



## Cost-effective policies for reaching India's 2022 renewable targets



Gireesh Shrimali\*, Saurabh Trivedi, Sandhya Srinivasan, Shobhit Goel, David Nelson

Climate Policy Initiative, Delhi, 110017, India

### ARTICLE INFO

#### Article history:

Received 25 August 2015

Received in revised form

24 November 2015

Accepted 19 February 2016

Available online 5 March 2016

#### Keywords:

India

Renewable targets

Cost-effective policies

Forecasting

### ABSTRACT

India has ambitious renewable energy targets by 2022: 100 GW of solar and 60 GW of wind. Both of these technologies are perceived to be more costly than conventional, fossil-fuel, power; and, therefore, require policy support. Using representative, project-level cash flow models, we examine two related questions: First, what would be the cost of policy support under existing federal policies; and, second, what would be the most cost-effective federal policy? We answer these questions by first forecasting the unsubsidized levelized cost of electricity for wind, solar, and the marginal fossil fuel; and then examining the cost of support under existing as well as proposed debt-related policies. We find that wind energy is already competitive with the marginal fossil fuel and, therefore, does not require any policy support. We also find that solar energy will become competitive by 2019; and prior to that the most cost-effective federal policy is provision of reduced-cost long-term debt, which can significantly reduce (by more than 90%) the total cost of support compared to accelerated depreciation, the most cost-effective existing federal policy.

© 2016 Elsevier Ltd. All rights reserved.

### 1. Introduction

For India, high import dependence (oil and increasingly coal), large peak power and energy deficits, and high energy intensity indicate serious challenges related to climate change, energy scarcity, and energy security [20]. On one hand, India's energy portfolio is dominated by fossil fuels, with 68% of the total power generated from coal and oil (IBEF, 2014). On the other hand, though the domestic production of energy sources is expected to increase, the dependence on the imports will also continue to rise. For instance, between 2005–06 and 2012–13, import of coal and crude oil increased approximately four-fold and two-fold, respectively [31].

To overcome these challenges, India has set highly ambitious renewable energy targets. As stated in the National Action Plan for Climate Change [43], deploying renewable energy is a strategic priority for India. Under India's most recent budget, Union Budget 2015–2016, India aims to install 100 GW of solar energy capacity and 60 GW of wind energy capacity by 2022 [14], which is more than six times the current installed capacities of approximately 22 GW of wind and 3 GW of solar [29]. The previously articulated targets under the 12th Five Year Plan (2012–2017) aimed to install

an additional 20 GW of solar and 30 GW of wind capacity by 2022.

Due to current accounting practices, which do not account for the social and environmental costs of fossil fuels, renewable energy is currently perceived to be more expensive than fossil fuels [44]. Therefore, in order to compete with energy generated from fossil fuels, renewable energy requires policy support from the government.

In India, policy support is provided for renewable energy at both the state and federal (i.e., central) levels. The existing federal government policies are (see Appendix for more details): (1) a generation based incentive of INR 0.5 per unit (USD 0.008 per unit) of electricity, (2) viability gap funding (i.e., capital grant) up to 30% of project cost, and (3) accelerated depreciation of 80%. The federal government's policies typically cover only some of the difference between the cost of unsubsidized renewable energy and the average pooled purchase cost (APPC), the average price paid by state-level public-sector utilities to procure power. The remaining difference is met by state governments through Power Purchase Agreements with renewable energy developers, agreeing to pay feed-in tariffs for 20–25 years.

In spite of these policy support mechanisms, which have deployed renewable capacity and brought down costs of renewable energy via learning [35], our analysis shows that renewable energy continues to be more expensive than conventional power [47]. Therefore, there is a need to continue policy support for renewables in India. However, this task is made difficult by the Indian

\* Corresponding author. Steyer-Taylor Center of Energy Policy and Finance at Stanford University, USA.

E-mail address: [gireesh.shrimali@cpidelhi.org](mailto:gireesh.shrimali@cpidelhi.org) (G. Shrimali).

government’s large fiscal deficit and multiple development priorities [13]. Given that subsidies require allocation of scarce public resources, it is imperative that RE deployment is cost-effective [12,19].

Based on discussions with policymakers in India, this paper investigates the following questions:

Q1) How much it would cost the Indian government to achieve its renewable energy targets?

We answer this question by forecasting levelized (or delivered) cost of electricity (LCOE)<sup>1</sup> from renewable energy and that from the fossil fuels in the absence of any policy support – whether explicit or implicit.<sup>2</sup> In this process, we also answer the following question:

Q2) What would be the most cost-effective policy mechanism to achieve India’s renewable targets?

To the best of our knowledge, such analysis has not been attempted. Prior work on the cost effectiveness of renewable policies [49,55] is based on developed economies. Further, their focus is on financial incentive policies without much “direct” focus on cost of capital, which happens to be a significant issue in developing countries [34].

Shrimali et al. [46] was the first study to examine impact of policy pathways on renewable financing in India [47]. extended this result to compare debt-related federal policies (i.e., low-cost, long-term debt) to existing policies. This paper further extends [47] to not only forecast cost of renewable energy until 2022 but also compare policy options in a dynamic fashion.

This paper is organized in four sections. Section 2 details the methodology used for the analysis; Section 3 presents the results; and Section 4 concludes. The Appendix provides further information on policies as well as a comprehensive literature.

2. Methodology

The primary objective of this paper is to calculate the cost of policy support and identify the most cost-effective policy mechanism to achieve the government’s renewable deployment targets.<sup>3</sup> Policy support reduces the effective (i.e., subsidized) levelized cost of electricity from renewable energy so that it is competitive with fossil-fuel based energy. The levelized cost of electricity represents the average life cycle energy cost for a project. It enables comparison of the cost of energy across different technologies, particularly when capital cost, scale and project life differ [5].

At a conceptual level, the levelized cost of electricity is calculated as the net present value of total project life cycle costs divided by the total amount of energy produced over system life. It is not easy to derive formulas for levelized cost of electricity, given the intricacies of project cash flows; however, a representative formula that provides intuition is as follows [46]:

$$lc = \frac{C - \alpha \sum_{t=1}^T \frac{D_t}{(1+r)^t} + (1 - \alpha) \sum_{t=1}^T \frac{W_t}{(1+r)^t} - (1 - \alpha) \frac{C_T}{(1+r)^T}}{(1 - \alpha) * 8760 * \sum_{t=1}^T \frac{CF_t * x_t}{(1+r)^t}}$$

where lc: levelized cost of electricity; T: the life of project, C: capital expenditure (or CAPEX); D: depreciation; W: operating expenditure (or OPEX); C<sub>T</sub>: terminal value; α: tax rate; CF: capacity factor (i.e., plant load factor); x: degradation factor; and r: cost of capital.

To calculate the cost of policy support, we began by forecasting the unsubsidized (i.e., in absence of any government support) levelized cost of electricity for three technologies up to 2022: utility-scale wind and solar, the dominant renewable energy technologies; and the marginal fossil-fuel based power plant. The unsubsidized levelized cost of fossil-fuel based power serves as the baseline cost of electricity. We then calculated the amount of policy support required to equate the subsidized (i.e., in presence of policy support) levelized cost of renewable energy equal to the baseline cost of electricity.

2.1. Baseline cost of electricity

Using the appropriate baseline cost of electricity is critical as it can provide a fair basis for government planning and budget allocation for renewable energy deployment. We use the levelized cost of electricity from a marginal fossil-fuel based power plant to indicate the baseline. Marginal fossil fuel is the most expensive form of fossil fuel based energy that is being added to the existing energy mix. In other words, a marginal plant is a new build power plant that uses the marginal fossil fuel which is expected to be commissioned after 2014. It represents the set of power plants most likely to be replaced by new renewable energy deployment.

We considered four possible options for estimating the levelized cost of electricity from the marginal fossil fuel based plant (Fig. 1), to arrive at the imported coal based power plant as the marginal fossil power plant.

First, the average pooled purchase cost, which is the cost of purchase for distribution utilities from all sources except renewable energy. This cost has to be approved by the state regulator and varies across states. It also includes the cost of purchase for old and depreciated plants, which may not be comparable with the cost of plants being set up today. Therefore, it is not an accurate baseline for comparing forecasts of levelized cost of electricity from renewable energy, and would overestimate the policy support

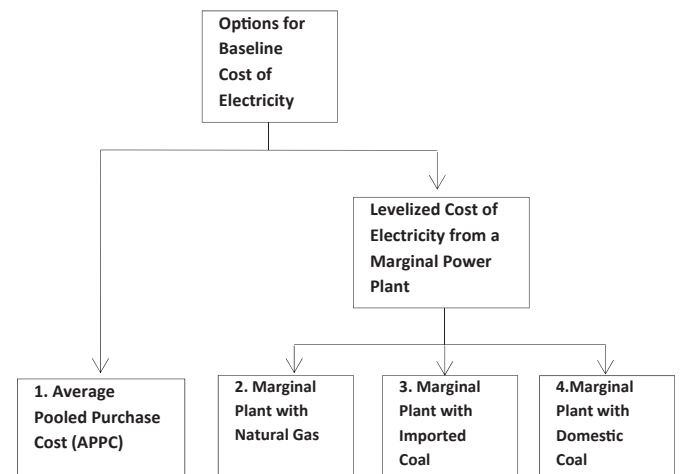


Fig. 1. Baseline cost of electricity.

<sup>1</sup> The levelized (or delivered) cost of electricity or LCOE is the average cost of electricity that helps to break even in terms of the return expected by the developer. It represents the minimum unit revenue required to meet the return on equity, given the project’s financial parameters.

<sup>2</sup> This is key to ensure that implicit subsidies, such as ones provided to domestic coal, do not distort the comparison.

<sup>3</sup> Similar work exists in other contexts, such as agriculture, irrigation, and drainage – e.g. Refs. [50,51] [52,53]; and [54].

requirement.

Second, *natural gas*, which is currently the most expensive fossil fuel in India. However, natural gas currently constitutes only 8.6% of the total energy mix due to the supply side constraints [31].<sup>4</sup> The share of natural gas has not changed significantly over time, with an increase of a mere 1.84% from 2012 to 2013 in estimated gas reserves. Therefore, natural gas based power plants are unlikely to be deployed at a significant scale over the next few years. Hence, we do not consider natural gas based power plants as the marginal power plant.

Third, *imported coal*, whose share of total coal consumption has risen steadily from 8.7% in 2006 to 16% in 2012 (Ministry of Power, 2006–13). Currently, imported coal accounts for 18% of total electricity [11], which is higher than India's target of 15% of generation from renewable energy [28]. Therefore, imported coal is the most expensive fossil fuel that is likely to be replaced by renewable energy. Hence, *imported coal based power plant is the marginal power plant and the levelized cost of such plant serves as the primary baseline cost of electricity.*

Fourth, *domestic coal*, whose supply is of inferior quality compared to imported coal. Furthermore, domestic coal price is artificially lowered by government regulations. Even after adjusting for heat content, imported coal is more expensive than domestic coal. Hence, domestic coal does not serve as an appropriate reference point for the unsubsidized cost of marginal fossil fuel based power.

However, since domestic coal remains the predominant source of electricity [11], accounting for ~55% of total power generation, we provide a comparison of renewable energy with the marginal domestic coal plant as a reference case. Since domestic coal prices are regulated, we use the price of imported coal adjusted downward by 15% for transport, or the import parity price, which indicates the unsubsidized market price of domestic coal [40].

## 2.2. Levelized cost of energy forecast

We forecasted the unsubsidized levelized cost of electricity from renewable energy and that from the marginal fossil-fuel based energy to calculate the difference between these two sources of electricity. Based on this difference, we calculated the required cost of support for renewable plants commissioned between 2015 and 2022.

In this section, we discuss the forecast of the primary baseline cost of electricity i.e. the levelized cost of imported coal based power, the unsubsidized levelized cost<sup>5</sup> of renewable based electricity (both solar and wind) and the levelized cost of electricity from a domestic coal based plant.

The forecasts of levelized costs are driven by the forecasts of certain variables that act as inputs for a project-level cash flow model<sup>6</sup> used to estimate the levelized cost of electricity for plants commissioned each year from 2015 to 2022 (Table 1). The assumptions used for the cash flow model are presented below.

For project level cash flow modeling, we used an *optimized leveraged* cash flow model instead of fixed leverage model. That is, we assumed that, given any tariff, the project developer would maximize debt to maximize the returns on equity [47]. This

optimization is typically subject to a minimum debt service coverage ratio condition, which is essentially the ratio of the cash flow available for distribution and the debt service requirement, of 1.3 for the entire course of a renewable project.

### 2.2.1. Drivers of levelized cost of electricity

Several factors, such as return on equity, interest rates, capital expenditure,<sup>7</sup> and capacity utilization factor<sup>8</sup> influence the levelized cost of electricity. Using project-level cash flow models and sensitivity analysis, we assessed the responsiveness of levelized cost of renewable energy to these factors (Table 2). The levelized costs of renewable energy are highly sensitive to capital expenditure and capacity utilization. Hence, these two variables<sup>9</sup> form the key inputs into the model used to calculate the levelized cost of electricity for solar and wind energy.

On the other hand, the levelized cost of electricity from coal based power plants is primarily driven by capital expenditure and the fuel cost.

**2.2.1.1. Capital expenditure forecast.** As discussed earlier, capital expenditure is one of the key factors driving the levelized cost of electricity. The forecasting for the solar and wind capital cost has been done for the period 2015–2022. We used multi-method forecasts [8], and used up to five approaches to forecast the capital expenditure prices of solar and wind in next eight years. We then classified these forecasts under three scenarios: best case (lowest capital cost series), worst case (highest capital cost series) and the average case (average of the best and worst case capital cost series). To improve forecasting accuracy, we combined the forecasts from all these approaches using a simple average [2].

#### a) Regression Analysis:

We used regression analysis as our main approach to forecast the capital expenditure of solar and wind power projects in India. We used multi-factor ordinary least squares (OLS) regression technique represented by the following equation:

$$Y = \beta_0 + \sum_{i=1}^n \beta_i X_i$$

where the dependent variable  $Y$  is the capital cost of the renewable power plant and  $X_i$  are the independent variables. We used a natural log transformation of all the variables so that the error sample is closer to the normal distribution.

As usual practice, we divided total capital cost of renewable power projects into two components: turbine cost (for onshore wind)/module cost (for solar PV) and Balance of Systems (BOS) cost. Given different drivers [3,33,35,42], we tried to estimate module/turbine cost and BOS cost separately. Based on [18], we also distinguished between global and local learning effects.

The use the following *Module/Turbine-Related* factors [3,33,35,42]:

<sup>4</sup> India's natural gas market is facing a supply deficit due to the low domestic production and an inadequate transmission and distribution infrastructure [15].

<sup>5</sup> Unsubsidized levelized cost is the actual levelized or the delivered cost of electricity without policy support.

<sup>6</sup> The assumptions (Table 1) for these models are drawn from a sample of projects from the Bloomberg New Energy Finance (BNEF) database, and validated through the Central Electricity Regulatory Commission's (CERC) benchmark tariffs [10], as well as our primary research.

<sup>7</sup> Capital Expenditure is an expense used to acquire or upgrade property, equipment etc. In case of renewable energy projects, it primarily includes turbine/module cost, land, civil and general works, and evacuation costs.

<sup>8</sup> Capacity utilization factor can be defined as fraction of time that a plant is producing energy.

<sup>9</sup> We have assumed all the other variables such as ROE, interest rates etc. to remain constant throughout the project life in the cash flow models used to calculate the levelized cost of electricity.

**Table 1**  
Assumptions for cash-flow models.

Assumptions	Wind	Solar	Coal
<b>Power generation</b>			
Capacity utilization factor (P50 PLF)	24.5% in 2015, and increasing by 0.5% per year <sup>a, c</sup>	20.5% <sup>d</sup>	75% <sup>d</sup>
Useful life	25 Years	25 Years	40 Years
<b>Capital cost</b>			
Capital cost (INR million/MW) (Details in Section 3)	Based on forecast of solar plant capital cost	Based on forecast of wind plant capital cost	Based on forecast of coal plant capital cost
<b>Operating expense</b>			
O & M Expenses(1st Year)	INR 1.01 million/MW	INR 1.23 million/MW	INR 1.63 million/MW (excluding fuel cost)
Fuel cost expenses (1st Year) including transportation cost	NA	NA	INR 16.60 million/MW
Escalation in O & M expenses	5.7%	5.7%	6.3%
Escalation in fuel cost and transportation cost	NA	NA	1.5% (for fuel); 5% (for transportation)
<b>Financial assumptions</b>			
Minimum debt service coverage ratio (DSCR) <sup>b</sup>	1.3	1.3	NA & (Fixed D/E = 75/25)
P90 PLF <sup>c</sup> (Debt condition)	22.5% in 2015, and increasing by 0.5% per year <sup>e</sup> .	19% <sup>d</sup>	Not applicable
<b>Debt</b>			
Repayment period	12 years	12 years	10 years
Interest Rate (Fixed)	12.30%	12.30%	12%
<b>Equity</b>			
Expected return on equity <sup>f</sup>	17.90%	17.30% <sup>d</sup>	15.50% <sup>d</sup>
TAX incentive			
Tax holiday	10 years	10 years	Not applicable
Minimum alternative tax	20%	20%	Not applicable

<sup>a</sup> The 0.5% per year increase is based on linear interpolation between 2015 and 2022.

<sup>b</sup> DSCR (in any year) is the ratio of cash flow available for debt servicing to the sum of interest and principal.

<sup>c</sup> P50 PLF represents the most likely output of the plant, while P90 PLF is a conservative estimate.

<sup>d</sup> We assume that these variables remain constant throughout the project life-cycle of all the projects to be commissioned till 2022.

<sup>e</sup> Increases by 0.5% every year for the projects to be commissioned in subsequent years.

<sup>f</sup> Return on Equity is the amount of net income returned as a percentage of shareholder equity.

Source: Author analysis

**Table 2**  
Average elasticities of LCOE of renewables to input parameters.

Parameter	Average elasticity
Capital expenditure	0.91
CUF	-1.04
Return on equity	0.44
Interest rate	0.29

Source: Author analysis

- **Learning-by-doing:** Learning-by-doing refers to process improvements due to cumulative experience with producing a particular technology. This is typically represented by cumulative global deployment (CGD) of the technology.
- **Scale:** Scale refers to economies of scale in production. We used annual global deployment (AGD), or market demand, as a proxy to measure scale. Since annual deployment measures scale at the industry level, it indicates market maturity as well as inbuilt efficiencies.
- **Technology/R&D:** Technology refers to improvements in solar modules (e.g., module efficiency) or wind turbines (e.g., rotor diameter). Module efficiency can be captured as power output per square meter (Watt/m<sup>2</sup>).
- **Input costs:** This refers to the cost of raw material used to create solar modules or wind turbines. In the case of solar, silicon is the primary input. For wind, steel and electrical machinery are significant components. We used world consumer price index (CPI) to capture the effect of input cost.

Similarly for the BOS component of the capital cost, we identified following factors [3,33,35,42]:

- **Learning-by-doing:** In this case, learning is captured by cumulative local deployment (CLD) which refers to the total solar/wind capacity deployed in India. Similar to global learning, this is used as an indicator of local level learning effects.
- **Scale:** Similar to global annual deployment, annual local deployment (ALD) indicates the increase in the scale of the solar/wind market within India (at country level).
- **Input cost:** Inflation in the cost of system components (inverter, land cost, labor cost, etc.) would drive overall BOS cost. These variables can be captured using relevant inflation indices. We used India's wholesale price index (WPI) as a proxy for the input cost.

We next discuss the regression analysis separately for solar and wind.

**2.2.1.1.1. Solar capital cost forecast.** Solar capital expenditure consists of module and BOS costs [26]. We use two separate regression equations: one for each.

**Solar PV Module cost forecast:** The market for PV modules is global; hence we used global level independent variables over 33 years (1980–2013). The (yearly) regression equation is below:

$$\ln(\text{Module Cost}(PV)) = \beta_0 + \beta_1 \ln(CGD_s) + \beta_2 \ln(AGD_s) + \beta_3 \ln(Inf_g) + \beta_4 \ln(ME)$$

where *Module Cost (PV)* is the average module cost<sup>10</sup>  $CGD_s$  is the

<sup>10</sup> Data Source: <http://go.bloomberg.com/multimedia/solar-silicon-price-drop-brings-renewable-power-closer/>.



cumulative global deployment capacity of solar<sup>11</sup>;  $AGD_s$  is the annual global deployment capacity of solar;  $Inf_g$  is the global inflation (consumer price index)<sup>12</sup>; and ME is the module efficiency of solar PV.<sup>13</sup>

*Solar BOS (non-module) cost forecast:* BOS cost are driven by local factors. Based on data availability in India, we used historical data of 6 years (2009–2014). The (yearly) regression equation is mentioned as below:

$$\ln(BOS) = \beta_0 + \beta_1 \ln(CLD_s) + \beta_2 \ln(ALD_s) + \beta_3 \ln(Inf_l)$$

where BOS is the average BOS cost of solar plant,<sup>14</sup>  $CLD_s$  is the cumulative local (India) deployment capacity of solar<sup>15</sup>;  $ALD_s$  is the annual local (India) deployment capacity of solar;  $Inf_l$  is the local (India) inflation (wholesale price index).<sup>16</sup>

*2.2.1.1.2. Wind capital cost forecast.* Wind capital cost has two broad components: Turbine and BOS. Turbine costs constitute about 65–84% of the total system cost [23]. Though it would have been ideal to run separate regressions, due to the non-availability of appropriate data, we ran the regression with total system cost only. We used historical data of 14 years (from 2001 to 2013). The (yearly) regression equation is mentioned as below:

$$\begin{aligned} \ln(\text{Total Capital Cost}) = & \beta_0 + \beta_1 \ln(CGD_w) + \beta_2 \ln(AGD_w) \\ & + \beta_3 \ln(CLD_w) + \beta_4 \ln(ALD_w) \\ & + \beta_5 \ln(Inf_l) + \beta_6 \ln(RD) \end{aligned}$$

where Total Capital Cost is the average system cost<sup>17</sup>;  $CGD_w$  is the cumulative global deployment capacity of wind<sup>18</sup>;  $AGD_w$  is the annual global deployment capacity of wind;  $CLD_w$  is the annual local (India) deployment capacity of wind<sup>19</sup>;  $ALD_w$  is the annual local (India) deployment capacity of wind;  $Inf_l$  is the local (India) inflation (wholesale price index); RD is the Rotor Diameter of the Wind Turbine<sup>20</sup>

We found that most of the independent variables were highly correlated; however, this is not too concerning for forecasting purposes [4]. Despite this, to be more prudent, we ran multiple regressions by selecting various combinations of independent variables and finally chose a regression equation for forecasting such that: a) the correlation between the independent variables was least; b) Results were in line with the existing theory.

#### b) Secondary research:

For solar, we considered estimates provided by Refs. [1,22,45]. For wind, we considered the forecasts provided by Refs. [1,45].

#### c) Linear trend analysis:

One method to forecast capital cost is to use a line of best fit over historical trends. Sources such as Bloomberg New Energy Finance (BNEF), Central Electricity Regulatory Commission (CERC)

provide project level capital costs of the renewable power projects commissioned over the years in India. We used these average project level capital cost yearly data and made simple forecasts using trend lines for this exercise. In this case, we implicitly assumed that historical trends will continue in future as well.

#### d) Primary research:

Due to limited data availability for Indian projects, we validated our findings through primary research. The three methods detailed above provided an estimate of the ranges within which capital cost estimates lie, and the changes observed with each level of refinement. Based on the several interviews of consultants, experts, developers and manufacturers, we drew inferences for expected trends and drivers of system level costs.

#### e) Inflation based forecast:

In this approach, we simply assumed that the capital cost of a renewable power project would increase based on India's future WPI inflation trend.

As mentioned earlier, the capital cost series determined through the above approaches were classified into three scenarios: best case, worst case and average case. In case of solar, the worst case is from Refs. [1]; the best case is from regression analysis, and the average case is the average of all the capital cost price series. In case of wind, the worst case is based on a yearly inflation factor of 5.3%, the best case capital is based on linear trend analysis, and the average case is the average of best case, worst case and the forecast based on regressions.

*2.2.1.2. Capacity utilization factor.* Capacity utilization factor is the fraction of a period of time that a plant is generating power, and indicates plant efficiency. A higher capacity utilization factor means lower levelized costs. The capacity utilization factor for a wind plant depends on the height of the turbine from the ground, or hub height, as well as wind speeds. The capacity utilization factor typically increases with hub height due to higher wind speeds at higher elevations. We used forecasts of capacity utilization of wind from Ref. [38]. The capacity utilization factor for solar would depend on solar irradiation and ambient temperature. We used estimates of resource availability from National Renewable Energy Laboratory (NREL), National Institute of Solar Energy (NISE) and Central Electricity Regulatory Commission (CERC).

### 2.3. Cost of support

The cost of support is calculated on the basis of capacity addition of renewable energy for each year and the forecasted difference between the unsubsidized levelized cost of renewable power and the baseline cost of electricity from imported coal. We use the Planning Commission's 12th Five Year plan cumulative capacity targets: 20 GW of solar capacity and 50 GW of wind capacity by 2022. While the Planning Commission has outlined interim cumulative capacity targets at the end of the 12th Five Year Plan (2017) and the 13th Five Year Plan (2022), it does not specify annual capacity addition targets. Therefore, we assumed that the cumulative targets follow a linear profile.

The cost of support refers to the required government spending under a policy mechanism to bridge the gap between the unsubsidized levelized cost of renewable power and the baseline cost of electricity, but only as long as unsubsidized renewable energy remains more expensive than the baseline. Estimating the cost of support under each policy enables us to identify the most cost-

<sup>11</sup> Data Source: [http://www.epia.org/fileadmin/user\\_upload/Publications/44\\_epia\\_gmo\\_report\\_ver\\_17\\_mr.pdf](http://www.epia.org/fileadmin/user_upload/Publications/44_epia_gmo_report_ver_17_mr.pdf).

<sup>12</sup> Data Source: World Economic Outlook, IMF.

<sup>13</sup> Data Source: [http://www.nrel.gov/ncpv/images/efficiency\\_chart.jpg](http://www.nrel.gov/ncpv/images/efficiency_chart.jpg).

<sup>14</sup> Data Source: BNEF Database.

<sup>15</sup> Data Source: <http://ireeed.gov.in/>.

<sup>16</sup> Data Source: <http://dbie.rbi.org.in/>.

<sup>17</sup> Data Source: BNEF Database.

<sup>18</sup> Data Source: [http://www.gwec.net/wp-content/uploads/2012/06/GLOBAL\\_INSTALLED\\_WIND\\_POWER\\_CAPACITY\\_WW\\_E2%80%93\\_Regional\\_Distribution.jpg](http://www.gwec.net/wp-content/uploads/2012/06/GLOBAL_INSTALLED_WIND_POWER_CAPACITY_WW_E2%80%93_Regional_Distribution.jpg).

<sup>19</sup> Data Source: <http://ireeed.gov.in/>.

<sup>20</sup> Data Source: BNEF Database.

effective policy to support renewable energy.<sup>21</sup> In previous work [47], we found that 100% support by state-level feed-in tariffs is the least cost-effective policy, and that the total cost of support decreases as federal policies cover more of the (viability) gap between the unsubsidized levelized cost of renewable energy and the fossil fuel baseline. Thus, for any federal policy, *the most cost-effective approach is to cover as much of the viability gap through federal policies as possible*, and we assumed that federal support is maximized.

We first measured the **nominal cost of support**. The nominal cost of support indicates the net annual cash outflow for the government in nominal terms, i.e. without discounting for time value of money. It is calculated as the sum of net government cash outflows for projects deployed in a particular year as well as continuing policy support obligations for projects deployed in previous years starting from 2015. We used the following formula to calculate the nominal cost of support

$$\begin{aligned} \text{Cost of Support} = & \text{Cash flow for Federal Support (due to existing/debt-related policies)} \\ & + \text{Cash flow for Tax Reductions (due to decrease in tax revenue compared to baseline)} \\ & + \text{Cash flow for State Level Support (the difference between the subsidized levelized cost of} \\ & \text{electricity for renewable Energy and the baseline fossil fuel)} \end{aligned}$$

To measure and compare the cost of support, we used the **total cost of support** as our key metric, which indicates the net present value<sup>22</sup> of all the government cash flows over the project life for projects commissioned during 2015 to 2022.<sup>23</sup> We used the government discount rate to discount the nominal cost of support: 7.8% (for existing policies), to reflect the government's cost of borrowing; and 10% (for debt-related policies), to also reflect the project risk premium.

While the total cost of support includes the effect of future cash flows over a project's life from the provision of a subsidy, the nominal cost of support only measures the net cash outflow for the government at a particular point of time, ignoring any future costs or recoveries for the government. Therefore, the total cost of support provides a complete, long-term measure of cost to the government. The nominal cost of support, however, is instructive from a budgetary perspective in showing government cash flow profiles for each year. However, it does not facilitate fair comparison of the cost-effectiveness of policies since it does not take into account all the costs over a project's life cycle costs, which is the focus of the total cost of support.

### 3. Results and discussion

We describe our results for the average case below. We discuss the results for other scenarios (i.e., best case, worst case, and domestic coal) in Section 3.4. In the best case, we expect minimum (or zero) cost of policy support, whereas in the worst case the cost of

policy support would be the highest. Domestic coal is an additional case where we compare the average unsubsidized levelized cost of renewable power with the levelized cost of domestic coal based power as the baseline.

#### 3.1. Drivers of levelized cost of electricity

##### 3.1.1. Wind

Our forecasts for capital expenditure for wind power from 2015 to 2022 indicate that it will increase by about 4% each year,<sup>24</sup> as depicted in Fig. 2.<sup>25</sup> The capital cost is expected to rise from INR 67.89 million/MW (USD 1.13 million/MW) in 2015 to INR 89.4 million/MW (USD 1.49 million/MW) in 2022.<sup>26</sup> The primary reason for this is the effect of inflation on component costs. We observe that there will also be a significant reduction in capital expenditure due to a strong learning effect, which is an increase in efficiencies over time as experience with a technology grows. However, the effect of inflation on component costs is much stronger, and out-

weighs the cost reduction from learning.

At present, most of India's wind deployment is at a hub height of 80 m, with an average capacity utilization of 25%. However, hub heights are steadily rising with turbines of 100 m becoming increasingly common [38]. Due to this, we expect that capacity utilization will rise gradually over the coming years. By 2022, we expect that most of the new wind plants will have a hub height of 120 m, with an average capacity utilization of 29%. At a hub height of 120 m, India's wind potential is estimated at ~100 GW with capacity utilization of 29% and above. Since our additional deployment by 2022 for wind is approximately 27 GW, much lower than the estimated potential, we assume an increase in average capacity utilization from 25% in 2014 to 29% due to increasing hub height up to 2022 [38].

Overall, we forecast an increase in the levelized cost of wind energy over time. The increase in capital expenditure will raise the levelized cost from wind energy, while an increase in capacity utilization factor will lead to a reduction in levelized cost indicating that the increase in capital expenditure outweighs any cost reduction from increased capacity utilization.

##### 3.1.2. Solar

We find that capital expenditure for solar power, or the cost of setting up a solar plant, will decrease by approximately 1.83% each year (Fig. 3).<sup>27</sup> The capital cost is expected to decrease from INR 71.25 million/MW (USD 1.19 million/MW) in 2015 to INR 62.6 million/MW (USD 1.04 million/MW) in 2022. This decrease is due to

<sup>21</sup> The cost of support is calculated as the sum of federal support, state support and tax reductions.

<sup>22</sup> Net present value is a key financial parameter used to allow comparison of cash flows in different years, by discounting future cash flows to convert them to today's values.

<sup>23</sup> We show the total cost of support in absolute terms i.e. INR billion as well as in INR/W terms. INR/W is the ratio of absolute value of the total cost of support to total renewable capacity deployed from 2015 to 2022.

<sup>24</sup> 4% is the compound annual growth rate (CAGR).

<sup>25</sup> We developed forecasts of capital expenditure for wind power from 2015 to 2022 using four approaches: a) regression analysis; b) trend analysis; c) primary research; and d) literature review.

<sup>26</sup> We assumed an exchange rate of INR/USD = 60.

<sup>27</sup> We developed forecasts of capital expenditure for solar power from 2015 to 2022 using four approaches: a) regression analysis; b) trend analysis; c) primary research; and d) literature review.

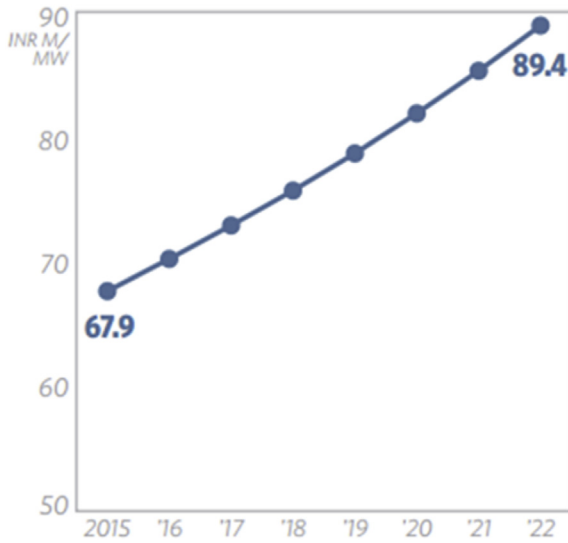


Fig. 2. Capital expenditure forecast for wind energy.

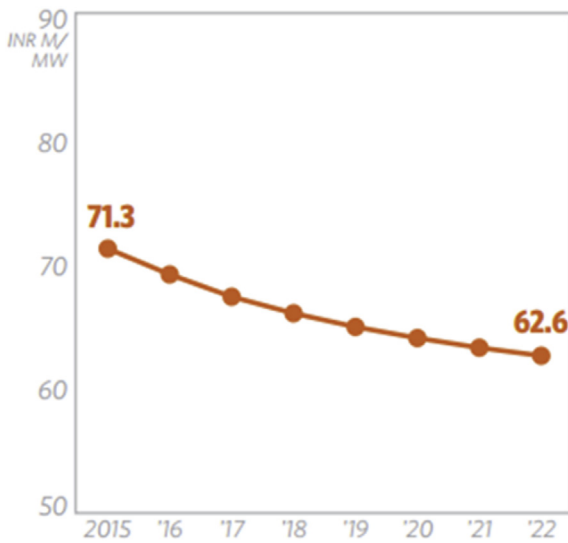


Fig. 3. Capital expenditure forecast for solar energy.

strong global learning effects (increased efficiencies due to experience gained over time), which push down the price of solar panels. We also observe local-level learning effects, which are not as strong, that marginally reduce non-panel costs over time.

The data shows that existing capacity utilization levels are sustainable for the proposed targets due to abundant resource availability. Therefore, we assume that the current level of capacity utilization of 20.5% will continue up to 2022 [9]. Any increase in capacity utilization would be based on a technology shift, such as the use of trackers or the use of different materials in the panel, which we do not model.

We forecast that the levelized cost of solar energy will decrease over time. Since our forecasts for capacity utilization are constant, the levelized cost of solar energy is driven downward by decreasing

<sup>28</sup> An increase in solar capacity utilization factors would be driven by an improvement in system-level technology, such as use of sunlight tracking devices, which we do not model in this paper.

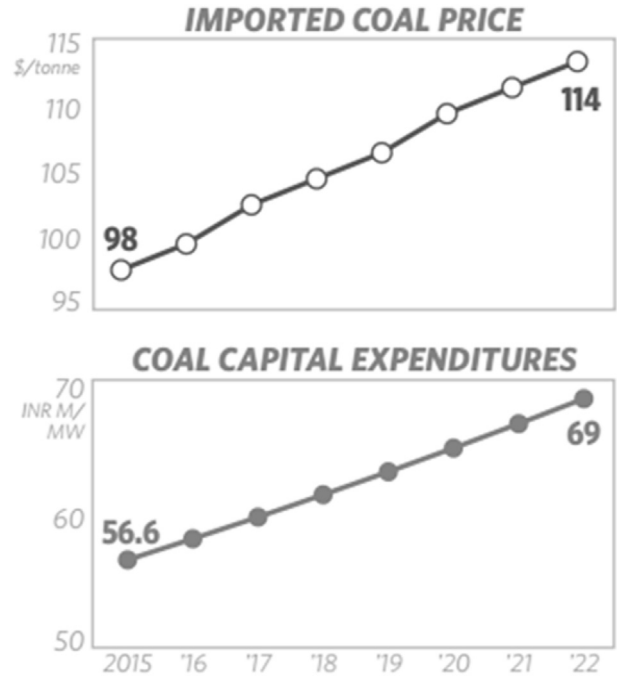


Fig. 4. Capital expenditure and fuel cost forecasts for coal energy.

capital expenditure.<sup>28</sup>

### 3.1.3. Fossil fuel

Capital expenditure and coal price are the main variables that drive the levelized cost of electricity for imported coal, so we use those to calculate the levelized cost of electricity from an imported coal-based plant.

Our forecast of capital expenditure for a coal plant shows a steady increase over time (Fig. 4).<sup>29</sup> Capital expenditure rises by about 2.86% per year from INR 56.6 million (USD 0.9 million) in 2015 to INR 68.9 million (USD 1.15 million) in 2022.

Forecasts for the second driver, fuel price, indicate an increase of 2.12% each year, from USD 98 per ton in 2015 to USD 114 per ton in 2022 (Fig. 4).<sup>30</sup> These imported coal prices are driven by global demand and supply.

Therefore, overall, we forecast that the levelized cost of electricity from imported coal increases over time, due to increasing capital expenditure and fuel prices. However, the rate of increase in fuel prices is significantly lower than the increase in capital expenditure, causing levelized costs to rise gradually over time.

## 3.2. Levelized cost of electricity

Our analysis shows that compared to the baseline of imported coal-based power, which has an unsubsidized levelized cost of INR 6.92/kWh (USD 0.12/kWh) in 2015, wind energy is already competitive (Fig. 5) at an unsubsidized levelized cost of INR 5.94/kWh (USD 0.1/kWh). In spite of the increase in the wind capacity utilization factor, which would decrease the levelized cost of electricity from wind power, we observe an increasing trend in wind levelized costs. The primary reason for this is the increase in capital

<sup>29</sup> Coal capital expenditure forecasts are based on a regression model with inflation as the independent variable.

<sup>30</sup> For fuel cost estimates, we use an average of two coal price forecast series: CPI's New Climate Economy forecasts and forecasts from the Institute for Energy, Economics and Financial Analysis.

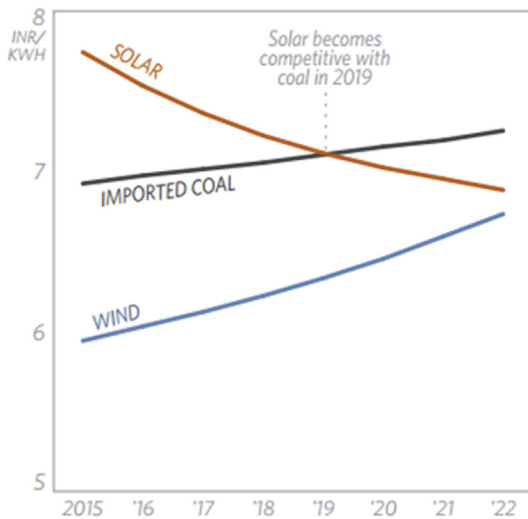


Fig. 5. Forecast of levelized cost of electricity.

cost, which outweighs the cost reduction from increased capacity utilization.

The levelized cost of imported coal-based power, which serves as our baseline for comparison, is also expected to increase due to an increase in capital expenditure forecasts, as well as rising fuel costs, measured by imported coal prices.

Overall, the gap between the unsubsidized levelized cost of wind power and imported coal-based power is expected to decrease from 14% in 2015 to 7% in 2022. This is primarily because inflation is expected to have a stronger impact on capital expenditure than fuel prices. In the case of wind power, all levelized cost increases are driven by capital expenditure. In the case of coal-based power, since capital expenditure only accounts for a part of the change in the levelized cost, and the increase in fuel price is much more gradual, the overall increase in the levelized cost is not as rapid. Finally, even though the gap between the costs will grow smaller, wind power will continue to be competitive with imported coal.

Unlike wind energy, solar energy continues to be more expensive than imported coal-based power (Fig. 5). The unsubsidized levelized cost of solar energy is INR 7.74/kWh (USD 0.13/kWh) in 2015, about 11.79% more expensive compared to imported coal. The levelized cost of electricity for solar power declines gradually, driven by the expected reduction in capital expenditure, and becomes competitive with imported coal-based power in 2019. By 2022, solar energy is expected to become around 5% cheaper than imported coal-based power. Despite the narrowing gap, solar energy still remains more expensive than wind energy up to 2022 (Fig. 5).

### 3.3. Cost of support

#### 3.3.1. Total cost of support

By comparing the unsubsidized levelized costs of electricity from wind power and solar power to the levelized cost of electricity from imported coal, which we use as our baseline, we can then estimate the cost of government support required to meet its renewable energy targets. As discussed above, wind energy is already competitive, whereas solar energy will require policy support from 2015 to 2019 in order to be competitive with imported coal-based power.

In India, policy support is provided through a combination of state and federal support. Our previous work [47] found that, in

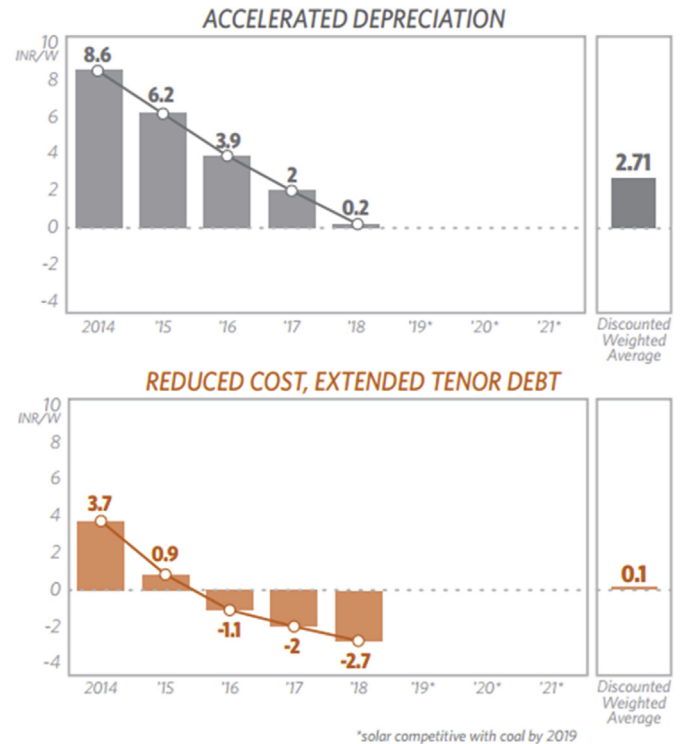


Fig. 6. Annual cost of support (INR/W).

general, any combination of federal and state support is more cost-effective than 100% state support; state support is usually in the form of feed-in tariffs.<sup>31</sup> Among existing federal policies, we give special attention to accelerated depreciation,<sup>32</sup> which is the most cost-effective of current policies. Among the proposed debt-related policies, we present all results with respect to a combination of reduced cost, extended tenor debt, which is the most cost-effective federal policy.

Under the existing policy of accelerated depreciation, which allows the developer to write off the asset value of a renewable energy project in its initial years, the **annual cost of support**, defined as the net present value of the cost of support for capacity deployed only in a particular year, declines from INR 8.6/W (USD 0.14/W) in 2014 to INR 0.23/W (USD 0.004/W) in 2018 (Fig. 6).<sup>33</sup> The corresponding total cost of support, which is the average cost of support over the full project life for plants installed during 2015–18, for solar energy is INR 2.71/W (USD 0.05/W), about 3.8% of the capital cost

<sup>31</sup> In our previous work (CPI, 2014), we found that 100% support by state-level feed-in tariffs is the least cost-effective policy. We also found that the total cost of support decreases as federal policies cover more of the (viability) gap between the unsubsidized levelized cost of renewable energy and the fossil fuel baseline. Thus, the most cost-effective approach is to meet the entire support requirement through federal policies. Feed-in tariffs may be used in addition to federal support in cases where the difference in levelized cost of renewables and the baseline cost is very high.

<sup>32</sup> Accelerated depreciation is a policy which allows the developer to write off the asset value of a renewable energy project in its initial years, thereby reducing tax liability. However, after the value of the asset has completely depreciated, taxes are higher in later years, which would lead to partial government recovery of the cost of support. The government currently provides accelerated depreciation of up to 80% for both wind and solar projects.

<sup>33</sup> Net present value for each year is calculated as of one period prior to the first cash flow. Therefore, for projects starting in 2015, the net present value is calculated for 2014.



of solar energy in 2015 (Fig. 6).<sup>34</sup> Based on the 12th Five Year Plan deployment targets of 20 GW of solar and 50 GW of wind by 2022, the total cost of support is INR 46.97 billion (USD 0.78 billion).

Accelerated depreciation is the most cost-effective policy among the existing federal policies. If the government were to provide policy support through viability gap funding (i.e., capital grant) instead, the total cost of support would be 19% higher.<sup>35</sup> In the case of generation based incentive, the total cost of support would be 61% higher compared to accelerated depreciation.<sup>36</sup>

This is primarily because accelerated depreciation is front-loaded, or in other words, the downward impact on subsidized levelized cost of electricity is higher since the entire benefit of the policy is available to the project developer from the first year, unlike other policies which may spread out the benefits over a longer period of time. Front loading is effective since the government cost of capital is lower than the weighted average cost of capital for the project itself. Accelerated depreciation also enables the government to recover subsidies, since some of the tax loss is recovered through higher taxes in later years, after the value of the asset is written off completely.<sup>37</sup>

However, our previous work shows that it is possible to further lower the total cost of support by using policies that address a key barrier for renewable energy projects -the cost of debt. Inferior terms of debt such as high cost, short tenor, and a variable interest rate add approximately 30% to the total cost of renewable energy in India compared to developed countries [46]. Therefore, debt-related policies that address these challenges can significantly reduce the total cost of support [47].

Under a policy of reduced cost, extended tenor debt, the government would make direct loans to project developers below the commercial rate of interest for longer than the usual commercial tenor. *If the government provides policy support through reduced cost, extended tenor debt instead of the existing federal policies, the total cost of support for solar energy can be reduced to an average of INR 0.10/W (USD 0.002/W).* Under reduced cost, extended tenor debt, the annual cost of support varies from INR 3.75/W (USD 0.06/W) in 2014 to a recovery (i.e., a profit) of INR 2.73/W (USD 0.05/W) by 2018 on account of loan repayments (Fig. 6). Based on the 12th Five Year Plan deployment targets of 20 GW of solar and 50 GW of wind by 2022, the total cost of support would be INR 1.81 billion (USD 0.03 billion) under reduced cost extended tenor debt, around 96% lower than under accelerated depreciation.

This is because as a policy mechanism, reduced cost, extended tenor debt offers a number of advantages. The net cash outflow for the government is recovered over time since policy support is provided in the form of a loan rather than a grant. It also provides an opportunity for interest arbitrage: in cases where the government lends at a higher rate of interest to the developer than its own cost of borrowing (7.8% on a 10-year government bond), the net cash flows for the government are positive. Lastly, when debt is cheaper, the developer can substitute equity with more debt in the project while meeting debt servicing conditions. By replacing expensive equity with cheaper debt, the overall cost of capital is reduced.

To summarize, since wind energy is already competitive, the government's targets for deploying wind energy can be met

quickly. The government can encourage rapid deployment of wind energy by creating a friendly policy environment that focuses on other barriers to wind deployment, for example, challenges in land acquisition and delays in environmental clearances. By 2022, we anticipate that solar energy will be cheaper than other sources of electricity. However, at present, solar energy is competitive only in the presence of policy support. Thus, in the absence of direct policy support, it is likely that a larger proportion of solar capacity will be commissioned after 2019, when solar energy becomes competitive.

A schedule of solar capacity addition in which a larger part of the capacity addition takes place after 2019 is tenable for the 12th Five Year Plan targets, and would also minimize the total cost of support for the government. However, the Budget 2015 targets of 100 GW of solar capacity by 2022 may be difficult to achieve if much of the capacity deployment is delayed to 2019. In order to accelerate solar deployment in the near term, the government will need to provide more financial support to solar project developers. The implication of changes in the capacity addition schedule on capital costs should also be considered.

### 3.3.2. Nominal cost of support

While reduced cost, extended tenor debt is much more cost-effective than accelerated depreciation over a project's life cycle, it would require a higher allocation of the budget in the initial years (Fig. 7).

While the net present value or the total cost of support for reduced cost, extended-tenor debt is significantly lower due to recovery of the subsidy amount invested by the government through loan repayments, the annual budget allocation, or nominal cost of support, for reduced cost, extended-tenor debt is much higher in the initial years, since the government needs to provide approximately 70% of the total project cost in the form of debt.

For example, in 2015, based on the 12th Five Year Plan deployment targets of 20 GW of solar and 50 GW of wind by 2022, the total budget allocation for reduced cost, extended-tenor debt would be INR 123.79 billion (USD 2.06 billion). In contrast, the nominal cost of support in 2015 under accelerated depreciation is INR 31.2 billion (USD 0.52 billion).

However, after 2019, once solar power becomes competitive, there would be a net cash inflow for the government thereafter, since solar power would no longer require additional support, and the policy support provided in the form of debt would be repaid by the project developers. As shown in Fig. 7, the subsidy recovery is approximately 25 times higher under reduced cost, extended tenor debt as compared to accelerated depreciation.

Therefore, although the government will need to make a budgetary commitment that is four times that of accelerated depreciation in the short term, the net cash outflow in the long term will be 96% lower with reduced cost, extended-tenor debt. In other words, in net present value terms, the total cost of support under accelerated depreciation is about 25 times higher than that of reduced cost, extended-tenor debt.

### 3.4. Sensitivity analysis: results for other scenarios

We now discuss the results for other scenarios: worst case, best case and the domestic coal case, and how the cost of support could differ from the average case.

In the best case (Fig. 8), we find that wind and solar power are expected to be cheaper than imported coal-based power. Therefore, both renewable technologies are already cheaper than imported coal based power in 2015, and do not require any policy support from the government.

In 2014, the unsubsidized levelized cost of wind is INR 5.87/kWh (USD 0.097/kWh) and is expected to slowly decline to INR 5.55/

<sup>34</sup> Since solar energy becomes competitive in 2019, the cost of support is calculated for plants installed prior to 2019.

<sup>35</sup> Viability gap funding (VGF) is a capital grant from the government to enable a project developer to supply renewable power at a pre-determined tariff.

<sup>36</sup> Generation based incentive (GBI) is a direct subsidy that is paid over and above the tariff for each kWh of power that the developer supplies to the grid.

<sup>37</sup> A detailed discussion of the relative cost-effectiveness of different policies is available in CPI (2014).

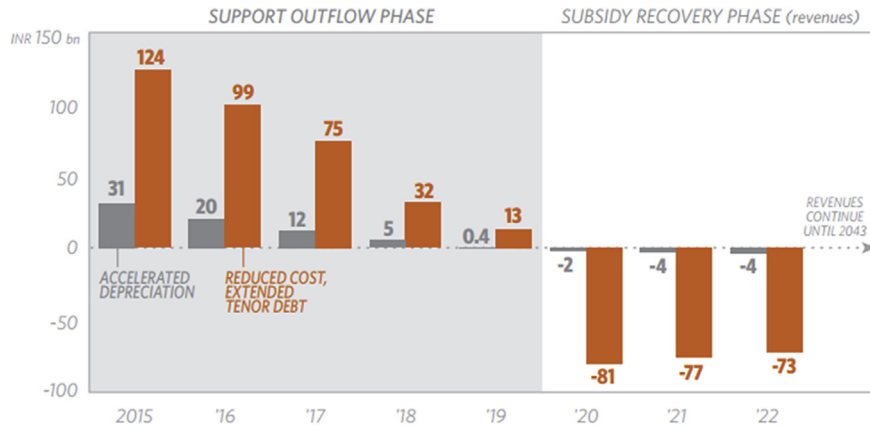


Fig. 7. Nominal cost of support for solar energy.

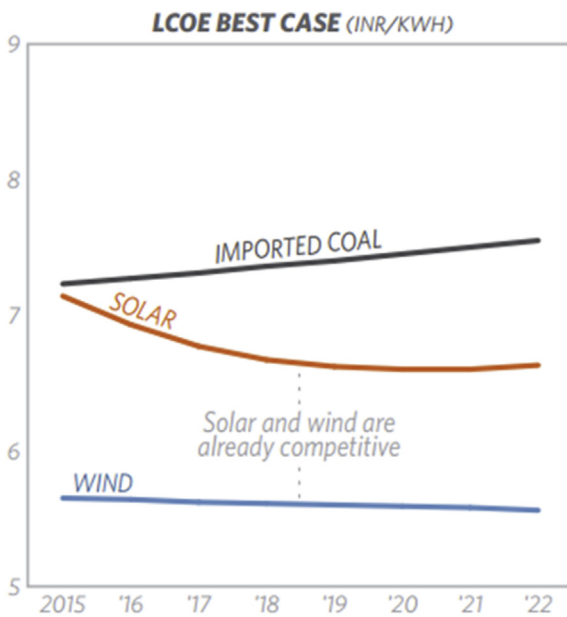


Fig. 8. Forecast of levelized cost of electricity – best case.

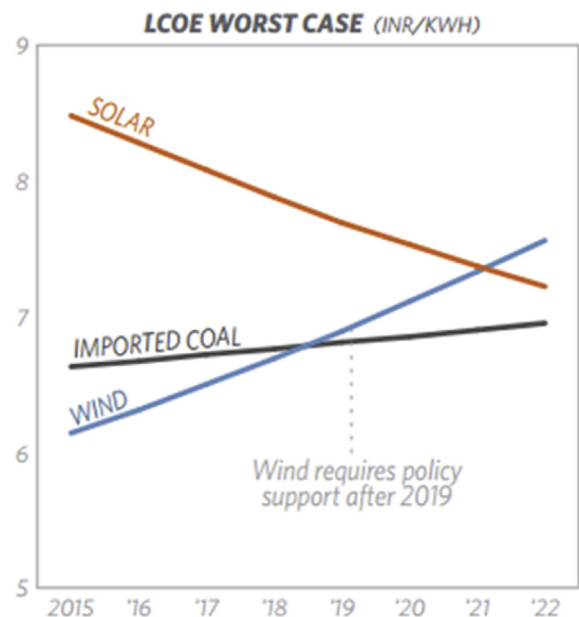


Fig. 9. Forecast of levelized cost of electricity – worst case.

kWh (USD 0.093/kWh) by 2022, primarily due to the increase in capacity utilization factor, which outweighs the effect of higher capital expenditure. The wind unsubsidized levelized cost is currently 14% cheaper than the levelized cost of imported coal, and is expected to become 26% cheaper by 2022.

In the case of solar, the forecasted unsubsidized levelized cost for 2014 is INR 7.13/kWh (USD 0.12/kWh), and is expected to steadily decline to INR 6.62/kWh (USD 0.11/kWh) by 2022 driven by declining capital expenditure. The levelized cost of imported coal is expected to increase from INR 7.22/kWh (USD 0.12/kWh) in 2015 to INR 7.54/kWh (USD 0.13/kWh) in 2022 on account of inflation and rising fuel prices. The unsubsidized levelized cost of solar power is expected to be 1.3% cheaper than that of the imported coal based power in 2015.

In the worst case (Fig. 9), the levelized cost of imported coal rises at a very gradual rate from INR 6.81/kWh (USD 0.11/USD) in 2014 to INR 6.95/kWh (USD 0.12/kWh) in 2022. On the other hand, wind unsubsidized levelized costs rise rapidly from INR 5.87/kWh (USD 0.10/kWh) in 2014 to INR 7.56/kWh (0.13/kWh) in 2022. The unsubsidized levelized cost of wind is expected to be 14% lower than imported coal in 2014 but will become 9% more expensive by 2022.

In this case, wind projects will begin to require policy support from 2019 since the effect of inflation on wind is more pronounced.

For solar, the decline in prices is much more gradual relative to the average case, starting at INR 7.53/kWh (USD 0.13/kWh) in 2014 and falling to INR 7.22/kWh (USD 0.12/kWh) in 2022. The unsubsidized levelized cost of solar is 10% higher than imported coal, but this gap would reduce to 4% by 2022. Hence, solar energy will continue to require policy support until 2022 in order to compete with fossil fuel-based power.

In our additional scenario with domestic coal as the baseline cost of fossil fuel-based power, we find that domestic coal prices are considerably lower than wind, solar and imported coal (Fig. 10). The levelized cost of domestic coal-based power is at INR 5.35/kWh (USD 0.09/kWh) in 2014. The price increases over time to INR 5.79/kWh (USD 0.097/kWh) in 2022, but remains cheaper than all the other technologies. The levelized cost of domestic coal based electricity is 41% and 9.7% cheaper than the unsubsidized levelized cost of solar and wind based power, respectively. As shown in Fig. 10, this gap will decrease to 19% in the case of solar power and increase to 16% in case of wind power.

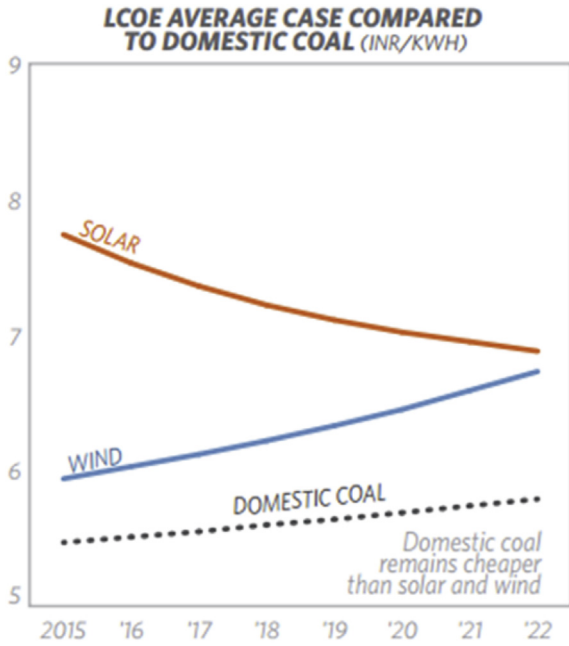


Fig. 10. Forecast of levelized cost of electricity – domestic coal case.

Based on the levelized cost estimates discussed above, we estimate the total cost of support in each of the four scenarios. The cost of support is zero in the best case since both wind and solar are already competitive with imported coal based power. However, in the worst case, the cost of support is over four times higher for solar, while wind begins to require policy support.

In the domestic coal case, the cost of support for solar is over seven times higher compared to the support required in the average case with imported coal. Fig. 11 summarizes these results with respect to two policies – accelerated depreciation, the most cost-effective among the existing policies, and reduced cost, extended-tenor debt, the most cost-effective of all policies examined in this paper.

4. Conclusions

We examine how much it would cost the Government of India to meet its renewable energy targets. By comparing the

unsubsidized levelized cost of electricity from wind and solar energy to a baseline of the levelized cost from imported coal-based power, we provide a fair basis upon which the government can plan and allocate its budget to meet its renewable energy targets. We also examine the cost of government support under different policy mechanisms to determine which is most cost-effective, and we examine the implications of different deployment pathways.

Imported coal-based power is playing an increasingly prominent role in India’s energy portfolio, accounting for about 18% of total electricity production, a proportion that is steadily rising. India targets 15% of power generation from renewable energy sources by 2020 (NAPCC, 2008), which will replace the most expensive fossil fuel. Since imported coal-based power is more expensive than domestic coal, and the share of natural gas is unlikely to grow due to supply constraints, it is likely that renewable energy will replace additional imported coal build.

Compared to imported coal-based power, wind energy is already cheaper, and is expected to remain so up to 2022. Therefore, it would be cheaper to meet additional energy requirements through wind energy rather than imported coal. The unsubsidized levelized cost for solar energy is expected to decline steadily and become cheaper than imported coal by 2019. Due to its continuing decrease in cost, we expect that solar energy will be the most viable source of renewable energy within the next ten years.

Wind energy does not require government support, since it is already competitive. Under the current federal policy of accelerated depreciation, the most cost-effective among existing policies, the total cost of support for solar energy is about 3.8% of its current capital costs, which is INR 2.71/W (USD 0.05/W) under accelerated depreciation. The annual cost of support varies with the unsubsidized levelized cost of solar and imported coal-based power, declining from INR 8.6/W (USD 0.14/W) in 2014 to INR 0.23/W (USD 0.004/W) in 2018. As discussed in Section 3.3.1, accelerated depreciation is the most cost-effective due to not only front-loading but also cost-recovery of taxes in later years.

A combination of reduced cost, extended-tenor debt is a more cost-effective policy option than the current policy of accelerated depreciation. Compared to accelerated depreciation, the total cost of support can be lowered by 96% by using reduced cost, extended-tenor debt. As discussed in Section 3.3.1, reduced cost, extended-tenor debt is the most cost-effective federal policy due to front-loading, cost-recovery, interest arbitrage, and increased leverage. However, as discussed in Section 3.3.2, this will require a larger allocation of the government budget for debt in initial years, which

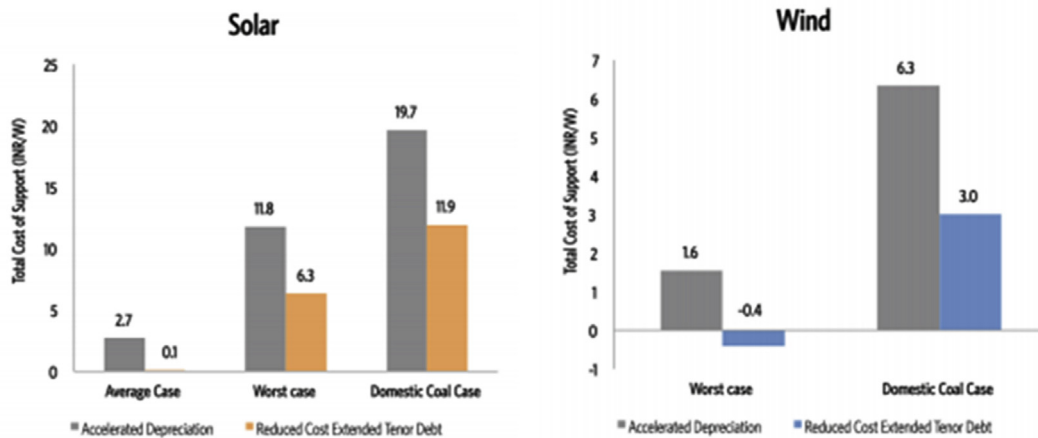


Fig. 11. Total cost of support for renewable energy under accelerated depreciation and reduced cost extended tenor debt.

will be recovered in later years.

Since wind energy is already competitive with imported coal-based power, it can be deployed very quickly without any policy support. In the case of solar energy, policy support would be more cost-effective if a larger proportion of the deployment targets were met after 2019, when solar energy will be competitive. In order to accelerate solar deployment sooner, the government would need to provide some policy support.

We believe that our work has implications beyond India; in particular, towards other developing countries. Our methodological contributions are as follows: (a) multifactor regression analysis to forecast the capital cost of solar and wind technologies; (b) optimized-leverage, project-level cash flow model to calculate the levelized cost of electricity; and (c) different metrics to calculate the government cost of support. These can be applied to any geography to calculate the government cost of support for corresponding renewable targets, and to select cost-effective policies.

Our analysis can be improved in future on many fronts. First, all risks associated with the renewable energy as well as coal based projects may need to be factored into corresponding returns of equity. Second, forecasting of capital costs may need to be further improved by incorporating more data as well as more explanatory variables (e.g., inflation). Third, the accuracy of analysis may be further improved by examining a representative sample of renewable energy technologies as well as projects. Future work may also focus on developing analytical frameworks to compare renewable energy and fossil fuels in other ways, including total cost to society (including carbon, resource, integration, etc.), cost of capital (due to different risk profiles), and energy security.

## Appendix

### Policies

In this section, we briefly discuss the existing state and federal policies for renewable energy in India. We also discuss a new class of proposed debt-related federal policies.

#### State-level policy

State level policy support is typically provided through feed-in-tariffs. A feed-in-tariff is a long-term power purchase agreement of 20–25 years. Under this agreement, the tariff is based on the cost of power production and is higher than the average pooled purchase cost.<sup>38</sup>

#### Existing federal policies<sup>39</sup>

In addition to the state-level policies, renewable energy also receives federal level policy support. A renewable energy project can avail any one of these federal policies at a time. However, for the purpose of comparison, we calculate the cost of support under all these policies for both technologies – wind and solar.

<sup>38</sup> Average pooled purchase cost (APPC) is the weighted average pooled price at which the power distribution companies purchased electricity in the previous year from all energy suppliers, except renewable energy sources.

<sup>39</sup> In addition to these federal policies, projects engaged in the generation (or distribution) of renewable power are eligible for a 10-year tax holiday. Although plants have to pay a minimum alternate tax (MAT) of ~21%, it can be offset in future years.

<sup>40</sup> Accelerated depreciation was withdrawn for wind in April, 2012 which led to fall in the investment and the deployment of wind projects but has been reinstated in 2014 again [7].

*Accelerated depreciation.* Accelerated depreciation<sup>40</sup> allows the developer to write off the asset value in the initial years of the project, thereby reducing the tax liability. However, after the value of the asset has completely depreciated, taxes are higher in later years, which would lead to partial recovery of the cost of support. The government currently provides accelerated depreciation of up to 80% for both wind and solar projects. This policy is similar to the investment tax credit (ITC) in the US which is a dollar-for-dollar reduction in the income taxes for qualified tax-paying owners based on capital investment in renewable energy projects.

*Generation based incentive.* Generation based incentive (GBI) is a direct subsidy that is paid over and above the tariff for each kWh of power that the developer supplies to the grid. The support can be availed at INR 0.50/kWh (USD 0.008/kWh) for a minimum of 4 years and a maximum of 10 years with a cap of INR 6.2 million/MW (USD 0.10 million/MW). The objective is to incentivize higher power production. The scheme is available for both wind and solar in parallel to accelerated depreciation, but on a mutually exclusive basis. While there is no minimum capacity fixed under the scheme for wind projects, solar projects in the range of 100 kW to 2 MW can avail this scheme [39]. The GBI policy is similar to the production tax credit (PTC) federal incentive in the US which provides a 2.3 cent/kWh incentive for first ten years of renewable energy facility's operations. PTC reduces the federal income tax liability on the qualified tax-paying owners of the renewable energy projects based on the electricity generation output (measured in kWh) of grid-connected renewable energy project.

*Viability gap funding.* Viability gap funding is a capital grant from the government to enable a project developer to supply renewable power at a pre-determined tariff. It was introduced for solar projects under Phase 2, Batch 1 of the National Solar Mission. The government provided a capital subsidy in installments with an upper limit of 30% of the project cost or INR 25 million per MW (USD 0.42 million per MW) [41]. This policy is similar to the KfW renewable energies capital grant programme which is a multi-sectoral policy applicable for small and large power plants in Germany.

#### Proposed debt-related policies

In our previous work [46], we found that the greatest barrier to renewable energy in India is the inferior terms of debt – i.e., high interest cost, short tenor, and variable rate. We found that the terms of debt raise the cost of renewable energy in India by ~30% compared to similar projects in the US. Hence, in addition to existing policies, we also consider four promising debt-related policies: interest subsidy, reduced cost debt, extended-tenor debt, and a combination of reduced cost, extended-tenor debt [47].

*Interest rate subsidy.* Under this policy, the federal government would service a part of the interest obligation of a project, by directly making a partial interest payment to the bank for a commercial loan. This would help reduce the effective rate of interest. Although no such policy currently exists for renewable power generation, the Ministry of Power provided an interest rate subsidy of 3% for 14 years under the National Electricity Fund to public and private power distribution utilities in order to improve their financial health. The government now plans to provide an interest subsidy for renewable projects using KfW's grant of EUR 1 billion to IREDA [6].

*Reduced cost debt.* The federal government would directly lend below the commercial rate of interest to renewable projects, either using funds earmarked for the purpose, or by raising money from



bond markets and on-lending the proceeds. For example, the Brazilian Development Bank's (BNDES) provides low-cost loans for renewable energy projects [20].

*Extended-tenor debt.* The federal government would directly lend to project developers at the commercial rate of interest, but for a longer than commercial tenor. It has been identified as one of the policies desired under the proposed National Wind Mission [30].

*Reduced cost, extended-tenor debt.* The government would make direct loans to project developers below the commercial rate of interest for longer than commercial tenor. For example, under the IREDA-NCEF refinance scheme, the debt of renewable projects can be taken out using concessional finance from IREDA, thereby reducing the effective rate of interest and increasing the tenor of debt.

#### Literature review

We first provide a high-level overview of literature on the effectiveness, especially cost-effectiveness, of renewable policies [25]; Neuhoﬀ et al., 2011 [16,17,27,48]. We then examine studies that are closest to our analysis, given their focus on project-level financial modeling of renewable projects (Wiser, 1997 [49,55] Mendelsohn et al., 2012; Mendelsohn and Feldman, 2013 [56]; BPC, 2011 Bolinger, 2014 [37]; USPREF, 2012; [46,47]. For a broader review of literature that examines the impact of policy on financing of renewable energy, we refer the reader to [46].

[25] [36]; and [17] provide general guidance on policy effectiveness [25]. studied renewable energy policies in Denmark, Germany and the United Kingdom, and found that policy design and commitment are key factors achieving to policy effectiveness [36]. argued that simple schemes and clear compliance mechanisms are necessary for achieving desired policy impact [17]. asserted that declining incentives bring down prices in the long-term and, therefore, necessary for cost-effective policy implementation in the long-term.

[48] [27]; and [16] examined cost-effectiveness of popular policies, such as feed-in tariffs, renewable obligations, and competitive bidding [48]. examined feed-in tariffs in Germany and Renewable Obligation in the U.K. and asserted that the former are more cost-effective [27]; argued that feed-in tariffs are dynamically more cost-effective than competitive bidding; however [16]; argued for the contrary regarding cost-effectiveness of feed-in tariffs.

Wiser (1997) and [49] showed that the costs of renewable energy is sensitive to financing terms [55]. examined the impact of policy pathways on financing costs in the U.S. and found that the duration of revenue support had the largest impact (11–15%) followed by revenue certainty (4–11%) Mendelsohn et al. (2012). examined the impact of U.S. federal policies and demonstrated that loan guarantees and treasury grants can reduce cost of renewable energy by approximately 20%.

In continuation to Mendelsohn et al. (2012) Mendelsohn and Feldman (2013), examined the impact of asset-backed securities, master limited partnerships, and real estate investment trusts, and showed that these instruments can reduce cost of renewable energy by 8%–16% [56]. studied federal incentives in USA and found that a taxable cash grant half the size of the current investment tax credit would be equivalent (BPC, 2011; Bolinger, 2014 [37]; USPREF (2012) examined the impact of the investment tax credit and found that it can deliver a 10% rate of return for the government.

However, these studies are based on developed economies, such as the U.S. and the EU. Further, the focus is on financial incentive policies without much “direct” focus on cost of capital, which happens to be a significant issue in developing countries [34,46,47];

in contrast, focus on financing issues in India.

Shrimali et al.(2013) [46] was the first study to examine impact of policy pathways on renewable financing in India, and found that inferior terms of debt add approx. 30% to the cost of renewable energy in India [47]. extended this result to compare debt-related federal policies (i.e., low-cost, long-term debt) to existing policies and found that the former can be 78% more (statically) cost-effective.

This paper further extends [47] to not only forecast cost of renewable energy until 2022 but also compare policy options in a dynamic fashion.

#### References

- [1] N. Abhyankar, P. Amol, S. Jayant, B. Ranjit, J. Alissa, M. Cathie, L. Bob, R. Ajith, Modeling Clean and Secure Energy Scenarios for the Indian Power Sector in 2030, Lawrence Berkeley National Lab report, 2013, <http://eetd.lbl.gov/sites/all/files/lbnl-6296e.pdf.pdf>.
- [2] Armstrong, Combining Forecasts. University of Pennsylvania Working Paper, 2001. [http://repository.upenn.edu/cgi/viewcontent.cgi?article=1005&context=marketing\\_papers](http://repository.upenn.edu/cgi/viewcontent.cgi?article=1005&context=marketing_papers).
- [3] D. Berry, Innovation and the Price of Wind Energy in the US, *Energy Policy* 37 (11) (2009) 4493–4499.
- [4] D. Belsley, Collinearity and forecasting, *J. Forecast.* 3 (1984) 183–196.
- [5] K. Branker, M.J.M. Pathak, J.M. Pearce, A review of solar photovoltaic leveled cost of electricity, *Renew. Sustain. Energy Rev.* 15 (Issue 9) (2011) 4470–4482. <http://www.sciencedirect.com/science/article/pii/S1364032111003492>.
- [6] Bridge to India, India's 100 GW Solar Roadmap Feasible, 2014. <http://www.bridgeindia.com/blog/weekly-update-is-indias-100-gw-solar-road-map-feasible/>.
- [7] Business Standard, Accelerated Depreciation Scheme for Wind Energy Restored, 2014. [http://www.business-standard.com/article/news-ians/accelerated-depreciation-scheme-for-wind-energy-restored-114071800777\\_1.html](http://www.business-standard.com/article/news-ians/accelerated-depreciation-scheme-for-wind-energy-restored-114071800777_1.html).
- [8] R. Calantone, A. Benedetto, D. Bojanic, Multimethod forecasts for tourism analysis, *Ann. Tour. Res.* 15 (3) (1988) 387–406.
- [9] CERC, Performance of Solar Power Plants in India, 2011. <http://www.cercind.gov.in/2011/Whats-New/PERFORMANCE%20OF%20SOLAR%20POWER%20PLANTS.pdf>.
- [10] CERC, CERC Tariff Revision Order, May 2014, 2014. <http://cercind.gov.in/2014/orders/SO354.pdf>.
- [11] CRISIL, Rising Fuel Imports for Power Generation, 2012. <http://www.crisil.com/pdf/infra-advisory/4-rising-fuel-imports-power-generation.pdf>.
- [12] P. del Rio, E. Cerda, The policy implications of the different interpretations of the cost-effectiveness of renewable electricity support, *Energy Policy* 64 (2014) 364–372.
- [13] Economic Times, High Fiscal Deficit Exposing India to Shocks, 2014. [http://articles.economicstimes.indiatimes.com/2014-06-19/news/50710918\\_1\\_credit-outlook-high-fiscal-deficit-capita-income](http://articles.economicstimes.indiatimes.com/2014-06-19/news/50710918_1_credit-outlook-high-fiscal-deficit-capita-income).
- [14] Economic Times, Renewable Sector Upbeat on Budget 2015 Proposals, 2015. [http://articles.economicstimes.indiatimes.com/2015-02-28/news/59613084\\_1\\_energy-sector-welspun-energy-infrastructure-bonds](http://articles.economicstimes.indiatimes.com/2015-02-28/news/59613084_1_energy-sector-welspun-energy-infrastructure-bonds).
- [15] Ernst and Young, Natural Gas Pricing in India – Current Policy and Potential Impact, 2014. [http://www.ey.com/Publication/vwLUAssets/EY-natural-gas-pricing-in-India/\\$FILE/EY-natural-gas-pricing-in-India.pdf](http://www.ey.com/Publication/vwLUAssets/EY-natural-gas-pricing-in-India/$FILE/EY-natural-gas-pricing-in-India.pdf).
- [16] M. Fronzel, N. Ritter, C.M. Schmidt, C. Vance, Economic impacts from promotion of renewable energy technologies: the German experience, *Energy Policy* 38 (Issue 8) (2010) 4048–4056.
- [17] A. Hobbs, E. Benami, U. Varadarajan, B. Pierpont, Improving Solar Policy: Lessons from the Solar Leasing Boom in California, Climate Policy Initiative Report, 2013, <http://climatepolicyinitiative.org/wp-content/uploads/2013/07/Improving-Solar-Policy-Lessons-from-the-solar-leasing-boom-in-California.pdf>.
- [18] J. Huenteler, C. Niebuhr, T.S. Schmidt, The effect of local and global learning on the cost of renewable energy in developing countries, *J. Clean. Prod.* (2014). In Press, <http://www.sciencedirect.com/science/article/pii/S0959652614006441>.
- [19] IEA, Deploying Renewables – Best and Future Policy Practice, 2011. [https://www.iea.org/publications/freepublications/publication/Deploying\\_Renewables2011.pdf](https://www.iea.org/publications/freepublications/publication/Deploying_Renewables2011.pdf).
- [20] IEA, Renewable Energy: Medium-term Market Report. International Energy Agency, 2012. [http://www.iea.org/publications/freepublications/publication/MTrenew2012\\_web.pdf](http://www.iea.org/publications/freepublications/publication/MTrenew2012_web.pdf).
- [22] IESS, India Energy Security Scenarios, Planning Commission, Government of India, 2014. [www.indiaenergy.gov.in/](http://www.indiaenergy.gov.in/).
- [23] IRENA, Wind power, *Renew. Energy Technol. Cost. Anal. Ser.* 1 (Issue 5/5) (2012) 19. [https://www.irena.org/DocumentDownloads/Publications/RE\\_Technologies\\_Cost\\_Analysis-WIND\\_POWER.pdf](https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-WIND_POWER.pdf).
- [25] Judith Lipp, Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom, *Energy Policy* 35 (Issue 11) (2007) 5481–5495.

- [26] A. Malla, A. Niraula, Importance of balance of system in solar PV application, *Rentech Symp. Compend. 2* (2012). [http://www.ku.edu.np/renewablenepal/images/rentech2/rentech\\_vol\\_2\\_13\\_am.pdf](http://www.ku.edu.np/renewablenepal/images/rentech2/rentech_vol_2_13_am.pdf).
- [27] P. Menanteau, D. Finon, M. Lamy, Prices versus quantities: choosing policies for promoting the development of renewable energy, *Energy Policy* 31 (Issue 8) (2003, June) 799–812.
- [28] MNRE, Renewable Energy Certificate Mechanism for India. Ministry of New and Renewable Energy, Government of India, 2009. [http://mnre.gov.in/file-manager/UserFiles/MNRE\\_REC\\_Report.pdf](http://mnre.gov.in/file-manager/UserFiles/MNRE_REC_Report.pdf).
- [29] MNRE, Physical Progress (Achievements). Ministry of New and Renewable Energy, Government of India, Ministry of New and Renewable Energy, Government of India, 2014a. <http://mnre.gov.in/mission-and-vision-2/achievements/>.
- [30] MNRE, "National Wind Mission: Objectives and Scope". National Level Consultation on National Wind Energy Mission, Ministry of New and Renewable Energy, Government of India, 2014b. <http://mnre.gov.in/file-manager/UserFiles/Presentations-NWM-09012014/Alok-Srivastava-JS-MNRE.pdf>.
- [31] MOSPI, Energy Statistics. Ministry of Statistics and Programme Implementation, Government of India, 2014. [http://mospi.nic.in/mospi\\_new/upload/Energy\\_stats\\_2014.pdf](http://mospi.nic.in/mospi_new/upload/Energy_stats_2014.pdf).
- [33] L. Neij, Use of experience curves to analyse the prospects for diffusion and adoption of renewable energy, *Energy Policy* 25 (Issue 13) (1997) 1099–1107 (1997).
- [34] D. Nelson, G. Shrimali, Finance Mechanisms for Lowering the Cost of Renewable Energy in Developing Countries, Climate Policy Initiative report, 2014. <http://climatepolicyinitiative.org/publication/finance-mechanisms-for-lowering-the-cost-of-renewable-energy-in-rapidly-developing-countries/>.
- [35] G.F. Nemet, Beyond the learning curve: factors influencing cost reductions in photovoltaics, *Energy Policy* 34 (2006) 3218–3232 (2006).
- [36] K. Neuhoff, et al., Using Tax Incentives to Support Thermal Retrofits in Germany, Climate Policy Initiative Report, 2011, <http://climatepolicyinitiative.org/wp-content/uploads/2011/09/Using-Tax-Incentives-to-Support-Thermal-Retrofit-Summary.pdf>.
- [37] K. Palmer, D. Burtraw, Cost-effectiveness of renewable electricity policies", *Energy Econ.* 27 (Issue 6) (2005, November) 873–894.
- [38] A. Phadke, R. Bharvirkar, J. Khangura, Reassessing Wind Potential Estimates for India: Economic and Policy Implications, Lawrence Berkeley National Laboratory report, 2011, <https://isswprod.lbl.gov/library/view-docs/public/output/rpt81160.PDF>.
- [39] PIB, Generation Based Incentive Scheme, Press Information Bureau, Government of India, 2011. <http://www.pib.nic.in/newsite/erelease.aspx?relid=78829>.
- [40] PIB, Coal Block Auction Methodology Approved, Press Information Bureau, Government of India, 2013. <http://pib.nic.in/newsite/erelease.aspx?relid=99642>.
- [41] PIB, Jawaharlal Nehru National Solar Mission, Press Information Bureau, Government of India, 2014. <http://pib.nic.in/newsite/PrintRelease.aspx?relid=108233>.
- [42] U. Pillai, Drivers of cost reduction in solar photovoltaics, *Energy Econ.* 50 (2015) 286–293.
- [43] PMI, PM Council on Climate Change, PM of India website, 2010. [http://pmindia.gov.in/climate\\_change\\_english.pdf](http://pmindia.gov.in/climate_change_english.pdf).
- [44] X. Ouyang, B. Lin, Impacts of increasing renewable energy subsidies and phasing out fossil fuel subsidies in China, *Renew. Sustain. Energy Rev.* 37 (2014) 933–942.
- [45] Shakti Foundation, Contribution of Renewable Power towards Eliminating Shortages and Meeting Economic Growth Aspirations, 2013. <http://shaktifoundation.in/wp-content/uploads/2014/02/power%20security%20report-%20final%20-%20feb%202013.pdf>.
- [46] G. Shrimali, D. Nelson, C. Konda, S. Goel, R. Kumar, Renewable deployment in India: financing costs and implications for policy, *Energy Policy* 62 (2013) 28–43.
- [47] G. Shrimali, C. Konda, S. Goel, S. Srinivasan, D. Nelson, Meeting India's Renewable Energy Financing Challenge: Which Federal Policies Can Be Most Effective?, Climate Policy Initiative report, 2014, <http://climatepolicyinitiative.org/wp-content/uploads/2014/03/Which-Federal-Policies-can-be-Most-Effective-Full-Study.pdf>.
- [48] D. Toke, Renewable financial support systems and cost-effectiveness, *J. Clean. Prod.* 15 (Issue 3) (2007) 280–287.
- [49] R. Wiser, S. Pickle, Financing investments in renewable energy: the impacts of policy design, *Renew. Sustain. Energy Rev.* 2 (4) (1998) 361–386.
- [50] M. Valipour, Drainage, waterlogging, and salinity, *Arch. Agron. Soil Sci.* 60 (12) (2014a) 1625–1640.
- [51] M. Valipour, Future of agriculture water management in Africa, *Arch. Agron. Soil Sci.* 61 (7) (2014b).
- [52] M. Valipour, A comprehensive study on irrigation management in Asia and Oceania, *Arch. Agron. Soil Sci.* 61 (9) (2014c).
- [53] M. Valipour, Future of Area equipped for irrigation, *Arch. Agron. Soil Sci.* 60 (12) (2014d) 1641–1660.
- [54] M. Valipour, et al., Agriculture water management in the world during past half century, *Arch. Agron. Soil Sci.* 61 (5) (2014) 657–678.
- [55] Varadarajan, et al., The Impacts of Policy on the Financing of Renewable Projects, Climate Policy Initiative report, 2011, <http://climatepolicyinitiative.org/wp-content/uploads/2011/12/Policy-Impacts-on-Financing-of-Renewables.pdf>.
- [56] Varadarajan et al., 2012 U. Varadarajan, B. Pierpont, A. Hobbs, K. Rowley, Supporting renewables while saving taxpayers money, *Clim. Policy Initiat. Report* (2012). <http://climatepolicyinitiative.org/publication/supporting-renewables-while-saving-taxpayers-money/>.