Renewable Energy in India: What It Means for the Economy and Jobs

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1 Background

Energy is an important input for spurring economic growth and development in that both fossil energy (FE) and renewable energy (RE) have strong interlinkages with crucial factors that characterize the macroeconomy, demographic profile, employment and energy economy of an emerging market economy such as India. Until 2017–2018, India recorded among the highest economic growth rates in the world, with an annual gross domestic product (GDP) growth of around 7–8%. However, in the second half of 2019, India began to experience a phase of economic slowdown attributed to the sluggish growth of industrial production, mainly, capital goods and electricity generation (Economic Times, 2020). In the last three quarters of the financial year (FY) 2019–20, the growth rate (at 2011–12 prices) witnessed a steady
decline from 4.3% in Q2 to 3% in Q4 (MoSPI, 2020). Moreover, it was during the last quarter of FY20 when the Indian economy reeled under an unanticipated shock with the outbreak of COVID-19 and the subsequent nationwide lockdown announced by the government. Therefore, as the nation grapples with the pandemic, the target of around 8% growth per annum during 2018–2023 (NITI Aayog, 2018) necessitates significant policy initiatives to fillip faster growth for the next 40 years. Under these extenuating circumstances, India’s energy needs cannot be overlooked (MoSPI, 2017). India’s economic growth has been estimated to have reduced to 4.2% in FY 2019–20 (ending in March 2020). Further, aggregate GDP is predictable to grow smaller by about 3.2–4.5% during the FY 2020–21, when the impact of COVID-19 will be felt the most. It is perceived that since stringent measures have been adopted to contain the spread of the virus, it will heavily curtail economic activity, resulting in an economic contraction in the short to medium term (IMF, 2020; World Bank, 2020). Notwithstanding the immediate impact of COVID-19, India aims to strive for a higher economic growth path in the medium to long run.1 In fact, the government policy think-tank, National Institution for Transforming India (NITI) Aayog, is optimistic that the economy is going to revive after the containment of the disease, as the effects of stabilization policies like the fiscal stimulus amounting to 10% of GDP and the repo rate cuts are realized (Economic Times, 11 June 2020). Energy being a vital input to the production and consumption processes of an economy, it is relevant that its steady supply to each of the sectors is guaranteed for an inclusive, sustainable and clean overall economic growth.

There are several policy imperatives that deem it necessary to propel the Indian economy on a sustainable long-run growth path. At present, India accounts for around 18% of the world population; however, its share in global energy consumption is a mere 6%. Even as India’s energy consumption almost doubled between the years 2000 and 2015, its per capita energy demand continued to be low, at around one-third of the world average, and much below the levels exhibited by the United States of America (USA) and the European Union (EU). However, the government is actively working towards strengthening distribution and access to modern and reliable energy sources through programmes such as the Integrated Power Development Scheme (IPDS), the Restructured Accelerated Power Development and Reforms Programme, the Saubhagya Scheme and the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY). The year 2018 marked the achievement of 100% rural electrification, and there has been a subsequent decline in the estimated population without access to electricity from 240 million in 2015 to 100 million in 2018 (IEA/IEO, 2020).

In the longer run, India’s energy consumption is slated to rise rapidly. According to India’s Energy Outlook, 2015, brought out by the International Energy Agency, some of these trends are quite incredible (IEA/IEO, 2015). India’s total energy demand is

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1In one such statement, the World Bank Chief Economist for South Asia, Hans Timmer seems to suggest that, in the short run, India ought to start planning for a growth rebound, involving creation of new job opportunities, particularly at the local levels, coupled with the financial programs to avert bankruptcies, especially of the small- and medium-sized enterprises. In the longer run, one needs to perceive this as an opportunity for course correction and progressing the Indian economy on a sustainable growth path, both fiscally and socially (ET, 13 April 2020).
expected to be risen by the year 2040 on account of the size of its economic output that would enlarge to more than five times its prevailing level in terms of aggregate GDP, and a population growth rate that would make it the most populous country. Accordingly, IEO/IEA (2015) envisages India’s aggregate energy consumption to more than double by 2040, with a tremendous rise in the offtake of coal, oil and natural gas, often registering it as among the top energy consumption growth countries of the world.

In particular, the power sector will continue to be pivotal to India’s future energy economy. The installed power capacity is expected to rise from around 380 gigawatts (GW) today to over 1000 GW in 2040 (Ministry of Power, 2020). Even as coal-fired generation would continue to play a key role (mostly at higher thermal efficiency levels), the rapid growth in RE, steered by solar and wind power, together with the increases in nuclear capacity would imply that these energy supply sources would account for over half of the new capacity additions between now and 2040 (IEA/IEO, 2015). However, these projections are sensitive to shocks created by the pandemic as worldwide energy demand has shrunk amidst dipping oil prices. While the government’s efforts to revive the economy through various stimulus packages would mitigate the looming current economic uncertainty, the outcomes are likely to be discernible only in the medium to long term.

In the present scenario, two relevant questions with regard to the implications for energy demand emerge: one pertaining to concerns of energy security and another relating to environmental sustainability. The pandemic itself testifies the growing vulnerability of nations and re-establishes the contentious free-trade debate. As most nations openly censure China with its alleged role in the spread of the virus, the gradual move towards anti-globalization is perceptible. Measures to reduce import dependence and to seek relatively secure sources of goods and services in the world market would largely influence the growth trajectory of India. With substantial energy import dependence and sizeable potential for growth in per capita consumption as well as energy access for larger sections of population, India encounters the challenge of placating its energy security concerns.

Specifically, India’s net energy import dependence has increased risen from around 31% in 2000 to 47% in 2015, and, recently to 49% in 2019, with little change in the diversity of supply sources (IEA Statistics; MoSPI, 2020). India has also set an ambitious target to set the share of natural gas in the energy mix to 30% in 2030 from 6% today. Despite the government’s intensive efforts to diversify the sources of energy supply, the International Energy Agency estimations point out that the country’s import dependency for oil (which was 80% in 2018) is likely to increase significantly in the coming decades. The IEA projections under the New Policy Scenario of India’s Energy Outlook, 2015, show that India is likely to occupy the centre stage of the global energy landscape, with its share at around a quarter of the incremental global energy use up to the year 2040, which exceeds the levels for any other country, and amounts to the largest additional rise in both coal and oil consumption (IEA/IEO, 2015). Notwithstanding these trends, it is important to note that India is also expected to emerge as a key RE producer, with the second-largest solar market in the world.
India’s increasing reliance on imported energy—especially oil and petroleum products—would have overwhelming implications for India’s energy security, with overall energy import reliance likely to rise to 90% in 2040 (amounting to around 9.3 million barrels/day in 2040) from 80% in 2018 (IEO/IEA, 2015). Thus, the adoption of appropriate policies helps enhance indigenous production as well as switch to alternative and sustainable sources of energy, such as solar and wind, is imminent. The government’s intensive efforts to diversify the sources of energy supply and to reduce import dependence have been reflected in the adoption of major upstream reforms like Hydrocarbon Exploration and Licensing Policy (HELP), increased investment in overseas oil fields in the Middle East and Africa, expansion of stockholding capacities and reforms in the natural gas market (IEA/IEO, 2020).

In the absence of stricter environmental regulation aimed at controlling energy-related emissions of gases, dust and fumes from the power generation, industry and transport sectors as well as biomass and stubble burning, India’s air pollution problems have been menacing. The reliance on conventional sources of energy (namely, coal, petroleum and natural gas) has posed a threat to environmental sustainability, at both local and global levels. The burning of fossil fuels and traditional biomass fuels releases carbon dioxide (CO$_2$), particulate matter (PM), nitrogen oxides (NO$_x$) and sulphur oxides (SO$_x$), all of which contribute to outdoor and indoor air pollution, global warming and climate change. India contributed 2238 million tons of CO$_2$ emissions in the year 2014, which is much higher than the 2000 level of 1032 million tons (World Bank, WDI). Projections by the World Resources Institute suggest that the level of emissions is going to rise significantly to 5271 million tons of CO$_2$ emissions in the year 2030 under the baseline inclusive growth (BIG) scenario (World Resources Institute, 2016). As countries negotiate to strike a cooperative mechanism in compliance with the Paris Agreement, the voluntary pledges of individual nations to lower greenhouse gas emissions may translate into a conceding on growth and development targets given the existing trade-offs. As for local pollution, the average annual exposure to particulate matter 2.5 (PM$_{2.5}$) ambient air pollution concentration in India in 2017 stood at 90.9 $\mu$g/m$^3$, which was found to be much higher than the world average of 45.5 $\mu$g/m$^3$, and way above the mean levels for high-income industrialized countries of 14.7 $\mu$g/m$^3$ (World Bank, WDI).

It is in this milieu that India’s ambitious resolve to achieve its RE targets over the next 5 years or so gains eminence. India has been striving to attain the target of 175 GW of RE capacity by 2022, which includes 100 GW of solar and 60 GW of wind energy. In the longer run, it has resolved to achieve an ambitious target of 450 GW of renewable energy by 2030 (Economic Times, 31 Jan 2020). Higher RE dissemination could not just help feed into energy demands resulting from a rebounding economy in the medium to short run, and it would also help create job opportunities in local or regional settings. At the micro-level, a way to mitigate the economic and humanitarian shocks faced by India, especially by the rural poor and the informal (often self-employed) workers migrating back from cities and towns to rural areas, to earn a living and gain access to health care, is to examine rigorously the role that RE could play in providing alternative employment opportunities. From a more macroeconomic perspective, RE deployment has interactions with key variables that
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include GDP, demography, fiscal stimulus, energy imports, and energy access (rural electrification and access to clean fuels), all of which are facing stressful dynamics arising out of a slowing down of India’s economic growth and made worse by the COVID-19 pandemic (ET, April 13, 2020). Resultantly, energy projections for the future serve as a guiding factor for the prevailing and proposed policy focus.

In light of all of the above, it is important to carry out a rigorous analysis to find answers to the following set of questions: (i) what are the key quantitative linkages between macroeconomic variables (such as GDP, population, employment, fiscal deficit, energy imports, energy access and return on capital) and RE growth in India? (ii) what will these relationship(s) imply for alternative paths for RE capacity development in India, both over medium- and long- time periods? (iii) what would be the predictions of RE generation in future? (iv) what will RE diffusion mean for creation of employment opportunities or jobs in the RE sector?

To answer the above questions, the paper delves into macroeconometric time-series methods to capture the potential role of RE in India, with special emphasis on the linkages that it may have with key macroeconomic variables, such as GDP, population, fiscal deficit, call money rate, energy imports and population’s access to energy. The analyses include tests of stationarity, Granger causality tests and estimating a long-run co-integrating relationship using the auto regressive distributed lag (ARDL) model for the estimation and future projection of RE potential under alternative assumptions on macroeconomic variables used as drivers of RE. Further, the contribution of RE to job creation is assessed in this study by utilizing the normative estimates of NRDC-CEEW data (CEEW & NRDC, 2015, 2017) and mapping these onto RE projections from our macroeconometric exercise.

In energy economics, a motley of techniques has been used in order to project future energy scenarios, viz., optimization models like the Market Allocation model (MARKAL) (Seebregts et al., 2002; The National Energy Map, TERI, 2006), AIM/end-use model (Akashi et al., 2014), TIMES (Koljonen et al., 2012); dynamic simulation models including the Global-Macroecometric Energy-Economy-Environment model (E3ME) and the Long-range Energy Alternatives Planning system (LEAP) (Dagoumas & Barker, 2010; Roinioti et al., 2012); computable general equilibrium (CGE) model (Proenca & Aubyn, 2013); and time-series modelling (Tiwari, 2011). Optimization models like MARKAL, AIM and TIMES employ linear programming techniques. While MARKAL takes into account the entire life cycle of an energy resource, starting with the point of their extraction to their end-use, in choosing the optimum activity levels of processes that satisfy the constraints, such as primary energy availability, access to certain technology, emissions standards, at minimum cost, AIM and TIMES are advanced versions of MARKAL with new sets of features. In contrast, simulation models like E3ME, LEAP and CGE capture interlinkages and interdependencies between different parts of the economic and energy systems through feedback effects. CGE modelling has been one of the most powerful approaches to develop energy projections including Nong and Simshauser (2020) who use a GTAP-E-Power Model, a global CGE structure that utilizes comparative statics and to encompass details of electricity generation from different technologies. They derive the change in the output of the energy sectors
using RE like wind power in India to be 408 in the baseline case, and this increases to 3941 under the scenario with a substantial push on input factor-augmenting technologies over the time span of 40 years from 2011 to 2050. With the expansion in RE systems in electricity generation, there is a concomitant fall in the percentage change in electricity output generated from FE; the percentage change being 474 and 69, respectively. A recent study by Laha et al. (2020) on energy demand for electricity generation develops a future RE scenario for the year 2030 with zero energy imports and exports and finds that the maximum share of RE in electricity generation would be around 32.7%, with an installed capacity of 80 GW of solar PV, 165 GW of wind and 15 GW of biogas. The corresponding projections by the International Renewable Energy Agency (IRENA) and The Energy and Resources Institute (TERI) stood at 31.3% and 37.8%, respectively. Chabadiya et al. (2020) use a simple logistic curve to simulate RE deployment in India under two scenarios, namely the realistic maximum and the theoretical maximum, and find that the solar power will attain saturation level in the year 2035, followed by bioenergy in 2040 and wind power in 2045.

The existing literature on time-series macroeconometrics modelling that aims to examine a time-based dependence structure between energy demand and/ or supply and macroeconomic drivers such as economic growth, employment, trade balance and emissions has provided mixed results as far as the time-dependent associations are concerned. Often, the disparate and equivocal conclusions are a result of varied methodologies used by these studies, for different groups of countries, different reference periods and utilizing diverse datasets. Most cross-country studies have relied on a structural vector autoregressive (SVAR) model or a vector error correction model (VECM) or a panel estimation (Silva et al., 2011; Onafowora & Owoye, 2015; Sasana & Ghozali, 2017). These examine the long-term association between RE consumption and economic growth. Furthermore, the aspect of employment generation from RE has been addressed by Wei et. al. (2010) and Lehr et. al. (2012), which suggests that the use of non-fossil fuel technologies generates more jobs than fossil fuel-based technologies. Studies on energy projections based on time-series estimation models have been quite sparse and unexplored to date.

The present analysis contributes to the existing literature on the long-run association between RE deployment and major macroeconomic variables, even as it takes into account the short- to medium-term economic implications of COVID-19 along with capturing the overall energy transitions in India. We take into account the inevitable short-run contraction in the RE markets in the country driven by the massive disruption in supply chains, labour supply shocks and policy changes resulting from tariff barriers to imports of solar PV panels and other RE equipment from China amidst the pandemic as well as the growing border tensions between India and China. Notwithstanding the sudden break in the energy transition path, it is expected that the market for RE will recover in the long run.
The key findings of this research were

- The ARDL model estimation pointed towards an equilibrium long-run co-integrating relationship between RE and select macroeconomic variables alluded to above. The long-run level of GDP, call money rate and ratio of renewable energy to fossil energy tariffs were found to be positively associated with RE diffusion, while variables such as the fiscal deficit, net energy imports, population access to electricity, population level and unemployment displayed a negative relationship with it.

- The growth of RE was found to be the maximum under the optimistic scenario, attaining a value of over 13.69 million tons of oil equivalent (MTOE) in 2022, 40 MTOE in 2032 and 104.48 MTOE in 2042. The analogous capacity levels for RE were estimated to be 105.34 GW in 2022, 285.87 GW in 2032 and a whopping 693.55 GW in 2042. The share of energy generated by RE in aggregate primary energy supply (TPES) (in MTOE) was found to rise from the prevailing less than 1–1.23% in 2022, 2.54% in 2032 and 5.18% in 2042.

- Under the pessimistic case, the growth of RE was found to be more sluggish, both in terms of energy supplied and RE capacity installed, as compared to BAU and OPT. It reached an energy supply level of 11.87 MTOE in 2022, 27.67 MTOE in 2032 and merely 50.90 MTOE in 2042. The associated capacity installed was estimated to be 102.34 GW, 209.32 GW and 337.88 GW in 2022, 2032 and 2042, respectively. Commensurately, it was estimated that the share of RE to TPES will be much lower at 0.92% in 2022, 1.60% in 2032 and 2.31% in 2042.

- Notably, relative to the initial official targets of RE capacity of 175 GW by 2022 projected by the government, our estimations show that these would be achieved with some delay. This finding conforms to the apprehensions voiced in this regard, given the available policy framework moving away from feed-in-tariffs to auction-based purchases, lack of grid infrastructure and evacuation constraints (LiveMint, 28 Dec 2017). More recently, the strain in India–China relations, and the consequent barriers to the imports of RE equipment from China, could also result in somewhat sluggish RE diffusion in the short- to medium-time frames. Specifically, we got that the official target is likely to be achieved during 2027–28 under the business-as-usual, a bit earlier, in 2026–27 under the optimistic case, and a lot later, in 2028–29 in the pessimistic scenario. Some of these outcomes could change as more recent data are incorporated in the analyses.

- More recently, the government of India has revised its RE capacity target to 227 GW by 2022, which according to our estimation will presumably be realized by
2029–30 under both—business-as-usual and optimistic scenarios—and by 2033–34 under the pessimistic case.

- The incremental jobs in the RE sector by the year 2022 would amount to 375 thousand, 379 thousand and 355 thousand in the business-as-usual, optimistic and pessimistic cases. In 2032, the cumulative jobs would expectedly rise to 1695 thousand, 1814 thousand and 1205 thousand, respectively, under the three scenarios. In 2042, the cumulative job creation levels would rise to 4390 thousand, 5055 thousand and 2227 thousand respectively, in the three alternative cases of business-as-usual, optimistic and pessimistic ones, respectively.

- Notwithstanding the delays in the achievement of RE targets, in addition to enhancing energy and environmental security, RE could offer significant employment co-benefits to the macroeconomy of India. This is especially relevant as India embarks on economic recovery in a post-COVID-19 phase.

The remaining sections of this paper are structured as follows. Section 2 provides a discussion of the specific methods and models that are used for quantifying the relationship between RE and key macroeconomic variables, lays out the results and provides a discussion on these in terms of its key implications. Section 3 lays down the assumptions for forecasting RE diffusion in the medium and long runs under alternative macroeconomic, policy and demographic scenarios for India, as well as discusses the results of this forecasting exercise. Section 4 utilizes the estimates of Sects. 2 and 3 to forecast the job creation potential for RE in India, based on normative data. Finally, Sect. 5 summarizes the important takeaways from this research and concludes.

2 RE Growth and Its Macroeconomic Linkages in India

2.1 Methods and Models

Select macroeconometric time-series estimation methods have been used to establish the long-run equilibrium relationship between RE supply/generation and other macroeconomic variables, namely, economic output, rate of unemployment, budgetary deficits, net energy imports, population size, call money rate and relative RE-FE tariffs for India. The aim was to ascertain the long-run co-movement of variables. To begin with, unit-root tests were carried out to check whether the time-series variables are stationary (non-stationary), that is, whether a shift in time causes a change in the shape of the distribution of the variable or not. For our analysis, the unit-root test utilized was the modified Dickey–Fuller test (also known as the DF-GLS test) as suggested by Elliott et al. (1996). Further, Granger causality tests

\[2\text{Stationarity implies the basic properties of the distribution, such as the mean, variance and covariance, remaining constant over time. The innovative work for deriving unit-root test in time series was done by Dickey and Fuller (Fuller, 1976; Dickey & Fuller, 1979).}\]
were attempted. Granger causality tests carried out for any pair of variables showed
the manner in which the causality between them would work. These were useful
in estimating the underlying relationships that helped to set up the macroecono-
metric model. Finally, an ARDL model was estimated for establishing the temporal
relationship between RE and the macro variables listed earlier. The ARDL model
typically derives the quantitative relationship between (economic) variables in a
single-equation time-series setting. ARDL method was introduced by Pesaran et al.
(2001) in order to incorporate a mix of stationary or integrated of order zero, i.e. \(I(0)\),
and non-stationary, integrated of order 1, i.e. \(I(1)\), time-series variables in the same
estimation. In case all the variables are stationary (i.e. \(I(0)\)), then OLS is appropriate,
and if all are non-stationary (i.e. \(I(1)\)), then it has been advised to use the vector error
correction (VECM) model (Johansen, 1988, 1991). This estimated ARDL equation
helped us predict RE generation and associated RE capacity in the future.

### 2.2 Dataset

The data used in this study were annual statistics for the 27-year period, spanning
1990–2016.

The macroeconomic variables considered were: gross domestic product (constant
prices) \(GDP_{CONS}\), population \(POP\), unemployment rate \(UNEMP\),
gross fiscal deficit \(FIS_{DEF}\), call money rates \(CALL RATE\), renew-
able energy generation (comprising solar, wind and biomass only) \(RE\),
total primary energy supply \(TPES\), net energy imports \(NET EN IMP\),
annual energy outlay of the government \(EN OUT\), population with
access to electricity \(POP ACCESS PERCENT\) and RE-FE tariff ratio
\(RE TO FE TARIFF\).

The data on \(GDP_{CONS}\), \(POP\), \(POP ACCESS PERCENT\) and
\(UNEMP\) were extracted from the World Bank data, specifically, from the World
Development Indicators (various issues). The time series on \(CALL RATE\) and
\(FIS_{DEF}\) was obtained from the Reserve Bank of India database. Next, the
dataset on \(RE\), \(TPES\) and \(NET EN IMP\) was derived from the country-level
energy balance tables of the International Energy Agency (online database). The
time series on \(EN OUT\) was from the Economic Survey (various issues) brought
out by the Ministry of Finance, Government of India. Finally, the series on the ratio
\(RE TO FE TARIFFS\) was worked out from the data published by the Central
Electricity Regulatory Commission (CERC’s annual reports, various issues).

The units of measurement of these variables as well as the detailed data sources
are provided in Table 1.

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3 Granger causality is a statistical concept of causality that is based on the prediction of a time series
by using prior values of another time series.

4 ARDL models are standard least squares regressions that include lags of both the dependent
variable and explanatory variables as regressors (Greene, 2008).
For select and variables, the data were missing. These missing data have been imputed by using the method of interpolation.

2.3 Results

2.3.1 Unit-Root Test Results

The specific test used in this research to investigate the presence of unit root in the variables was DF-GLS method. The modified Dickey–Fuller t-test was carried out.\(^5\)

| Variable                        | Code used   | Unit                                           | Source                                                                 |
|---------------------------------|-------------|------------------------------------------------|------------------------------------------------------------------------|
| Gross domestic product          | \textit{GDP\_CONS} | Billion INR (constant 2011–12 prices)          | World Bank\(^a\)                                                      |
| Population                      | \textit{POP}   | Billions                                      | World Bank\(^b\)                                                      |
| Unemployment rate               | \textit{UNEMP} | Percent                                       | World Bank\(^c\)                                                      |
| Gross fiscal deficit            | \textit{FIS\_DEF} | Billion INR (current prices)                  | Handbook of Statistics on the Indian Economy, Reserve Bank of India\(^d\) |
| Call money rate                 | \textit{CALL\_RATE} | Percent                                      | Database on Indian Economy, Reserve Bank of India\(^e\)               |
| Renewable energy (solar, wind, biogas) | \textit{RE}   | Million tons of oil equivalent (MTOE)         | Country Statistics, International Energy Agency\(^f\)                |
| Total primary energy supply     | \textit{TPES}    | MTOE                                          | Statistics, International Energy Agency\(^g\)                        |
| Net energy imports              | \textit{NET\_EN\_IMP} | MTOE                                         | Statistics, International Energy Agency\(^h\)                        |
| Energy outlay of government     | \textit{EN\_OUT} | Billion INR at current prices                 | Handbook of Statistics on the Indian Economy, Reserve Bank of India\(^i\) |

\(^5\)Basically, this test is an expanded version of the Augmented Dickey–Fuller test, where the time series are transformed through generalized least squares (GLS) regression before doing the test.
Studies by Elliott et al. (1996), and some later research, have shown that this test has a significantly higher power over the earlier variants the augmented Dickey-Fuller test.

The main results of the DF-GLS test for all the variables considered for our analysis are tabulated in Table 2.

The results in Table 2 show that the variables GDP\_CONS, FIS\_DEF, RE, TPES\_, NET\_EN\_IMP and ratio of RE\_to\_FE\_TARIFF are non-stationary, i.e. integrated of order one or I(1). The remaining variables such as POP, CALL\_RATE, UNEMP, EN\_OUT and POP\_ACCESS\_PERCENT were found to be stationary, namely, integrated of order zero or I(0).

### 2.3.2 Granger Causality Test Results

Two tables (Tables 3 and 4) display the results of the Granger causality tests for different variables with alternative lag structures.

As can be seen in Table 4, RE was found to Granger cause CALL\_RATE, while FIS\_DEF and RE display a two-way causality. Further, GDP\_CONS Granger causes RE, RE Granger causes NET\_EN\_IMP, and there is a two-way causality between RE and RE\_TO\_FE\_TARIFF, RE and POP and RE
### Table 2  Results of DF-GLS unit-root stationarity test

| Variable          | Order of integration found |
|-------------------|----------------------------|
| GDP_CONS          | I(1)                       |
| POP               | I(0)                       |
| UNEMP             | I(0)                       |
| FIS_DEF           | I(1)                       |
| CALL_RATE         | I(0)                       |
| RE                | I(1)                       |
| TPES              | I(1)                       |
| NET_EN_IMP        | I(1)                       |
| EN_OUT            | I(0)                       |
| POP_ACCESS_PERCENT| I(0)                       |
| RE_TO_FE_TARIFF   | I(1)                       |

Source Authors’ calculations

### Table 3  Results of the Granger causality tests

| Granger causality from $X \rightarrow Y$ | Number of lags | Level of significance corresponding to these alternative lags |
|-----------------------------------------|----------------|-------------------------------------------------------------|
| $D\_RE \rightarrow CALL\_RATE$          | 5              | 10%                                                         |
| $D\_FIS\_DEF \rightarrow D\_RE$          | 2, 3           | 5%, 5%                                                      |
| $D\_RE \rightarrow D\_FIS\_DEF$         | 5              | 5%                                                          |
| $D\_GDP\_CONS \rightarrow D\_RE$         | 2, 3, 4        | 5%, 5%, 5%                                                  |
| $D\_RE \rightarrow D\_NET\_EN\_IMP$     | 2, 3, 4        | 5%, 5%, 5%                                                  |
| $D\_RE\_TO\_FE\_TARIFF \rightarrow D\_RE$ | 5, 6, 7        | 10%, 5%, 5%                                                 |
| $D\_RE \rightarrow D\_RE\_TO\_FE\_TARIFF$ | 7              | 5%                                                          |
| $PO\_P \rightarrow D\_RE$               | 2, 3           | 5%, 10%                                                     |
| $D\_RE \rightarrow PO\_P$               | 3, 4           | 10%, 5%                                                     |
| $PO\_P\_ACCESS\_PERCENT \rightarrow D\_RE$ | 2, 3, 4        | 5%, 5%, 5%                                                  |
| $D\_RE \rightarrow PO\_P\_ACCESS\_PERCENT$ | 2, 4          | 5%, 5%                                                      |
| $D\_RE \rightarrow UNEMP$               | 2, 4, 5, 6     | 10%, 10%, 10%, 5%                                          |

Source Authors’ calculations

and $PO\_P\_ACCESS\_PERCENT$. Finally, $RE$ Granger causes $UNEMP$. These causalities helped in explaining later the relationships that were derived from the co-integration ARDL equation.
Table 4  Direction of relation between key variables

| Direction of the causality relationship | Cases                  |
|-----------------------------------------|------------------------|
| Unidirectional from RE to others        | $RE \rightarrow CALL\_RATE$ |
|                                         | $RE \rightarrow FISCAL\_DEFICIT$ |
|                                         | $RE \rightarrow NET\_ENERGY\_IMPORTS$ |
|                                         | $RE \rightarrow UNEMPLOYMENT\_RATE$ |
| Unidirectional towards RE from others   | $RE \leftarrow GDP$       |
| Bidirectional causality                 | $RE \leftrightarrow FISCAL\_DEFICIT$ |
|                                         | $RE \leftrightarrow RE\_TO\_FE\_TARIFF$ |
|                                         | $RE \leftrightarrow POPULATION$ |
|                                         | $RE \leftrightarrow POPULATION\_ACCESS\_PERCENT$ |

Source: Authors’ estimations

2.3.3  ARDL Model Estimates and Interpretation

The Johansen co-integration test results pointed to the fact that the variables are co-integrated. The VECM estimation results were not found to be acceptable as the error correction term was non-converging. Furthermore, the VECM procedure was unable to combine I(0) and I(1) variables. So, we relied upon an ARDL model estimation, especially in view of the unit-root test results that showed that some of the variables mentioned in were I(0), while some other important ones were I(1) (see Table 2 for these details). Several combinations of variables were assessed that could potentially drive the dissemination of RE in India. Also, different lag structures were tested to estimate most accurate ARDL model.

The following long-run equilibrium co-integrating ARDL relationship was found among the specified variables:

$$ RE = 9.2186 + 0.0017 CALL\_RATE - 0.00004 FISCAL\_DEFICIT $$
$$ + 0.00013 GDP\_CONS - 0.0017 NET\_ENERGY\_IMPORTS - 11.6036 POP $$
$$ - 0.005474 POP\_ACCESS\_PERCENT $$
$$ + 0.05937 RE\_TO\_FE\_TARIFF - 0.1475 UNEMP. $$

(1)

Further, the coefficient estimated for the previous period error correction term [ECM(-1)] was found to be negative and significant and also lying-in range $-1$ and 0. Specifically, this was found to be $-0.46$, which indicated that any short-run deviation in the last period was corrected for in the next period by almost 46%, implying convergence in values over time.

The equilibrium co-integrating long-run relationship in Eq. (1) implied that, in the long run, $GDP\_CONS$, $CALL\_RATE$ and $RE\_TO\_FE\_TARIFF$ are positively associated with the $RE$ diffusion, while variables such as $FISCAL\_DEFICIT$, $NET\_ENERGY\_IMPORTS$, $POP$, $POP\_ACCESS\_PERCENT$ and $UNEMP$ have a negative relationship with $RE$ dissemination in India.
Table 5  ARDL bound test results

| Calculated F-statistics | Df | 10% Critical value | 5% Critical value | 1% Critical value |
|-------------------------|----|-------------------|-------------------|-------------------|
|                         |    | Lower bound       | Upper bound       | Lower bound       | Upper bound       |
|                         |    |                   |                   |                   |                   |
| 5.47                    | 8  | 1.85              | 2.85              | 2.11              | 3.15              |
|                         |    |                   |                   |                   |                   |
|                         |    | 2.62              | 3.77              |                   |                   |

*Source* Authors’ estimations

The results of the bound test for above estimations are reported in Table 5. As can be seen from Table 5, the calculated F-statistics was found to be higher than both the lower bound critical values and as well as the upper bound critical values at all the levels of significance. Thus, the null hypothesis of the non-existence of no long-run relationship among the variables is rejected.

In intuitive terms, the results in Eq. (1) can be explained as follows.

RE generation (RE) is positively associated with $CALL\_RAT\_E$, as the coefficient of $CALL\_RAT\_E$ in the right-hand side of Eq. (1) is estimated as 0.0017. In general, a higher $CALL\_RAT\_E$ constitutes either the cost of capital (that may dampen investment in RE) or a return on capital investment (that encourages investment in RE equipment). From a macroeconomic perspective, for the period being analysed, the latter effect would have outweighed the former, implying that $RE$ and $CALL\_RAT\_E$ have been found to move together.

Further, according to Eq. (1), the coefficient of the budgetary deficit variable $FIS\_DEF$ is found to be negative, at $-0.00004$, implying that RE generation (or $RE$) moves counter-cyclically with $FIS\_DEF$. Note that, ARDL captures the co-movement of the macro variables. Here, in the aggregate, a higher $FIS\_DEF$ is primarily indicative of higher fiscal support to FE generation. Moreover, RE prices are now derived from reverse-price auction bids by the private companies in this sector. This has reduced the dependence on feed-in-tariffs, and the associated reliance on subsidies or other forms of fiscal support. Consequently, a higher level of RE penetration could move concomitantly with a lower fiscal deficit on account of a relatively contracting share of FE generation. The direction of this relationship might undergo a change as more recent data become available on RE diffusion or else the support policies provide for higher fiscal support.

RE generation (that is, $RE$) is also found to be positively linked to $GDP\_CONS$. The coefficient estimated for $GDP\_CONS$ in Eq. (1) is 0.00013, which could be interpreted as higher incomes inducing a higher willingness to pay for $RE$ or a higher demand for RE, entailing this positive relationship. This could also take to mean that RE is a normal good, implying cleaner energy is demanded more at higher incomes at the macro-level.

$RE$ is found to have been negatively correlated with reduced the $NET\_EN\_IMP$, which is as one would expect. This derived from the sign of the coefficient of $NET\_EN\_IMP$ being $-0.0017$. On average, a higher RE generation translates into lower energy imports, which in India, which are mainly
FE imports of hydrocarbon and coal. Thus, RE substitutes for FE in the aggregate, implying a countering relationship between these two variables over time.

Interestingly, with both aggregate $POP$ and $POP\_ACCESS\_PERCENT$, RE generation ($RE$) is found to have a negative correlation for the time period being analysed. The respective numerical coefficients are found to be $-11.6036$ and $-0.005474$. Seemingly, a bigger population size or a larger access of the population to power supply places a heavier demand on the economy in terms of demand for energy. Given the limited time-series dataset (for 27 years only) and India’s excessive dependence on FE in a large measure so far, the estimation shows that both—higher $POP$ and $POP\_ACCESS\_PERCENT$—tend to inhibit RE penetration—or that these move in opposite directions over time. The direction of this link is likely to undergo a change as more RE diffusion occurs, especially in remote geographical locations.

A positively signed coefficient of 0.05937 for $RE\_TO\_FETARIFF$ points to the fact that RE and relative RE to FE tariffs are linked positively. This is straightforward, as a higher $RE\_TO\_FETARIFF$ implies a more lucrative tariff for RE, implying a larger diffusion level for it.

The coefficient of $UNEMP$ in the right-hand side of Eq. (1) is found to be $-0.1475$. That is, RE generation ($RE$) is estimated to move negatively, or countercyclically, with aggregate $UNEMP$ rate in India. A higher RE diffusion is typically associated with lower unemployment rate, at the economy-wide level, pointing towards significant job creation potential in the RE sector.

On the whole, the study finds that RE diffusion in India is positively related to $GDP\_CONS$, $CALL\_RATE$ and $RE\_TO\_FE\_TARIFF$ and negatively with $FIS\_DEF$, $NET\_EN\_IMP$, $POP$, $POP\_ACCESS\_PERCENT$ and $UNEMP$. These relationships carry important policy messages. For example, a higher economic growth rate, a higher return on investment and more remunerative RE tariff would incentivize RE growth. Alternatively, a higher budgetary support (by running larger fiscal deficit) and energy imports will tend to dampen RE diffusion and vice versa. Likewise, for India, a case can be made for the fact that a higher level of population or a higher energy access of the population would generally translate into greater reliance on FE rather than RE. This last effect can be offset or even inverted as more stable, cheaper and technologically advanced RE supply options are discovered and deployed.

Next, by utilizing the ARDL Eq. (1), three alternative features, namely, business-as-usual (BAU), pessimistic and optimistic are charted out for RE penetration in India’s energy economy. These both—RE generation and associated RE capacity—are done for the years 2020–2042, for each of the three cases. Among these alternative scenarios, it is the pessimistic case that captures most accurately the present-day reality of the impact of COVID-19 pandemic on macroeconomic aggregates and government policies, both in the short- to medium-time frames.

In what ensues, a discussion on the assumptions made to characterize these three scenarios, and the forecasted values of RE (both generation and capacity) into the future are presented.
3 Forecasting of RE Generation and Associated Capacities in India Under Alternative Scenarios

By relying on the estimated long-run co-integrating relationship for the temporal behaviour of the concerned variables using the ARDL model, as defined in Eq. (1), three different scenarios, namely, BAU, pessimistic and optimistic were articulated.

The three scenarios have been constructed by linking these to the alternate official trends or policy targets that would have consequences for trends in key macro variables for the Indian economy going forward. This is based on a detailed reading of the official documents and other policy papers towards judicious construction of these alternative futuristic cases. The ARDL equation can be further relied upon for creating additional configuration of assumptions to derive more scenarios and carry out the sensitivity analysis with respect to RE growth and job creation potential; the latter are discussed in the next section.

BAU depicts the business-as-usual scenario for RE penetration, which hypothesizes a continuation of the older trends and policies, with no significant discontinuities. The optimistic scenario (OPT) subsumes the movement of the key driving variables being such that these encourage a higher growth of RE as compared to the BAU. Alternatively, the pessimistic scenario (PES) defines a case where all the main driving macroeconomic variables move in a fashion in the future so that they dampen RE diffusion. It is this last case that replicates the prevailing economic situation of slower economic growth and higher unemployment rates as is being faced by the Indian economy (at least in the short to medium term) due to the recent lockdown on account of the COVID pandemic. The OPT and PES cases imply important policy and structural changes, which are not modelled explicitly but rather driven through changes in the macroeconomic variables.

In the next section, the assumptions made about the path of the key macro variables that drive these three different scenarios are presented and discussed.

3.1 Assumptions Underlying Alternative RE Forecasts

3.1.1 Call Rate

The call money rate (\(CALL\_RAT\_E\)) was taken to be the same across all the three cases, resting on the premise of an independent central bank that basis its decisions on the economic fundamentals and monetary policy of the country, and has no association with any policy framework for promoting RE. The average weighted monthly call money rate of the Reserve Bank of India (RBI) for most of the months in 2019 was found to be around 6%. At the beginning of 2020, RBI announced a 75 basis points (bps) reduction in the repo rate, following RBI’s COVID-19 measures (Economic Times, 30 Mar 2020). To incorporate this reduction in the repo rate in our model, we have taken into account the call money rate for the year 2020 to be
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5.2%, which is a reduction of 80 bps from the previous year. Furthermore, we have assumed that the call rate will be 5.8% from the next year onwards till 2024 as the economy begins to recover from the COVID-19 shock. Over the longer time period, the call money rate is assumed to fall slowly and become constant at around 5% for the remaining years up to 2042. The specific assumptions are listed in Table 6.

### Table 6
Forecasted values of call money rate for the BAU, optimistic and pessimistic scenarios (percent)

| Year     | Call rate |
|----------|-----------|
| 2020     | 5.2       |
| 2021–24  | 5.8       |
| 2025–29  | 5.6       |
| 2030–34  | 5.5       |
| 2035–42  | 5         |

3.1.2 Gross Fiscal Deficit (as a Percentage of GDP)

As regards gross fiscal deficit percentage ($F_{IS\_DEF}$), the baseline (BAU) scenario was described based on the figures suggested by the NITI Aayog report titled, “Three Year Action Agenda, 2017–18 to 2019–20” (NITI Aayog, 2017). Under the optimistic scenario, $F_{IS\_DEF}$ was assumed to plummet at a slower rate than in the case of the BAU, assuming an increase in the public expenditure for developmental infrastructure and others. Contrasting with this, the pessimistic scenario is characterized by a fall in $F_{IS\_DEF}$ at a rate higher than in the case of the optimistic scenario as well as the BAU. As a measure to tackle COVID-19, the central government of India has announced a Rs 20 lakh crore⁶ package on 12 May 2020 to stimulate the economy. This stimulus package is put at around 10% of GDP. The entire package of Rs 20 lakh crore had been criticized on several grounds as having a smaller direct impact (The Hindu BusinessLine: 19 May 2020; The Wire: 17 May 2020). Specifically, it is being claimed that a mere 1–2% of GDP would be directed as the net stimulus package for the economy to mitigate the impact of COVID-19. In light of these arguments, the $F_{IS\_DEF}$ as a percentage of GDP for 2020 was assumed to be 5.2%, 5.5% and 4.8% under the BAU, optimistic and pessimistic scenarios, respectively. For other years, the specific values postulated are provided in Table 7.

3.1.3 GDP Growth Rate

*Business-as-Usual*

In the year 2020, the GDP ($G_{DP\_CONS}$) growth rate declined significantly on account of a weaker growth experience of the previous year and the economic shock

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⁶1 lakh = $10^5$ and 1 crore = $10^7$. 
Table 7  Forecasted values of gross fiscal deficit under different scenarios (percent)

| Year    | BAU  | Optimistic | Pessimistic |
|---------|------|------------|-------------|
| 2020    | 5.20 | 5.50       | 4.80        |
| 2021–24 | 3.30 | 3.45       | 3.20        |
| 2025–29 | 3.20 | 3.30       | 3.10        |
| 2030–34 | 3.00 | 3.20       | 3.00        |
| 2035–42 | 3.00 | 3.00       | 2.90        |

Table 8  Forecasted values of annual GDP growth rate under different scenarios (percent)

| Year    | BAU  | Optimistic | Pessimistic |
|---------|------|------------|-------------|
| 2020    | −3   | −1.5       | −3.5        |
| 2021–24 | 7.5  | 8          | 6.5         |
| 2025–29 | 8    | 8.2        | 6           |
| 2030–34 | 8    | 8.5        | 5.5         |
| 2035–39 | 8.2  | 8.8        | 5           |
| 2040–42 | 8.5  | 9          | 5           |

of COVID-19. Following the forecast of the World Bank, we have assumed that the growth rate for the year 2020 under the BAU scenario would be (-)3% (a negative growth experience). However, the Indian economy would witness a faster recovery or rebound in the following years, such that during 2021–2024, the growth rate has been assumed to rise to 7.5% per annum, followed by an even higher rate of 8% annually for the next ten years. For 2035–2039, the annual GDP growth rate was assumed at 8.2%. Further, from 2040 onwards, it was assumed to be around 8.5% (see Table 8 for this).

**Optimistic**

Under this scenario, the annual GDP growth rate in constant prices (GDP_CONS) was assumed to accelerate faster in comparison with the other two scenarios. In 2020, despite the COVID-19 shock, GDP would shrink by a smaller amount, registering a (negative) growth rate of (-)1.5%, and from 2021 onwards, GDP would recover and grow at a rate of 8% per annum up until 2024, and then by 8.2% annually till 2029. From 2030 onward, the annual growth rate was assumed to be around 8.5% followed by an even higher 8.8% annual rate for 2035–2039. These can be found in Table 8.

**Pessimistic**

The pessimistic scenario is portrayed by a slowing down of the annual GDP growth rate (GDP_CONS) from 6.5% in 2021–24 to 5% in 2035–2042, again with the

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7The Indian economy is assumed to contract by 3.2% according to Global Economic Prospects, June 2020, a World Bank group’s flagship report. Following this we have assumed a 3% contraction in the Indian economy for our analysis.
Table 9  Future values of share of NET_EN_IMP in TPES under different scenarios (as fraction)

| Year   | BAU  | Optimistic | Pessimistic |
|--------|------|------------|-------------|
| 2020–24 | 0.450 | 0.430      | 0.470       |
| 2025–29 | 0.420 | 0.400      | 0.440       |
| 2030–34 | 0.419 | 0.399      | 0.439       |
| 2035–39 | 0.415 | 0.395      | 0.435       |
| 2040–42 | 0.412 | 0.392      | 0.432       |

significant exception for the year 2020 where (a negative) GDP growth rate was assumed to be at (-)3.5% due to COVID-19. This follows the commonly available estimates of growth in this year. The trend of these growth rates is tabulated in Table 8.

3.1.4 Net Energy Imports (as a Percentage of Total Primary Energy Supply)

The BAU scenario assumptions for net energy imports share (\(\text{NET\_EN\_IMP} \) to \(\text{TPES}\) ratio) are derived from the projections made by the India Energy Outlook, World Energy Outlook Special Report, 2015. The NITI Aayog’s report on “Draft National Energy Policy (2017)” predicts \(\text{NET\_EN\_IMP}\)’s share in \(\text{TPES}\) to be around 36–55% (which include imports of non-commercial energy as well). In addition, the “Report on Energy Efficiency and Energy Mix in the Indian Energy System (2030), Using India Energy Security Scenarios, 2047” (2015) also presupposes it to be around 45–59.3% under the optimistic scenario. Since we have excluded non-commercial energy from our analysis, the ratio of \(\text{NET\_EN\_IMP}\) to \(\text{TPES}\) was assumed to be slightly lower than the above-mentioned levels. For the pessimistic scenario, we have made a 2-percentage point addition to the BAU figures. More details can be found in Table 9.

3.1.5 Population

The aggregate population \((\text{POP})\) of India in the year 2016 was estimated at 1.32 billion. From the year 2020 onward, population \((\text{POP})\) increases are predicted at five-yearly intervals as shown in Table 10. Accordingly, the average population level for 2020–24 was put at 1.353 billion, and similarly for the later years, on each five-yearly basis. Furthermore, the level of population was assumed to remain unchanged across all the three scenarios.
Table 10  Forecasted levels of population for BAU, optimistic and pessimistic scenarios (billions)

| Year   | Population |
|--------|------------|
| 2020–24 | 1.353      |
| 2025–29 | 1.37       |
| 2030–34 | 1.39       |
| 2035–39 | 1.4        |
| 2040–42 | 1.45       |

Table 11  Forecasted values of population with access to electricity for BAU, optimistic and pessimistic scenarios (percent)

| Year   | Population percentage with access to electricity |
|--------|--------------------------------------------------|
| 2020   | 85                                               |
| 2021   | 85.009                                           |
| 2022   | 85.011                                           |
| 2023   | 85.013                                           |
| 2024   | 85.015                                           |
| 2025–42| 100                                              |

3.1.6 Share of Population with Access to Electricity

As per the Pradhan Mantri Sahaj Bijli Har Ghar Yojana (‘Saubhagya’) and Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY), it has been planned that by the end of the year 2018, every family in rural and urban India would have been fully electrified. But, the analysis of the data seems to suggest that, in 2016, only 82% of the population had access to electricity in India. Even though, through DDUGJY, almost all the villages in India are now electrified, making electricity available for $24 \times 7$ h as well as its last-mile supply remains a challenge for the government (LiveMint, 29 Dec 2019). Thus, it would be somewhat optimistic to assume that full electrification of the country with complete access by the end of 2018 was accomplished. We have, thus, moderated this level by assuming a slower (though steady) rise in the fraction of the population with access to electricity ($POP_ACCESS_PERCENT$), such that according to our assumptions, the country would get fully electrified (with last-mile connectivity) only by the year 2025. The anticipated population share with access to electricity has been taken as the same across the three scenarios (Table 11).

3.1.7 RE Versus FE Tariffs

The report of the Expert Group on 175 GW RE by 2022 (2015) by NITI Aayog has projected that the price of RE to conventional coal-based thermal power price would be equalized by 2031–32. Beyond this time point, RE prices would in fact fall below the coal-fired power prices. Since this target seems to be rather ambitious, we have assumed more realistic numbers under each of our three scenarios. We expect that the ratio of these prices ($RE_TO_FE_TARIFF$) would reach 1:1 the quickest in the
Table 12  Forecasted values of RE versus FE tariff under different scenarios (ratio)

| Year | BAU      | Optimistic | Pessimistic |
|------|----------|------------|-------------|
| 2020 | 1.2399685| 1.2828201  | 1.1256978   |
| 2021 | 1.2056873| 1.2592517  | 1.0628489   |
| 2022 | 1.1714061| 1.2356834  | 1           |
| 2023 | 1.1371249| 1.2121151  | 1           |
| 2024 | 1.1028437| 1.1885467  | 1           |
| 2025 | 1.0685624| 1.1649784  | 1           |
| 2026 | 1.0342812| 1.14141    | 1           |
| 2027 | 1        | 1.1178417  | 1           |
| 2028 | 1        | 1.0942734  | 1           |
| 2029 | 1        | 1.070705   | 1           |
| 2030 | 1        | 1.0471367  | 1           |
| 2031 | 1        | 1.0235683  | 1           |
| 2032–42 | 1    | 1          | 1           |

pessimistic scenario, followed by the BAU case and the optimistic scenario. This is plausible as we consider these prices to be supply-side tariffs. Since relative prices change based on the regulatory regime, which occurs with a time lag, the numbers unavailable for a few intermittent years have been worked out by interpolation. For the specific values, see Table 12.

3.1.8 Unemployment Rate

Business-as-usual

Due to the COVID-19 pandemic shock to the labour market in the year 2020, it has been assumed that under BAU, the unemployment rate (UNEMP) would increase to an average of 8%. From the year 2021, the unemployment rate would be moderated to 7.2%, which was assumed to fall further to 6.8% during 2022–2024. Then onwards, it has been assumed that the unemployment rate would change only every four to five years. The specific assumptions on unemployment rates under BAU are shown in Table 13.

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8During January 2020 and February 2020, the unemployment rate in India was 7.2% and 7.7%, respectively (CMIE), even though during March, April, May and June, unemployment is expected to rise sharply but may decrease in the later part of the year as the economy is expected to have a strong recovery later (India’s economy will see strong recovery next year- S& vil P, RT, 15 June 2020, https://www.rt.com/business/491827-india-economy-strong-recovery/), accessed 20 Jun 2020. Thus, unemployment for the entire year is assumed to be 8% under BAU.
Table 13  Forecasted values of unemployment rate under different scenarios (percent)

| Year    | BAU | Optimistic | Pessimistic |
|---------|-----|------------|-------------|
| 2020    | 8   | 6.8        | 9.5         |
| 2021    | 7.2 | 6.4        | 8.5         |
| 2022–24 | 6.8 | 6.3        | 8           |
| 2025–29 | 6.5 | 6          | 7.5         |
| 2030–34 | 6   | 5.7        | 7           |
| 2035–39 | 5.7 | 5.3        | 6.5         |
| 2040–42 | 5.5 | 5          | 6           |

**Optimistic**

In case of the optimistic scenario, for the year 2020, the unemployment rate was taken to be 6.8%, and for 2021, it was assumed to be 6.4%. But, for the subsequent years (that is, post 2021), it was assumed that \( \text{UNEMP} \) will decrease and will fall at a faster rate as compared to the BAU scenario. Like in BAU, in the optimistic scenario as well, it has been taken that \( \text{UNEMP} \) will change every four to five years, whose details are provided in Table 13.

**Pessimistic**

In the year 2020 and 2021, under the pessimistic scenario, the unemployment rates have been assumed to be the highest, at around 9.5% and 8.5%, respectively. Later, from the year 2022 to 2024, \( \text{UNEMP} \) has been assumed to fall. For the other years starting from 2025, unemployment rate would change every four to five years. More details are compiled in Table 13.

### 3.2 RE Energy and Capacity Forecasts Under Alternative Scenarios

\( \text{RE} \) forecasts have been made using the estimated co-integration ARDL equation in (1) and by imputing assumed future values of the variables in the right-hand side of the equation as laid out in the discussion of the last subsection. As for the specific projections, the following results were derived.

As shown in Table 14, the growth of \( \text{RE} \) was found to be the highest under the optimistic (OPT) scenario, reaching a value of over 13.69 MTOE in 2022, 40 MTOE in 2032 and 104.48 MTOE in 2042. The corresponding capacity levels for \( \text{RE} \) were found to be 105.34 GW in 2022, 285.87 GW in 2032 and a whopping 693.55 GW in 2042. For this, we have used initial average capacity utilization factors for \( \text{RE} \) be in the range of 15–16% and slowly rising to 20% in the future years. The estimates for the year 2040 and 2041 were derived to be 581.98 GW and 635.58 GW, respectively,
## Table 14  RE (Solar, wind and biogas) energy and capacity forecasts under alternative scenarios

| Year | BAU case | Optimistic case | Pessimistic case |
|------|----------|-----------------|------------------|
|      | RE forecast in BAU (in MTOE) | RE capacity BAU (in GW) | RE forecast in OPT (in MTOE) | RE capacity OPT (in GW) | RE forecast in PES (in MTOE) | RE capacity PES (in GW) |
| 2020 | 9.78     | 81.17           | 10.40            | 81.21            | 9.17             | 81.13             |
| 2021 | 11.36    | 93.30           | 12.05            | 93.45            | 10.55            | 92.17             |
| 2022 | **12.89**| **104.84**      | **13.69**        | **105.34**       | **11.87**        | **102.34**        |
| 2023 | 14.48    | 116.57          | 15.44            | 117.94           | 13.20            | 112.35            |
| 2024 | 16.19    | 129.03          | 17.33            | 131.43           | 14.62            | 122.83            |
| 2025 | 17.99    | 141.93          | 19.28            | 145.08           | 15.89            | 131.76            |
| 2026 | 20.12    | 157.06          | 21.55            | 161.00           | 17.37            | 142.14            |
| 2027 | **22.41**| **173.22**      | **24.01**        | **178.08**       | **18.94**        | **152.96**        |
| 2028 | 24.89    | 190.47          | 26.68            | 196.41           | 20.60            | 164.24            |
| 2029 | 27.58    | 208.87          | 29.57            | 216.07           | 22.37            | 176.01            |
| 2030 | **30.35**| **227.54**      | **32.64**        | **236.77**       | **23.94**        | **185.91**        |
| 2031 | 33.49    | 248.54          | 36.17            | 260.42           | 25.75            | 197.40            |
| 2032 | **36.88**| **270.96**      | **40.00**        | **285.87**       | **27.67**        | **209.32**        |
| 2033 | 40.55    | 294.90          | 44.16            | 313.27           | 29.69            | 221.70            |
| 2034 | 44.51    | 320.46          | 48.67            | 342.76           | 31.83            | 234.56            |
| 2035 | 48.84    | 348.08          | 53.74            | 375.67           | 33.85            | 246.27            |
| 2036 | 53.59    | 378.09          | 59.27            | 411.28           | 36.00            | 258.51            |
| 2037 | 58.74    | 410.20          | 65.29            | 449.72           | 38.26            | 271.15            |
| 2038 | 64.31    | 444.56          | 71.84            | 491.20           | 40.64            | 284.23            |
| 2039 | 70.34    | 481.33          | 78.97            | 535.99           | 43.13            | 297.76            |
| 2040 | **76.56**| **518.64**      | **86.39**        | **581.98**       | **45.25**        | **308.36**        |
| 2041 | 83.90    | 562.65          | 95.04            | 635.58           | 48.01            | 322.88            |
| 2042 | **91.88**| **609.88**      | **104.48**       | **693.55**       | **50.90**        | **337.88**        |

Source: Authors’ calculations

Bold refer to the RE capacity forecasts for years that serve as milestones with regard to the goals of the government of India on RE generation.

which were found to be closer to the estimates by NITI Aayog under Vision 2040. The share of energy supplied by RE to TPES was found to rise from the prevailing less than 1–1.23% in 2022, 2.54% in 2032 and 5.18% in 2042.

In comparison, the growth of RE under the BAU was estimated to be closer to OPT in the early years, but the gap tends to widen over the longer period of time. It was estimated at lower levels of 12.89 MTOE in 2022, 36.88 MTOE in 2032 and 91.88

9Draft National Energy Policy, NITI Aayog, GOI (Version as on 27.06.2017). It says that “by 2040 a likely capacity (for renewables) of 597–710 GW is expected to be achieved”, page 41, Chapter 6, Sect. 6.1.
MTOE in 2042. These amounted to capacity requirements of 104.84 GW, 270.96 GW and 609.88 GW in the respective years, based on the same plant utilization factor levels as in OPT. Moreover, these amounted to the shares of RE to TPES (both measured in MTOE) of 1.18% in 2022, 2.41% in 2032 and 4.58% in 2042.

Finally, under the pessimistic (PES) outlook, the growth of RE was found to be much slower, both in terms of RE energy supplied and associated required capacity to be installed, as compared to BAU and OPT. It reached an energy generation level of 11.87 MTOE in 2022, 27.67 MTOE in 2032 and merely 50.90 MTOE in 2042. The associated capacity needed to be installed, assuming the same levels of plant capacity utilization factors, would be 102.34 GW, 209.32 GW and 337.88 GW in 2022, 2032 and 2042, respectively. Accordingly, it was estimated that the share of RE to TPES will be 0.92% in 2022, 1.6% in 2032 and 2.31% in 2042.

The following three graphs capture these trends over time (see Figs. 1, 2 and 3). Notably, in comparison with the earlier announced official goal of RE capacity of 175 GW by 2022, and the later revised capacity of 227 GW projected by the government, our estimations have shown that these are likely to be achieved with a delay. This ties in with the recent forebodings expressed about the prevailing policy regime for encouraging RE development now moving away from feed-in-tariffs to auction-based purchases as well as lack of grid infrastructure and evacuation constraints (LiveMint, 28 Dec 2017). More recently, tensions between India and China have led to some concerns about the rise in tariff barriers on imports of RE equipment from China, which would potentially further slowdown RE diffusion. Specifically, our estimations have shown that the initial government targets of 175 GW would likely be achieved only by 2027–28 under the BAU, a bit earlier, in 2026–27 in case of the OPT, and much later, in 2028–29 in the PES scenario. The Government of India revised its targeted RE capacity to a more ambitious level of 227 GW by 2022. According to our estimations, these capacities would presumably be realized only by 2029–30, both under BAU and optimistic scenarios, whereas the same are likely
Fig. 2  RE capacity forecasts under the three scenarios. Source Based on authors’ calculations

Fig. 3  Share of RE in total primary energy demand under the three cases. Source Authors’ calculations

to be achieved by 2033–34 under the pessimistic scenario. Thus, the revised official forecasts have been found to be a bit too bold, and plausibly, likely to be achieved somewhat later in time, depending on how the macroeconomic scenarios, policy execution and technical (grid-related) constraints unfold over time. Much, of course, depends on how the RE technology evolves to deal with issues of intermittency and storage and extent of supportive policies for faster RE diffusion.
4 Future RE Capacity and Job Creation Potential

As India endeavours to augment the share of RE generation in its total primary energy supply, an important thought is the job creation potential of RE-based power capacity. This aspect gains even greater importance in light of massive job losses faced by the workforce in India consequent upon the recent lockdown deemed necessary due to the COVID-19 pandemic. Additional avenues for creating jobs, such as those in the RE sector, could be a way forward to mitigate the job losses faced by the Indian labour force, especially in the rural and informal sectors. In fact, Jain and Patwardhan (2013), who also studied the employment impacts of RE, state that RE technologies create a higher number of jobs per unit of installed power capacity and per unit of power generated than conventional FE technologies.

While not attempting to do any comparisons with FE, our analysis in this section aims to estimate the direct employment generation from the incremental RE capacity that would be installed, as those worked out in Sect. 3.

This section lays out the methodology and estimates the number of jobs created due to diffusion of solar (distinctly for ground-mounted and rooftop solar PV) and wind power projects in India. For working out the shares of solar PV and wind, we had assumed the proportions of incremental capacities and jobs created per unit capacity to be similar to CEEW and NRDC (2017) (refer to Table 15). According to CEEW and NRDC (2017), the levels of the job years comprise those for the purpose of business development, design and pre-construction, actual construction and project commissioning and operations and maintenance. The specific values used are also compiled in Table 15.

By relying on these values and utilizing the assumption that the shares across different RE technologies would not change over the time frame of forecasting, we obtained the following direct jobs generation potential for India (see Tables 16, 17 and 18 for these estimates). The additional jobs by 2022 would be around 375 thousand, 379 thousand and 355 thousand in case of BAU, OPT and PES scenarios, respectively. In 2032, the cumulative additional green jobs are expected to increase to 1695 thousand, 1814 thousand and 1205 thousand, respectively, under the three cases. Further into the future, in 2042, the cumulative job creation levels would mount to 4390 thousand, 5055 thousand and 2227 thousand respectively, in the case of BAU, OPT and PES, respectively.

It is important to emphasize that the specific variable pertaining to unemployment considered for estimating the ARDL equation (in Sect. 3) is the rate of unemployment in the economy (denoted by UNEMP). Despite our efforts, we could not access

| RE technology           | Shares in total capacity | Job years/MW |
|-------------------------|--------------------------|--------------|
| Ground-mounted solar PV | 0.375                    | 3.45         |
| Rooftop solar PV        | 0.25                     | 24.72        |
| Wind                    | 0.375                    | 1.27         |

Source CEEW and NRDC (2017)
Table 16  Incremental and cumulative job creation under BAU scenario (‘000 jobs)

| Year | Incremental jobs in ground-mounted solar | Incremental jobs in rooftop solar | Incremental jobs in wind | Cumulative jobs (solar + wind) |
|------|----------------------------------------|----------------------------------|--------------------------|--------------------------------|
| 2022 | 61                                     | 291                              | 22                       | 375                            |
| 2032 | 215                                    | 1027                             | 79                       | 1695                           |
| 2042 | 438                                    | 2095                             | 161                      | 4390                           |

Source Authors’ calculations

Table 17  Incremental and cumulative job creation under optimistic scenario (‘000 jobs)

| Year | Incremental jobs in ground-mounted solar | Incremental jobs in rooftop solar | Incremental jobs in wind | Cumulative jobs (solar + wind) |
|------|----------------------------------------|----------------------------------|--------------------------|--------------------------------|
| 2022 | 62                                     | 294                              | 23                       | 379                            |
| 2032 | 234                                    | 1116                             | 86                       | 1814                           |
| 2042 | 527                                    | 2519                             | 194                      | 5055                           |

Source Authors’ calculations

Table 18  Incremental and cumulative job creation under pessimistic scenario (‘000 jobs)

| Year | Incremental jobs in ground-mounted solar | Incremental jobs in rooftop solar | Incremental jobs in wind | Cumulative jobs (solar + wind) |
|------|----------------------------------------|----------------------------------|--------------------------|--------------------------------|
| 2022 | 58                                     | 276                              | 21                       | 355                            |
| 2032 | 138                                    | 661                              | 51                       | 1205                           |
| 2042 | 166                                    | 795                              | 61                       | 2227                           |

Source Authors’ calculations

data on a consistent time series on the level of unemployment, or the number of unemployed people, for India for the 27-years period which our analysis spans. Thus, we could not estimate the aggregate macro-level (net) job creating potential of RE. Nevertheless, the results presented here will be useful for policymakers in estimating the employment potential of RE generation, subject to the proviso that these numbers may not necessarily be incremental. For the latter, a more elaborate, economy-wide general equilibrium analysis is deemed necessary, which was outside the scope of this study.
5 Conclusion and Key Takeaways

India’s energy consumption and supply are expected to rise substantially in coming decades. According to India’s Energy Outlook, 2015, brought out by the International Energy Agency, some of these future trends are quite overwhelming (IEA/IEO, 2015). India’s aggregate energy demand is expected to rise by 2040, on account of the sheer size of its economic output (GDP), which is likely to expand to more than five times its prevailing level and population growth that would make it the most populous country in the world. Accordingly, IEO/IEA, 2015, predicts that India’s aggregate energy consumption would more than double by 2040, implying that this would be among the highest energy consumption growth experienced by any country across the globe.

The growing demand for energy has raised two key concerns: those pertaining to environmental sustainability and energy security. Absent stringent regulation to control and mitigate energy-related emissions of gases, dust and fumes from the power sector, industry and transport, India’s air pollution problems loom large, especially in urban and industrial towns and cities. The tremendous dependence on imports of conventional energy like coal, oil, natural gas has posed a grave threat to India’s energy security. With the substantial potential for growth in consumption per person as well as the emphasis on providing greater energy access, India faces the challenge of placating its energy security concerns. Consequently, adoption of customized policies aimed at enhancing indigenous production as well as encouraging the use of cleaner, sustainable and decentralized sources of energy, such as solar and wind, is impending. Apparently, the recent policy push towards RE and indigenous production of energy substantiates an optimistic scenario for the future of India’s energy economy.

The Government of India has ramped up the ambitious plan of achieving 175 GW of RE by 2022 to approximately 227 GW, of which the break-up proposed across technologies is: 113 GW of solar, 67 GW of wind, 10 GW of biomass, 6 GW of small hydro and 31 GW of floating solar and offshore wind.

RE (as much as FE) tends to have a strong interface with the key factors that describe the macroeconomy, demographics and the energy economy of India. Accordingly, the scope of this research was charted out. In the aggregate, this research aimed to quantify the relationships between macroeconomic and demographic variables (namely, GDP, population, employment, fiscal deficit, energy imports, energy access, return on capital and so on) with RE deployment in the Indian context. Using macroeconometrics and time-series methods, these relationships were captured under alternative cases of RE diffusion (linked to the key macroeconomic and demographic variables), in the short-, medium- and long-run time frames. These comprised of tests of stationarity, Granger causality tests and co-integration using an ARDL model framework. Based on these relationships, forecasts of RE generation and associated capacity requirements were worked out for three different scenarios (business-as-usual, optimistic and pessimistic). The research also ascertained the impact of RE
diffusion on the incremental job generation in the RE sector, using prescriptive data on job creation per unit of capacity installed in the solar and wind sectors.

The key results and takeaways from our analysis were as follows.

The ARDL model equation derived an equilibrium co-integrating long-run relationship between RE and important macroeconomic variables. The long-run levels of GDP_CONS, CALL_RATE and RE_TO_FE_TARIFF were found to have a positive association with the diffusion of RE, while variables such as FIS_DEF, NET_EN_IMP, POP, POP_ACCESS_PERCENT and UNEMP displayed a negative link with RE in India. Intuitively, we have the following takeaways.

RE generation was found to be positively linked to CALL_RATE. In general, a higher CALL_RATE could be perceived either as the cost of capital (that may inhibit investment in RE) or a return on capital investment (that boosts investment in RE technologies). At the macro-level for the years being considered, the latter effect seemed to be more important than the former, implying that RE and CALL_RATE moved pro-cyclically. RE generation was found to move inversely with FIS_DEF. That is, a higher FIS_DEF pointed towards higher financial support to FE generation. A higher level of RE diffusion was, thus, commensurate with a lower fiscal deficit on account of a lower share of FE generation.

As expected, RE generation was also found to be positively related to GDP_CONS, implying positive income effects on the demand for RE. Further, RE displayed a negative relationship with NET_EN_IMP. Thus, RE could be a strong substitute for FE in the aggregate, implying a mutually offsetting movement between the two.

Interestingly, with aggregate POP and POP_ACCESS_PERCENT, RE generation displayed a negative correlation or counter cyclicity. Intuitively, a larger population size or higher access of the population to power supply tends to place a heavier demand for energy. Given the limited time-series dataset (for 27 years only) and India’s excessive dependence on FE so far, the estimation seems to point out that both—higher population or population’s access to electricity—were inclined towards lowering RE penetration. We reckon that the direction of this link would change as more RE diffusion happens.

RE and RE_TO_FE_TARIFF moved together in a direct fashion. This was due to the fact that a higher RE_TO_FE_TARIFF implied a more lucrative tariff for RE-based technologies, entailing its higher diffusion. Further, RE generation was found to move counter-cyclically with aggregate UNEMP rate. A higher RE diffusion is generally believed to have a larger employment potential at the economy-wide level.

Utilizing the ARDL equation in (1), three different scenarios, namely business-as-usual (BAU), pessimistic and optimistic, were postulated for forecasting different levels of RE diffusion in India’s energy economy. The forecasts of RE generation and associated RE capacity were made for the years 2020–2042, for each of the three scenarios.

The growth of RE was found to be the sharpest under the optimistic (OPT) scenario reaching a level of over 13.69 MTOE in 2022, 40 MTOE in 2032 and 104.48 MTOE in 2042. The corresponding capacity levels for RE technologies were found to be of the order of 105.34 GW in 2022, 285.87 GW in 2032 and a whopping 693.55 GW in 2042. The estimate for the year 2040 was 510 GW, which is closer to those put out
by the NITI Aayog. Commensurate with these numbers, the share of energy supplied by RE in aggregate TPES was found to rise from the existing around 1% to 1.23% in 2022, 2.54% in 2032 and 5.18% in 2042. The predictions for BAU were found to be nearer to those in OPT in the early years, but the gap tended to widen over the longer run. RE generation was estimated slightly lower at 12.89 MTOE in 2022, 36.88 MTOE in 2032 and 91.88 MTOE in 2042. This amounted to a required capacity of 104.84 GW, 270.96 GW and 609.88 GW in these respective years. Moreover, these translated into a share of RE to TPES of 1.18% in 2022, 2.41% in 2032 and 4.58% in 2042. For the pessimistic (PES) case, the growth of RE was substantially sluggish, both in terms of energy supplied and capacity installations, as compared to BAU and OPT. It reached an energy supply level of 11.87 MTOE in 2022, 27.67 MTOE in 2032 and merely 50.90 MTOE in 2042. The associated capacity installation levels were estimated at 102.34 GW, 209.32 GW and 337.88 GW in 2022, 2032 and 2042, respectively. Accordingly, the share of RE to TPES was lower at 0.92% in 2022, 1.60% in 2032 and 2.31% in 2042.

Notably, relative to the initial official targets of RE capacity of 175 GW by 2022 projected by the government, our estimations show that these are likely to be achieved later in time. This could be ascribed change in the policy support that has moved away from feed-in-tariffs to auction-based purchases, lack of grid infrastructure and evacuation constraints (LiveMint, 28 Dec 2017) and, more recently, the strained India–China relations and the consequent impact on imports of RE equipment. Specifically, we get that the target is likely to be achieved during 2027–28 under the BAU, a bit earlier, in 2026–27 under the OPT case, and a lot later, in 2028–29 in the PES scenario. More recently, the government of India has revised its RE capacity target to 227 GW by 2022, which according to our estimation will presumably be realized by 2029–30 under both—the BAU and the optimistic scenario—and by 2033–34 under the pessimistic case.

Using these RE capacity addition requirements, assuming that the shares across different RE technologies (solar, wind and others) remain stable over the years of forecasting, and relying on select norms of job creation for the individual technologies, we obtained the following direct additional job creation potential for India. It was found that the incremental jobs by 2022 would be about 375 thousand, 379 thousand and 355 thousand in BAU, OPT and PES scenarios, respectively. In 2032, the cumulative additional jobs were expected to rise to 1695 thousand, 1814 thousand and 1205 thousand, respectively, under the three cases. In 2042, the cumulative job creation levels would rise to 4390 thousand, 5055 thousand and 2227 thousand respectively, in the case of BAU, OPT and PES.

Furthermore, the results of our research have important policy implications. The study pointed out that key macroeconomic factors are links with RE penetration in India. RE diffusion was found to have a positive association with GDP_CONS, CALL_RATE and RE_TO_FE_TARIFF and a negative one with FIS_DEF, NET_EN_IMP, POP, POP_ACCESS_PERCENT and UNEMP. These carry significant messages, such as a higher economic growth rate, a higher return on investment, and a more remunerative RE tariff would stimulate RE technology growth. Alternatively, higher subsidies to FE and greater reliance on energy imports
will inhibit RE diffusion. Similarly, for India, a case can be made for the fact that a higher population level or higher energy access could translate into greater reliance on FE rather than RE. Thus, for a clear switch to RE, a greater technological and policy push would be needed.

The study would be useful to policymakers in estimating the employment potential in general and green jobs in particular associated with RE generation. This is, of course, subject to the proviso that these numbers may not necessarily be incremental. To come up with the additional job creation potential of RE, a more extensive, economy-wide general equilibrium analysis may be required. Nevertheless, given that employment generation is high on the priority of the government, any quantified estimates of potential employment opportunities in the RE sector constitute useful co-benefits for policy formulation.

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