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Trade-offs and synergies in power sector policy mixes: The case of Uttar Pradesh, India

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ABSTRACT

Policymakers in the electricity sector in several developing countries must perform a balancing act between ensuring financial viability of utilities, extending electricity access and minimizing the environmental impact of electricity supply. However, it is often not clear how multiple policy goals and instruments in an electricity sector policy mix interact with each other in a dynamic manner. This study uses a mixed-method approach to analyze synergies and trade-offs between policies for financial reform of utilities, extending electricity access, and solar PV deployment in the case of Uttar Pradesh in India. First, it uses qualitative methods to trace the evolution of Uttar Pradesh's electricity sector policy mix from 2012 to 2018 and to highlight key interactions therein. Second, it uses financial modeling to analyze the impact of the identified key interactions on utilities' financial performance from 2019 to 2022. The study finds that the policies often do not consider their mutual interactions, even though policy design and sequencing can have a major role in determining policy outcomes. Thus, this study provides recommendations on how to develop a more integrated approach to policy mix design in the electricity sector. Ex-ante assessments of policy mixes that take into account multiple policy goals, instruments as well as their sequencing could prove to be particularly fruitful.

1. Introduction

Energy policy must perform a balancing act between multiple policy goals. The multiple goals and their mutual interactions have been portrayed as an 'energy trilemma', which involves finding a balance between limiting the cost of energy, ensuring security of supply, and minimizing its environmental impact (Gallagher et al., 2006; Gunningham, 2013; Helm, 2002). This trilemma can be particularly pronounced in the electricity sectors of several developing countries, which are often characterized by poor financial performance, low rates of electricity access, and an increasing urgency to reduce air pollution and mitigate climate change.

There are a few empirical studies that analyze all three policy goals in the electricity sector in a developing country context, highlighting the synergies and trade-offs among them (Gunningham, 2013; Hughes and Lipscy, 2013). However, an increasing number of empirical and conceptual studies indicate that policies in the electricity sector should not only aim to find a balance between these *policy goals*, but also try to ensure consistency among the *instruments* used to achieve them in a policy mix (del Río, 2014; Flanagan et al., 2011; Howlett and Rayner, 2013).

For example, the *empirical literature* on power sector reform, beginning in the 1990s, prescribed what is now known as the 'standard model' for power sector reform. It includes a suite of policy instruments primarily aimed at improving the financial performance of utilities (Bacon, 1995), assuming that financial viability of the electricity sector is a prerequisite to achieving other policy goals (Huenteler et al., 2017; Kessides, 2012). However, there is increasing recognition that a narrow focus on policy instruments for financial reform may be insufficient and even ineffective. Thus, the literature on power sector reform has shifted towards recommending that such policy instruments should be integrated with explicit measures to achieve context-specific goals related to extending electricity access and reducing environmental impact (Dubash, 2002; Eberhard and Godinho, 2017; Jamasb et al., 2017).

Furthermore, the *conceptual literature* on policy mixes highlights that policies never act in isolation. In fact, particularly in complex policy fields such as the electricity sector, policies can often be layered on top of each other unsystematically in response to changing policy goals or unforeseen outcomes (Adrian. Kay, 2006; Rayner and Howlett, 2009). This can lead to a lack of consistency among policy instruments, which

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can hinder the achievement of policy goals. Thus, policy analysis and design should ideally take into account interactions between different policy goals and instruments (Howlett, 2009; Howlett and Rayner, 2013; Kern and Howlett, 2009), as well as the inherent trade-offs involved (Quitzow, 2015).

To summarize, *financial reform* of the electricity sector is an important prerequisite to achieving other electricity sector policy goals. Furthermore, goals related to *provision of universal electricity access* and *reducing the environmental impact* of the electricity sector are gaining in importance and urgency. Despite this, few studies have investigated how these goals and the instruments used to achieve them interact with each other. In addition, few studies quantify the impact of measures to support electricity access and renewable energy deployment on the financial performance of utilities in electricity sector policy mixes (del Río González, 2007; Rogge and Reichardt, 2016; Schmidt and Sewerin, 2019; Schwarz et al., 2018).

To address this gap, this study draws on concepts from the literature on policy mixes to investigate how different policy goals and instruments in the electricity sector interact with each other in a dynamic manner. Specifically, it analyzes interactions between policies for *financial reform of utilities*, *provision of electricity access* and *solar PV deployment*. It uses a mixed method approach, focusing on the case of Uttar Pradesh, India, to analyze policy interactions in two steps. In the first step, it uses qualitative methods to trace the evolution of Uttar Pradesh's electricity sector policy mix from 2012 to 2018 and to highlight key interactions therein. In the second step, it uses financial modeling to analyze the impact of the key interactions on utilities' financial performance from 2019 to 2022. It finds that even though interactions in the policy mix can play an important role in determining policy outcomes, they are not always taken into account in policy design.

The remainder of this paper is structured as follows: Section 2 reviews the literature on policy goals and instruments in the electricity sector in developing countries (2.1), and how concepts from the literature on policy mixes can contribute to it (2.2). Section 3 describes the research case for this study – the state of Uttar Pradesh in India. It further describes the mixed-method approach used to address the research gap, consisting of an analysis of qualitative data from semi-structured interviews, and financial modeling of distribution utilities. Section 4 presents the main findings of the study. The implications for policymakers, limitations for the current analysis, and avenues for further research are discussed in Section 5.

2. Literature review

2.1. The 'energy trilemma' and power sector reform in developing countries

The 'energy trilemma' represents three overarching policy goals with synergies and trade-offs between them (Gallagher et al., 2006; Gunningham, 2013; Helm, 2002; Hughes and Lipscy, 2013). While the specific goals included can vary, they are usually classified as limiting the cost of energy, securing energy supply, and reducing its environmental impact. Particularly for policies in the electricity sector in developing countries, cost limitation, achieving universal electricity access and climate change mitigation are becoming increasingly important policy goals because of several reasons.

First, electricity utilities in many developing countries are experiencing perennial technical and financial underperformance due to factors such as the pressure to keep electricity retail prices low, inefficiency in billing and collection, and high technical losses (Huenteler et al., 2017). These factors can all act as mutually reinforcing mechanisms, resulting in a 'vicious cycle' involving an increasing need for public subsidies and constraints utilities' ability to invest into infrastructure and improve the quality of service (Dubash, 2018). *Second*, in the past decade, a global consensus has emerged regarding the need to achieve universal access to modern energy services for sustainable development (Alstone et al., 2015). With the launch of the Sustainable Energy for all (SE4All) initiative in 2011, and the announcement of ensuring "access to affordable, reliable, sustainable and modern energy for all" by 2030 as one of the Sustainable Development Goals (SDGs), several countries are looking to scale up both public and private sector investments in the electricity sector (IEA and World Bank, 2017). *Third*, national governments are increasing their ambition to mitigate climate change and scaling up efforts to decarbonize their electricity sectors (UNFCCC, 2021). For developing countries, this means that they will have to achieve a decoupling between growth in economic output and carbon emissions to achieve global climate goals (Rogelj et al., 2016).

In the past three decades, measures for power sector reform have formed a cornerstone for addressing this trilemma in the electricity sector (Bacon, 1999; Eberhard and Godinho, 2017). Early efforts at power sector reform were based on experiences in OECD contexts, advocating for commercialization and corporatization of utilities, passage of an energy law, establishment of an independent regulator, vertical unbundling, and private sector participation in electricity generation and retail (Gratwick and Eberhard, 2008). Together, these measures constitute what is now known as the 'standard model' of power sector reform, which primarily aims at increasing the economic efficiency of the electricity sector (Bacon, 1995).

With the ever-increasing experience in enacting measures for power sector reform in developing countries, a rich body of empirical literature has emerged to document, explain, and learn from diverse contexts (Besant-Jones, 2006; Kessides, 2012; Williams and Ghanadan, 2006). Although best practice prescribed caution in applying the 'standard model' indiscriminately (Bacon, 1995; World Bank, 1993), in many cases, its on-ground implementation was ideologically driven, inflexibly applied, and with a narrow focus on financial reform and cost recovery (Huenteler et al., 2020; Williams and Ghanadan, 2006). In addition, there was little evidence of progress towards policy goals related to electricity access and environmental sustainability (Bacon, 1999; Dubash, 2002; Foster and Rana, 2020; Joskow, 2006).

Thus, there is now agreement in the literature that there is no one-size-fits-all approach and that measures for power sector reform need to take a 'with-the-grain' approach (Eberhard and Godinho, 2017; Levy, 2014). That is, policy measures need to take into account the local capabilities, institutional setup, political economy and socio-economic conditions (Nepal and Jamasb, 2015; Victor and Heller, 2007; Wamukonya, 2003). Further, it is acknowledged that financial reform of the electricity sector is a prerequisite for other policy goals, thus making it a core objective of power sector reform (Huenteler et al., 2017; Kessides, 2012). For example, persistently poor financial performance of power utilities leads to high counterparty risks for power generators, making it difficult to mobilize private finance for renewable energy deployment, and can thus endanger the long-term sustainability of renewable energy deployment targets. Similarly, poor financial performance can constrain utilities' ability to invest into grid infrastructure, and often even their ability to pay for ongoing O&M and power purchase expenses. This, in turn, leads to de-prioritization of customers that live in relatively remote or sparsely populated areas (typically found in rural settings), or with lower ability to pay, contributing to low electrification levels and poor grid reliability. However, policies for financial reform also need to explicitly consider other context-specific policy goals such as provision of electricity access and climate change mitigation at an early stage to prevent technical, institutional and political 'lock-in' (Dubash, 2002; Jamasb et al., 2017).

While the existing literature has significantly contributed to our understanding of the conditions that have been conducive or unfavorable to financial reform of utilities, it can be further extended in two ways.

First, while it recommends that policies should take into account other context-specific policy goals in a country's power sector, it does not systematically address how they interact with each other in a dynamic manner. Particularly, with increasing priority being given to achievement of social and environmental goals through provision of electricity access and to renewable energy deployment, few studies have investigated how progress towards these goals might impact financial viability of utilities. Recent studies provide fragmented insights on the interaction between policies for financial reform, rural electrification and renewable energy deployment. For example, in a study on Spain (Eid et al., 2014), find that deployment of solar PV with net-metering can affect a utility's ability to recover fixed costs through volumetric charges. Similarly (Mukherjee, 2014), briefly mentions that a sudden increase in the rural electrification rate under India's village electrification scheme[1] may have contributed to the need for subsidy support mechanisms for state distribution utilities.

Second, the existing literature focuses on the influence of institutional and macroeconomic conditions, as well as policy instrument types on financial viability of utilities. However, there has been insufficient attention towards policy design, even though there is a growing body of literature arguing that policy design might be just as important, if not more important than policy type (Kemp and Pontoglio, 2011; Schmidt and Sewerin, 2018). Particularly in complex policy mixes, policy design can play an important role in determining the nature of interaction between policies (del Río and Cerdá, 2017; Duan et al., 2017).

Thus, this study uses concepts from the literature on policy mixes to highlight synergies and trade-offs in electricity sector policy mixes, and to further enhance our understanding of how policy instrument design and sequencing could be used to increase their effectiveness.

2.2. *Literature on policy mixes*

The literature on policy mixes emphasizes that a policy mix consists of mutually interacting policy instruments, rather than an array of individual, non-interacting instruments that can be analyzed in isolation (A. Kay, 2006; Kern and Howlett, 2009). Thus, a large number of conceptual studies have been devoted to characterizing the building blocks and interactions within a policy mix (Flanagan et al., 2011; Rogge and Reichardt, 2016), different types of policy mixes (Howlett and del Rio, 2015), and how to avoid sub-optimal policy mixes (Kern and Howlett, 2009).

According to these studies, at a basic level, policies can be said to be comprised of two elements: goals and instruments (Cashore and Howlett, 2007; Howlett and Cashore, 2009). As the names suggest, policy goals specify what is to be achieved, and policy instruments are the means that are used to achieve them. Several studies have suggested that the various policy instruments and goals in a policy mix should ideally be aligned with each other to ensure that they do not work at cross-purposes. Specifically, different policy instruments should ideally reinforce each other to ensure 'consistency', different policy goals should be able to co-exist with each other to ensure 'coherence', and instruments should work towards achieving goals to ensure 'congruence' (Kern and Howlett, 2009).

Besides conceptual studies, scholars such as Howlett and del Rio (2015), Kern et al. (2017) and Schmidt and Sewerin (2018) have highlighted that there is still very little empirical work in the literature on policy mixes. Only since recently, there is a small but fast-growing body of literature applying policy mix concepts to analyze interaction between policies in real world cases. For example, del Río (2010) analyzes the interactions between policies for renewable energy deployment and energy efficiency, highlighting the role of instrument choice and design. Similarly, in a study focusing on the interaction between climate and renewable electricity policies in the European Union, del Río and Cerdá (2017) find that negative interactions are highly dependent on policy design features, and can be mitigated through policy coordination. Duan et al. (2017) conduct an analysis of China's policy mix comprising of emissions trading and other direct mitigation policies to provide recommendations on how to ensure effectiveness of policy outcomes. In a study focusing on distributed solar PV and battery storage, US, Schwarz et al. (2018) develop an agent-based model to quantify the interactions in California's policy mix. Thus, concepts from the policy mix literature have the potential to yield valuable insights regarding multiple policy goals and instruments in the electricity sector.

This study adds to the growing body of empirical literature on policy mixes. While concepts from the literature on policy mixes provide a useful analytical framework for this study, there are two key considerations that must be taken into account to operationalize and empirically apply the concepts to derive insights for real-world policy mix design.

First, some scholars have suggested that real-world policy goals often cannot always be coherent because of the inherent trade-offs involved in complex policy domains. Thus, it is proposed that rather than searching for an elusive optimal policy mix, policy making "involves normative decisions on the relative priority of certain goals over others and striking a politically feasible balance between partially conflicting (yet potentially equally valid) policy goals" (Quitzow, 2015, p. 234). In such a framing, "a key role for innovation policy studies should be to highlight the trade-offs and tensions inherent in any policy mix and to promote open debates about them" (Flanagan et al., 2011, p. 711). Using this framing should be particularly fruitful in highlighting different priorities accorded to different policy goals with inherent trade-offs in 'with the grain' approaches to power sector reform.

Second, with a few exceptions, there is a notable lack of quantitative ex-ante assessments of interactions in electricity sector policy mixes (Schwarz et al., 2018). Instead, most empirical studies have used a qualitative approach to highlight interactions in policy mixes. This study takes a mixed-method approach, combining a qualitative ex-post analysis of interactions in the policy mix with a quantitative ex-ante estimation of their extent, as described in Section 3.2.

3. Research case and methods

3.1. *Case selection and background*

This section explains the rationale for choosing the state of Uttar Pradesh (UP) in India as the research case for the study. It also provides a brief background on UP's framework policies, which help place the results presented in Section 4 in context.

UP was chosen as the research case using a typical case selection strategy (Seawright and Gerring, 2008) for an exploratory analysis. First, distribution utilities in UP have been incurring heavy financial losses since several years. Second, historically, a relatively large section of UP's population has lacked access to electricity. Third, UP has ambitious renewable energy deployment targets, the majority of which is planned to be met through deployment of solar PV. Thus, its electricity sector simultaneously exhibits several features typical of developing country contexts, meaning the results of this study may offer insights for other contexts.

Electricity is a concurrent subject in India, which means that it falls under the jurisdiction of both the national and state governments. At the *national level*, the Electricity Act (2003) consolidated and replaced the previous mix of legislations governing the power sector at the national level[2] and provided the framework for the next phase of reforms in India's power sector. It provided the legal basis for policies and regulations with the goals of developing the electricity industry, promoting competition, increasing transparency, protecting consumers and extension of electricity access, ensuring cost recovery and commercial

[1] Mukherjee (2014) here refers to India's Rajiv Gandhi Gram Vidyutikaran Yojana (RGGVY), a policy for village electrification launched in 2005.

[2] Key legislations prior to the Electricity Act, 2003 include the Indian Electricity Act, 1910, the Electricity (Supply) Act, 1948, and the Electricity Regulatory Commissions Act, 1998.

viability of utilities, and promoting environmental protection. Section 3 of the Act directed the central government to further define and operationalize these goals under follow-up legislations, namely the National Electricity Policy (2005) and the National Tariff Policy (2006). Similarly, Section 5 of the Act directed the central government to formulate a national rural electrification policy in consultation with state governments, which led to enactment of the Rural Electrification Policy (2006).

In parallel, the National Action Plan on Climate Change was issued by the government in 2008, with the goals of climate change mitigation, economic development and achieving energy security. It complements the provisions for promotion of renewable energy under the Electricity Act (2003) and the National Tariff Policy (2006) by instituting the National Solar Mission.

At the *state level*, the process of power sector reform was initiated with the UP Electricity Reform Act (1999) in consultation with the World Bank. The reforms followed the 'standard model', with the goals of increased efficiency, financial viability and mobilization of private finance. This was to be achieved through vertical unbundling and corporatization of the former vertically integrated public utility,[3] setting up of an independent regulator[4] and allowing private sector participation in the power sector. Further, the distribution business was transferred to five independent subsidiaries of the state transmission and distribution company.[5] This was followed by the UP Power Policy (2003), which reiterated the goals of the UP Electricity Reform Act (1999) and further included the goals of universal access and providing reliable, quality and affordable power, reflecting a shift away from the 'standard model' to include context-specific goals.

Fig. 1 provides an overview of UP's current policy mix, analyzed in more detail in the results section (Section 4). Further background on the policies analyzed in Section 4 can be found in Appendix A.

3.2. Methods

This study uses an embedded mixed-method case design, with the qualitative analysis informing and providing inputs for the quantitative analysis.

First, similar to several previous studies on policy mixes, qualitative analysis of policy documents and interview data was used to trace the historic evolution of the policy mix and to highlight the key interactions between policies. Specifically, a list of 25 policy documents from 2003 to 2018 was compiled based on desk research and during subsequent interviews (see Fig. 1). Each policy was coded in terms of its goals and instruments, as well as explicit considerations of interaction with other policies.

Further, 20 interviews with policymakers, regulators, policy consultants and researchers were conducted in India's capital, New Delhi, and Uttar Pradesh's state capital, Lucknow, in September and October 2018 (see Table 1). The interviews served three purposes. First, they were used to ensure comprehensiveness of the list of analyzed policies. Second, they were used to develop deeper insights regarding the evolution of the policy mix, the interaction between different policies, as well as of policy outcomes in terms of financial reform of utilities, provision of electricity access and solar PV deployment. Third, the derived insights were used to define the interactions to be modeled and the scenarios for the quantitative model. Each interview lasted between 45 and 90 minutes. These insights were supplemented with newspaper articles, official documents and independent reports, as well as during public talks and informal conversations at an international renewable energy investment conference in Noida, Uttar Pradesh.

Second, the study uses quantitative methods to model key interactions in the policy mix and to quantitatively estimate their impact on future financial performance of utilities. Specifically, it uses a bottom-up financial model of distribution utilities to evaluate the impact of renewable energy deployment and provision of electricity access on the financial performance of distribution utilities for the period FY2019 to FY 2022.[6] The basic structure of the model is illustrated in Fig. 2.

The financial model is used to calculate the historical and modeled revenues and costs of utilities in a bottom-up manner (see (1) in Fig. 2). It consists of two modules, the power system module (2) and the utility module (3).

First, the power system module calculates the historical revenue from sale of electricity using customer category-wise data on the number of connections, average specific consumption and average tariff obtained from tariff orders issued by the UP Electricity Regulatory Commission (UPERC). Second, it calculates the historical power purchase costs using plant-level data on variable and fixed costs obtained from the Central Electricity Authority (CEA), tariff orders issued by the UPERC, the Bloomberg New Energy Finance (BNEF) database, and industry reports and press releases on solar PV auction results. Both sets of data were triangulated and additional data on financial performance was obtained from audited financial statements of the five distribution utilities in Uttar Pradesh. Third, it calculates future revenue from sale of electricity by projecting forward customer category-wise data on average specific demand, number of customers and average tariff. The projected customer category-wise electricity demand was triangulated using data obtained from the Nineteenth Electric Power Survey of India (CEA, 2017). Fourth, it calculates future projections for technology-wise power purchase costs based on past trends, adjusting for global and local learning effects for solar PV deployment.

Finally, the intermediate outputs of the power system module are fed into the utility module (3). The utility module calculates the future total power purchase cost using a least-cost dispatch model, taking into account existing power generation capacity, planned power generation capacity up to 2022 (using data obtained from the CEA), and scenario-specific technical losses and future generation capacity additions to meet increasing demand. It calculates the future cash flows and income statements of the distribution utilities based on the projected costs, revenues, and financial parameters. More information about the model inputs can be found in the Supplementary Information.

The impact of policy design and sequencing on the financial performance of UP's distribution utilities is modeled under six policy scenarios, which are informed by the qualitative results (4). Under the Base Scenario 1 (see B1 in Table 2), it is assumed that the targets for aggregate technical and commercial (AT&C) loss reduction, collection efficiency improvement and tariff hikes set under the UDAY scheme are all met as per schedule.[7] This means that during the period FY2015 to FY 2022, AT&C losses are reduced from 38% to 15% through formalization of household connections and reduction of technical losses, and an average annual tariff hike of 6% is maintained across all consumer categories.

[3] UP State Electricity Board (UPSEB) was unbundled in 2000 into UP Rajya Vidyut Utpadan Nigam (UPRVUNL - UP State Electricity Generation Corporation) and UP Jal Vidyut Nigam (UPJVNL - UP Hydro Electricity Corporation) for power generation and UP Power Corporation Limited (UPPCL) for transmission and distribution.

[4] The UP Electricity Regulatory Commission (UPERC) was set up in 1999.

[5] The five distribution companies are Kanpur Electricity Supply Company Ltd. (KESCO) formed in 2000, and Pashchimanchal Vidyut Vitran Nigam Ltd. (PVVNL), Madhyanchal Vidyut Vitran Nigam Ltd. (MVVNL), Dakshinanchal Vidyut Vitran Nigam Ltd. (DVVNL), and Purvanchal Vidyut Vitran Nigam Ltd. (PuVVNL) formed in July 2003.

[6] FY denotes the financial year, which begins on April 1 and ends on March 31. For example, FY2015 begins on April 1, 2015 and ends on March 31, 2016.

[7] AT&C losses are a measure of energy and revenue losses due to technical and commercial inefficiencies. They are calculated as follows: $AT\&C\ Losses = (1 - BE \times CE)$ Where BE is the billing efficiency and CE is the collection efficiency (both in percent). The billing efficiency and collection efficiency are calculated as follows.
$BE = \frac{Total\ energy\ billed\ to\ consumers\ [kWh]}{Total\ energy\ input\ [kWh]}$; $CE = \frac{Revenue\ collected\ [Rs.]}{Billed\ amount\ [Rs.]}$

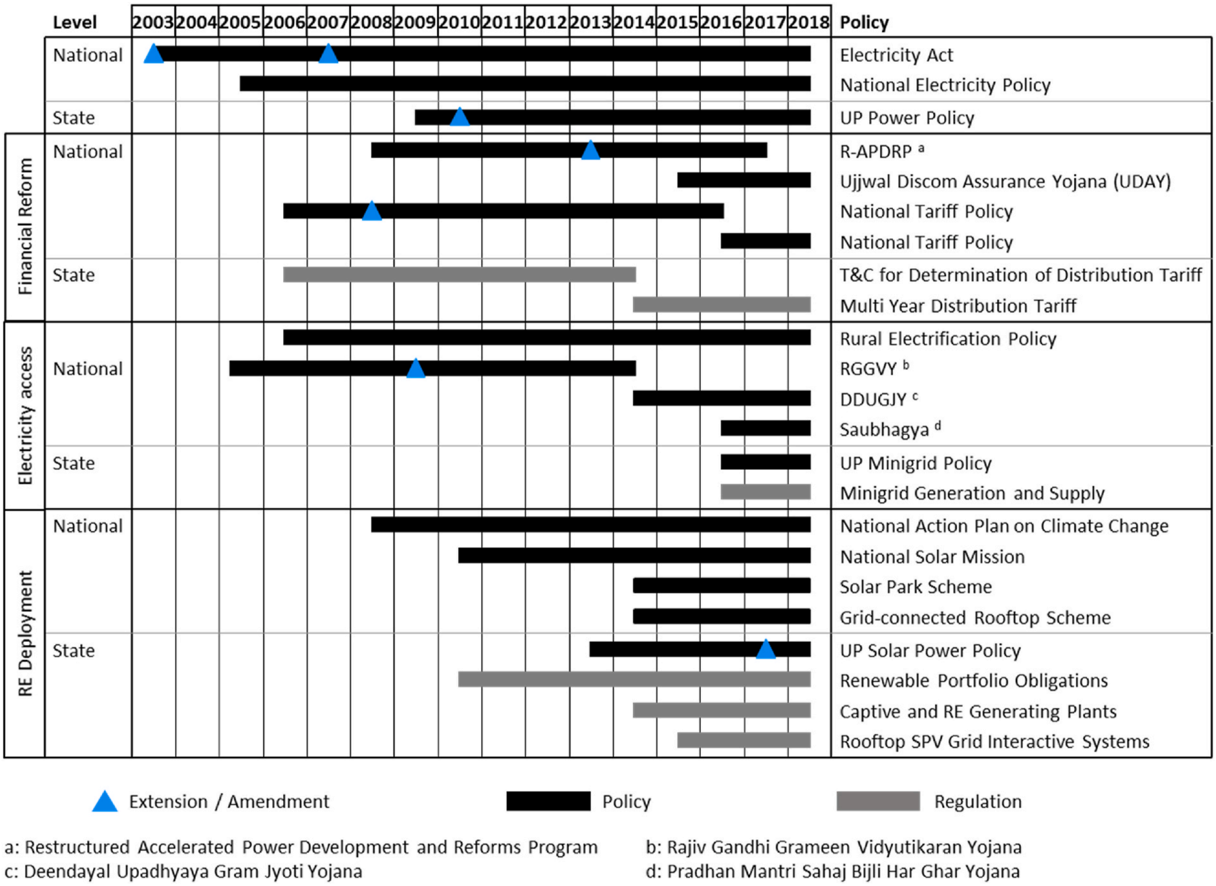

Fig. 1. Uttar Pradesh's electricity sector policy mix.

Table 1
List of interviewees for policy mix analysis.

S. No.	Interviewee Role	Organization Role	Scope of interview
1	Policymaker	Ministry of Power	National
2	Policymaker	Rural Electrification Corporation	National
3	CEO	Industry Association	National
4	Senior Clean Energy Specialist	International Organization	National
5	Senior Sector Specialist	International Organization	National
6	Senior Fellow and Associate Director	Research Institute	National
7	Senior Manager	Policy consultant	National
8	Co-founder and Director	Policy consultant	National
9	Managing Partner	Policy consultant	National
10	Senior Program Lead	Industry expert	National/ State
11	Associate	Industry expert	National/ State
12	CEO	Solar Developer	National/ State
13	Policymaker	UP New & Renewable Energy Development Agency	State
14	Regulator	UP Electricity Regulatory Commission	State
15	Regulator	UP Electricity Regulatory Commission	State
16	Chairperson	Consumer Association	State
17	Senior Researcher	Research Institute	State
18	Executive Director	Industry expert	State
19	Senior Manager	Industry expert	State
20	Managing Director	Industry expert	State

The intermediate financial reform scenario or Base Scenario 2 (B2) reflects the observation made by several interviewees that the policy goals of the UDAY scheme are too ambitious, and will most likely only be partly achieved by 2022. Thus, in this scenario, the influence of policy sequencing is modeled, assuming that the goals of UDAY scheme are deferred. That is, during the period FY2015 to FY 2022, AT&C losses are reduced from 38% to 25%, and an average annual tariff hike of 4% (equal to the rate of inflation) is maintained across all consumer categories.[8]

For comparison, a business-as-usual scenario (BAU) is also modeled. In this scenario, it is assumed that utility operational parameters (such as AT&C losses and collection efficiency), number of consumers, average electricity demand, retail tariffs, government subsidies, power generation capacity additions, power purchase costs and continue along the trend based on historical data from FY2007 to FY 2018.

The interaction of policies for solar PV deployment and rural electrification with the base scenarios is evaluated in four scenarios. Policy Interaction Scenario 1 (PI1) assumes that all stated goals related to extension of electricity access are met. Specifically, it assumes that universal electrification is achieved by 2019 with metering of all household connections. Policy Interaction Scenario 2 (PI2) assumes that universal electrification is achieved by 2019, but informal connections are not regularized. This reflects the interviewees' observation that the practical implementation of measures to extend electricity access often prioritizes provision of household-level grid connectivity, while

[8] In both base scenarios, the UDAY debt transfer scheme is assumed to be implemented, which means that 75% of the long-term debt of distribution utilities as on September 30, 2015 is transferred to the state government over a period of two years.

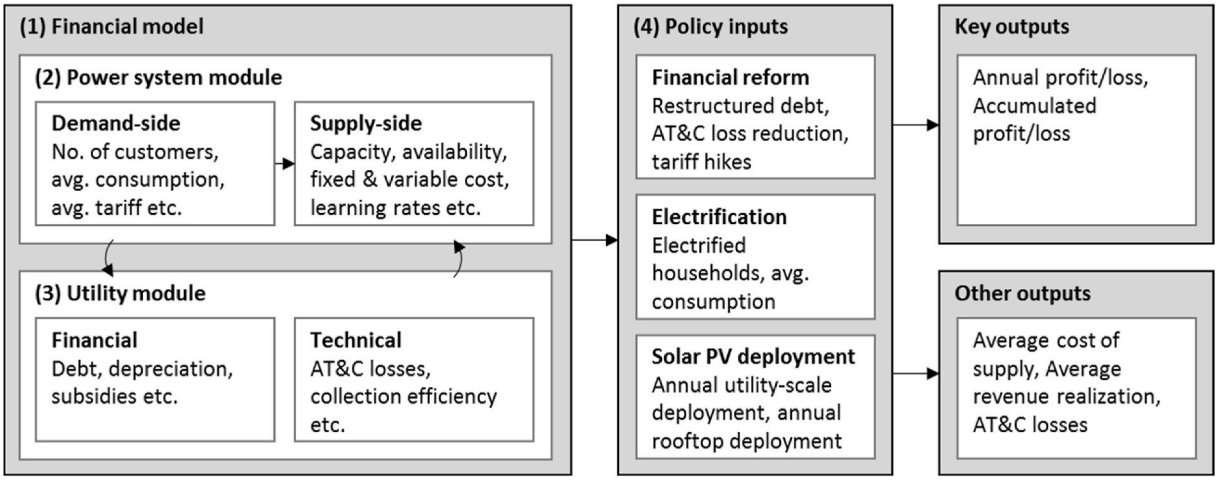

Fig. 2. Schematic representation of the structure of the bottom-up financial model employed for the quantitative analysis.

additional investments for improved metering and billing are neglected. Policy Interaction Scenario 3 (PI3) assumes that deployment targets for utility-scale and rooftop solar PV for 2022 are met following an exponential deployment trajectory. Policy Interaction Scenario 4 (PI4) assumes that only the rooftop solar PV deployment target is met, while rooftop solar PV continues to be deployed at historic rates, thus falling short of its target. This reflects the interviewees' observation that there are several barriers to deployment of rooftop solar PV that remain unaddressed. It is assumed that input parameters remain the same for all scenarios.

4. Results

This section presents the result of the study in two parts. Section 4.1 presents the qualitative results, describing policy goals and instruments in Uttar Pradesh's electricity sector policy mix, outcomes and interactions within and across policy goals. For the sake of brevity, the outcomes and interactions are indicated in the text using the following abbreviations: positive [+] or negative [-] outcomes and interactions between policies for financial reform [FR], universal electrification [UE] and solar PV deployment [PV]. Section 4.2 presents the modeling results quantifying the influence of key interactions on future financial performance of distribution utilities.

4.1. Uttar Pradesh's electricity sector policy mix

4.1.1. Policies for financial reform of utilities (2012–2018)

Goals and instruments: Achieving financial viability has been a long-stated policy goal in India's electricity sector. This goal has been operationalized by a series of policies in two interrelated ways.

First, the Accelerated Power Development and Reforms Program (APDRP, 2003) and its successor, the Restructured APDRP (R-APDRP, 2008) aimed to increase operational efficiency of utilities, as measured by aggregate technical and commercial (AT&C) losses. Both policies aimed to reduce AT&C losses to 15% within a set time frame[9] and provided for performance-based incentives to distribution utilities, allocating loans for investment into distribution infrastructure, 50% of which were convertible to grants on achieving targets[10].

Second, the Financial Restructuring Plan (FRP), a bailout package announced by the central government in 2012, aimed to improve financial performance, as measured by debt levels and the gap between average cost and revenue. It took the form of a tripartite agreement between the central government, government of UP and the distribution utilities. According to the agreement, 50% of the utilities' short-term liabilities were taken up by the state governments and issued as bonds. The remaining 50% of debt was subject to a three-year moratorium, half of which was convertible to central government grants, subject to meeting R-APDRP targets. Operational losses and interest payments for the next three years were financed by the central government on a diminishing scale. In return, the states agreed to submit a schedule for annual retail tariff hikes. However, soon after the 2012 bailout, the distribution utilities were on the same pre-bailout trajectory of high AT&C losses, large annual losses, and mounting debt.

Thus, in 2015 the central government announced the Ujjwal Discom Assurance Yojana (UDAY) – an integrated policy with the goal of "financial turnaround of distribution utilities". It combines features of previous policies in terms of its goals and instruments (see Fig. 4). First, like R-APDRP, it sets utility-specific annual targets for AT&C losses, aiming to reduce them to 15% by 2019. It incentivizes reduction in AT&C losses through performance-linked disbursal of central government funds. Second, like the FRP (2012), it aims at reduced debt and closure of gap between average cost and revenue, to be achieved through transfer of debt to the state government, financing utility losses for three years through central government funds and setting an annual schedule of retail tariff hikes. The goals and instruments of UDAY are summarized in Table 3.

Outcomes: There has been a huge gap in terms of the on-ground implementation of measures for financial reform in UP. While there was some progress in terms of metering of distribution lines under the R-APDRP, AT&C losses remained high at around 40% (see Fig. 3). The Financial Restructuring Program (2012) provided temporary relief by reducing outstanding short-term liabilities [+FR], enabling payments due to power generators, and helping raise further debt. However, the agreed retail tariff hikes were not implemented, with no apparent repercussion[11] [-FR]. In fact, accumulated losses (after subsidy) for the five distribution utilities increased from Rs. 336 billion in 2012 to Rs. 730 billion in 2016.

Thus, UDAY is the latest in a long line of programs to improve operational efficiency and financial performance. By packaging different goals and instruments together, it increases the congruence of the policy

[9] APDRP set a target year of 2007. R-APDRP focused on urban areas and specified annual goals for AT&C loss reduction ranging from 1.5% to 3% to bring them down to 15% by 2013 and later 2017.

[10] Under R-APDRP, additional funding was provided for monitoring and evaluation and for capacity building in distribution utilities.

[11] This is despite the fact that UP shifted from annual tariff setting under the UP Distribution Tariff Regulation (2006) towards multi-year tariff setting under the UP Multi-Year Distribution Tariff Regulations (2014).

Table 2
Overview of policy designs under scenarios analyzed in the study.

	Scenario Name	Financial Reform	Rural Electrification	Solar PV deployment
BAU	Business as usual	• Reduction of AT&C losses to 35% in FY 2022 (BAU) • 3% average annual tariff hike (BAU) • Transfer of 75% debt in 2015 to state govt	BAU	BAU
B1	Base Scenario 1	• Reduction of AT&C losses to 15% in FY2022 • 6% average annual tariff hike (UDAY) • Transfer of 75% debt in 2015 to state govt	BAU	BAU
B2	Base Scenario 2	• Reduction of AT&C losses to 25% in FY2022 • 4% average annual tariff hike (inflation) • Transfer of 75% debt in 2015 to state govt	BAU	BAU
PI1	Interaction Scenario 1	B1; B2	Performance-linked grants (60%) incentivizing new connections and universal metering	BAU
PI2	Interaction Scenario 2	B1; B2	Performance-linked grants (60%) incentivizing new connections	BAU
PI3	Interaction Scenario 3	B1; B2	BAU	Auctions (utility scale) and net-metering (rooftop)
PI4	Interaction Scenario 4	B1; B2	BAU	Auctions (utility scale)

mix. However, with state-wide AT&C losses still at 33% as of December 31, 2018, interviewees remained pessimistic about AT&C loss reduction targets being met within time due to prioritization of financial restructuring. In fact, there was already talk among state- and national-level policymakers about UDAY-II, which would primarily focus on AT&C loss reduction. Its degree of success and long-term sustainability is likely to be contingent on whether and how other policy goals are achieved, as explained in the following sections (Section 4.1.2 and 4.1.3).

4.1.2. Policies for provision of electricity access (2012–2018)

Goals and instruments: India's previous national electrification policies were consolidated under the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) announced in 2005 and its successor, Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY), announced in 2014.

A series of successive goals were set under both policies to achieve universal village-level electrification[12,13]. Under RGGVY, Rs. 160 billion were initially allocated for universal village-level electrification and provision of free connections to households below the poverty line,[14] which were expected to subsidize 90% of the overall project costs. Furthermore, it required state governments to provide revenue subsidies to utilities in advance, in accordance with Section 65 of the Electricity Act. In addition, the instruments employed under DDUGJY reveal two implicit goals. First, modeled on Gujarat's highly successful Jyotigram Yojana, funds were allocated for separation of distribution lines for agricultural and non-agricultural consumers as a means to improve duration and quality of supply for domestic users, and to provide scheduled supply for agricultural users. Second, allocation of funds for installation of meters at distribution lines, transformers and customers was intended as a measure to reduce AT&C losses [UE + FR].

In parallel, the provisions for standalone systems in the Rural Electrification Policy (2006) translated into the UP Minigrid Policy (2016). Its goal is to encourage decentralized renewable power through private sector participation in electrification and to provide power to 20 million households. Several interviewees indicated that its implicit goal was also to address concerns related to increasing losses of distribution utilities [UE + FR]. It prescribed regulated tariffs and 30% subsidy for mini-grids set up at sites identified by the state government, and no subsidies or tariff regulations for sites self-identified by private entrepreneurs.

However, the Pradhan Mantri Sahaj Bijli Har Ghar Yojana (Saubhagya) announced in 2017 signaled a shift in emphasis back towards investment in extending the grid. It aimed to achieve universal household-level electrification by providing connections to 30 million households not covered under DDUGJY by March 31, 2019. Rs. 123.2 billion were allocated by the central government, which were expected to cover 60% of the connection cost and were to be released in phases based on achievement of intermediary goals. No additional funds were allocated for metering of existing unmetered and 'informal' connections. In addition, 50% of the loan amount was convertible to grants upon reaching universal household connectivity by December 31, 2018.

Thus, the policy instruments represent a prioritization of providing physical grid connections over metering and technical loss reduction (see summary in Table 4).

Outcomes and interactions: In practice, at the state level, none of the goals of RGGVY or DDUGJY were achieved. However, many interviewees regarded the goals as aspirational in nature, highlighting that significant progress has been made in terms of extending electricity access [+UE]. In addition, there have been multiple shifts over time in terms of emphasis on concomitant loss reduction.

In the first phase under RGGVY, the emphasis of policy goals and instruments remained on investments in infrastructure for electrification. As a result, with no policy mechanism to ensure timely provision of revenue subsidies by the state government, it is considered to have

[12] According to the government of India's definition, a village is considered electrified if it has a transformer and 10% of its households, as well as public places such as schools and health centers, are connected to the grid.

[13] The number of unelectrified villages and households in 2005 was estimated to be 125,000 and 78 million respectively. Although the stated goal of RGGVY according to several official policy documents is universal household-level electrification, the policy instruments (purpose and amount of fund allocation) indicate that electrification of villages and below poverty line households was the actual goal. While this goal was not achieved, RGGVY was twice extended beyond its initial period – in 2008 and 2013. This represents a lack of congruence between goals and instruments.

[14] Out of the total funds allocated, about Rs. 81 billion were for village-level connectivity, Rs. 35 billion for the 23 million households below poverty line covered under the Kutir Jyoti program, and Rs. 46 billion were for augmentation of infrastructure in electrified villages.

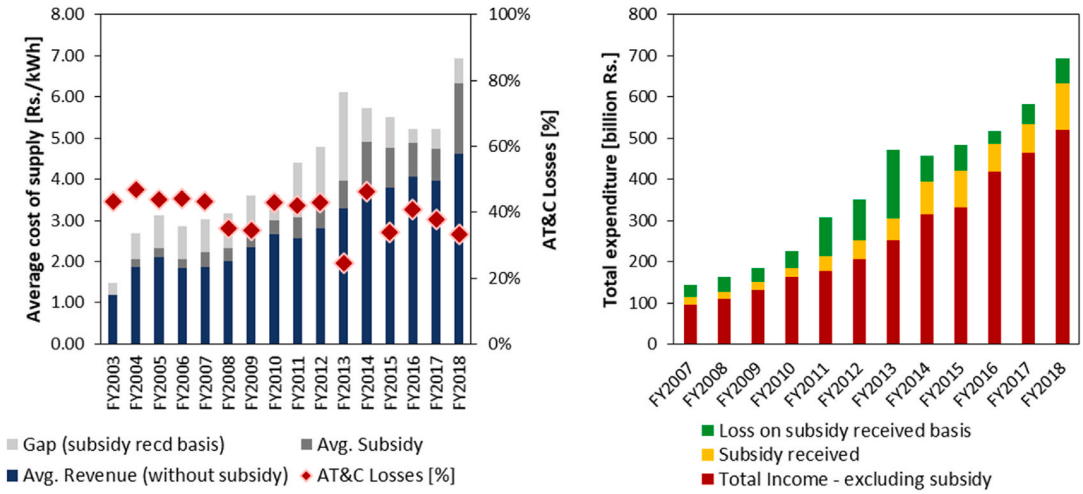

Fig. 3. (a): The average cost of supply, average revenue, tariff gap and aggregate technical & commercial losses from 2003 to 2018, and (b) The annual total expenditure, total income, subsidy received and loss from 2007 to 2018 for the power distribution sector in Uttar Pradesh.

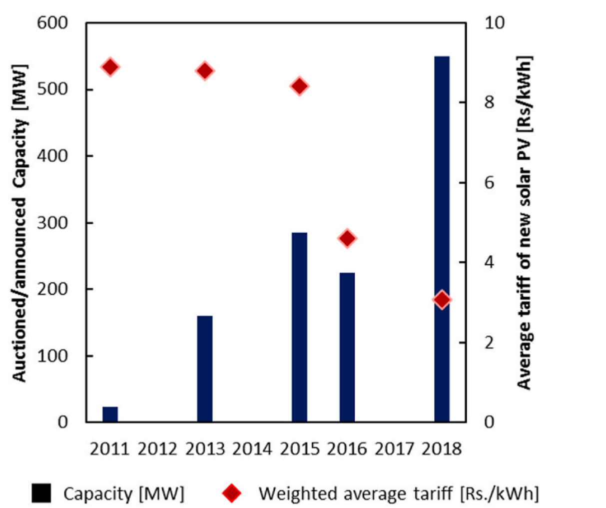

Fig. 4. Annual auctioned capacity and average bid prices for utility-scale solar PV in Uttar Pradesh.

Table 3
Overview of goals and instruments of UDAY policy for financial reform of distribution utilities.

Goals	Instruments
Reduction of AT&C losses to 15% in FY 2019. **Closure of gap between average cost and revenue by FY 2019.**	Performance-linked funds for T&D investment. • Annual schedule of retail tariff hikes. • Transfer of 75% debt to state govt over two years and issuance of 10-year bonds. • Partial transfer of annual losses to state government.

contributed to the worsening finances of utilities[15] [UE-FR]. In the next phase under DDUGJY, efforts were made to minimize this trade-off through increased emphasis on metering and separation of distribution lines for households and agricultural loads [UE + FR]. However, goals for AT&C loss reduction remained implicit and were not tied in with existing schemes such as R-APDRP.

[15] It is also considered to have led to increased neglect for reliability and quality of supply in rural areas. Particularly, interviewees noted that areas with a large share of agricultural loads were seen as loss-making and hence experienced extensive demand-side management in the form of load-shedding by utilities.

Table 4
Overview of goals and instruments of Saubhagya policy for universal household level electrification.

Goals	Instruments
Provision of electricity connections and meters to 14 million households by March 31, 2019.	• Performance-based grants from central government (Rs. 123.2 billion). • Funding structure: 60% grant, 30% loans, 10% own funds. • Conversion of 50% of loan component to grant upon achieving targets by December 31, 2018.

In addition, the UP Minigrid Policy was intended to address concerns related to extending electricity access without further deteriorating utility finances [UE + FR]. However, the absence of a concrete rural electrification plan (as directed by the Rural Electrification Policy) and lack of clarity regarding exit strategy in case the main grid is extended to the project site has posed high risks for mini-grid investments, and mini-grids have not scaled significantly in the state [-UE].

Particularly since the announcement of the Saubhagya policy for universal household electrification in 2017, investment risk for mini-grids has increased significantly due to grid extension [UE-UE]. Instead, the central government, state government and state utilities worked in 'mission mode' to achieve universal household connectivity. Household-level connectivity in UP increased at an unprecedented rate [+UE], with the government of UP announcing on December 31, 2018 that universal household electrification had been achieved, amidst anecdotes suggesting that it excludes 'informal' connections and 'unwilling' customers.

To summarize, given UP's tariff structure with high cross-subsidy, there is a trade-off between household electrification and financial reform. The trade-off can be mitigated through timely allocation of commensurate revenue subsidies to utilities, using electrification as an opportunity for metering and regularization of connections, and encouraging private sector driven off-grid electrification.

4.1.3. *Policies for solar PV deployment (2012–2018)*

Goals and instruments: The Jawaharlal Nehru National Solar

Mission (JNNSM) was launched in 2009. In terms of its goals, it established clear periodic targets for deployment of solar power, aiming for deployment of 20 GW solar PV by 2022.[16] Furthermore, it aimed at cost reductions to achieve grid parity by 2030. While the JNNSM also aimed to set up 4–5 GW of manufacturing capacity by 2020, the actual policy instruments reveal an implicit prioritization of deployment and cost reduction. In fact, it was so successful in achieving its targets for deployment and cost reductions [+PV] that in 2015 the deployment goal for 2022 was revised upwards from 20 GW to 100 GW.

The policy instruments reflect consideration of two major trade-offs. First, high off-taker risk due to poor finances of distribution utilities was a major concern, which could lead to lower investor interest, higher cost of financing, and further worsening of utility finances due to procurement of expensive solar power[17] [PV-FR]. This was addressed to some extent by designating NTPC Vidyut Vyapar Nigam Limited (NVVN), a public sector power trading company, as the off-taker in Phase 1, and the Solar Energy Corporation of India (SECI) in subsequent phases. In addition, the power was bundled with cheaper thermal power before being sold to state distribution companies. Second, the high cost of locally manufactured crystalline silicon solar PV cells and modules was also a major concern[18] [PV-FR]. Thus, although local content requirements were placed on in Phase 1, its applicability was reduced to 375 MW out of the 750 MW tendered in Phase 2 in 2013–14, and it was gradually phased out in subsequent auctions.

At the state level, UP was a relative latecomer to solar PV deployment. The UP Solar Power Policy was announced in 2013, aiming at deployment of 500 MW solar PV by 2017, which was achieved and updated to 6.4 GW utility scale and 4.3 GW rooftop solar PV by 2022 (see Table 5). Similar to JNNSM, it prioritized deployment and cost reduction through reverse auctions, providing exemption from transmission charges and 'must-run' status to solar PV. It specified that for projects in Bundelkhand (a relatively underdeveloped region within Uttar Pradesh), the cost of construction of transmission lines and substations would be borne by the state government, to support deployment and job creation in the region.

To meet the target for rooftop solar PV, the Grid Connected Rooftop and Small Solar Power Plants Program was launched by the MNRE in 2014. It provided 30% subsidy, as well as guidelines for connectivity, tariffs and agreements to be designed and implemented by state agencies. At the state level, the regulation for Rooftop SPV Grid Interactive Systems (2015) provided flexibility to choose between net- and gross-metering. It limited the maximum capacity of a rooftop installation to the approved peak demand of the consumer. Finally, it directed UPPCL and distribution utilities to prepare and implement procedures for application and registration of rooftop solar PV systems.

Table 5
Overview of key design features of Uttar Pradesh Solar Power Policy (2017).

Goals	Instruments
• **6400 MW utility scale by 2022**	• Reverse auctions • Offtake guarantee • Conversion of 50% of loan component to grant upon achieving targets by December 31, 2018
• **4300 MW rooftop solar by 2022**	• Net/gross metering • 30% up-front grant • Registration of system through distribution licensee

Outcomes and interactions: At the state level, the first large auction conducted in 2015 for 215 MW capacity saw relatively high tariffs ranging between 7.02 and 8.60 R/kWh[19] due to several reasons such as high off-taker risk, small individual project size and short duration of power purchase agreements (PPA – 12 years instead of the more usual 25)[20] [PV-FR]. However, subsequent auctions conducted in 2016 succeeded in bringing costs down and closer to the national average by designating NVVN and SECI as off-takers (thus reducing counterparty risk), and by extending the duration of the PPA to 25 years. The latest round of auctions for 550 MW in 2018 received an average bid of 3.06 R/kWh (see Fig. 4). While this is still higher than average bid tariffs for auctions in other states due to high off-taker risk and lower solar irradiation, it is already competitive with the variable cost of existing coal power plants[21] [PV + FR].

In comparison, the deployment of rooftop solar PV lagged behind, with only an estimated 50 MW deployed in 2018, primarily for commercial and industrial customers under the net-metering scheme [-PV]. This is due to several reasons. First, provisions for net- and gross-metering have only been in place for rooftop solar PV since 2015. Second, there were delays from distribution companies in terms of preparation of procedures for application and registration of net-metering systems. Third, once the distribution utilities had established the net-metering system, there have been reports of delays in terms of receiving technical approvals, installation of bidirectional meters, and registration under net-metering scheme for individual installations. Several interviewees suggested that this may partly be due to fears of loss of revenue from cross-subsidizing commercial and industrial customers [PV-FR].

To summarize, initially, poor utility finances and deployment of expensive utility scale solar were mutually reinforcing. However, subsequent reductions in bid tariffs mean that utility-scale solar PV deployment and financial reform are synergistic in nature. In contrast, the deployment of rooftop solar PV is yet to pick up. Given the high degree of cross-subsidy, net-metering for rooftop solar PV and policies for financial reform are not aligned with each other due to loss in revenue resulting from reduced demand from commercial and industrial consumers.

The key findings of this section are summarized in Fig. 5.

4.2. *Modeled interactions and policy outcomes*

The following results quantify the key interactions discussed in Section 4.1. To do so, the UDAY scheme for financial reform for distribution utilities is taken as the focal policy, and its interactions with policies for universal electrification and solar PV deployment are analyzed for the period of FY2019 to FY 2022.

4.2.1. *Base scenarios*

Fig. 6 (a) illustrates the annual profit (or loss) before subsidies for the business-as-usual and the two base scenarios (see BAU, B1 and B2 in Table 2). The historical data indicates that annual losses are reduced in FY2016 due to financial restructuring (and resulting reduction in

[16] The JNNSM set intermediate targets of 1 GW grid-connected solar power by 2013 in Phase 1 and 4 GW by 2017 in Phase 2. In addition, it envisioned deployment of 1 GW off-grid solar by 2017, and 2 GW by 2022, and installation of 20 million square meters of solar thermal collectors by 2022.

[17] The average bid tariff for selected projects in Phase 1 of JNNSM was 12.16 R/kWh.

[18] Local cell and module manufacturers were unable to compete with imports due to at least two reasons: global oversupply for solar PV cells and modules, and exclusion of thin-film solar PV from local content requirements. Thin film imports were further supported by cheap international financing from EXIM banks.

[19] For comparison, the average bid price for utility-scale solar PV in India in 2015 was 4.37 R/kWh without local content requirements and 4.83 R/kWh with local content requirements (Probst et al., 2020).

[20] The tariffs were later renegotiated by the government of UP.

[21] It should be noted that cost reduction was prioritized to such an extent that the auction conducted in July 2018 was canceled since the submitted bids were considered too high, with the lowest bid at 3.48 R/kWh.

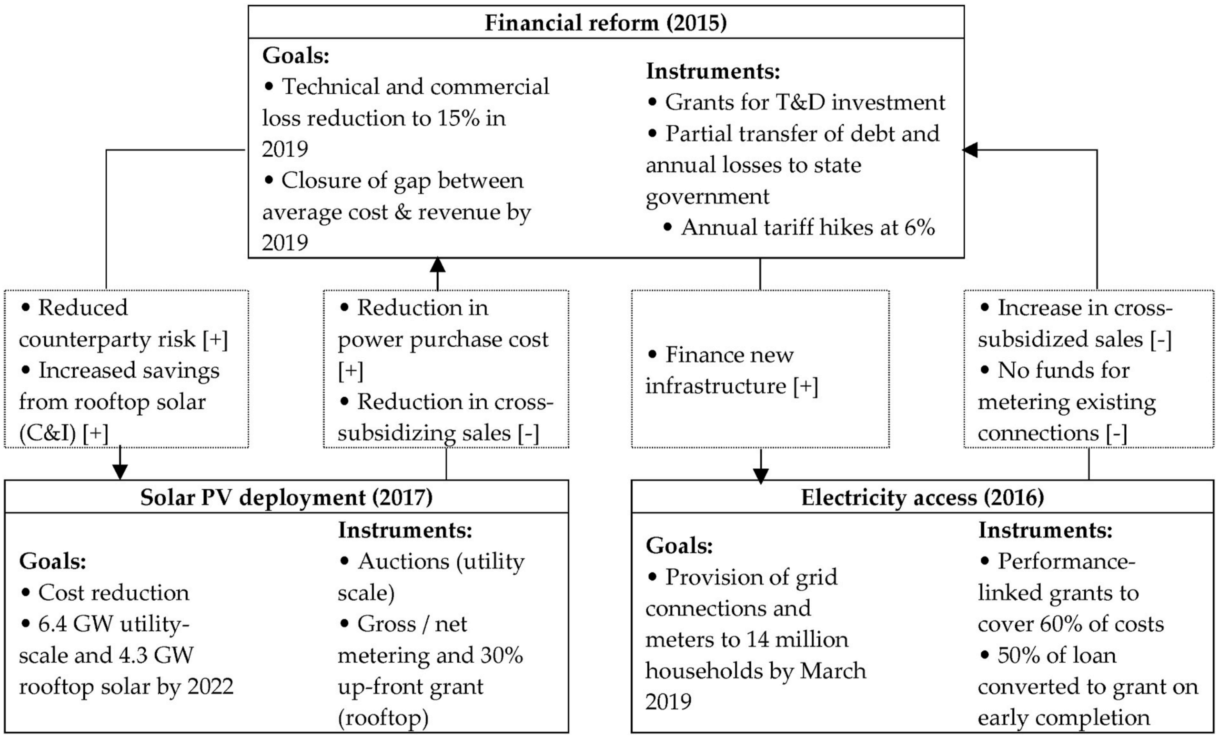

Fig. 5. Key synergies and trade-offs on Uttar Pradesh's electricity sector policy mix as of 2018. Synergies are indicated with positive signs [+] and trade-offs are indicated with negative signs [-].

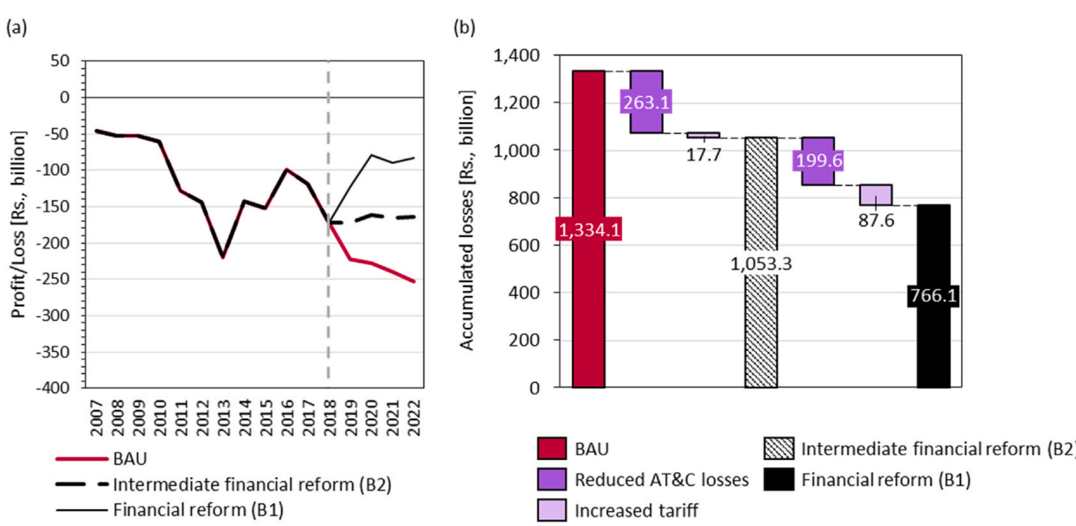

Fig. 6. Model results for (a) annual profit/loss (excluding subsidies), and (b) accumulated losses for the period FY2019 to FY2022 in BAU and Base Scenarios for the distribution sector in Uttar Pradesh.

interest expenses), before increasing again and embarking on widely divergent trajectories under the three different scenarios. In the BAU scenario, annual losses steadily increase after FY 2016, reaching Rs. 253.6 billion in 2022. At the other end of the spectrum, in the first financial reform scenario (B1), annual losses steadily reduce, reaching Rs. 83.6 billion in 2022. In the intermediate financial reform scenario (B2), annual losses are maintained at a steady level, reaching Rs. 164.5 billion in 2022.

Fig. 6 (b) illustrates the total accumulated losses over the period FY2019 to FY2022 for scenarios BAU, B1 and B2, and the individual contributions of AT&C loss reduction and tariff hikes to the differences between them. The results indicate that as AT&C losses go down, the marginal benefit of each unit reduction in AT&C losses also goes down. That is, the benefits of reducing AT&C losses from 35% to 25% are higher than reducing them from 25% to 15%. This is because of two reasons. First, at a higher percentage of AT&C losses, each percentage point represents a higher absolute quantity of foregone revenue. Second, AT&C loss reduction from a higher initial level leads to greater benefits in terms of average cost of power purchase, since it eliminates the need for relatively expensive power if merit-order dispatch is followed. Thus, from a techno-economic sequencing perspective, AT&C loss reduction from 35% to 25% represents a relatively low-hanging fruit.

4.2.2. *Policy Interaction Scenarios 1 and 2: rural electrification*

Next, the model is used to analyze the influence of layering rural electrification on top of the Base Scenarios (B1 and B2). In Policy

Interaction Scenario 1 (PI1), it is assumed that the utilities meet targets related to universal household electrification and metering of informal connections, increasing the household electrification rate from 45% in FY2015 to 100% in FY 2019.[22] In Policy Interaction Scenario 2 (PI2), it is assumed that the utilities prioritize universal household electrification, and do not regularize and meter informal connections over the same timeline. Fig. 7 (a) illustrates the annual profit (or loss) before subsidies for PI1 and PI2 with reference to the Base Scenarios. Fig. 7 (b) illustrates influence of PI1 and PI2 on accumulated losses for the period FY2019 to FY 2022.

Overall, four key observations can be made based on the results. First, annual losses in PI1 are consistently lower than those for PI2. This is due to comparatively lower AT&C losses and higher revenues resulting from metering of informal connections in scenario PI1. Second, in PI1, the benefits of reduced AT&C losses and higher revenues resulting from metering of informal connections even outweigh the cost of rural electrification. Third, since the average revenue from the new connections is lower than the average power purchase cost, the accumulated loss for the period FY2019 to FY2022 is greater in PI2. Fourth, we find that sequencing between financial turnaround and rural electrification matters, since the additional accumulated losses due to rural electrification are lower in the first financial reform scenario (B1) as compared to the second financial reform scenario (B2). This is due to two effects. First, the greater AT&C losses in B2 raise the average cost of supply, and hence increase the cost incurred to service each additional newly electrified household. Second, the lower tariff hikes in B2 reduce the revenue recovered from the newly electrified households.

4.2.3. Policy Interaction Scenarios 3 and 4: solar PV deployment

This section presents the model results for scenarios in which solar PV deployment is layered on top of the Base Scenarios (B1 and B2). In Policy Interaction Scenario 3 (PI3), it is assumed that the annual targets for utility-scale solar PV capacity addition are met to reach a cumulative deployed capacity of 6.7 GW by 2022, and the rooftop solar PV deployment targets are also met under a net-metering scheme, reaching a cumulative installed capacity of 4.3 GW by 2022. In Policy Interaction Scenario 4 (PI4), it is assumed that only the annual targets for utility-scale solar PV capacity addition are met. Once again, Fig. 8 (a) illustrates the annual profit (or loss) before subsidies for PI3 and PI4 with reference to the Base Scenarios. Fig. 8 (b) illustrates influence of PI3 and PI4 on accumulated losses for the period FY2019 to FY 2022.

Three key observations can be made. First, although utility-scale PV helps in marginal reduction of annual losses, this effect only becomes significant in FY2021 and FY 2022, when the cost of solar PV becomes significantly lower than the variable cost of coal power. Second, the directions of the respective effects of utility-scale and rooftop solar PV deployment on utility finances is as expected, with utility-scale solar PV deployment resulting in lower annual losses and rooftop solar PV deployment resulting in higher annual losses. However, it is notable that the loss in revenue due to rooftop solar PV deployment is far greater in magnitude than the benefits from utility-scale deployment, despite rooftop solar PV having relatively lower installed capacity. Third, the increment in accumulated losses due to rooftop solar PV deployment is significantly greater in Base Scenario 1 as compared to that in Base Scenario 2. This is because in Base Scenario 1, greater tariff hikes for commercial and industrial customers also results in greater loss in revenue when they migrate to net-metering.

5. Conclusions and policy implications

The results of this study provide general insights on interactions between different policies in electricity sectors in developing countries. While previous studies have argued that power sector reform should also include the social and environmental considerations, the qualitative and quantitative results of this study have important implications for policy design and sequencing.

To summarize, the results indicate that there are a number of emergent and conditional trade-offs between different policy goals. On one hand, financial reform through improvement in operational efficiency, reduced cost of power generation, and reduced debt should be an enabler for universal electrification and for solar PV deployment. However, the reverse is only conditionally true, and may depend on the concrete goals for rural electrification and solar PV deployment, as well as on how the instruments are designed and sequenced.

In terms of *goals*, the emphasis thus far in power sector reform has mostly been on ensuring financial viability of utilities. However, in the presence of multiple and competing top-down policy goals, a siloed approach towards financial reform may be insufficient since other policy goals can place additional constraints on utilities' operation. Thus, the scope, magnitude and prioritization of policy goals need to be adjusted to take into account potentially conflicting policy goals at an early stage.

For example, rural electrification policies with the narrow goal of provision of grid connections or its excessive prioritization over other policy goals can negatively impact utilities' finances and hence impair their ability to provide quality service. In contrast, an integrated approach would also explicitly take into account goals related to financial reform. That is, the goal of extending electricity access in a financially sustainable manner would ideally necessitate ex-ante studies on impacts of rural electrification on utility finances. This would, in turn, inform policy designs that would incorporate commensurate measures such as AT&C loss reduction, increased revenue subsidy allocation and changes in tariff structure in lockstep with rural electrification.

While such an approach can place additional strains on utilities, regulators and policymakers with different jurisdictions in terms of closer coordination for setting goals and conducting ex-ante studies to design instruments that take into account interactions in the longer term, it may be necessary to ensure consistency of instruments in the policy mix.

Second, in terms of *instruments*, both the type and calibration matter in terms of determining implicit prioritization of policy goals and nature of interactions in the policy mix. For example, while Uttar Pradesh's policy goals of achieving cost reductions in solar PV and financial reform of utilities are potentially synergistic in nature, instrument type and calibrations play a critical role in realizing this potential. For utility-scale solar PV, the price pressure from competitive auctions, reduction of off-taker risk through use of intermediary off-takers and relaxation of constraints related to domestic content requirement have helped minimize trade-offs and create synergies between solar PV deployment and financial reform. On the other hand, for rooftop solar PV, revenue loss due to net-metering, lack of reduction in cross-subsidy, and lack of incentives for distribution utilities to implement net-metering have resulted in a lack of consistency between policy instruments, thus nullifying net synergies, accentuating trade-offs, and reducing congruency between the two policy goals of solar PV deployment and financial reform.

Finally, and related to the first two points, the results indicate that policy *sequencing* can impact the extent of interactions and outcomes. Thus, the design of goals and instruments should ideally take into account not only static interactions among different policy goals, but also a longer-term perspective of how they should be sequenced. For example, the quantitative results show that prioritization of financial reform reduces the need for revenue subsidies for rural electrification.

In addition, the qualitative results indicate that the rapid expansion of low-voltage network could impair utilities' ability to increase operational efficiency, and the expansion of the subsidy net could further entrench pre-existing tariff structures and make tariff rationalization politically even more difficult due to institutional lock-in. In cases where

[22] In comparison, under the business as usual scenario the electrification rate only reaches 70% by FY 2022.

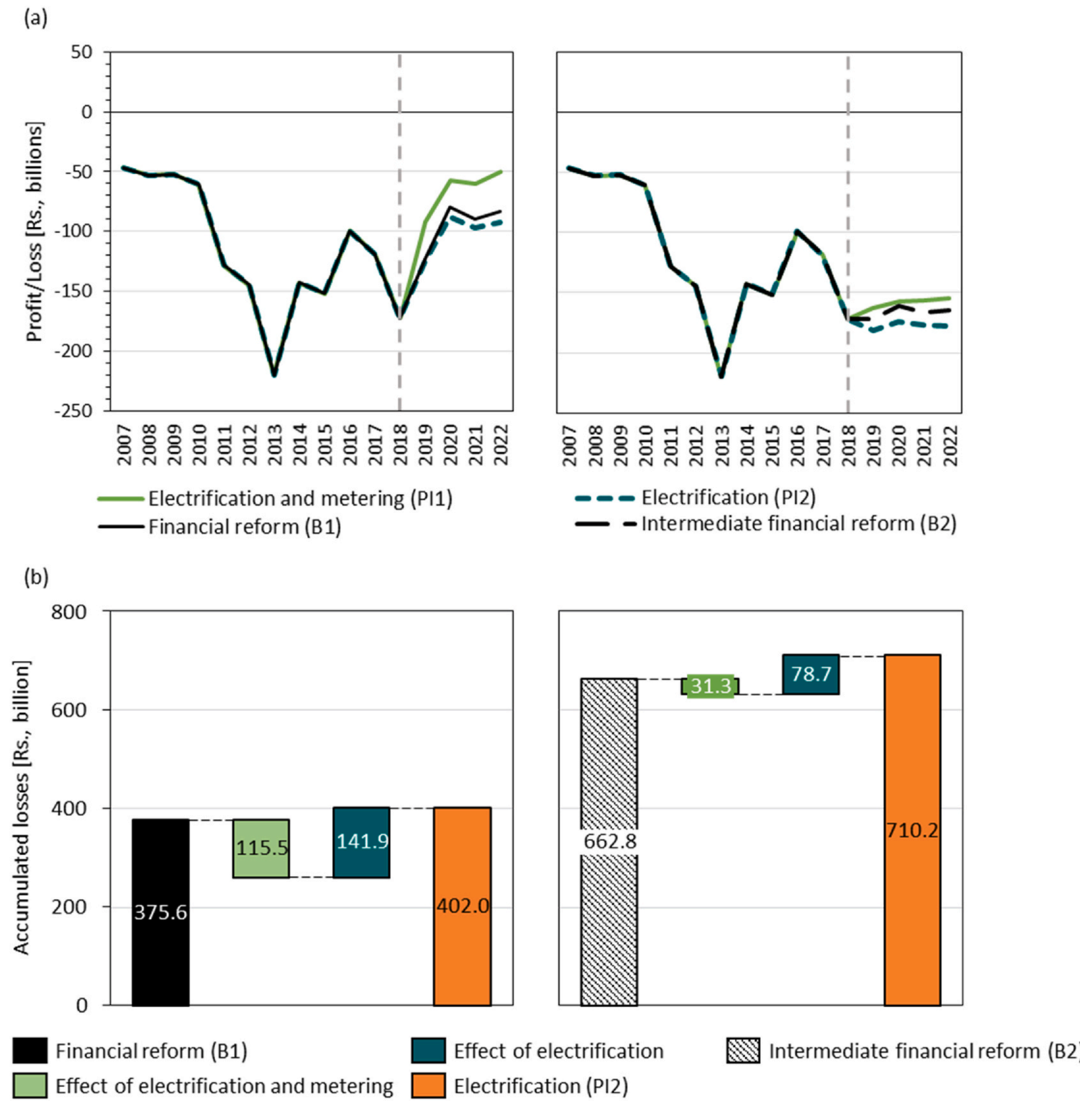

Fig. 7. Model results for (a) annual profit/loss (excluding subsidies), and (b) accumulated losses for the period FY2019 to FY2022 in Policy Interaction Scenarios 1 and 2 for the distribution sector in Uttar Pradesh.

the prevalent political economy prioritizes short-term goals even if they are detrimental to long-term policy goals in other domains, the integrated approach to setting policy goals and designing policy instruments proposed earlier could, at the very least, help mitigate some of the inherent trade-offs.

While this study has focused on the case of Uttar Pradesh in India, its findings also have implications for other parts of the world. It demonstrates that *goals* and *instruments* for extension of electricity access and renewable energy deployment need to be more deliberately packaged with measures for power sector reform in terms of their *design* and *sequencing* to develop integrated policy strategies (Howlett and Rayner, 2013; Rayner and Howlett, 2009), rather than simply layering them on top. It also demonstrates the value of conducting quantitative analyses for evaluation of policy mixes.

The approach used in this study has certain limitations, which also provide indications for future avenues for research. First, the quantitative method used in this study constructs scenarios for policy outcomes (i.e. AT&C loss reduction, households electrified, and solar PV deployment) based on real-world policy goals. However, the actual outcomes themselves could vary depending on the effectiveness of policy instruments. Future studies could more take this into account by combining the financial modeling used in this study with other modeling techniques, such as agent-based modeling. Second, although this study chooses Uttar Pradesh as the research case using a typical case selection strategy, generalizing from a single case study to other contexts is always challenging. Future work could focus on conducting large-n analyses of contexts with variation along parameters such as financial health of utilities, electrification levels, income levels of electricity customers, power mixes, market structures, and policy ambition to test the relationship between financial performance of utilities and various policy measures. Finally, this study remains agnostic to the political economy of power sector reform. Future work should focus on exploring how power structures, institutional setups, and actor constellations affect the feasibility and effectiveness of different policy designs and sequences.

CRediT authorship contribution statement

Abhishek Malhotra: Conceptualization, Investigation, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

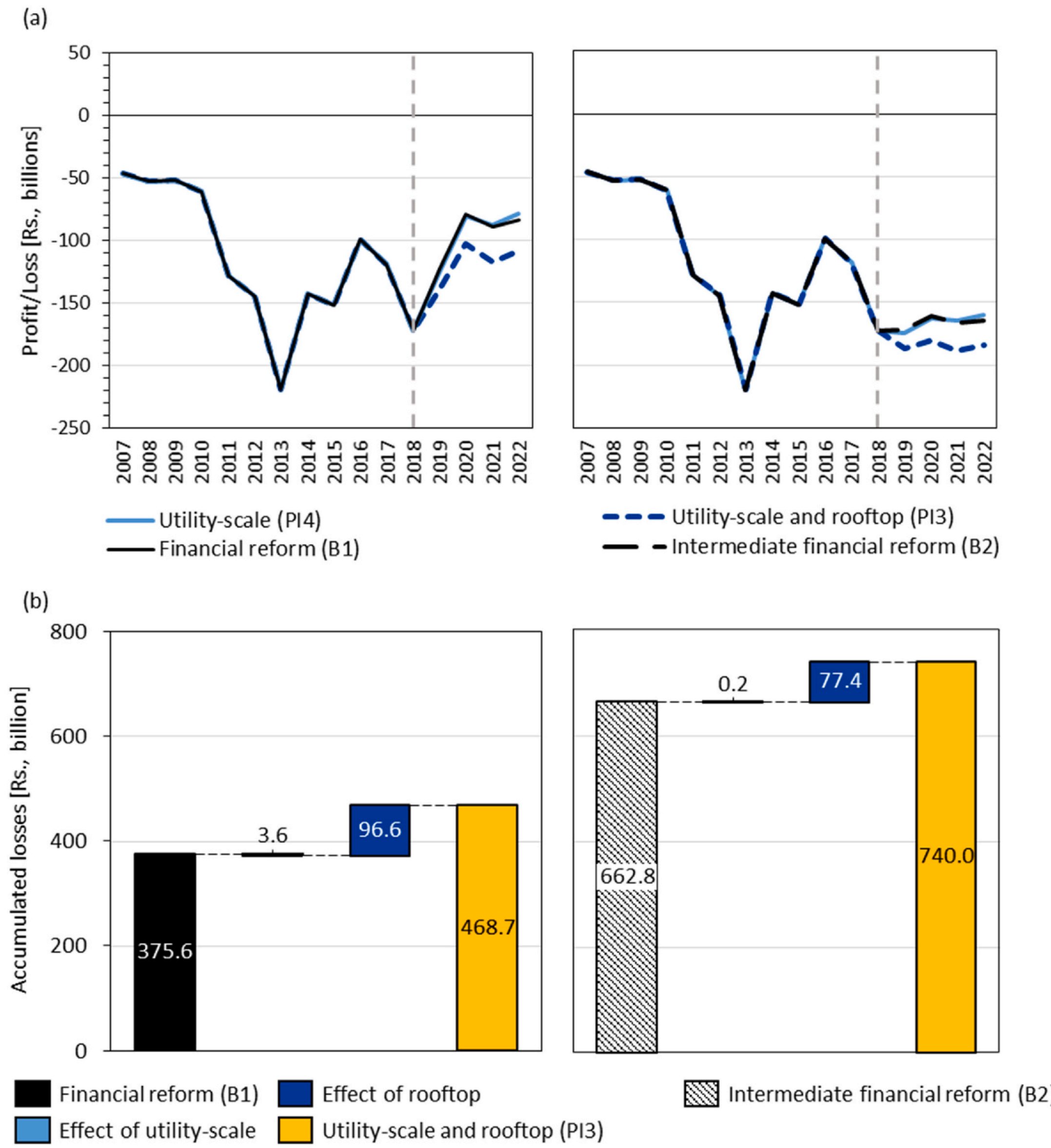

Fig. 8. Model results for (a) annual profit/loss (excluding subsidies), and (b) accumulated losses for the period FY2019 to FY2022 in Policy Interaction Scenarios 3 and 4 for the distribution sector in Uttar Pradesh.

the work reported in this paper.

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Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2022.112936.

Appendix A

The history of power sector reform in India started in October 1991, shortly after the initiation of liberalization of the nation's economy, with the primary goal of promoting private sector participation to boost generation capacity (Dubash and Rajan, 2001). In the following decade, a series of measures in accordance with the 'standard model' were recommended under the Common Minimum National Action Plan on Power (1996), such as vertical unbundling of State Electricity Boards (SEBs) and establishment of independent regulators. However, growing concerns over deteriorating financial and technical performance of the SEBs culminated in the formation of an expert committee led by Mr. M.S. Ahluwalia, which recommended a major bailout and reform plan in 2001, and resulted in the passing of the landmark Electricity Act, 2003 (Singh, 2006).

A.1. Policies for financial reform of utilities (2003–2012)

The Electricity Act (2003) directed the state governments to unbundle SEBs and reorganize the resulting companies to ensure their profitability and viability (Section 131). It also mandated the formulation of the National Tariff Policy and directed regulatory commissions to ensure that generation, transmission, distribution and supply of electricity are conducted on commercial principles (Section 61). The National Tariff Policy (2006), in turn, recognizes that to be able to attract adequate investment in the power sector for universal electrification and adequate, reliable and quality supply, it is essential to provide an appropriate return on investment. Keeping this in mind, it provides guidelines for tariff setting, thus providing guidelines and setting constraints on future policy goals and instruments. Particularly for electricity distribution, it specifies that tariffs should reflect the efficient cost of electricity supply by achieving two policy goals. First, on the cost side, reduction in average cost of supply[23] is to be achieved through competitive power procurement in accordance with Section 63 of the Electricity Act,[24] and reduction of aggregate technical and commercial (AT&C) losses. Second, on the revenue side, the State Electricity Regulatory Commissions (SERCs) were required to revise retail tariffs such that the average realized revenue[25] reflects the average cost of supply by the end of 2010–11, and to reduce cross subsidy such that the retail tariff for any consumer category is within ±20% of the average cost of supply. Instead of cross-subsidies, state governments were encouraged to provide direct subsidies to poorer consumers, as deemed necessary. However, in accordance with Section 65 of the Electricity Act, subsidized tariffs can only be approved by the Regulatory Commission once the corresponding subsidy amount has been issued by the state government to the utility in advance.

A.2. Policies for provision of electricity access (2003–2012)

Rural electrification regained priority as a development imperative after passing of the Electricity Act (2003), which for the first time obligated the government to provide electricity access to all households. The Electricity Act provided impetus for policies to channel funds from the central government to state-level implementation agencies in the form of loans, interest subsidies and grants targeted towards providing grid connections.

For example, the Kutir Jyoti Yojana launched in 1988 allocated funds to SEBs for the free provision of a single point light connection to below poverty line households. During the period 2002 to 2007, Rs. 6.27 billion were allocated to states in proportion to their unelectrified population in the form of grants under this policy. Similarly, the Accelerated Rural Electrification Program (AREP) was introduced in 2003 to provide an interest rate subsidy of 4% on loans for village and household electrification provided by public financial institutions such as the Rural Electrification Corporation (REC) to SEBs and distribution utilities. During the period 2002–07, Rs. 5.6 billion were allocated under this scheme.

While neither of these schemes had explicit goals initially, they were merged together under a single scheme in February 2004 and provided the concrete goal of electrifying 100,000 villages and 10 million households by 2007.[26] The new policy thus created further expanded the scope of the pre-existing policies beyond public utilities, and could be used to allocate funds to independent rural electricity providers, as permitted by Section 5 of the Electricity Act (2003). However, this meant that the scheme overlapped in scope with the Remote Village Electrification Program (2001) initiated by the Ministry of New and Renewable Energy to provide electricity to remote locations through the use of off-grid renewable technologies.

To address these overlaps and inconsistencies in the policy mix, all existing electrification programs were subsumed under the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) in April 2005, which aimed to electrify all villages by 2009. The Rural Electrification Policy (2006) issued by the Ministry of Power reiterated and extended the goals of RGGVY to provision of electricity access to all households by 2009, ensuring quality and reliable supply at reasonable rates, and providing at least 1 kWh electricity per day to all households by 2012. To achieve this goal, it directed state governments to develop rural electrification plans, outlining electrification delivery mechanisms (grid or standalone). It further included provisions for setting up of distribution franchisees in rural areas, and for permitting privately run standalone systems, exempting them from licensing obligations and allowing them to set tariffs based on mutual agreement with consumers.

A.3. Policies for solar PV deployment (2003–2012)

Compared to achieving commercial viability and extending electricity access, the domain of renewable energy policy has gained prominence relatively recently in India's power sector. Even among renewable energy technologies, solar power has been a relative latecomer. While the Electricity Act (2003) and National Electricity Policy (2005) provided the framework for renewable energy policy, there was no major policy push for solar PV until 2008. However, the National Action Plan on Climate Change (2008) established solar as a priority at the national level by calling for National Solar Mission as one of eight missions to address climate change. The NAPCC called for a renewable purchase obligation (RPO) to be established at the state level to ensure that renewable energy technologies constitute 5% of states' energy mixes in FY 2009–2010, and thereafter increase by 1% year-on-year for the next 10 years. As a result, the Jawaharlal Nehru National Solar Mission (JNNSM) was launched in November 2009 with the goal of establishing India as a global leader in solar energy.

[23] Average cost of supply (ACS) is defined as the ratio of the total cost incurred by the distribution utility to the total input energy for the distribution utility.

[24] In contrast, Section 62 of the Electricity Act provides guidelines for determination of regulated tariffs for power generation, transmission and retail using a corporatist governance logic.

[25] Average realized revenue (ARR) is defined as the ratio of total revenue to total input energy for the distribution utility.

[26] The new scheme was named the 'Accelerated Electrification of One Lakh Villages and One Crore Households' scheme.

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