. Though those costs might not be high in a global sense, they might be costly for the actors responsible for emissions in that sector. Technological innovation can, of course, bring these costs down, as we have seen with solar technologies in recent years, but current costs at least provide a snapshot of economic barriers that may be salient to decision-makers until those costs change.

We mostly rely on existing studies to assess these two dimensions. This conjunction of sub-dimensions yields a second nested

<sup>5</sup> In some areas, such as fertilizers, withdrawal of subsidies may not be credible because large voting constituencies would oppose such action.

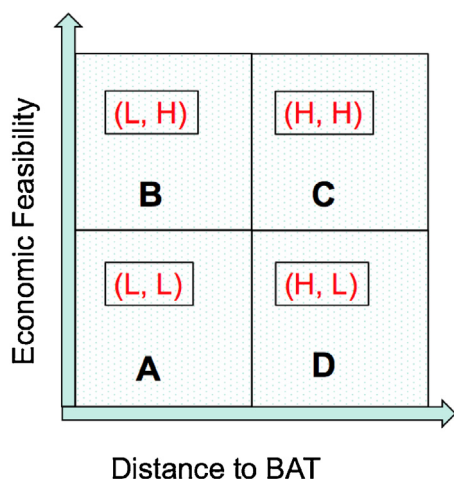


Fig. 3. Techno-Economic Feasibility.

$2 \times 2$  matrix. We code high costs as low economic feasibility and low costs as high economic feasibility. We code high distance from BAT as high technological feasibility and low distance from BAT as low technological feasibility (Fig. 3).

In cells A and B, there is low technical feasibility as the sectors are already at or close to BAT. There is thus limited room for further mitigation. Cell B is more favorable than Cell A: to the extent that there are efficiency gains left, they do not cost much (high economic feasibility). Cell C contains favorable cases because it possesses both room for efficiency gains (high technical feasibility) and low abatement costs (high economic feasibility). Cell D contains harder cases where there is abatement potential (high technical feasibility) but high costs of abatement (low economic feasibility). We see the combined techno-economic feasibility in these terms: cell C as most favorable and cell A as least favorable. Cell B has limited room for efficiency gains but the changes are not costly, thus we rate these cases somewhat favorably. Cell D present challenging cases for an overall judgment of techno-economic feasibility as there is great scope for emissions reductions, but they are costly. Our decision rule for such split decisions is to suggest lower techno-economic feasibility than cell C but higher than cell A and somewhat less favorable than cell B. To capture this in terms of our overall typology in Fig. 1, we locate such mixed cases further north on the diagram. The bottom half of cases in Fig. 1 represent cases of low techno-economic feasibility and further north suggests somewhat improved techno-economic feasibility.

### 3. Key sectors contributing to India's emissions

We isolate the most important sectors in the Indian economy, using the World Resources Institute's CAIT database [29] that captures emissions in 2010 and a study by McKinsey Global Institute ([13], p. xii) that projects likely emissions in 2030 for the "reference case" (see Fig. 2).<sup>6</sup>

The electricity sector currently contributes the largest slice of direct emissions, nearly 39% of the total (see Fig. 4). It will continue to be the largest sector in 2030, with its contribution increasing to 50%.<sup>7</sup> Industry currently contributes 25% of net direct emis-

<sup>6</sup> The McKinsey reference case assumes a medium rate of growth of 7.5% from 2005 to 2030, with emissions patterns accounting for policies and programs announced by 2009. It does not take into account India's INDC submissions to the UNFCCC in 2015.

<sup>7</sup> The McKinsey projections pre-date India's renewable energy commitments at Paris. However, even if the ambitious renewables targets are achieved, electricity

sions, made up of process emissions and emissions due to fossil fuels burnt *in situ*. This will grow, making up 27% of net emissions by 2030 ([13], pp. 2–3). Agriculture is currently the third-largest contributor at 14% of net direct emissions, but its relative contribution is projected to decline to less than 8% in 2030. Road transport is the fourth-largest,<sup>8</sup> comprising about 6% of the current total, but this will grow to nearly 11% by 2030. The above sectors have been defined on a supply-side basis. A key demand-side sector, namely buildings, is also discussed (see Appendix 4 in Supplementary material for buildings' share of electricity).

Thus the key sectors for this study are electricity, industry, and road transport with agriculture and buildings analyzed briefly. Together, these account for 84% of India's current GHG emissions and could be as much as 96% in 2030. These figures imply large increases in total GHG emissions in some sectors (namely electricity, industry, and transport) and largely flat emissions in transport (see Appendix 3 in Supplementary material). What this means is that independent of our structural analysis, avoided future emissions in the electricity sector are the most important. A 2012 IEA scenario analysis generated country-level sectoral emissions associated with a 2 degree and 4 degree Celsius increase in global temperatures. In the 2 degree scenario, nearly 58% of India's emissions reductions in 2040 came from the power sector with transport and industry each providing roughly 13% and 12% respectively [30].

#### 3.1. Electricity

Electricity is the largest sector in terms of direct GHG emissions and has been growing at an annual growth rate of 5.5% in recent years. Coal dominates India's utility-based electricity sources, contributing about 75% of net generation (see Appendix 3 in Supplementary material). Though large hydropower is the second largest source of Indian electricity currently with about 12% of net generation, its expansion has stalled and several environmental and land acquisition barriers will reduce its future salience. Natural gas and nuclear contribute only about 3.8% and 3.2% to generation currently and face major barriers to expansion.

Plans call for continued reliance on coal, with production to be doubled by 2019 [31]. National targets of 175 GW of renewable capacity by 2022 were announced in 2014.<sup>9</sup> Much will come from solar (100 GW) and wind (60 GW), the remaining from biomass (10 GW) and small hydro power (5 GW). India's INDC submission to the UNFCCC in October 2015 also effectively envisaged renewables capacity increasing to 350 GW by 2030 [6].

Clearly, India's future electricity growth is expected to come mainly from coal and renewables. Within the latter, solar and wind dominate. Therefore, we concentrate on coal, solar, and wind.

##### 3.1.1. Political/organizational feasibility

Nearly 1/3 of India's power generation capacity is currently in private hands (see Appendix 5 in Supplementary material), though the private sector adds about two-thirds of new capacity each year. Coal has traditionally been state-dominated; however, private sector capacity has grown. The largest portion of thermal generation remains in state hands through the centrally managed public sector

will remain by far the largest contributor to emissions, at roughly 45% of the total based on a back-of-the-envelope calculation by the authors.

<sup>8</sup> The category "Other Fuel Combustion" is not strictly a sector in CAIT. Rather it is an agglomeration of methane and nitrous oxide contributions from multiple sectors due to incomplete fossil fuel combustion. It also contains contributions to CO<sub>2</sub> emissions from household and commercial use, including cooking. See ([78], pp. 19–20).

<sup>9</sup> As of November 2015 renewable power capacity according to the Government of India was more than 38 GW with wind dominating at 24.8 GW and solar at 4.7 GW with other renewables amounting to 8.8 GW [79].

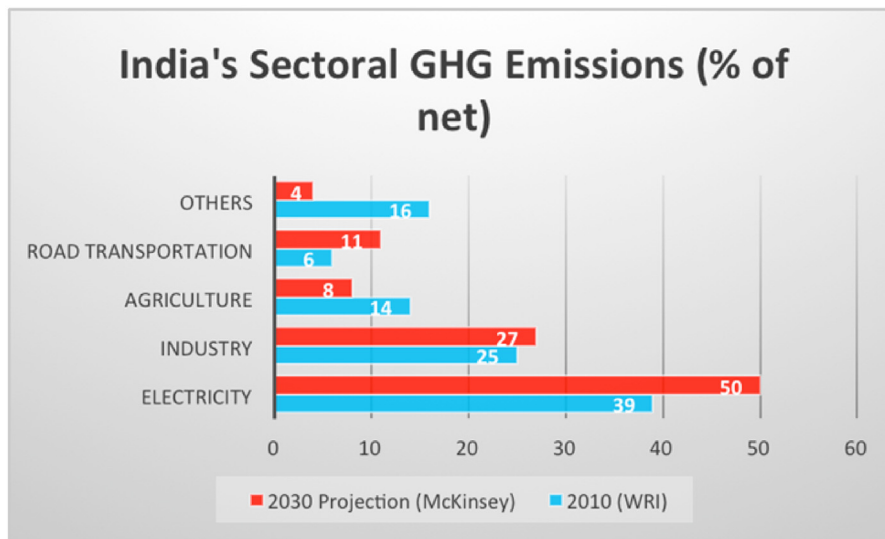


Fig. 4. Sectoral contributions to GHG emissions in India, excluding land use change in 2010 and 2030.

National Thermal Power Corporation (NTPC) and several generators owned by state governments. Renewables such as solar and wind are almost entirely private-sector dominated.

NTPC is the largest national thermal power company, with more than 20% of net thermal capacity. Various state-owned and private companies own smaller portions including Tata, Adani, Mahagenco, Reliance, and others (see Appendix 6 in Supplementary material).

The market share of the top four thermal power companies (CR4) is only 34.6% of the total. The equivalent value for the solar sector is 21.4% [32]. This implies that the thermal and solar sectors are fragmented. The wind market is also fragmented with many smaller-scale generators.

Though the end product (units of electricity) is undifferentiated, electricity is far from a commodity market and is heavily regulated in India. The market is also not integrated nationally, with most generators supplying their respective states. For larger plants set up by some private players or major national companies such as NTPC, the supply area is confined to a few neighboring states. We therefore assess market concentration for electricity to be **low**.<sup>10</sup>

Turning to government concentration, electricity is a concurrent subject in the Indian constitution. This means both state and central governments have roughly equal power over the sector. The central government exercises influence through subsidies, taxes, owning most interstate transmission capacity, and direct ownership of several large generating plants. The central government is in charge of auctioning coal mines for thermal power plants and defines some parameters of new projects. The central regulator also indirectly influences emissions intensity of thermal plants by specifying minimum performance parameters.

State governments are instrumental in land acquisition, have their own fiscal regimes, operate a large share of generation, and have their own independent regulators to decide state-level tariffs. States also own and operate most Indian distribution companies (Discoms),<sup>11</sup> thus effectively acting as buyers representing bulk consumer interests.

<sup>10</sup> Electricity is somewhat unique in that its fragmented local markets mostly represent local monopolies. From the vantage point of a given local geography therefore, the market concentration appears high. Nevertheless, since mitigation at the nationwide level is the focus of this study it is more appropriate to classify market concentration as low due to the large number of actors involved.

<sup>11</sup> For more on experiments in Discom privatization in India see [80].

Though renewable energy industry ownership is almost entirely private-led, the government remains highly influential through an array of policy tools such as feed-in-tariffs, capital subsidies, land acquisition facilitation, and (through Discoms), committing to buy power from the generators through Power Purchase Agreements (PPAs).

Generators thus have to contend with substantial government power in tariff setting, fuel linkages, performance and infrastructure access. However, this power is fragmented and held across two levels of government (central and state) as well as independent central and state regulators. Moreover, several central government ministries exercise power over electricity – such as Ministries of Power, New & Renewable Energy, Coal, Atomic Energy, and Petroleum and Natural Gas. This large number of separate and cross-cutting government actors leads us to characterize government concentration in the sector to be **low**.

Since market concentration is also **low**, the overall score for political/organizational feasibility is also **low**.

### 3.1.2. Techno-economic feasibility

Two technological barriers to climate mitigation in the Indian power sector are inadequate grid infrastructure and dominance of low-efficiency subcritical technology in coal plants. This positions the sector well short of BAT.

A critical challenge in ensuring that renewable power is integrated into the grid is the management of variability and uncertainty. This requires retooling the grid and ensuring maximum geographic dispersal of renewable energy generation [33]. There is insufficient capacity to evacuate power to the grid from many renewable generation sites, which requires significant future investment. Solar electricity is a growth area, and though some policy tools have been effective [34,35], meeting the ambitious INDC target of 100 GW by 2022 is challenging due to financial [36] and other barriers [85].

In the thermal sub-sector, more than 90% of Indian coal-fired plants use older, less efficient subcritical boiler technology. This can mean an efficiency shortfall of as much as 15 percentage points compared to BAT. The problem is concentrated in older, state government-owned generators. Retrofits to newer supercritical and ultra-supercritical technologies can lead to large avoided

emissions but have not been attempted seriously.<sup>12</sup> A relatively high capital cost for retrofits, especially for ultra-supercritical technologies, is one barrier, as is the loss of generating capacity during the months-long process for individual plants ([37], p. 71).

Thus on the first sub-dimension, namely distance from the BAT frontier, we rank the sector as **high**. On the second, namely economic feasibility, the ranking is **low**, given high costs of the transition. Therefore we assess the techno-economic feasibility score for the electricity sector as **low (mix)**; there are ample opportunities for emissions reductions but they are potentially expensive, which substantially tempers their feasibility. This leads us to locate the energy sector further north in cell A in Fig. 1.

### 3.2. Industry

Industry is the second-largest contributor to GHG emissions in India with about 25% of the total, and industry's share is expected to grow [13]. Three sub-sectors dominate industrial emissions, namely steel, cement and chemicals, accounting for nearly 80% of net industrial direct emissions (see Appendix 7 in Supplementary material) [38]. We examine these sub-sectors along the two dimensions of political/organizational and technical feasibility for mitigation.

### 3.3. Steel

India is the world's third-largest producer of steel with projected output of nearly 90 million tonnes in 2015 [39]. Steel production generates 6.2% of India's total emissions [40]. However, India currently has low per capita steel consumption of 59.4 kg compared to, say, China with 510 kg. This implies large increases in Indian steel production.

The industry is made up of two segments. The integrated or primary steel segment, with typical plant capacities of over 1 million tonnes, produces steel from iron ore through blast furnaces. The non-integrated or secondary segment is comprised of smaller steel mills using electric furnaces that use scrap or Direct Reduced Iron (DRI) as inputs, as well as plants that produce DRI from iron ore.

Approximately 55% of steel is produced in primary plants and 45% in the secondary segment. Of the latter, 30% originates from DRI plants with the balance manufactured from scrap. The primary and DRI segments contribute the overwhelming share to emissions.

#### 3.3.1. Political/organizational feasibility

Political/organizational feasibility is assessed by examining its two sub-dimensions. More than 80% of Indian steel is produced by the private sector (see Appendix 8 in Supplementary material), though some key primary plants are in state hands. Major contributors to direct CO<sub>2</sub> emissions are the primary and DRI plants, as 70%–80% of carbon emissions in steel production originate in the process of reduction of iron ore to iron [41].

Six companies dominate, with the market share of the top four yielding a CR4 value of 52.4% (see Appendix 9 in Supplementary material). State-owned Steel Authority of India Ltd. (SAIL) is the largest with 19.5 million tonnes capacity followed by JSW, Essar Steel, Tata Steel, state-owned RINL, and Jindal Steel and Power (JSPL).

However, the DRI segment is more fragmented with 70 producers responsible for about 75% of production [42]. Since 85% of DRI

is manufactured in coal-based plants, this segment contributes a disproportionate share to steel's total emissions.<sup>13</sup>

Steel has minimal product differentiation (although niche specialized markets exist, such as the automotive industry). The market is nationally integrated, with plants in central and eastern India, while demand is concentrated in southern, western, and northwestern regions.

However, considering the large number of players in the high-emitting DRI segment, steel is assessed to have **low** market concentration from a GHG emissions perspective.

Steel is liberalized, so government regulation and protectionism are limited. The central government is the main actor through its ability to levy tariffs and regulate pollution. Steel is covered under the Ministry of Power's flagship Perform Achieve and Trade (PAT) scheme, which is a cap-and-trade type approach for enhancing energy efficiency of major industrial sectors, with a direct impact on GHG emissions. The central government also has a dedicated Ministry of Steel, which acts as a coordinating agency in various areas, for example industry data collection.<sup>14</sup>

We assess government concentration in the steel sector as **high**, with influence residing with the central government and apportioned mainly between two ministries.

With the market concentration sub-dimension being low, we need to examine the relative power of the market and government to estimate overall feasibility. In general the market has been more influential than the government in driving mitigation, though the PAT scheme has increased leverage of the government and has demonstrated a level of "asymmetric agency." On the other hand, current high indebtedness and low capacity utilization act as major market-driven barriers to further transformations [43]. We therefore assess political/organizational feasibility of the steel sector as relatively **low**.

#### 3.3.2. Techno-economic feasibility

The primary steel segment in India still falls short of global emissions intensity standards [44,45]. A 2010 study concluded the gap between emissions intensities in blast furnaces of primary plants was as much as 40% with those achievable with BAT, though improving [46].

The DRI segment is also a major contributor to GHG emissions. Gas-based DRI plants emit much less CO<sub>2</sub> than coal-based plants. However, in India, the building of gas-based plants has stalled due to a crisis in availability and cost of natural gas. Thus 72% of DRI capacity is currently coal-based, with this fraction growing over the last decade [47]. The substitution of natural gas presents high abatement costs and is challenging to implement ([37], p. 12).

Incorporating energy-efficient practices in the steel sector involve variable costs but significant implementation challenges. The PAT scheme has led to improved process efficiencies since 2012, though it has faced implementation challenges [45]. Improvements in energy efficiency and emissions intensity are expected to continue until at least 2020, but analysts have concluded the steel industry is unlikely to achieve BAT levels soon due to the high cost of such technologies ([37], p. xviii). Thus on distance from BAT (technological feasibility) the assessed score is **high**. Costs are high, therefore economic feasibility is coded as **low**. Therefore, we assess the techno-economic feasibility of mitigation in the steel sector as **low (mix)**. Like electricity, we locate steel further north in Cell A in Fig. 1 accordingly.

<sup>12</sup> The high cost and commercial uncertainty associated with IGCC and CCS coal technologies means that these will most likely be unviable for India until at least 2030.

<sup>13</sup> Based on IEA values for emission intensities for DRI and primary segments [81], the contribution from the DRI segment was calculated to be above 40% of the net steel sector emissions.

<sup>14</sup> The ministry's Joint Plant Committee acts as a central resource for pooling industry capacity, production, export, and import data. See [82].

### 3.4. Cement

As the second-largest industrial sector contributor to emissions, the cement sector is crucial for India's climate efforts. India is the world's second-largest cement producer with an annual capacity of 350 million tonnes, projected to grow by more than 8% annually to triple by 2027 [48].

#### 3.4.1. Political/organizational feasibility

Practically the entire sector (98%) is in private hands. 188 large plants produce 95% of cement in India, while 365 small plants produce only 5% [48]. For our purposes, only the large players need to be taken into account. The industry is home-grown, but recent acquisitions have placed about 20% of capacity in foreign hands.

The market share of the top four yields a CR4 value of 48.2, which is close to a concentrated market. The leading players include the recently merged ACC-Ambuja-Lafarge, Ultratech, Jaypee, Shree Cement, and others (see Appendix 10 in Supplementary material).

The industry association of Indian cement companies, the Cement Manufacturers Association, is highly coherent with a long history of fostering cooperation between the major players. The high level of cooperation between Indian cement companies has triggered accusations of price collusion [49–51].

Cement is a commodity with little product differentiation. However, the market is not nationally integrated. As transport costs are a major portion of overall costs-to-market, Indian cement plants are largely regional, with most buyers within a 300 km radius.

Our assessment is of an industry with a high degree of “supplier power” and concentrated capacity for joint action. Thus we rate its market concentration as **high**.

Cement is liberalized with significant foreign investment and has no major subsidy regime. Unlike steel, there is no specific ministry focused on cement. However, cement is covered by the PAT scheme for energy efficiency, with 84 large plants included. The score for government concentration is assessed to be **high**.

Although both sub-dimensions are high, the sector is predominantly market-driven with limited government power. Thus we assess the political/organizational variable for cement as **high**.

#### 3.4.2. Techno-economic feasibility

In contrast to steel, the cement industry in India is highly emissions and energy efficient, exceeding levels of many advanced countries in North America and Europe [52]. Energy intensity in India's large cement plants, which dominate production, is among the lowest in the world, below only Japan ([38], p. 36). This means the performance of the cement sector is at or above BAT levels.

Further technological improvements could yield emissions intensity reductions. One option is blended cement production, which incorporates clinker substitutes such as fly ash from thermal power plants. This trend is increasing, with blended cement at 72% of total cement production [53].

The second approach is greater use of biomass and alternative fuels instead of coal. Using waste as an alternative fuel has the added benefit of improving air quality as high temperatures in cement kilns destroy most hazardous emissions [54]. However, biomass and waste sectors in India are not organized in a way that these transitions can be easily implemented. Use of alternative fuels in cement is currently below the global average of 10% [48].

The sector is adopting the above technologies and actively engaged with the global Cement Sustainability Initiative to launch a roadmap in 2013 for a further 45% reduction in carbon intensity by 2050 [55]. However, this target is ambitious and may be challenging to meet.

To conclude, the industry's distance from the global BAT frontier is **low**, and the challenges and costs of further abatement beyond BAT levels are broadly speaking high, making economic feasibility

of further emissions reductions **low** ([37], p. xviii). Thus techno-economic feasibility for cement is assessed to be **low**.

### 3.5. Fertilizers and Petrochemicals

The Indian chemicals industry is the third-largest industrial sub-sector in terms of GHG emissions. The industry is diverse with about 70,000 commercial products [56]. Ammonia production (for manufacturing urea) within the fertilizer segment contributes more than half of total direct emissions of the entire chemicals sub-sector ([38], p. 43). In terms of trends, the fertilizer sector is slow-growing whereas petrochemicals is projected to grow at the rate of 11–13% and will potentially be the largest segment [57]. These two segments are therefore our focus.

#### 3.5.1. Political/organizational feasibility

India is the world's third-largest producer and consumer of fertilizers. The fertilizer industry has traditionally been seen in strategic terms, as food self-sufficiency has been a high priority for all Indian governments since independence. The industry benefits from large subsidies and is subject to regulation.

Nitrogenous fertilizer (urea) manufacture dominates the fertilizer segment in terms of GHG emissions. Urea manufacture alone contributes 3% of India's total GHG emissions [58]. The state owns a significant component with the cooperative model, which has substantial state influence, also prominent (see Appendix 11 in Supplementary material).

The top nine companies in the urea segment account for nearly 80% of capacity, with the top four market shares yielding a CR4 value of 53.3% – a concentrated market. The fertilizer product market is differentiated, but the total number of products is not very large. The market is also substantially integrated nationally. Plants are concentrated in a few states, and consumption, though uneven, is spread mostly across more affluent districts in different parts of the country (see Appendix 12 in Supplementary material) [59].

The central government has a high degree of influence in fertilizer production. The four largest companies (IFFCO, NFL, RCF, and KRIBHCO) in urea production are all in the public or cooperative sector. The government also has enormous power in setting prices of inputs (such as natural gas) and outputs. Annual subsidies for fertilizers from the central government amount to more than \$11 billion, being second only to food subsidies [60]. Fertilizers is also under the PAT scheme on energy efficiency with 29 plants covered.

We assess the market concentration of the fertilizer segment as **high**. Government concentration is also **high**. Government power is significantly greater than market power. Thus the overall political/organizational feasibility of fertilizers is **high**.

The smaller but fast-growing petrochemicals segment also has a mix of private and public players. A key set of intermediate products (upstream in the petrochemicals supply chain) forms the industry's building blocks and, along with feedstocks, contributes most to net GHG emissions in this sector. Prominent among these are ethylene and propylene, the manufacture of which involves naphtha or natural gas as feedstocks. Government control is much less in this segment as compared to fertilizers. Though natural gas prices are regulated, naphtha is decontrolled, and all intermediates and downstream sectors have been liberalized.

As an approximation, we take two sub-segments as a measure of the petrochemicals market. The first is the dominant intermediate ethylene, which accounts for the bulk of sectoral process energy use, while the second is oil refining, which produces the dominant feedstock naphtha.

Ethylene production is mostly the preserve of four key players – private sector Reliance, public sector companies OPaL, GAIL and Indian Oil Corporation (IOC). The CR4 value based on their market shares is 83.8, which qualifies as highly concentrated (see Appendix

13 in Supplementary material). The product market has minimal differentiation and is nationally integrated. This is also true for the oil refinery segment, where the top four players own more than 72% of net capacity (see Appendix 14 in Supplementary material).

Market share data for refineries and ethylene production leads us to rate market concentration for key intermediates and feedstocks for petrochemicals as **high**. Since the central government (acting through the Ministries of Chemicals and Petroleum and ownership of public sector companies) is the dominant player, government concentration is also rated as **high**.

The petrochemical industry is not covered in the PAT scheme. However, with the central government owning a large share of oil refining and ethylene/propylene segments, the relative power of the government and private sector slightly favors the government. The overall political/organizational feasibility of the sector may also be a function of whether the government and private petrochemicals producers have a long history of structural conflict. We found no evidence of this, and therefore we rate the political/organizational feasibility of petrochemicals as **high**.

### 3.5.2. Techno-economic feasibility

Indian fertilizer plants have implemented various energy efficiency measures since the 1980s. As a result of these measures and the addition of newer more efficient plants, the energy efficiency of ammonia plants improved by almost 30% by 2012 [61]. These figures have improved further since the PAT scheme was inaugurated, with the Indian fertilizer production close to the global BAT frontier (Interview 2). Thus, the distance from the BAT frontier for fertilizers is **low**.

Natural gas is ideal for fertilizer manufacture. However, due to serious bottlenecks in natural gas supply, many Indian fertilizer companies use naphtha and fuel oil instead. This results in lower efficiencies and higher GHG emissions. Thus availability of natural gas can further improve emissions intensities in Indian fertilizer plants beyond BAT. However, the challenge and costs of this transition are high, thus making economic feasibility **low**. Thus we assess the techno-economic feasibility for the fertilizer segment as **low**.

Data are more difficult to obtain for energy efficiencies and emissions trends for petrochemicals. The segment is not currently covered by the PAT scheme. One study of three oil refineries estimated a 20–40% reduction potential of emissions intensity in the near term [62]. From a global standpoint, U.S. studies have also indicated substantial potential for energy and process efficiency improvements ([63], pp. 32–37). On the other hand, interviewees indicated the segment was close to BAT levels in the private sector but not in the public sector (Interviews 24, 25, 26). On balance, we assess the distance from BAT frontier as **high**. The challenge and cost of mitigation is rated are low, thus making economic feasibility **high**. Therefore the techno-economic feasibility for petrochemicals is assessed to be **high**.

## 3.6. Buildings

Residential and commercial buildings are a major contributor to electricity consumption, responsible for approximately 12% of emissions. This value is projected to grow in the future to more than 20%, particularly due to rapid scale-up of air-conditioning in Indian homes and offices [64].

Nearly 70% of buildings that will exist in India in 2030 are yet to be built. Buildings consume 35% of Indian electricity and this share is rising at the rate of 8% per year, higher than the growth rate of electricity consumption [65]. These facts, coupled with low current penetration of air conditioners in Indian homes and offices in a country notorious for hot weather, indicate major opportunities for future avoided emissions.

Buildings is different from other sectors, as it is primarily a demand-side arena. There is some fuel burnt onsite, primarily for cooking, and diesel generators supply part of electricity demand in high-end commercial or residential buildings during India's frequent power blackouts. However, most energy consumption is from the utilization of centralized electricity from the grid.

### 3.6.1. Political/organizational feasibility

The buildings sector is composed of hundreds of property developers across India's many cities and towns. In addition to real estate developers, the number of users of built property run into hundreds of millions of private and commercial entities.

Thus, market concentration in this sector is **low**. However, some leading property developers have been first-movers on green buildings, as their clients are willing to pay upfront for energy efficient real estate. However, high-end developers are concentrated in the largest and most affluent cities. Regional developers dominate scores of smaller cities.

A central challenge in this sector is the problem of "split responsibility" in which real estate developers and financiers that construct a building are typically not its users. Thus they have no incentive to build in energy efficiency measures that entail upfront capital costs but yield returns only over time. There is also a widely-held perception that energy efficiency is expensive.

The buildings industry and urban land come under the purview of state and local governments under the 74th Amendment of the Indian constitution. This means all of India's 29 states and hundreds of city governments have primary jurisdiction over this sector. In addition, the central government also plays a role through the Ministry of Urban Development which sets standards and designs and disburses funding for urban renewal projects.

Thus government concentration in the buildings sector is **low**. Since market concentration is also low, political/organizational feasibility for the sector is assessed to be **low**.

### 3.6.2. Techno-economic feasibility

The BAT frontier in the buildings sector is represented by energy efficient, or "green buildings", which deliver energy savings of 30–40% over conventional designs, with an added upfront cost of 3–5%. India currently has about 3 million sq. ft. of green buildings constructed out of about 40 million sq. ft. of built up space (Interview 14).

The Energy Conservation and Building Code (ECBC) promulgated by the central government in 2007 is an attempt to enhance the prospects for green buildings. Only a small minority of India's 29 states have adopted the code. These factors lead us to rate the distance to the BAT frontier in buildings as being **high**.

Practically all technologies needed for green buildings are available in India. These include such things as higher performance glass, wall and roof insulation, and high albedo materials to reduce the need for cooling. The somewhat higher upfront costs are more than paid for in reduced operating costs, though India's high interest rates are a barrier. This can be overcome with more innovative financial models [66], or by offering developers incentives such as extra floor space index.<sup>15</sup>

Ultimately, city governments will have to integrate the ECBC into their by-laws and structure policies with penalties and incentives for those under its rubric. These governments will also need enforcement training and capacity-building in verification and software tools to evaluate compliance.

These are significant but not massive challenges from the techno-economic standpoint and lead us to rate the costs of miti-

<sup>15</sup> As has been tried out in the city of Noida. Interview 4.

gation actions as relatively low, making economic feasibility **high**. Thus techno-economic feasibility for buildings is assessed to be **high**.

### 3.7. Road transport

Transport is the fourth-largest sector contributing to direct GHG emissions in India, with nearly 7% of the total (see Appendix 15 in Supplementary material). Due to the sector's high growth rate, it is projected to be the third-largest contributor by 2030. Road transport makes up 87% of total emissions within the transport sector and is therefore our focus [67].

Rapid urbanization and the adoption of more consumerist lifestyles have driven major increases in vehicle use in India. The total number of vehicles on Indian roads increased by 240% in the decade up to 2012, which amounts to a compounded annual growth rate of 13% ([43], p. 1). This growth is expected to continue, with most originating in urban areas [18].

Key components on Indian roads include 4-wheeler automobiles, 2-wheeler motorcycles and scooters, and 3-wheeler "autorickshaws", and light freight vehicles and buses. All these come under the Light Duty Vehicle (LDV) category. Heavy trucks and larger buses are classified as Heavy Duty Vehicles (HDV). Close to 60% of GHG emissions on Indian roads originate from HDVs, while approximately 40% are from LDV component ([68], p. 79).

#### 3.7.1. Political/organizational feasibility

While the end-user in road transport is highly fragmented, the automotive producer segment is highly concentrated with the leading player in each sub-segment commanding more than 40% of the market. Three sub-segments are particularly relevant – 2-wheelers (which account for nearly 80% of vehicles sold in India), cars and SUVs, and HDVs [69]. The market share of the top four firms in each of the three sub-segments is 75%, 94%, and nearly 100% respectively (see Appendices 17 and 18 in Supplementary material). Product differentiation in automobiles is considerable with scores of models. The market however is nationally integrated and also considerably globalized. An ancillary market relevant to producers is oil refining, which makes the fuel that must meet mandated standards. Oil refining is a highly concentrated sector (see above). Thus the market concentration of the overall auto producer segment is **high**.

Although the producer segment is largely deregulated and dominated by market forces, the government theoretically has a regulatory role in issuing standards and guidelines and fiscal power to levy tariffs and taxes. The relevant actor on the producer side is the central government through the Bureau of Energy Efficiency, Ministry of Road Transport, and Ministry of Petroleum. These ministries have a history of being at odds over environmental standards [70]. Therefore the government concentration on the producer segment is assessed as being **low**.

This combination indicates high feasibility for market action, should the market actors undertake self-regulation, with the caveat that regulatory capture is also a possibility. The empirical evidence (see below) indicates strong and successful resistance by producers to attempts by the government to issue tough standards.

Indian automakers have opposed rules mandating improved efficiency standards in the past and their market concentration coupled with a fragmented government provides them with political leverage to resist change. Nevertheless, from a structural vantage point, were they to acquiesce due to drivers such as reputational costs or if there was a sufficient increase in the government's concentration and asymmetric agency, changes would radiate quickly throughout the sector and have wide impact on the market given market concentration. Therefore, from a purely *structural*

standpoint, the political/organizational feasibility of the producer segment is assessed to be **high**.

#### 3.7.2. Techno-economic feasibility

On the producer side, many technologies required for transition to cleaner vehicles are available in India. However, some need adaptation to Indian conditions, with their lower speeds, poor road quality, and multi-modal transport patterns. Industry has opposed higher fuel efficiency standards, citing cost and lead times of migration [70]. Fuel efficiency standards for LDVs were notified, that is published officially by the government, only as late as 2014 and they are weaker than comparable standards in the EU and the US [71]. These standards allow for a cost recovery (due to fuel savings) in three years. HDVs are far from BAT frontier on multiple counts, with engine standards and tires as the most critical area of change [72]. Standards for HDVs remain under discussion, but have not yet been notified. One of the ministries in the central government has been resisting their promulgation.<sup>16</sup>

On balance, we rate the distance from the BAT frontier for automobile producers as being **high**. The ease and cost of making the transition to higher fuel efficiency standards are significant but achievable, and are therefore assessed to be low, making economic feasibility **high**. Thus overall techno-economic feasibility is rated as **high**.

Given fragmentation in the end-user segment and the challenges posed by a consumer car culture taking off in India, it is clear that avoided emissions in the transport space must involve more than efficiency standards in automobiles. Clearly, other policies such as mass transit will be required. Innovations like bus-rapid-transit have had mixed success in India, and though Delhi now has a functioning metrorail system, greenhouse gas emissions will continue to rise if cars, albeit more efficient, proliferate. The air pollution challenges that have beset Indian cities provide added impetus for change in this space from the co-benefits arena.

### 3.8. Agriculture

Agriculture is currently the third-largest contributor in GHG emissions in India with 14.1% of the net emissions, but its relative share is falling and it will slip to fourth place before 2030 [13]. Nevertheless, it remains an important sector for potential mitigation actions. The three dominant segments within agriculture are methane production from enteric fermentation in livestock, rice cultivation, and nitrous oxide production from application of fertilizers to soils ([73], p. 22) (see Appendix 18 in Supplementary material).

#### 3.8.1. Political/organizational feasibility

The number of producers in the agriculture sector runs into hundreds of millions of mostly poor rural farmers, as most Indian land and livestock holdings are small by global standards. Farmers are the largest bloc of voters in India. They are also politically organized in key states. The products in the sector are numerous, and market integration is mixed with markets being both local and national. We thus assess market concentration for the sector as **low**.

The Indian government has traditionally kept agriculture out of mitigation actions due to livelihood concerns. Food crops in particular are protected in India, relatively insulated from global competition.

In key segments such as foodgrains, the government is the monopoly buyer, setting a minimum support price, and procuring the bulk of crops through the Food Corporation of India. Purchased

<sup>16</sup> Interview 13.

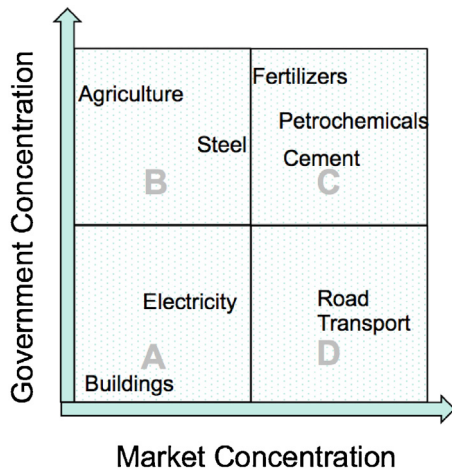


Fig. 5. Coding of India's Sectors for Political/Organizational Feasibility.

grains are then sold at subsidized prices through the Public Distribution System. This is aimed to shelter farmers from uncertainties in international food prices. The Ministry of Agriculture also sets minimum support prices for cash crops such as cotton, jute, and sugarcane.

Thus government is the strongest actor in the sector, acting in concert with state procurement agencies.

In spite of the role of both state and central governments, we assess the government concentration as **high**. This is due to the general political consensus in India for protecting farmers from market volatility.

Though the government is far more concentrated than the market, it decidedly does not have asymmetric agency over the market due to the unusually high political power of farmers, who constitute the majority of Indian voters. Therefore, we assess the political/organizational feasibility of this sector as **low (mix)**. Like electricity and steel, we locate agriculture further north in Cell A accordingly in Fig. 1.

3.8.2. Techno-economic feasibility

Technologies to achieve mitigation in agriculture include crop rotation, carbon sequestration, conservation agriculture practices such as altering water and organic management practices in rice cultivation, altering feed composition of animals, and the use of nitrification inhibitors in soils, among others ([74], pp. 11, 222). The distance to BAT frontier is generally **high**.

The farm sector in India has been in crisis for many years, with significant numbers of farmer suicides occurring due to high levels of debt and uncertain monsoon patterns. Thus from the perspective of the individual farmer, we rate the cost and ease of transition to low-carbon approaches as high, making economic feasibility **low**. Therefore the techno-economic feasibility for the agriculture sector is assessed to be **low**.

3.9. Conclusion and policy implications

Combining these observations, we mapped the nine sectors in terms of our typology (see Appendix 19 in Supplementary material for a complete table) in Figs. 5–7. Fig. 5 shows our coding for political and organizational feasibility, with two cases of government and market fragmentation (electricity and buildings), three cases of market and government concentration (fertilizers, petrochemicals, cement), two cases of market fragmentation but government concentration (steel, agriculture), and one case of market concentration but government fragmentation (road transport).

Fig. 6 shows our coding for techno-economic feasibility, which yields three cases of high economic and technological feasibility (road transport, petrochemicals, buildings), two cases of low economic and technological feasibility (cement, fertilizers), and three mixed cases of high technological feasibility but low economic feasibility (steel, agriculture, electricity).

Fig. 7 shows our overall coding combining political/organizational and techno-economic feasibility. We code two cases in Cell D (cement and fertilizers), where future mitigation potential is limited, largely because the sectors are already near their efficiency frontier. Two cases appear to be structurally favorable cases in Cell C (petrochemicals and road transport) where production is concentrated and there is significant mitigation potential that appears to be relatively affordable. We find several hard cases in cell A, including the most important one, electricity, as well as agriculture and, to a lesser extent, steel. While all are far from their efficiency frontier, mitigation options are expensive and the sectors tend to be more fragmented, both on the market side as well in terms of government regulation. We also find the case of buildings in cell B to be challenging. Despite large relatively inexpensive mitigation potential in these arenas, the market and government arenas are extremely fragmented, leading to major political/organizational challenges.

These are largely but not exclusively ordinal rankings, that is to say, we are more confident about the placement of the cases in specific cells than their placement relative to each other within

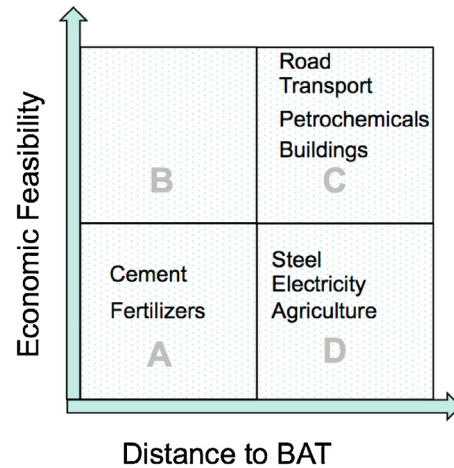


Fig. 6. Coding of India's Sectors for Techno/Economic Feasibility.

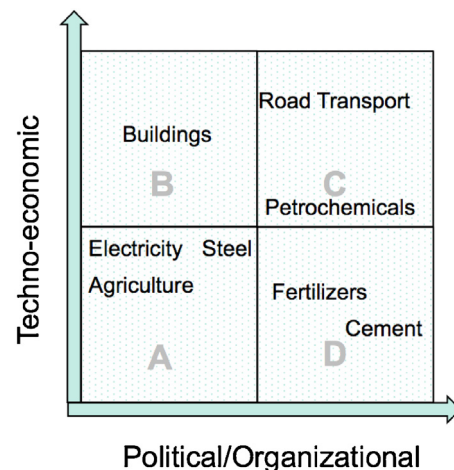


Fig. 7. Coding of India's Sectors for Overall Emissions Mitigation Feasibility.

cells. That said, recognizing that the cases in cell A all possess large potential for emissions reductions, we locate those three cases further north in A closer to the threshold for high techno-economic feasibility. Similarly, we locate steel further east in A, recognizing that high government concentration in steel potentially counteracts high market fragmentation. Petrochemicals is rated to have a lower relative techno-economic feasibility than automobiles due to a part of it being close to the efficiency frontier. However, we wish to emphasize again that we consider the precise placement of the sectors within cells less important than whether we have surfaced important attributes of sectors that may shape emissions reductions efforts going forward.

While our analysis speaks to the structural potential for sectoral emissions mitigation, whether those opportunities are taken advantage of will depend on the agency and preferences of the actors involved, which may change. Our research implies policy interventions tailored to address each sector's barriers. Of the four "hardest" sectors, electricity is clearly the most critical given its massive current and future carbon footprint. While the mobilization of domestic and international finance may help overcome some of the barriers, the government will also have to overcome difficult collective action challenges. The solar sector, given its newness and dynamism, may provide a qualitatively different landscape for new market entrants and regulation, facilitating rapid scale-up.

In future research, we aim to explore the electricity sector in detail, since it will remain the most important sector in terms of net emissions. The project focuses on India's ambitious non-fossil commitments, particularly its solar targets, articulated by the Indian government in its INDC. We will explore the potential for enabling rapid scale-up of renewables, either through market or governmental consolidation (such as large-scale solar parks that are already envisioned) or, alternatively, through organic bottom-up innovation and diffusion (as has occurred in cell phones).<sup>17</sup> While our structural analysis facilitated cross-sectoral comparison, the electricity sector in India may face idiosyncratic barriers and opportunities. Already, we have made tentative forays into unpacking them [85]. For example, the salience of air pollution in India's major cities is providing independent incentives for a clean energy transition that may deliver co-benefits for climate change [75,76]. These incentives we submit largely enter in to the preferences of actors to support climate mitigation but do not alter the structural challenges they face, though may surface opportunities for lower cost interventions that improve air quality and provide climate mitigation co-benefits.

While our analysis speaks to the barriers of national action on climate mitigation, it should be noted that in a large federal system such as India, we observe and should continue to see sub-national experimentation in Indian states, even where central government action is potentially impeded by fragmentation. In the electricity sector, states like Tamil Nadu were early leaders in wind deployment. Other states like Gujarat and Rajasthan (and more recently Tamil Nadu, Andhra Pradesh, and Telangana) are leading the way with policies to encourage solar energy ([77], p. 35). With air pollution providing added impetus for action in urban areas, we should expect to see not only diversity of effort between Indian states but potentially within them.

One additional idea for future study is to examine the fungibility of experience in related sectors that are already near the efficiency frontier, such as fertilizers (which is intimately related to agriculture) and cement (which is directly related to buildings). Can upstream or downstream linkages or concentrated producer

interests or organizations facilitate mitigation in related sectors? For example, while many companies may construct buildings, only a handful of firms produce air conditioners so some aspects of buildings efficiency such as appliances could be enhanced by looking for concentrated nodes where large-scale mitigation efforts might be successful. Finally, our theoretical framework also lends itself to understand other emerging economies such as China, where we aim to carry out companion and comparative research to assess mitigation and implementation challenges.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.erss.2016.11.011>.

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