IRENA
International Renewable Energy Agency

REMAP
RENEWABLE ENERGY PROSPECTS FOR INDIA

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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Abbreviations

°C	degrees Celsius
AC	air conditioner
ADB	Asia Development Bank
AHEC	Alternate Hydro Energy Centre
BEV	battery electric vehicles
CEA	Central Electricity Authority
CEEW	Council on Energy, Environment and Water
CERC	Central Electricity Regulatory Commission
CO_2	carbon dioxide
C-Si	crystalline silicon
CSP	concentrated solar power
CTU	Central Transmission Utility
DALYs	disability adjusted life years
DDUGJY	Deendayal Upadhyaya Gram Jyoti Yojana
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessments
EIB	European Investment Bank
EJ	exajoule
ESCO	Energy Service Company
ETC	evacuated tube collectors
FICCI	Federation of Indian Chambers of Commerce and industry
FiT	feed-in tariff
FYP	Five Year Plan
GCAM	Global Change Assessment Model
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule
GOI	Government of India
Gt	gigatonne
GW	gigawatt
GW_e	gigawatt electrical
HVAC	heating, ventilation and air conditioning
ICT	information and communication technology
IEGC	Indian Electricity Grid Code
IEP	Integrated Energy Policy
INDC	Intended Nationally Determined Contribution
INR	Indian Rupee
IPCC	Intergovernmental Panel on Climate Change.
IPDS	Integrated Power Development Scheme
IREDA	Indian Renewable Energy Development Agency
IRENA	International Renewable Energy Agency,
JNNSM	Jawaharlal Nehru National Solar Mission
km/l	kilometres per litre
kWh	kilowatt-hour
kW_e	kilowatt-electrical
LCIG	Low Carbon, Inclusive Growth
LCOE	levelised costs of electricity
LPG	liquefied petroleum gas
m^2	square metre

m^3	cubic metres
mbd	million barrels per day
mpg	miles per gallon
MNRE	Ministry of New and Renewable Energy
MW	megawatt
NAPCC	National Action Plan on Climate Change
NBARD	National Bank for Agriculture and Rural Development
NISE	National Institute of Solar Energy
NIWE	National Institute of Wind Energy
NREA	National Renewable Energy Act
NRDC	Natural Resources Defense Council
NTP	National Tariff Policy
OECD	Organisation for Economic Co-operation and Development
PJ	petajoule
$PM_{2.5}$	Particulate matter of less than 2.5 micrometres
PNGRB	Petroleum & Natural Gas Regulatory Board
POWERGRID	Power Grid Corporation of India
PPA	Power Purchase Agreement
PV	Photovoltaic
RBI	Reserve Bank of India
REC	Renewable Energy Certificates
REmap	Renewable Energy Roadmap
RPO	Renewable Energy Purchase Obligation
RVEP	Remote Village Electrification Programme
R&D	research and development
SERCs	State Electricity Regulatory Commissions
SMEs	small and medium enterprises
SREC	Solar Renewable Energy Certificates
TERI	The Energy and Resources Institute
TFEC	total final energy consumption
t	metric tonnes
TTRC	tradable tax rebate certificate
TWh	terawatt-hour
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	The United Nations Industrial Development Organization
USD	United States dollar
VAR	voltage and reactive power
YLLs	Years of Life Lost
yr	year

EXECUTIVE SUMMARY

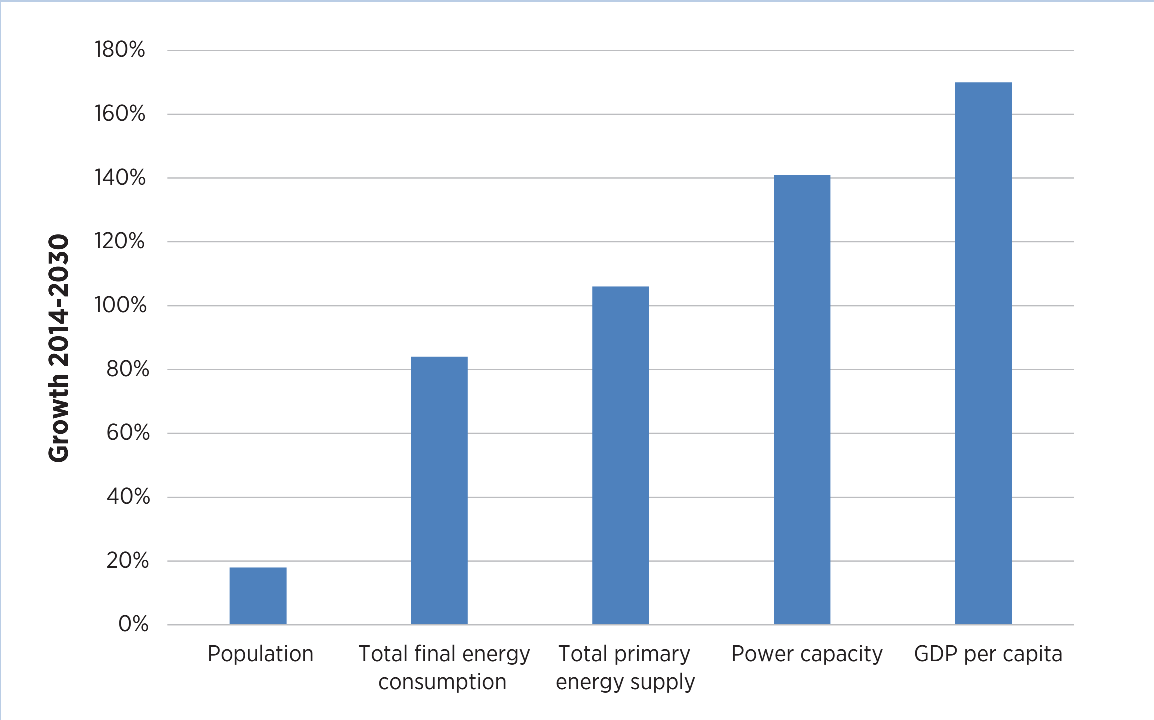
Rapidly rising energy demand and reliance on fossil fuels

India's energy needs are rising fast, with growth in electricity demand and other energy uses among the highest in the world. In one direction lies a future heavily reliant on fossil fuels; and in the other, a more diverse energy mix based on greater use of renewables. If India follows the first route, it risks locking its energy system into today's pattern – with increasing levels of air pollution, uncertainties around meeting its sustainability targets and concerns about supply and sourcing for coal, oil and natural gas. The government, contemplating a better path, has taken steps to increase renewables and move the country towards a sustainable future. Still, much remains to be done. This report provides a perspective on the changes required for India to achieve an affordable, secure, inclusive and environmentally friendly energy system.

India's socio-economic characteristics make it unique among the world's major energy-consuming economies. Per capita income is low, but is expected to grow quickly as India becomes the world's most populous country towards the end of this decade. Population and economic growth, combined with accelerating urbanisation, will increase the number of people living in cities and towns from approximately 435 million in 2015 to 600 million by 2030. Urban populations consume more energy and – importantly in India's case – significantly more electricity.

India's total demand for energy will more than double by 2030, while electricity demand will almost triple. Ensuring that India's growing population has access to energy, and meeting the country's ambitious economic growth targets, will require massive investments in the power, transport, buildings and industry

Figure 1: Growth in key economic and energy indicators for India, 2014 to 2030



Note: GDP – gross domestic product

Source: IRENA analysis

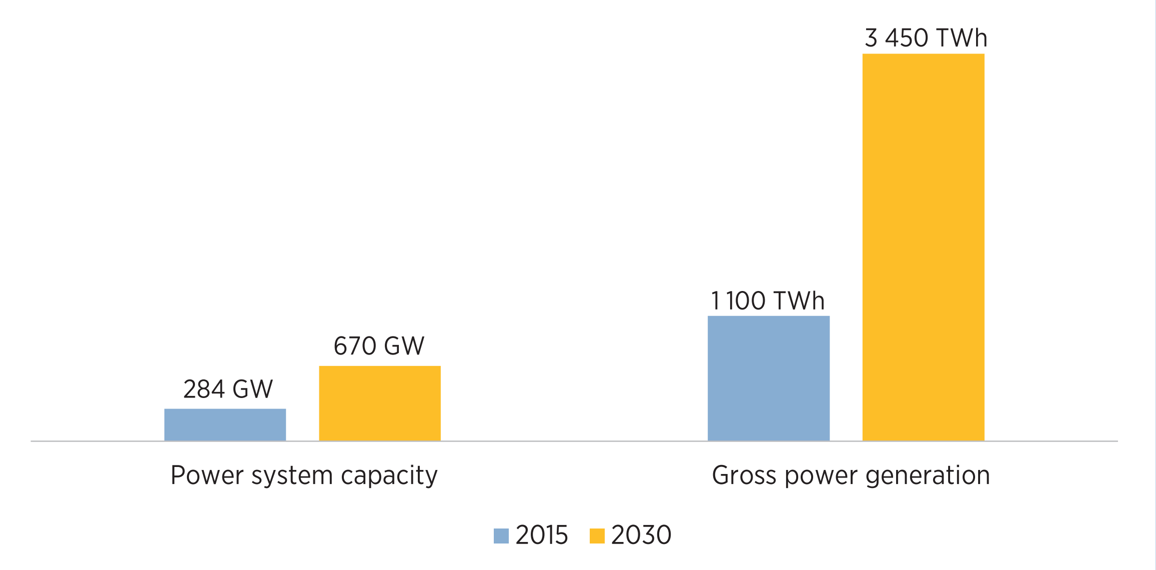
sectors. Despite rapidly growing demand and significant renewable energy potential, India is set to install less renewable power-generation capacity than China, Germany or the United States. India's electricity demand has grown by 10% a year over the past decade. Rapid growth is expected to continue, requiring massive investments in power-generation capacity and related infrastructure. This creates an important opportunity for renewable energy deployment, assuming the right policies are in place and policy makers start planning for it now.

Despite rapid strides in adding power capacity, India continues to be plagued by widespread energy poverty. Much of the population lacks access to clean and affordable energy. Estimates suggest that 80 million households, or more than 300 million people, have limited or no access to electricity. While the electricity grid now covers much of the country, reaching rural or remote areas with the necessary transmission and distribution infrastructure often remains a challenge. Supply constraints, therefore, persist.

In economic terms, the health impact of outdoor air pollution costs about 3% of India's annual gross domestic product, and indoor air pollution adds significantly to this total. The World Health Organization estimates that the number of deaths from ambient air pollution reached 700 000 in 2010. Besides, 400 million Indians (90% of them women) are exposed to respiratory, pulmonary and vision hazards associated with indoor air pollution from burning traditional biofuels. Both outdoor and indoor air pollution must be addressed through clean and sustainable rural and urban energy supplies.

If business continues as usual and present energy and environmental policies persist, fossil fuels will still dominate India's total energy mix in 2030 and beyond. Such a pathway, known as the *Reference Case* in this report, relies heavily on fossil fuels along with unsustainable and inefficient uses of bioenergy to meet most of the country's rising energy demand. While the growth of renewable power generation will accelerate, even faster increases are expected in the use of coal for industry, natural gas in residential and commercial buildings, and oil in transport. India's demand for coal is set to triple by 2030. As a result, the share of modern renewables could decrease from around 17% to only 12% of India's total energy mix by 2030. A large share of energy demand will need to be supplied by imports, increasing energy security risks. Growing reliance on coal imports will add to India's existing import dependency for oil and gas.

Figure 2: Power system capacity and generation, 2015-2030



Source: IRENA analysis

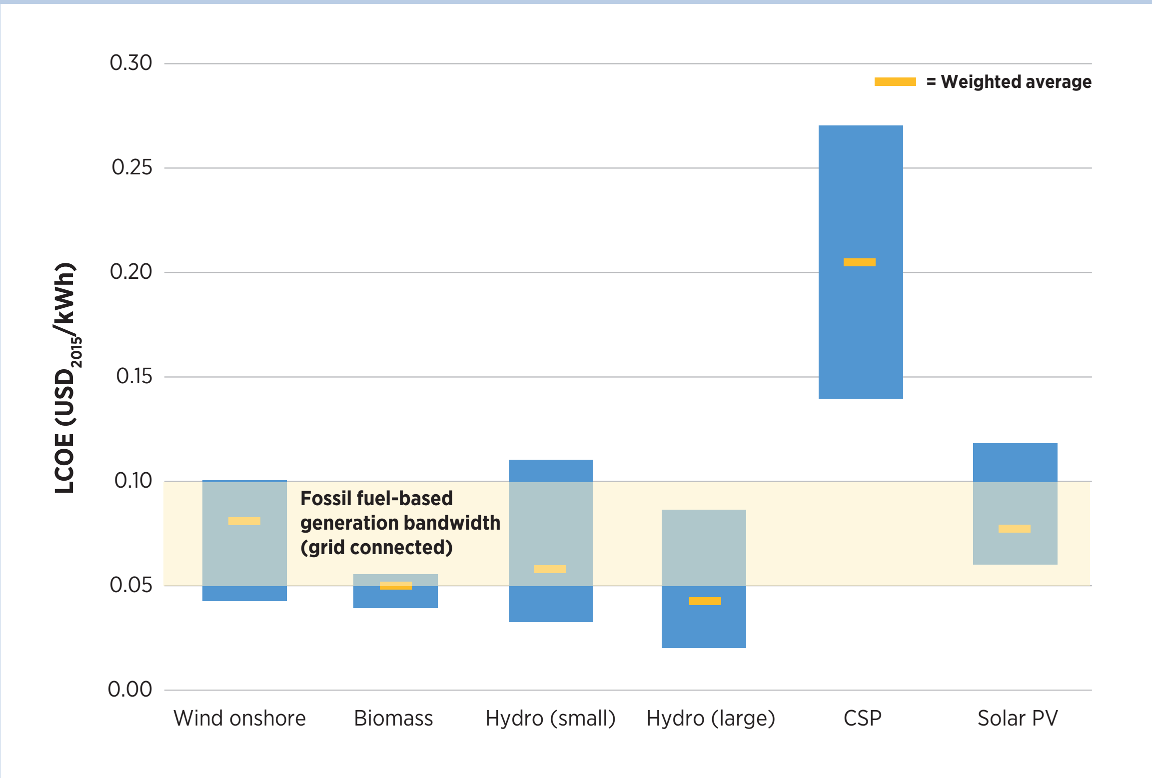
India's total gross power capacity will more than double from 284 gigawatts (GW) in 2015 to an estimated 670 GW by 2030, while electricity generation more than triples from 1100 terawatt-hours (TWh) per year to over 3 450 TWh per year. More than three-quarters of this new production is to be met by new coal-based capacity, according to current plans and policies (the Reference Case in this study). The planned growth in renewable power capacity, while significant, is low by comparison. India has set a target of 175 GW of renewable energy in power generation by 2022, but developments after that date are uncertain.

Policy makers have thus far overlooked the potential of renewable energy in heating, cooling and transport. Apart from the rising electricity demand, India has started to witness very rapid energy demand growth for heating, cooling and transport. National plans currently envisage the vast majority of this being met with fossil fuels. The significant renewable potential in these end-use sectors could also be harnessed to address India's energy supply challenges.

An affordable, secure and sustainable energy mix

With one of the world's largest and most ambitious renewable energy programmes, India can take a leading role in a renewable energy transformation both regionally and globally. The International Renewable Energy Agency (IRENA) has developed a roadmap to 2030 (REmap) to explore different energy technology options, highlighting ways to increase the uptake of renewable energy beyond the country's present policies and plans. This report has benefited from consultation and input over the course of two

Figure 3: LCOE range of commissioned or proposed renewable power systems in India, 2013-2015



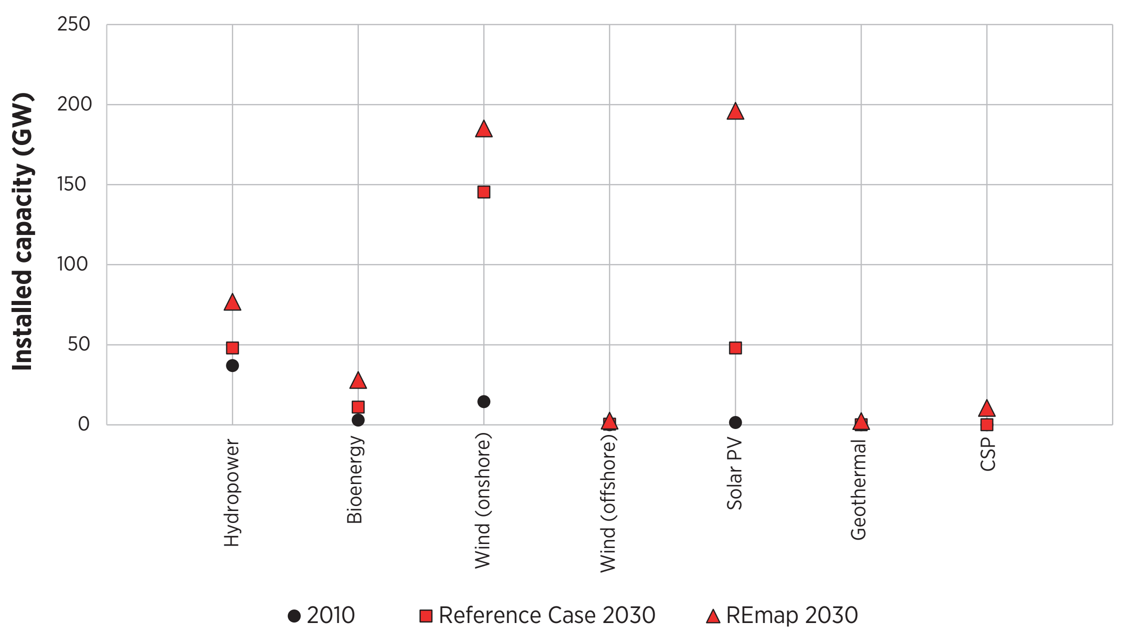
Based on IRENA (2015d), with updates to solar PV and wind data from IRENA (2016f)

Note: Discount rate of 10% is assumed. The horizontal black bars show the weighted average for the 2013-2015 period. Levelised cost of electricity (LCOE) years from India's Ministry of New and Renewable Energy (MNRE) and numerous other stakeholders. The country has already devoted considerable attention to renewables in its energy policy, becoming the first in the world to set up a ministry dedicated exclusively to new and renewable energy sources as long ago as 1992. Wind and solar policy and targets have, however, only achieved mixed success over the past two and a half decades. India has set a target to install 175 GW of renewable energy capacity by 2022, showing an awareness of how the marketplace for renewable energy technologies is changing.

Renewable energy has emerged, with growing frequency, as the least-cost option to meet India's rising energy needs. Wind, bioenergy, small hydropower and solar photovoltaics (PV) have all become increasingly competitive with fossil-fuel-based power generation: a 2016 tender for solar PV in India, for example, produced bids of around United States dollar (USD) 0.06-0.07 per kilowatt-hour (kWh) (Indian Rupee (INR) 4.78/kWh). But increasingly competitive production costs are not the only reason to promote renewable energy. Other motivations include reducing exposure to fossil-fuel price volatility, improving a heavily burdened grid infrastructure, further expanding access to modern energy services, curbing air pollution and meeting the country's sustainability targets.

India must help to drive a comprehensive solution to climate change. Its Intended Nationally Determined Contribution (INDC), submitted in October 2015, confirmed the country's previous, voluntary goal to reduce its greenhouse gas (GHG) emission intensity by 20-25% by 2020 (compared with 2005 levels) and went further to pledge a reduction target of 33-35% by 2030 and to increase the share of renewables in installed capacity to up to 40% by the same year. This report confirms that India can achieve these targets – and shows how far it can realistically go beyond them. In addition, the REmap analysis also shows that the country has the potential to contribute 10% of the global carbon dioxide (CO_2) emission mitigation potential from renewable energy by 2030 that is needed, when combined with increased energy efficiency, to set the work on a pathway consistent with the Paris Agreement.

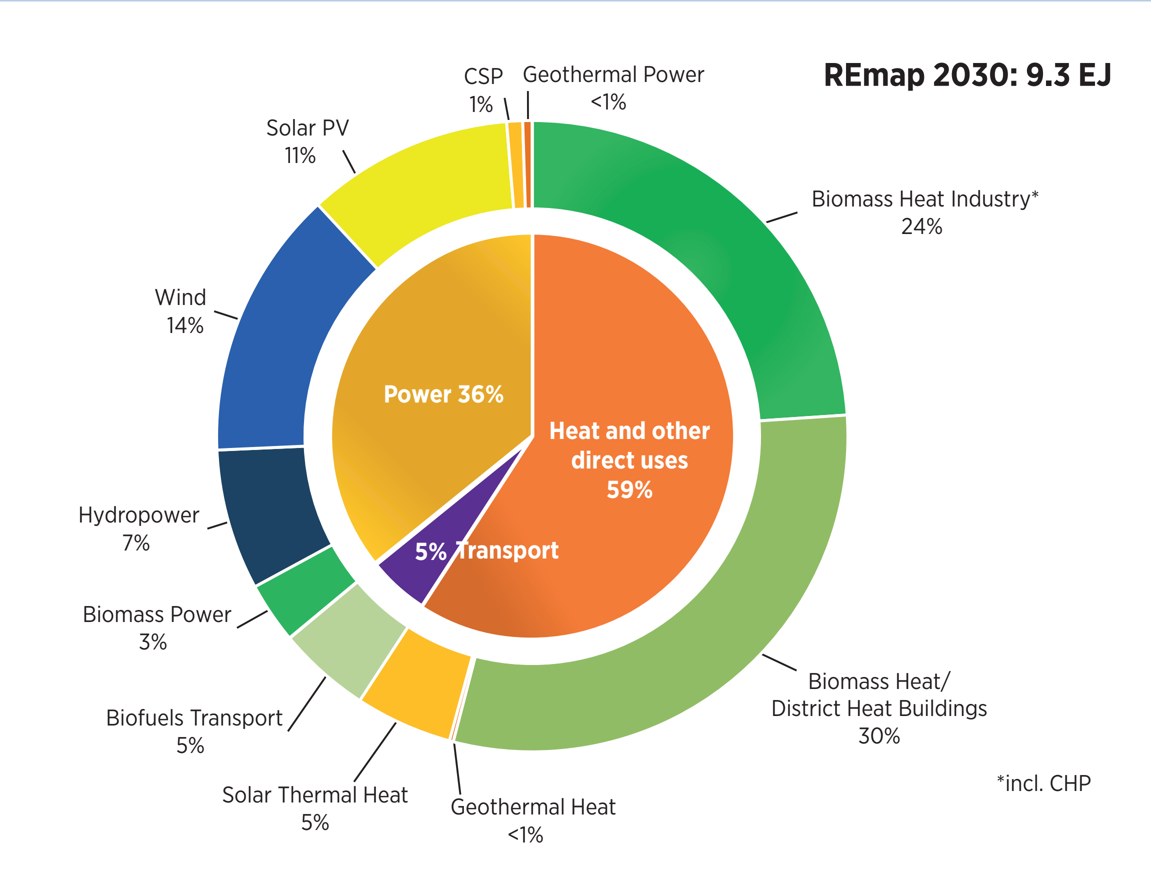
Figure 4: Renewable power capacity developments



Renewable power will maintain its strong growth in the Indian market reaching 35% share of generation, and 60% share of power generation capacity. The REmap Options – outlined in this report represent accelerated uptake of renewable energy beyond the country's current plans to 2030. Accordingly, total wind power capacity would reach 185 GW by 2030, almost eight times its level at the end of 2015. Solar PV capacity would increase even more than wind, a total installed capacity of almost 200 GW by 2030, with additional capacity in off-grid. Renewable power's share of total power generation capacity would increase to 60% in REmap, compared to 39% with expected developments (the Reference Case). Thus, India's INDC pledge of reaching a renewable energy share of 40% by 2030 is possible – and much more can be achieved. Similarly, the country can achieve a 35% share for renewables in power generation.

Integrating large shares of variable power generation requires planning, and developing a future grid. Much of the additional renewable electricity generation deployed in REmap would be variable (such as solar PV and wind), and often split into relatively decentralised generation units. As a result, variable renewable electricity would account for around 20% of total electricity generation, and 45% of installed power capacity in REmap by 2030, placing an increased strain on India's already stressed transmission and distribution grid. Solutions are needed to reinforce, expand and increase the grid and enhance the flexibility of power-system infrastructure, while incorporating storage options, demand-response, flexibility measures and reducing grid losses.

Figure 5: Breakdown of renewable energy use by application and sector in REmap in 2030



Source: IRENA analysis

India can raise its final renewable energy use to approximately 9.3 exajoules (EJ) by 2030 – equivalent to 222 million tonnes of oil or a quarter of the country's total final energy demand. Realising this potential, however, calls for more than increasing renewable power generation. Electricity would account for around only 40% of the country's total final renewable energy use by 2030, even with REmap Options put into effect. The remaining 60% of renewables would be used in heating, cooling and transport.

Bioenergy and solar energy are essential parts of the resource mix to realise India's renewable energy potential. Various forms of biofuel – for transport, as well as for generating electricity and heat – could account for 62% of total final renewable energy use in REmap in 2030. Solar (both photovoltaics and thermal), at 16%, would represent the second largest source of renewable energy use, followed by wind at 14%, and hydropower at 7%.

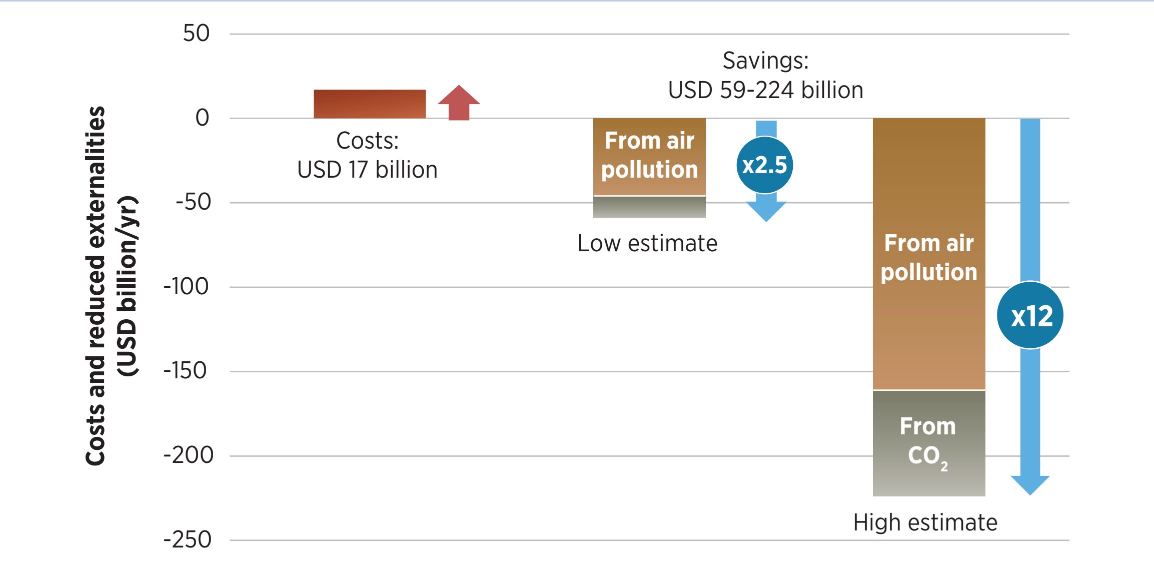
India could have 23 million electric four-wheeled vehicles and 300 million electric two-and-three-wheelers on the road by 2030. While biofuels are also becoming prominent, the use of electricity in transport needs to increase as part of the country's transition to renewables. Structural changes – including highly improved, increasingly sustainable options for both urban and longer-distance travel – could shift 7% of the country's passenger activity from individual vehicles to electrified mass transit.

India could become the fourth largest renewable energy market worldwide by 2030. It could account for 9% of all global final renewable energy use, after China, the United States and the European Union, assuming all countries achieve the potential highlighted in REmap studies. REmap – IRENA's global roadmap – indicates the technology and policy choices needed to significantly increase the share of renewables in the global energy mix by 2030.

Benefits of more renewable energy

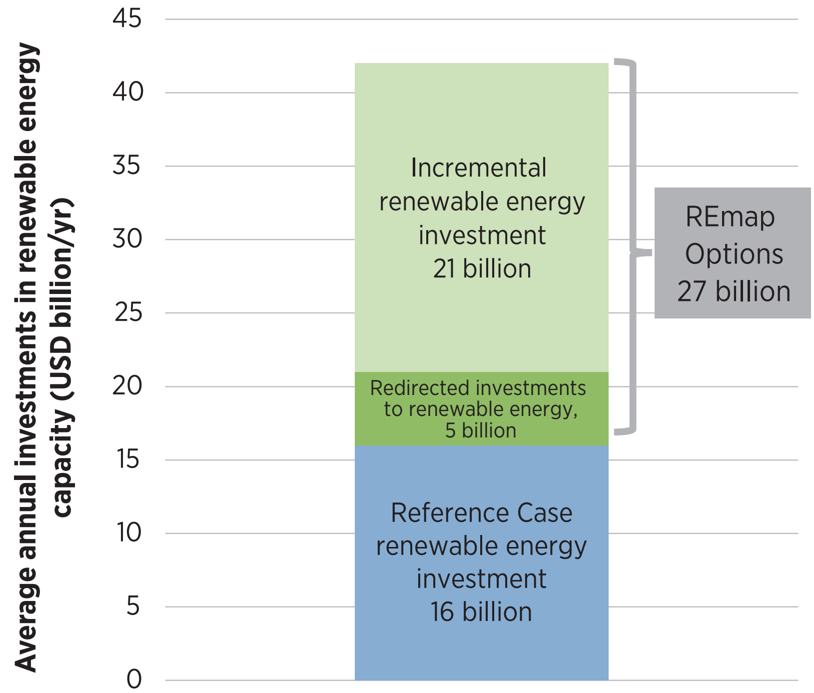
The higher renewable energy uptake taking place in REmap would result in savings twelve times higher than costs. This is the result of reduced costs from fossil fuel externalities related to air pollution

Figure 6: Annual costs and savings in REmap in 2030



Source: IRENA analysis

Figure 7: Annual investments in renewable energy capacity



Source: IRENA analysis

and climate change related savings due to renewable energy. Savings from reduced air pollution alone would total between USD 45 billion and USD 160 billion per year. Cutting energy-related CO_2 emissions by 750 megatonnes a year by 2030 would save another USD 13 billion–USD 63 billion per year. Other benefits of renewables – related to energy access, energy security and other macroeconomic factors (e.g. impact on the trade balance or gross domestic product (GDP)) – would add more to India's savings.

Accelerated energy efficiency improvements can ease India's supply constraints as well as yield a higher renewable energy share. Along with restraining overall demand, improved energy efficiency will help to meet India's ambitious GHG emission-reduction goals.

Studies indicate that India could have over a million jobs in solar energy and over 180 000 in wind energy by 2022. The prospect of rapid job creation, a major driver of policy in India, is among the strong macroeconomic benefits of the transition to renewables. To achieve this employment potential, the country must first meet an urgent, and currently unsatisfied, need for training and skills development in the renewable energy sector.

India has limited sources of fossil fuels and is not geographically adjacent to any major sources of oil or natural gas supply, making it vulnerable to geopolitical and geo-economic shocks. Local coal resources are of poor quality (with high ash content), prompting the country to turn increasingly to imports. This will add to concerns about the security of energy supply. Renewable energy offers the dual advantage of improving energy access for poor communities and bolstering energy security through diversified, and largely indigenous, sources of supply. The renewable energy technologies identified in REmap would lower the demand for coal and oil products between 17% and 23% by 2030.

Investment in renewables can help drive India's future economic growth. The energy transition envisaged in this report would involve average annual investments of USD 42 billion in renewable energy technologies between now and 2030. These include the USD 16 billion annually taking place in the Reference Case, and the USD 26 billion for additional renewable energy options identified in REmap.

Challenges for renewable energy deployment

Investment in renewable energy capacity needs to gain impetus to meet near-term targets, as well as achieve India's longer term potential. The investment challenge must address the higher upfront costs of renewables and the uncertainty of long-term revenue generation. Currency hedging can impede project development: investing in local currency adds 6-8 percentage points to the weighted average cost of capital, compared to investments made in US dollars.

While the transition to renewables calls for a more decentralised energy market, this entails its own set of challenges. One of these is public perception, which continues to favour centralised grid-based electricity: this is compounded by the absence of strong regulatory frameworks for distributed renewable energy. The big challenge for distributed renewables is to develop business and financing models that trigger rapid deployment and growth in ownership, particularly at the residential scale. At present, the decentralised market is characterised by numerous different subsidies and standards, which are often not monitored or implemented effectively.

Reliable, affordable, secure electricity production is essential to ensure continued industrial and commercial growth and satisfy rising residential demand. India's grid infrastructure is already strained and needs major improvements. Transmission and distribution losses are among the highest in the world: one-quarter of total electricity generation, rising as high as two-thirds in some states. As the share of variable renewables (solar and wind) increases, the pressure will continue to mount on India's already stressed transmission and distribution grid. Integrating this growing variability will require greater flexibility in power-system infrastructure and storage.

India needs to develop a skilled and knowledgeable workforce to realise significant growth in renewable energy. The lack of employees trained in the skills needed to construct and operate decentralised renewable energy systems is a continuing challenge and a barrier to meeting renewable energy targets.

Modern bioenergy can be a key source of heat and power, particularly for rural populations. There is a pressing need to increase access to modern energy sources for hundreds of millions of India's people. Households consume nearly 39% of total energy in India, with around three-quarters of this consisting of traditional uses of bioenergy, which is unhealthy and unsustainable. In contrast to such traditional sources, modern bioenergy offers important socio-economic and human health benefits, particularly through efficient cookstoves.

Transport accounts for more than half of India's total petroleum consumption, and electrification offers a way to reduce this demand. The country requires massive infrastructure investments to realise the potential of electric mobility and electrified mass-transit. It must also make the resulting electricity use secure and sustainable.

The interlinkage between water, energy and food supply is a major consideration in India. Demand for all three is rising fast as the population and economy grow. 79% of India's new energy capacity is expected to be built in areas that already face water scarcity or water stress.

Areas for Action

India is a country with a tremendously dynamic and vibrant renewable energy market. The country is seeing activity taking place on many fronts, with lots of on the ground innovation and technology development occurring, and policy measures being taken on many levels. However, there are key areas where additional solutions are needed for India to realise significantly higher renewable energy uptake.

The full report discusses these solutions and associated challenges in greater depth. It outlines five main areas of action:

1. Establishing transition pathways for renewable energy

Policy support for renewables needs to be durable and credible. It should be supplemented by intermediate targets that are monitored and, when necessary, revised. Specific advances would include:

- Improving the enforcement of renewable energy purchase obligations (RPOs);
- Creating conducive land acquisition policies; and
- Establishing priority-sector lending for renewables;
- Increasing outreach to banks and establish a Green Bank; and
- Promoting energy efficiency and renewable-based energy access.

2. Creating an enabling business environment

Improvements in the business environment and the development of new business models would help to scale up renewable energy technologies in India. Unstable policies, administrative delays, bureaucratic malpractice and the absence of clear information all hinder the growth of renewables in the country's energy mix.

Solutions include:

- Developing policy frameworks that provide a level playing field for renewable energy and facilitate the formation of markets;
- Ensuring transparent bidding processes, with rigorous selection criteria and broad stakeholder participation;
- Reduce or mitigate red tape. Existing policies are often shackled by slow-moving bureaucratic procedures that discourage interest from investors and project developers;
- Mobilise investments and reduce the costs of financing and currency risks by establishing risk mitigation instruments and other funds and facilities dedicated to renewables; and
- Reflect the true costs of fossil fuels in energy pricing by including externalities relating to air pollution and carbon emissions.

3. Integrating renewable energy

The Indian transmission and distribution grid is strained. Increasing its robustness and capacity is paramount for the transition to a sustainable energy future. Along with integrating renewable power, India needs a holistic approach to energy development that recognises the linkages between electricity, heating and transport needs. These linkages include both an emphasis on utilising renewable power in end-uses, but also better collection of biofuel wastes and their utilisation.

Some solutions include:

- Strengthen transmission grids, reducing grid losses, and improving the resilience of the power system by investing in more flexible, dispatchable capacity, demand-response, interconnectors and storage, as well as utilising transport/power-sector synergies.
- Giving incentives to renewable energy project developers, such as first access to the power grid through priority dispatch schemes;
- Encouraging the use of information and communication technologies for managing peak loads, especially in cities, which can also help to integrate renewable power;
- Supporting research into the synergies between electric mobility and renewable power, while developing renewable solutions that are applicable to India's often unique energy environment; and
- Creating a national bioenergy mission focused on helping to meet industrial energy demand, including increasing the collection of agricultural, forest and waste residues.

4. Managing knowledge

India needs better data and increasingly specialised skills and knowledge to maximise its renewable energy potential. Timely and robust data must be made available, and relevant skills must be developed.

Knowledge-management measures could include:

- Regular data collection from developers on the status of projects, capacity added per year, and the jobs created;
- Information platforms for lending institutions to encourage partnerships between banks;
- Improved air pollution emission standards raised to the level of those in Organisation for Economic Co-operation and Development (OECD) countries; and
- Programmes to increase the awareness of modern energy technologies and their maintenance.

5. Unleashing innovation

Renewable energy deployment around the world depends on a combination of technological improvements, new applications of existing technologies, systemic creation of new business or financing models, and new, more inclusive policy mechanisms. India, with its endemic problem of access to energy, has seen much innovation in low-cost renewable applications and is constantly evolving distribution and financing models.

Further ways to spur innovative solutions include:

- Incorporating renewable energy standards into the building codes for all new buildings in cities; and
- Promoting technological development in energy storage, energy monitoring and mechanisms to maintain a system balance.

1. INTRODUCTION

REmap is the global renewable energy roadmap of the International Renewable Energy Agency (IRENA). It shows how accelerating the penetration of renewable energy in individual countries could contribute to doubling its share of the global energy mix by 2030.

Key factors in achieving such a doubling include increased use of wind and solar technologies, greater electrification, and the use of biomass for heating, cooking, power generation and biofuels. Based on analysing 40 countries, representing 80% of global energy demand, REmap suggests that existing and future renewable energy expansion, as currently planned, will result in a 21% share of total renewables worldwide in 2030 (IRENA, 2016a). A doubling would result in a 36% share, so there is a 15% gap (World Bank, 2015). Each country will play a role in the global doubling, but this does not mean that every country would double its renewable energy share.

REmap is the result of a collaborative process between IRENA, national REmap experts within the individual countries and other stakeholders. The current report focuses on the actual and potential role of renewable energy in India, a major energy producer and consumer, which accounts for a growing share of carbon dioxide (CO_2) emissions. India is one of the world's largest energy consumers with a total final energy consumption (TFEC) of 17.4 exajoules (EJ) in 2010, 5% of the total global TFEC (International Energy Agency (IEA), 2014). India's TFEC is growing on average by 5% per year and stood at more than 20 EJ in 2014. The country is home to 16% of the world's population, has very low per capita energy consumption and is growing rapidly – so many see it as one of the world's largest sources of increased energy demand in the coming decades.

India's TFEC is projected to more than double between 2010 and 2030, according to the baseline scenario of the Planning Commission of the Government of India (GOI, 2014b). Over the same period, – according to this study and estimates by the Council on Energy, Environment and Water (CEEW) – the share of modern renewables in India's TFEC would decrease from 17% in 2010 to 12% in 2030 (excluding traditional uses of biomass[1]). This Reference Case is conservative on renewables and does not include all the accelerated commitments, such as in India's Intended Nationally Determined Contribution (INDC).

India has significant potential to go further if all the potential renewable energy options identified in REmap are deployed in addition to those in the Reference Case. The deployment required to fill the gap is called the 'REmap Options:' these include – but also go beyond – meeting India's commitments in the INDC. Given the size of the country, renewable energy technologies – and their related potentials – vary from region to region: which include geothermal, wind and various forms of solar and biomass.

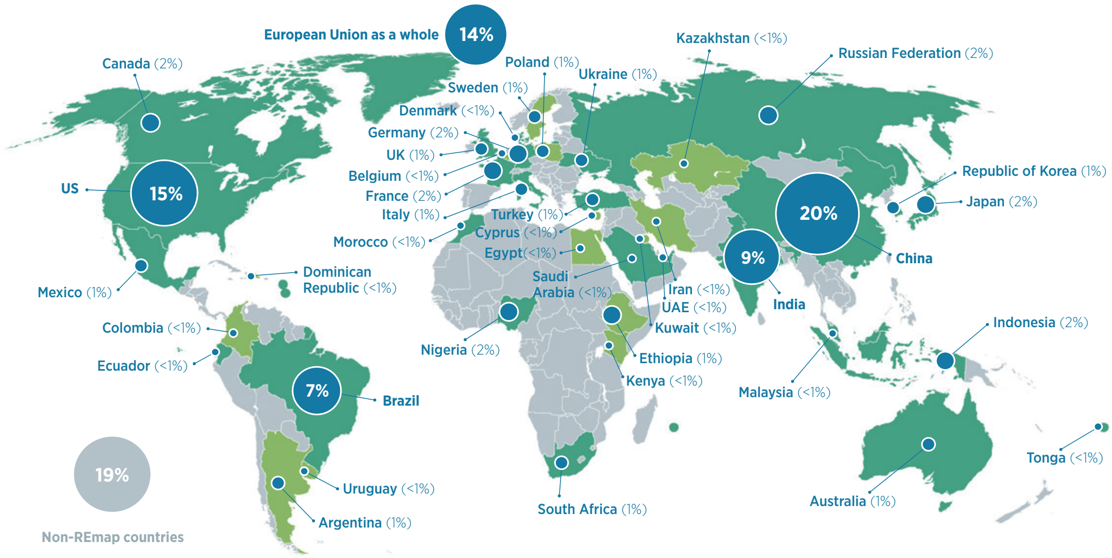
This national potential is of global importance. Figure 8 provides a breakdown of total renewable energy use across the 40 countries that have developed REmap Options. Four countries account for half of the total renewable energy that could be consumed by 2030, and if the European Union (EU) is considered the share rises to two-thirds. India would be the third largest country consuming renewable energy, accounting for 9% of the global total. So engaging India – together with the other largest users such as Brazil, China, the EU and the United States (US) – is essential if the goal of doubling renewable energy's global share is to be achieved.

Four countries (Brazil, China, India and the US) could account for half of global use of renewable energy by 2030

The objective of this report is to provide detailed background data, and the results of the India REmap country analysis, and to then make suggestions as to how these results could be translated into action.

1 Estimates for traditional uses of biomass vary widely depending on the source.

Figure 8: Contribution of countries to total global renewable energy use in REmap in 2030



Note: Percentages indicate how much renewable energy each country consumes in 2030 if a doubling of the renewable energy share is achieved. Based on IRENA estimates.

Source: IRENA (2016a)

This report starts with a brief description of the REmap methodology (Chapter 2). It continues by explaining the present energy situation and recent trends of renewable energy use (Chapter 3). Chapter 4 discusses the current policy framework and drivers for renewables in India. Chapter 5 discusses the potential of different renewable energy resources in India. Chapter 6 provides details of the India Reference Case findings – the business-as-usual scenario – to 2030. Chapter 7, the heart of the report, quantifies the REmap Options – the potential to go beyond the uptake of renewable energy outlined in the Reference Case. This is followed by a discussion of the opportunities and barriers for renewable energy use in India (Chapter 8), while Chapter 9 provides policy recommendations for accelerating renewable energy uptake.

2. METHODOLOGY AND DATA SOURCES

This section explains the REmap methodology and provides information about the background data used for the analysis of India. Annexes A-G provide the data and background assumptions in greater detail.

REmap is an analytical approach for assessing the gap between current national renewable energy plans, additional renewable technology options potentially available in 2030, and the Sustainable Energy for All (SE4All) objective of doubling the share of global renewable energy by 2030.

As of March 2016, 40 countries representing 80% of global energy use, are included in Remap: Argentina, Australia, Belgium, Brazil, Canada, China, Colombia, Cyprus, Denmark, the Dominican Republic, Ecuador, Egypt, Ethiopia, France, Germany, India (the present study), Indonesia, Iran, Italy, Japan, Kazakhstan, Kenya, Kuwait, Malaysia, Mexico, Morocco, Nigeria, Poland, the Republic of Korea, the Russian Federation, Saudi Arabia, South Africa, Sweden, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom, the US and Uruguay.

The analysis starts with national-level data covering both the power generation and end-use energy demand (in buildings, industry, transport and agriculture). Current national plans, using 2010 as the base year of this analysis, form the starting point.[2] The Reference Case represents policies in place or under consideration, including any energy efficiency improvements contained in these projections. It includes the TFEC of each end-use sector and the total generation of power and district heat sectors, and a breakdown by energy carrier for the period 2010–2030. The Reference Case for India was based on the estimates from the Planning Commission of the Government of India (GOI, 2014b) and the CEEW. Where necessary, 2010 IEA energy balances for India have been updated with information originating from other national sources or other estimates. The Reference Case assessment was prepared before the release of India's INDC in late 2015. The choice of this approach for the selection of what constitutes a Reference Case was made based on discussions with the Ministry of New and Renewable Energy (MNRE), as many of the aims of India's INDC are consistent with an accelerated renewables case.

Once the Reference Case was prepared, additional technology options were identified, known in this report as the REmap Options. The choice of an options approach instead of a scenario one is deliberate: REmap is an exploratory study, not a target-setting exercise.

The sources of the REmap Options for India originate from a range of research that includes:

- For the power sector: Planning Commission (GOI, 2014b) and Global Change Assessment Model (GCAM) estimates of the CEEW, and India's INDC;
- For heating (in the buildings and industry sectors): Solar Water Heaters in India (GOI, 2010) and the IRENA renewable energy in industry roadmap (IRENA, 2014b) with its accompanying data;
- For the transport sector: Planning Commission (GOI, 2014b), Vision 2020 – A Blueprint for Railway Electrification Programme (GOI, 2011), and National Electric Mobility Mission Plan 2020 (GOI, 2012) were mainly used; and
- Additionally, expert opinions from MNRE, IRENA and external authorities were incorporated into the analysis. These were primarily the sources of some biomass, off-grid and renewable power technology assessments.

IRENA has developed a REmap tool that allows users to input data into an energy balance for 2010, 2020 and 2030, and then assess technology options that could be deployed by 2030 that are consistent with an accelerated deployment of renewable energy. A detailed list of these technologies and the related background data are provided online, in addition to

2 To the extent data availability allows, information for more recent years (*e.g.* 2013, 2014) is provided where relevant.

what is contained in the Annexes to this report. The tool includes the cost (capital, operation and maintenance) and technical performance (reference capacity of installation, capacity factor and conversion efficiency) of renewable and conventional (fossil fuel, nuclear and traditional use of biomass) technologies for each sector that is analysed: industry, buildings, transport, power and district heat.

Each renewable energy technology is characterised by its costs, and the cost of each REmap Option is represented by its substitution cost – the difference between the annualised cost of the REmap Option and that of a conventional technology used to produce the same amount of energy, divided by the total renewable energy use in final energy terms (in 2010 real US Dollar (USD) per gigajoule (GJ) of final renewable energy).[3] This indicator provides a comparable metric for all renewable energy technologies identified in each sector.

Substitution costs are the key indicators for assessing the economic viability of REmap Options. They depend on the type of conventional technology substituted, on energy prices and on the characteristics of the Option. The cost can be positive (incremental) or negative (savings), as many renewable energy technologies are already cost-effective compared with conventional technologies, or could be so by 2030 as a result of cost-reduction driven by technological learning and economies of scale.

Based on the substitution cost and the potential of each REmap Option, country cost supply curves were developed from two perspectives – government and business – for the year 2030. In the government perspective, costs exclude energy taxes and subsidies, and a standard 10% discount rate was used, allowing comparison across countries and aggregation of results on a regional, sector or global level. Estimating a government perspective allows for a country cost-benefit analysis and for comparison of the 40 REmap countries with each other; it shows the cost of doubling the global renewable energy share as calculated by governments.

For the business perspective, the process was repeated to include national prices (including, for example, energy taxes, subsidies and a national cost of capital of 12% for India) in order to generate a national cost curve, showing the cost of the transition as calculated by businesses and investors. Assessment of all additional costs related to complementary infrastructure – such as transmission lines, reserve power needs, energy storage or fuel stations – are excluded from this study. However, the report discusses the implications of infrastructure needs on total system costs, where relevant, based on a review of comparable literature.

Throughout this study, the share of renewable energy estimated is related to TFEC.[4] It includes all six forms of renewables: biomass, geothermal, hydropower (small and large), ocean, solar and wind. It can be estimated including, or excluding, traditional forms of biomass: if they are excluded, the share would refer only to modern renewables. It can be estimated for the total of all end-use sectors of India or for each of them individually (with or without the contribution of renewable electricity). The share of renewable power generation is also calculated. Further details of the REmap methodology can be found online in IRENA's REmap webpage at: *www.irena.org/remap* and in the REmap global reports (IRENA 2014a, 2016a).

This report also discusses the financial needs and avoided externalities that relate to renewable energy. Several financial indicators are developed:

Incremental system costs: This is the sum of the differences between the total capital (in USD/yr) and operating expenditures (in USD/yr) of all energy technologies based on their deployment in REmap and the Reference Case in a given year;

- Incremental investment needs: This is the difference between the annual investment needs of all REmap Options and the investment needs of the substituted conventional technologies. Investment needs for renewable energy capacity are estimated for each technology by multiplying its total deployment (in gigawatts (GW)) to deliver the same energy service as conventional

3 Indian Rupee (INR) was equivalent to 0.0219 US Dollars (USD) in 2010.

4 The share of renewable energy share is estimated by dividing total final renewable energy use by the TFEC. Total final renewable energy use includes: (i) total renewable fuel use in end-use sectors to generate heat (process heat, space/water heating, cooking, etc.); (ii) renewable motor fuels in the transport sector; and (iii) total power and district heat consumption generated from renewable sources.

capacity and the investment costs (in USD per kilowatt (kW)) for the period 2010-2030. This total is then annualised by dividing the number of years covered by the analysis;

- Subsidy needs (also labelled as 'investment support' in the report): Total subsidy requirements for renewables are estimated as the difference in the delivered energy service costs for the REmap Option (in USD/GJ final energy) relative to its conventional counterpart multiplied by its deployment in a given year (in petajoules (PJ) per year).

- External effects related to CO_2 emission reductions and improvements in outdoor and indoor air pollution from the decreased use of fossil fuels have also been estimated. As a first step, CO_2 emissions from fossil fuel combustion are estimated for each sector and energy carrier, multiplying the energy content of each type of fossil fuel by its default emission factors (based on lower heating values) as provided by the Intergovernmental Panel on Climate Change (IPPC) (Eggleston et al., 2006). Emissions were estimated separately for the Reference Case and REmap: the difference between them yields the total net CO_2 emission reduction from fossil fuel combustion due to increased renewable energy use. A carbon price range of USD 17-80 per tonne of CO_2 is assumed (IPCC, 2007) and is applied only to emissions of CO_2, and not for other greenhouse gases. According to the IPCC (2007), the carbon price should reflect the social cost of mitigating one tonne of CO_2 equivalent in GHG emissions.

The external costs related to human health are estimated separately, which excludes any effect related to GHG emissions. Outdoor air pollution is evaluated from: outdoor emission of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter of less than 2.5 micrometres (PM2.5) from fossil fuel-based power plant operation; and outdoor emissions of NOx, and PM2.5 from road vehicles

To evaluate the external costs related to outdoor emissions of SO_2, NO_x and PM2.5 from fossil power plant operation, the following parameters were used: the emission factor (i.e. tonne per kWh for 2010 and 2030 taken from the International Institute for Applied Systems Analysis (IIASA) GAINS database ECRIPSE scenario (IIASA, 2014)); and the unit external costs (i.e. Euro-per-tonne average for the EU, adapted for India from the EU CAFE project (AEA Technology Environment, 2005)). Values for the potential differences in external effects between the EU and India are accounted for based on the difference in gross domestic product (GDP). An extended version of the methodology of the REmap analysis can be found online.[5]

5 www.irena.org/remap

3. RECENT TRENDS FOR RENEWABLE ENERGY AND THE PRESENT ENERGY SITUATION

Key points

- India can take the lead in driving the energy transformation both regionally and globally with one of the largest, and most ambitious, renewable energy programmes anywhere in the world. It has set a target of 175 GW of installed renewable energy capacity by 2022, including 100 GW of solar, 60 GW of wind, 10 GW of biomass and 5 GW of small hydropower.

- Government agencies are producing increasingly strong financial support schemes for renewables. Support from regional and international development banks has reached over USD 1 billion per year. Most of the focus has so far been on generating renewable power. Efforts on end-use are concentrated around improving energy efficiency and enabling access to modern energy services.

- India's TFEC has been growing at around 5% per year over the past decade. In 2010 – the base year for this analysis – it stood at 17.4 EJ per year. Renewable energy's share of that was 40% – split into 17% for modern renewables and 23% for traditional uses of biomass for cooking in the residential sector. The share of modern renewable energy included 2.6% for renewable power, 6.9% for biomass industrial process heat and 7.8% for modern biomass for cooking.

- Total power generation has been growing at an average annual rate of 6% per year during the past decade – exceeding 1000 TWh in 2014/15, double the 2000 level of 500 TWh.

- By March 2016, India's installed power generation capacity had reached 302 GW: 69% of it is thermal. Most of the remainder is large hydropower (42.6 GW) and other renewables (37.4 GW). Nuclear power accounts for the remaining 2% (5.8 GW). The share of renewables fluctuated between 13% and 19% between 2000 and 2015, meeting 17% of electricity supply in 2015.

- As of 2012, 75% of India's population had reliable access to electricity. Annual growth in grid electrification has attained 2% per year, but renewables-based off-grid systems are often the most economical solution. There are a significant number of rice husk gasification mini-grids and solar systems, including solar-with-storage mini-grids.

- India's grid infrastructure is already strained and needs major improvements. Its transmission and distribution losses are among the highest in the world, averaging 26% of total electricity generation. When such non-technical losses as energy theft are included, average losses are as high as 50% in some regions.

- Bioenergy remains the main source of renewable energy in the buildings and industry sector. Solar heating, cooling and cooking technologies are also used. Total installed solar water heating capacity reached 8.61 million m^2 (6 GW) in 2014 and solar water heaters meet 0.1% of the building sector's total final energy demand. By March 2013, there were 4.75 million biogas and manure plants in India, around one third of the estimated potential. But the consistency and availability of data on the use of renewables for heating and cooling is mixed

- India submitted its INDCs to the United Nations Framework Convention on Climate Change (UNFCCC) in October 2015, pledging to reduce the emission intensity of its economy, by 2030, by between 33% and 35% from the 2005 level. It has also committed to increasing its share of renewable energy capacity to 40% by 2030. The Reference Case shows this share growing to 37%: the REmap Option increased it to 60%.

- India increasingly is importing fossil fuels. Its demand for coal is expected to reach 1300 million tonnes per year (Mt/yr.) (35 EJ) by 2025 with 15% of it (200 Mt) being met from other countries. The country's crude oil production has reached 1.6 EJ, and it imported an additional 7.9 EJ. Annual domestic production has been stagnant at 0.83 million barrels per day over past years, and the import dependency of crude oil and refinery throughput are 76% and 84.7%, respectively. The Twelth Five-Year Plan (FYP) expects imports to increase by 50% between 2012 and 2017. Total natural gas production was 1.3 EJ with 0.3 EJ being imported. Consumption of natural gas is growing the fastest among fossil fuels, increasing by 12% per year, between 2007 and 2012.

3.1 Recent developments and long-term objectives

India ranks sixth in the world in total installed renewable power generation capacity after China, the US, Germany, Spain and Italy. It recently set a target of 175 GW for 2022, which implies that renewable energy would then contribute close to 20% of the country's total power consumption. The Government has raised the increase in solar power capacity from 22 GW to 100 GW by 2022, while wind is to increase to 60 GW. There are also targets of 10 GW for biomass and 5 GW from small hydropower for 2022 (Cleantechnica, 2015a). No target for concentrated solar power (CSP) exists.

This would require 15 GW of annual solar installations in the next five years, slightly higher than China achieved in 2015. India's new government plans to use solar power to electrify the homes of over 300 million people who do not now have access to power by 2019, as part of enhancing its plans to implement the National Solar Mission (Cleantechnica, 2014b) using panels designed to light two bulbs and to operate a cooker and a TV set in each home (Bloomberg, 2014a; Cleantechnica, 2014b).

According to Desert Power India, the national target is to add 455 GW of renewable energy capacity by 2050. About two-thirds of this would be installed in desert regions in northern and western parts of the country. The plan is to use 5-15% of the wasteland available in these regions to realise their large potential for solar and wind. Using 95% of the available potential on 10% of the area would be equivalent to 271 GW of total solar photovoltaic (PV) capacity and 29 GW of total wind.

The new Indian government is pushing for investments in renewable power generation technologies amounting to USD 100 billion over the period to 2019. There is also strong financial support for renewables in the country. In 2015 clean energy investment increased to USD 10.9 billion, in line with expectations. This represented an increase from the previous two years, but was still below the 2011 record of USD 13.1 billion. The amount of support received from such institutions as the US Export Bank, KfW, the Asia Development Bank (ADB) and the European Investment Bank (EIB) has reached USD 1 billion in recent years. India is also to receive funds from the World Bank to support one of its first ultra-mega solar projects, with a total installed capacity of 750 megawatts (MW), in Madhya Pradesh. (Cleantechnica, 2014c). The Government is now permitting full foreign direct investment and is encouraging the transfer of foreign technologies, including renewables (GOI, 2014a): so far, co-operation frameworks have been established with 44 countries. (MNRE, 2016a).

A target of 4460 MW additional capacity has been set for 2015/16, just a quarter higher than the one set for 2014/15. The Government has allocated USD 400 million to facilitate deployment (Cleantechnica, 2015a). It is collecting considerable tax revenue from coal imports and production, which goes to the National Clean Energy Fund to finance renewable energy projects. Coal taxes have been doubled to USD 3.3 per tonne (t) of coal to increase revenue (Cleantechnica, 2015a). But the industry views the fund availability as limited, when set against the growing renewable energy targets (The Hindu, 2015).

So far, most of the focus on renewable energy is in the power sector, while efforts in end-use sectors are concentrated around improving energy efficiency. The Government has set a fuel economy standard for new cars and trucks: petrol mileage was projected to increase by 14% by the beginning of 2016, followed by a mandate to increase it by 38% between 2021 and 2022. The current average efficiency of 37.6 miles per gallon (mpg) (16 kilometres per litre, (km/l)) should increase to 42.8 mpg (18.2 km/l) by 2016/17, and 51.7 mpg (22 km/l) by 2021/22 as a result (GreenCarReports, 2014). The Jawaharlal Nehru National Solar Mission (JNNSM) Phase-II set targets of 15 million square metres of solar water heating collectors by 2017, and 20 million by 2022, respectively.

India should take a leadership role in driving the energy transformation both regionally and globally with one of the largest and most ambitious renewable energy programmes in the world

India submitted its INDC to the UNFCCC Secretariat in October 2015. In the past it had declared a voluntary goal of reducing the emission intensity of its GDP by 20% to 25%, from the 2005 level, by 2020, despite having no binding obligations for mitigation. The INDC pledged that India will increase this target from 33% to 35% by 2030, again from the 2005 level (Cleantechnica, 2014a). It also committed to increase its share in renewable energy to 40% of installed capacity by 2030. The INDC includes numerous specific goals, including increasing solar and wind energy to 100 GW and 60 GW respectively by 2022, biomass to 10 GW by 2020, and nuclear power to 63 GW by 2032.

3.2 Recent developments in the renewable energy sector

Power sector

Installed power capacity in India reached 284 GW in December 2015, and 302 GW in March 2016. Of the total 69% is thermal capacity (coal, natural gas and oil). Large hydropower makes up 42.6 GW and other renewables 38.8 GW, together they represent 27% of the total installed capacity (excluding off-grid and captive renewable power capacity). Nuclear power accounts for just under 2% at around 5.8 GW of capacity (MNRE, 2016b; Central Electricity Authority (CEA), 2016).

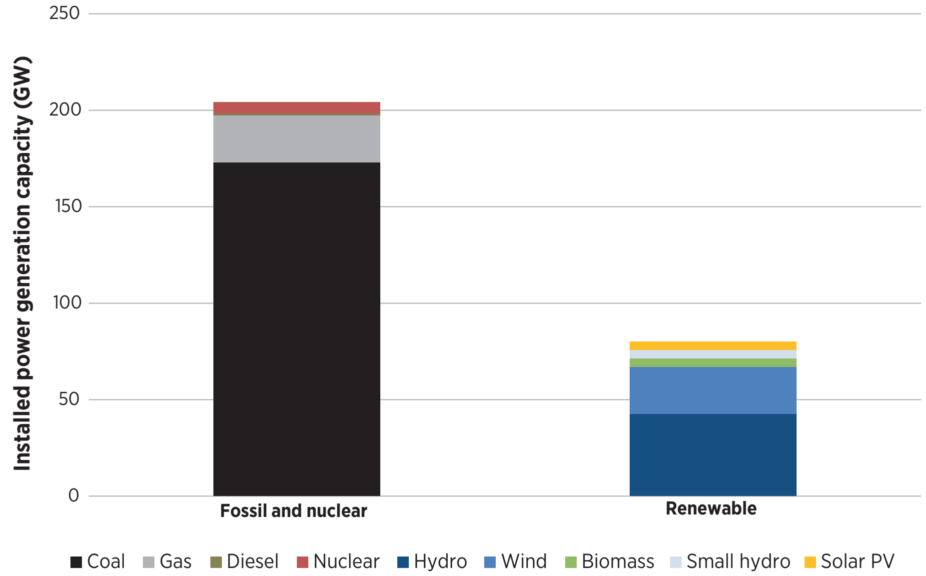
In the past five years, renewable energy capacity (excluding large hydropower) has experienced impressive annual growth that reached 20%. It has more than doubled since 2009 from 14.8 GW to 38.8 GW. When installed off-grid and captive renewable power capacity is included, renewable power capacity in India increases to around 42 GW. In 2015-16, 3.1 GW of new grid-connected renewable power capacity (excluding large hydropower) was installed. By the end of 2015, wind energy accounted for the largest share of total capacity at 25.1 GW, followed by solar power at 4.9 GW, biomass power at 4.6 GW and small hydropower at 4.2 GW (MNRE, 2016b).

Wind power has accounted for the majority of the capacity growth, with an average installation rate of 2 GW a year, though this fell to 1.65 GW in 2015/16. The year 2011 was exceptional, with 3.2 GW wind capacity installed. Annual solar PV capacity installation is increasing, averaging 900 MW per year since 2011 (2015/16 saw an annual 1.1 GW increase). Prior to 2011, annual installed capacity was below 30 MW (MNRE, 2014b). Indian Railways now has 10 MW of solar capacity in small solar PV plants in about 500 stations and buildings, and is targeting 1 GW solar power capacity over the coming years (Cleantechnica, 2014d).

Announcements for new solar PV projects indicate a significant scale up of utility-scale ones, including single projects as big as 1 GW (Cleantechnica, 2014d; 2014e; CEEW, 2015e). The utility National Thermal Power Corporation Limited has completed a successful 2 GW tender for solar, and additional tenders were expected into 2016. One of the cheapest solar power purchase agreements (PPA) in 2015 – at a rate of USD 0.077/kWh – was announced in Madhya Pradesh (Hindustan Times, 2015a), and more recent bids early 2016 came in at around USD 0.06-0.07/kWh.

The annual installation of biomass power averages 150 MW (excluding off-grid and captive power plants). Biomass is used in bagasse and non-bagasse cogeneration plants as well as in gasifiers, biomethanation and power-alone plants. There were more than 300 biomass cogeneration plants (500, including non-cogeneration) with a total installed capacity of 4.5 GW at the end of 2015. The majority of this capacity (close to 3 GW) is located in sugar mills producing power from bagasse. Other grid-connected biomass power and gasification plants follow with a total installed capacity of around 1.5 GW (MNRE, 2016b). Andhra Pradesh, Punjab, Uttar Pradesh and Uttarakhand – which are also the largest sugar cane producing states in India – account for a large share of

Figure 9: Installed power generation capacity in India



Note: Refers to the situation at the end of 2015

Source: MNRE (2015c); CEA (2015)

the total biomass (non-bagasse) and waste-to-energy generation capacity (MNRE, 2013; 2014b).

MNRE estimates showed that biomass-based grid-connected and off-grid power capacity targets have been missed. The key issues were the availability, collection, processing, and pricing of such agro-residues as rice husk, cotton stalk, coconut shells, soya husk, coffee waste, and sawdust. (AIREC/SSEF, 2014).

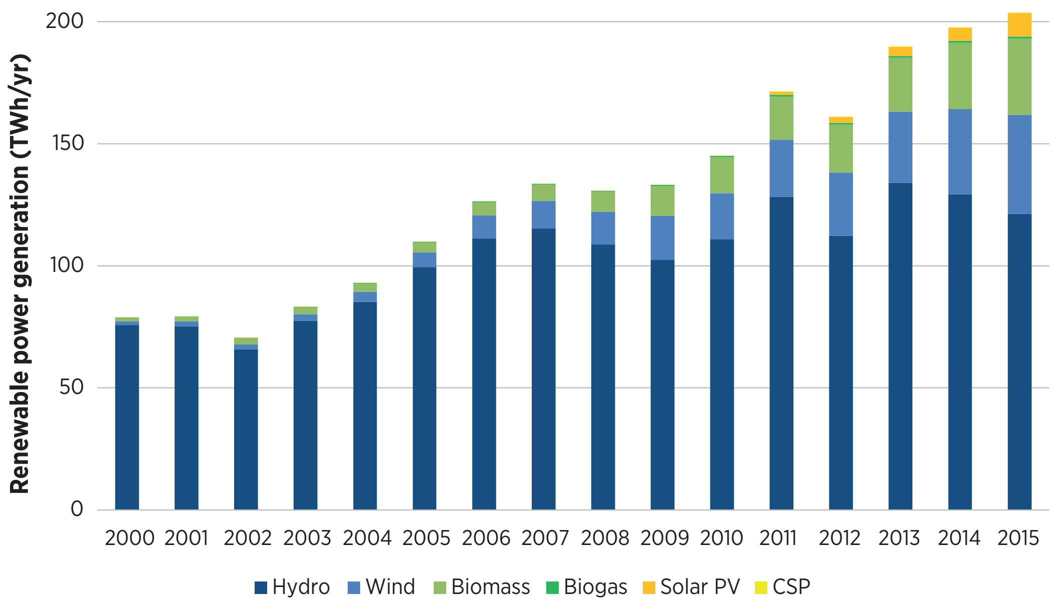
Biomass power generation receives about USD 100 million of investment each year in India: the various incentives to promote it include accelerated depreciation, concessional import duty, and excise duty. (see Box 1) (MNRE, n.d. a).

The total installed off-grid and captive renewable power generation capacity reached 1237 MW by the end of 2015 (excluded from Figure 9). Half of it (603 MW) was biomass (non-bagasse) cogeneration. The total installed capacity of biomass gasifiers stood at 179 MW, nearly all of it (161 MW) in industrial plants with little (18 MW) in rural areas. The capacity of solar home systems is growing fast: 55 MW capacity was installed in 2015. Waste-to-energy (147 MW) is the other important capacity installed (MNRE, 2015a).

Box 1: Bagasse-based CHP policy

The Indian Government is pursuing its bagasse-based cogeneration potential through financial and fiscal incentives. Plants benefit from a capital subsidy ranging from USD 24 000 to USD 28 800 for privately owned sugar mills. The subsidy is also available to existing co-operative or public sugar mills – up to a maximum of USD 1.3 million per project – and includes support for surplus power exported to the grid. Fiscal incentives are also provided, including 80% accelerated depreciation and concessional import and excise duties. Tapping the total industrial co-generation potential in India would require wider policy programmes that also included non-bagasse co-generation applications. Such measures as a more comprehensive co-generation feed-in tariff (FiT) system, that included biomass and other co-generation applications and open access without cross-subsidy surcharge, could help achieve greater deployment of co-generation (IEA, 2014).

Figure 10: Total renewable power generation, 2000-2015



Source: GlobalData (2016)

Total power generation in India has been growing at an average annual rate of 6% during the past decade. In 2015/16, total generation reached 1107 TWh (CEA, 2016b), more than double the level in the year 2000 of 500 TWh. The country now accounts for approximately 4% of total global electricity generation.

Renewable power generation has also more than doubled over the same period, from about 80 TWh in 2000 to over 200 TWh in 2015 (see figure 10). It represented 17% of total generation in 2015 made up of: 10% hydropower, 3% wind, 3% biomass, 1% solar PV and 0.1% CSP (GlobalData, 2016). Renewable power generation's share of the total fluctuated between 13% and 19% in the period 2000-2015.

Rural electrification

Seventeen percent of the world's population – an estimated 1.16 billion people – now live without access to electricity. An estimated 615 million of these people live in Asia, almost half of them – 304 million – in India. Renewables-based off-grid systems are often the most economical solution to their needs (Szabo et al., 2011; Breyer, 2012). By 2012, India's electrification rate had reached 75% and the urban electrification rate that year was 94%, with the rural areas reaching 67%. Growth rates for grid electrification in India – as in Indonesia and the Philippines – have reached 2% per year. (The simple arithmetic of expanding centralised grids is misleading, however, especially in view of the geographic realities of mountain ranges with limited access such as in northern India.) Fuel and light-related expenditures account for 7-10% of total household expenditures in India, significantly higher than in other developing countries (Dalberg, 2013).

Renewables for distributed generation are becoming common to minimise the impact of blackouts and load-shedding. India frequently experiences blackouts ranging from a few to eight hours per day, as a result of inadequate transmission and distribution capacity, as well as energy theft. Some cities and states have load shedding schedules, giving some populations access to electricity for only 4-6 hours per day. Kerala, for example, has load-shedding scheduled between 6-10 p.m. each day. So households are adopting renewables to secure their electricity supply during these hours, and manufacturing industry is installing biomass supplies and other renewable units to ensure continuous power to their businesses.

Bringing electrification to more than 90% of India's rural population would require USD 90 billion -190 billion in total investment between 2010 and 2030, mainly in transmission grids (Daioglou, V., et al., 2012). Mini-grid and off-grid systems offer an important alternative for reducing these investments, and India is already a leading country for off-grid systems.

Off-grid systems play an increasingly important role in rural electrification in India. Mini-grids are seen as stepping stones towards centralised grid extension. The Jawaharlal Nehru National Solar Mission (JNNSM) is the main policy initiative promoting solar energy, including off-grid power development, but there are several other programmes for other renewable energy technologies.

About 860 000 solar home systems, and around 750 mini-grid systems, were installed in India by March 2012. The latter include 135 biomass rice husk gasification systems and 599 solar PV mini-grids, each with between 10 and 400 customers and a total capacity of 8.2 MW. Sales of solar lanterns in Asia amounted to as high as 3.2 million systems per year in 2011, much of them in India. Biomass-based power systems are promoted inter alia where a handful of companies are installing them. One company, Husk Power Systems, started in 2007, operated around 80 rice husk-based mini-grids in 2013: their capacity ranged from 32-100 kW and they provided electricity to over 200 000 people across 300 villages and hamlets.

Some 40% of the power required by India's 740 000 telecom base stations – averaging 3-5 kilowatt electrical (kW_e) each and requiring 2-4 GW of capacity in total – comes from the grid, the rest from diesel generators. The government mandated that half of rural sites be

Box 2: Renewable energy manufacturing in India

India's National Manufacturing Policy seeks to increase the contribution of manufacturing to 25% of GDP with a focus on 'greener and cleaner' technologies. The policy recommends that a green manufacturing committee apply objective criteria to identify such technologies, consistent with the National Action Plan on Climate Change (NAPCC). Yet, the Indian wind and solar manufacturing industries have seen significant fluctuations in the last decade. Once highly competitive, the solar sector has recently been unable to compete in the global market both on price and quality. This has led to a decline in exports and an increasing presence of foreign manufactured products in domestic installations.

Indian wind manufacturers are still able to meet domestic expectations. Both industries have had to rely largely on their overseas suppliers and collaborators. Indian manufacturers suggest that the high cost of finance, lack of working capital and an insufficient credit line also put them at a disadvantage. It has been noticed that – while the Indian wind sector is the more competitive of the two as a result of maturity over time – its solar counterpart has been propped up by the demand created by the MNRE's proposed minimum Domestic Content Requirement for all solar projects.

Domestic module manufacturing capacity stood at approximately 2.3 GW at the end of March 2014, but only 0.9 GW of solar PV plants were installed in India that year, a significant portion of them using imported crystalline silicon (C-Si) and thin film modules. At the time domestic PV cell production capacity, which amounted to approximately 1.2 GW, was close to overall PV installations during 2014. However the cell manufacturers were exposed to extremely low capacity utilisation, producing around 250 MW that year, because module manufacturers could source imported PV cells on account of their lower costs

The Chinese and other growing markets were supported by increased local deployment of renewables and policies that promoted research and development (R&D) and expansion of domestic manufacturing. These policies included co-ordination with state and local governments, providing low-cost finance, making significant economies of scale and ensuring the availability of such supporting infrastructure as cheap electricity and domestic sourcing of components. Indian manufacturers, on the other hand, faced a number of challenges such as high interest rates, imported machinery, high electricity costs, slow technology upgrade, and high lead times.

The domestic content requirement imposed to promote solar manufacturing has been controversial and widely debated, and has failed to be effective. One reason is that it favoured local manufacturing for crystalline silicon-based cells and modules and not thin-film. Secondly, the policy was focused on manufacturing rather than adding value. This meant that the focus was merely on making cells and modules, inadvertently ignoring the large value-creation opportunities further upstream and in the balance of the projects' systems. Thirdly, it ran the risk of attracting trade disputes from countries that considered such a policy to be in violation of World Trade Organization rules: the resulting global surge of trade disputes has created further uncertainty in an already fragile market. And finally, the policy was bypassed by other countries using their donor and export credit agencies to finance installations that used thin-film technology. Besides creating distortions, this created a false sense of financial comfort among developers while failing to prepare the domestic financial sector to take on a greater burden of financing solar projects in subsequent phases.

The domestic content requirement provisions were modified in the second phase of the National Solar Mission. They became technology-neutral but applied to only 375 MW of the 750 MW central government procurement of solar power in the first round of bidding. Subsequently, the GOI committed to providing financial support up to approximately USD 167/kW to central government public sector units for setting up large scale solar capacities with domestically manufactured panels (at around 10-15% of the installation's costs). The government has termed this scheme 'World Trade Organization compliant'.

Nineteen firms in India manufacture wind turbines in the 225 kW to 2 500 kW range. Indian manufacturing – representing a capacity of over 9.5 GW – caters to both domestic and global markets, providing systems to the US and countries in the Middle East, South Asia, Africa and Latin America. As average wind turbine size increases worldwide, Indian manufacturers are losing their share of the global export market. Once a large player, their export share of 12% in 2008, has since been on the decline. With the exception of one manufacturing company, no other wind or solar manufacturer has any exports from its Indian manufacturing base.

powered by renewables by 2015. By 2020, 75% of rural and 33% of urban stations will need to run on alternative energy (Scientific American, 2013). In 2013, 9 000 telecom based stations were operating on renewable electricity, and India installed 1 417 wind water pumps that year (IRENA, 2015a).

Transport sector

Global fuel ethanol production reached 97 billion litres in 2015 (RFA, 2016), of which India produced about 800 million litres or 0.8%. By comparison, its total ethanol production is about 2.2 billion litres, with the end-products of the spirits industry representing three-quarters (USDA, 2015). Its total fuel ethanol production ranks third among Asian countries, after China and Thailand. India is also the world's second largest sugar cane producer, and sugarcane molasses is the main raw material for its ethanol production (USDA, 2014). Meanwhile, national biodiesel production reached 135 million litres in 2015 (USDA, 2015). Typically, vegetable oil, animal fats and used cooking oils are used as feedstock for biodiesel production in India.

The government planned to achieve an ethanol blending mandate to 10% in 2015, up from just under 5% today. Government-owned petroleum companies – known colloquially as oil marketing companies (OMCs) – procured 550 million litres of ethanol in 2014, a slight increase from 475 million in 2013. If the mandate increase succeeds, production could reach up to 700 million litres (USDA, 2014). However, the goal of achieving 5% blending was for 2013, and is only expect to be reached by the end of fiscal year 2016, so achieving 10% looks unlikely in the near future (Business Standard, 2016).

There is growing government interest, largely driven by air pollution, in electrifying transport. It has allocated USD 12.5 million to accelerate the domestic production of electric and hybrid vehicles. This, combined with renewable electricity, could result in increasing the share of renewable energy in the national mix.

In early 2015, a memorandum of understanding was signed in the Punjab for constructing the first cellulosic bioethanol plant in India, using paddy straw as a feedstock, with a total capacity of 60 000 tonnes per year (75 million litres). Using this straw for biofuel production will minimise the environmental impact of burning it (Hindustan Times, 2015b).

Heating and cooling sectors

Bioenergy remains the main source of renewable energy in Indian buildings and industry, but the consistency and availability of data for the use of renewables in heating and cooling is mixed: data is not available for the most recent years.

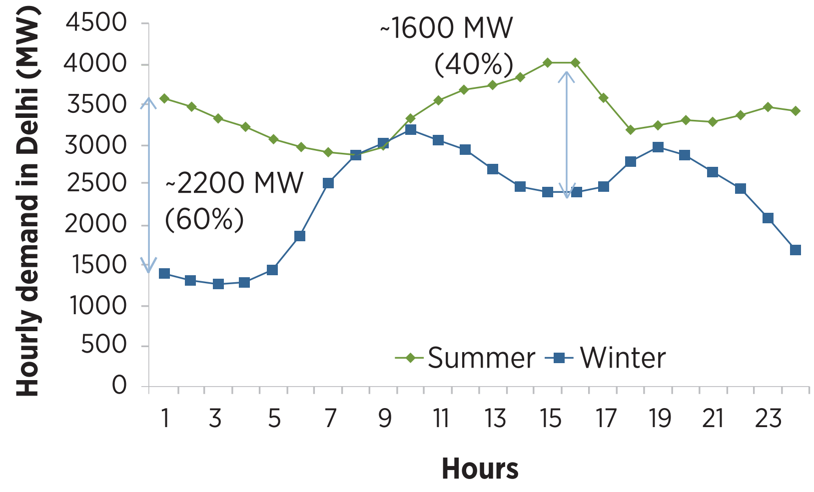
According to the IEA (2015a), a total of 7.3 EJ of solid biomass was used in India in 2012 – 6 EJ in the building sector and 1.3 EJ in the industry sector. The bioenergy used in the residential sector, mainly for cooking, is defined as a traditional use of biomass (see the next section for a detailed discussion). Bioenergy represented 55% of the total final energy demand of the industry and building sectors (excluding electricity use and the total energy demand of the agriculture sector).

As of March 2013, there were 4.75 million biogas and manure plants in India, about one third of the estimated potential of 12.3 million. Solar heating, cooling and cooking technologies are also used in the end-use sectors and there were about 70 concentrated solar cooking units, and 680 669 box type and 25 185 dish type solar cookers in India. (MNRE, 2015a).

In 2014, total installed solar water heating capacity reached 8.61 million m^2 (6 GW), and in that year, 0.53 million m^2 capacity was installed. This was higher than the target of 0.5 million m^2, but lower than the achieved installations in previous years, which exceeded 1 million m^2. Eighty percent of the total capacity is installed in the residential sector, 14% in the commercial sector and 6% in the industry sector (MNRE, 2014b). About three-quarters of the total installed capacity is flat-plate collectors, the other quarter is made up of evacuated tube collectors (ETC). Solar water heaters in India have an average capacity utilisation factor of approximately 14%. The result is total generation of about 7 TWh per year of solar heat, which represents about 0.1% of the building sector's total energy demand. Examples of the use of solar thermal in Indian industry include plants in such large energy-intensive industries as iron and steel or pulp and low-energy consuming textile or food plants. In 2013, there were 28 concentrated solar thermal plants in India for process heating: a new one was commissioned in October 2014 with a total concentrator area of 450 m^2 to provide process heat at 280 degrees Celsius (^{o} C) for a drug processing company.

Cooling is one of the largest energy consuming applications in Indian industry, with a current demand of about 35 GW. It is traditionally provided by electric units, causing significant spikes in electricity demand on hot days. Increasingly these units could be powered by renewable sources such as wind and solar PV: electricity production by the latter generally coincides well with cooling demand on hot days. Figure 11 gives an example of how cooling demand in New Delhi can result in an increased electricity load of around 1600 MW in summer compared to winter, and this effect is expected to increase as demand for cooling in cities rises. By 2013, however, there were fewer than five concentrated solar cooling units in India.

Figure 11: Hourly demand in MW for cooling in New Delhi for summer and winter



Source: Lawrence Berkeley National Laboratory (2012)

3.3 Base year renewable energy situation

Sector-level breakdown

The REmap analysis base year is 2010. India's total primary energy supply was then 29 EJ (excluding non-energy use of around 1.3 EJ) (IEA, 2015a).[6] In terms of final energy, this translates to 17.4 EJ. The buildings and industry sectors accounted for 41% each of this total, with 13% consumed by the transport sector and 5% by the agriculture sector (Figure 12). Electricity accounted for 12% of the TFEC. Industry accounted for nearly half of the total consumption, with one-third consumed in buildings and 18% by the agriculture sector, which for example, requires power for irrigation pumps.

This TFEC breakdown has changed in the past three decades (IEA, 2015a). In the 1980s building energy demand accounted for more than 60%, the industry sector's share was about 25%, and transport had a share of around 10%.

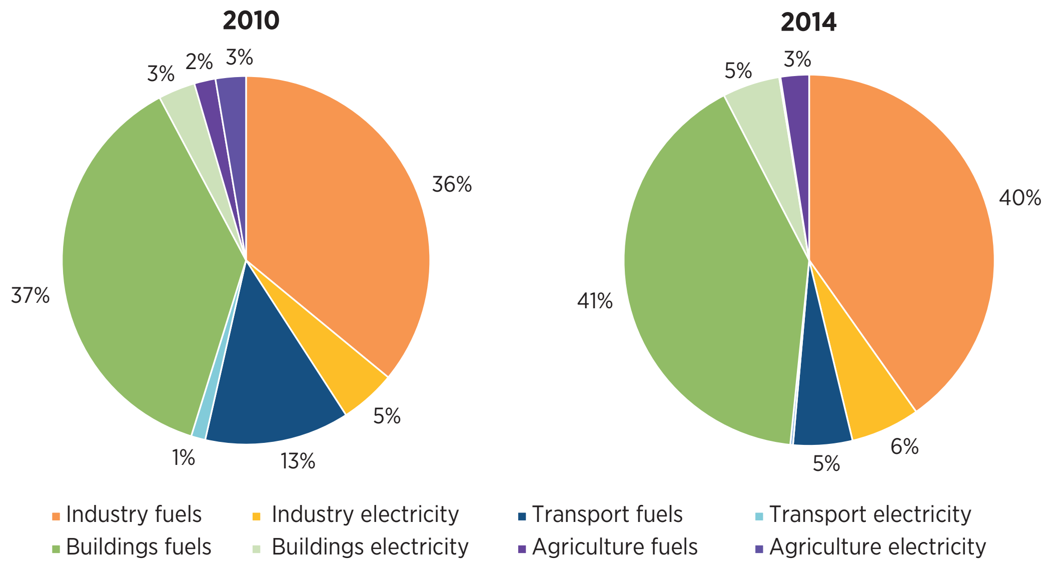
6 Primary energy supply refers to the direct use or supply of all energy carriers (*e.g.* crude oil) without their being converted or transformed to another form of energy (*e.g.* heat). It is therefore higher than TFEC, which only looks at the consumption of energy carriers such as fuels for the transport sector or electricity for appliances (see footnote 1).

In 2014 the shares are slightly different from what they were in 2010, which is partly due to differences in sources for statistics and energy growth. By then a larger share of the TFEC was consumed in the building sector, with 40% in the form of fossil fuels and biomass, and 6% as electricity. This shows the increasing use of electricity as electrification increases. Modern fuels include liquefied petroleum gas (LPG). The share of TFEC consumed in industry also increases from 37% to 41% for fuels, and 3% to 5% for electricity. Both agriculture and transport saw a decline in their relative shares. The share of electricity in the TFEC was relatively low, so the consumption of renewable electricity adds relatively little to the renewable energy share when expressed in TFEC.

Modern and traditional forms of renewable energy accounted for 40% of the TFEC in 2010. Distinguishing between the amount of biomass used in traditional versus modern forms is not easy, as little data is available about whether the cookstoves currently in use are modern or traditional. When traditional uses of bioenergy are excluded from the mix, modern renewables account for 16% of TFEC (IEA, 2015a).

Excluding the use of electricity, the share of renewable energy in India's building sector was 84%. This is because of the significant volume of traditional biomass used for cooking: when this is not counted as renewables, the

Figure 12: India TFEC breakdown, 2010 and 2014



Based on: IEA (2015a); MOSPI (2015)

renewable energy shares drop to 4%. By comparison, renewable energy use is 20% in the industry sector, as a result of various forms of gasifier, residue boiler and other specific applications (e.g. in small-scale steel mills). Its share in transport is negligible,[7] but 13% of total electricity generation was renewable in 2010.

India is leading in renewables for industrial applications, but somewhat lagging in the power and building sectors

The building and industry sectors are equally the largest energy users in India, each accounting for 41% of its TFEC. Cooking accounts for the majority of total energy demand in both rural and urban areas. Electricity demand has been growing at annual rates reaching more than 10% in the past decade. In 2010, India's building sector consumed 236 TWh electricity, of which 72% was in the residential sector and 28% in the commercial sector. Fans (34%), lighting (28%) and refrigeration (13%) account for three-quarters of total power demand in the residential sector, while in commercial buildings 55% of the total power demand is related to heating, ventilation and air conditioning (HVAC) systems (GOI, 2014b). India has the largest air conditioning demand worldwide, accordingto Davis and Gertler (2015), with an average of 3 120 cooling degree days[8] (Pune, for example, has 2 485 cooling degree days, Mumbai has 3 567) (GBPN, 2014). Its total potential cooling demand is more than 12 times higher than that of the US. However, as in other low-income countries, the use of air conditioning is still limited. The same study also shows that household income and space cooling adoption are closely related, especially in warmer areas: ownership levels increase by 2.7 percentage points per USD 1 000 increase in annual household income. So demand for cooling – and the installation of equipment to meet it – can be expected to increase significantly in the next few decades.

India's grid faces its peak at around 7 p.m., and cooling has a significant impact. Peak load in New Delhi, for example, is between 3-4 GW in summer and 1.3-3.2 GW in winter. Cooling demand is 40-60% of summer peak load (Shah, Wei and Phadke, 2015), and this peak will grow. The room air conditioner (AC) market has grown from one million in 2003 to 3.5 million in 2012, with split units accounting for three-quarters of the total. In 2010

7 The renewable energy share, excluding power and district heat demand, provides the contribution of renewable technologies in the sector's total fuel use only. This is important to know to exclude the effect of renewable power and district heating, which are often outside the boundaries of end-use sectors.

8 Degree-day is a measure of heating or cooling, which is the integral of a function of time that varies with temperature.

AC use in urban households reached the low saturation level of 3%. AC demand in India has been growing at around 20% per year in the past decade. Estimates show that related electricity demand could reach 239 TWh/yr by 2030. That would translate to a peak demand contribution of about 143 GW, or an increase in units from around 3.5 million to 116 million. Three hundred new coal-fired power plants of 500 MW each would be needed to power them. By contrast, there is a potential to reduce the demand by 40% with efficient ACs: these could reduce the need for 100 new coal-fired power plants, and have a peak-saving potential of 60 GW (Phadke, Abhyankar and Shah, 2014).

Air conditioning demand growth has averaged 20% over the past ten years, and by 2030 the number of AC units is expected to increase from around 3.5 million today to 116 million

India's industrial energy demand has been growing fast. Large shares of it come both from bulk materials production – such as cement, steel and textile fibres – and from small and medium enterprises (SMEs) that produce various goods from food products to textiles: indeed, much of India's bulk material production is from small-scale sectors. (The United Nations Industrial Development Organization, (UNIDO) says there are 388 energy-intensive SMEs manufacturing clusters). There are also about 13 million micro, small and medium-size enterprises (MSME) in India contributing about 45% of its total manufacturing output, and 40% of its exports. Nearly 70 million people were directly and indirectly employed in SMEs (Kumar, 2012).

In 2010, more than 90% of the transport sector's energy use was related to road transport, with 6% related to railways. 85% of its passenger activity was related to road transport with buses and omnibuses making up three-quarters of this total. The share of cars was low, at approximately 10%. The remaining passenger activity was largely related to rail transport, with aviation's share remaining less than 1% of the total. Meanwhile road accounted for 58% of freight transport, with rail taking the remaining 42%.

Every year India's railways transport 927 million tonnes of freight and every day they carry 21 million passengers. The Government is expanding railway systems in the congested western and eastern parts of the country. Improvement in the rail sector, which will shift freight traffic from roads to rail, and is one of the key determinants of energy use in transport: efforts are ongoing, but are likely to take a long time.

Car ownership in major cities ranged from as low as 10 cars per 1000 people in Aurangabad to as high as 175 cars per 1000 in New Delhi. Two-wheelers made up 75% of on-road passenger vehicles in 2011. Buses accounted for 75% of the total road-based passenger activity. They are also responsible for half of the total road passenger vehicle energy use, followed by cars/jeeps and two wheelers, which each account for 19% of energy demand (The Energy and Resources Institute (TERI), 2015).

Coal has played an important role in the Indian energy industry. It made up 42% of the total primary energy supply in 2010 and 70% of it was used for generating electricity, accounting for two-thirds of the total power generation of 960 TWh/yr. Generation from natural gas was 12% of the total, while and nuclear and oil products each accounted for 3%.

Hydropower accounted for 70% of total renewable electricity generation in 2010

Current issues faced by the Indian power sector include: capacity shortages in the order of 15% of peak power demand and 10% of total demand, with about 75% of all households being connected to the grid; regular blackouts; structural under-investment; and market and institutional failures. Besides, the average electricity price covers only a limited share of the average production cost. As a result, power is not used efficiently, and is being wasted – especially in the agriculture sector, where electricity is used excessively. Furthermore, the conversion efficiency of Indian power plants is quite low: the average gross efficiency of thermal power plants is about 30% or even less – according to a time series analysis of the 1990-2011 period (Hussey et al., 2014) – thanks to the high ash content of India's coal. The average age of the existing coal-based power plant stock is 13 years, and larger new coal power plant capacity is being rapidly added: the average capacity of the plants added in 2014 was 500 MW. These include an increasing number of new ultra large coastal power plants burning imported coal with lower ash content and higher conversion efficiencies.

Still, the average conversion efficiency of coal-based power generation is much lower than in other countries.

Traditional uses of biomass

The largest populations relying on the traditional use of biomass for cooking are found in the developing regions of Asia: by far the largest number of these people live in India. The total population relying on traditional biomass ranges from 700 million to more than 800 million (IRENA, 2013a).[9] Using biomass for cooking is inconvenient, and procuring the fuel takes time and effort – while its use in traditional cookstoves imposes severe ill effects on health. Women spend up to 7-8 hours per day in cooking, with 20% of that time devoted collecting fuel. Four hundred million Indians (90% of them women) are exposed to respiratory, pulmonary and vision problems associated with indoor air pollution from burning biomass. The pollution causes 875 000 deaths – and 16.9 million Disability Adjusted Life Years (DALYs), a measurement of overall disease burden – in India each year. About 525 000 of the total fatalities can be attributed to acute lower respiratory infections, the other 350 000 to chronic pulmonary diseases. One hundred and forty thousand children under the age of five die each year from indoor air pollution related diseases (Dalberg, 2013). Advanced biomass cooking stoves (or other options with clean fuels) can avoid 570 000 premature deaths in India – as well as 4% of India's total annual GHG emissions (Venkataraman et al., 2010). It is vitally important to obtain current, robust energy statistics for the traditional use of biomass and then identify realistic potential for substitution. There is a particular need for modern cook stove initiatives in Central and South India, where the scale and intensity of solid fuel use for cooking is high (Dalberg, 2013).

Available data for traditional biomass use in India is mixed. About 60-70% of the total population relied on solid fuels for cooking in 2010, and ten states account for three-quarters of the total solid fuel use in India (Dalberg, 2013). Three-quarters, or at least 700 million people, rely on biomass for cooking and heating (Fernandes and Mesquita, 2014). Other surveys (based on the 2011 Indian census) mention that between two-thirds and 70% of all households use traditional biomass.

Three-quarters of rural, and approximately 20% of all urban, homes in India use biomass fuel (Fernandes and Mesquita, 2014). The conversion to modern fuels has been relatively high in urban areas: two-thirds of the urban households, according to the 2011 census, used LPG for cooking: just 3% relied on crop residue and cow dung cake. By contrast, 86% of rural households use firewood, cow dung cake and crop residues.

India has the world's highest bovine population, which produces significant amounts of dung (Ravindranath and Balachandra, 2009). Wood and crop residues are other typical biomass feedstocks (Mukhopadhyay et al., 2012). According to the IEA (2015a), biomass accounted for around 8 EJ, or a quarter of India's total primary energy supply of 31.4 EJ per year in 2011. Eighty percent of this biomass use was in the residential sector. In the absence of detailed information, the IEA defines this as traditional uses of biomass burned in inefficient cookstoves or on open fires mainly for cooking, but also for water and space heating. In most cases, such biomass is unsustainably sourced.

The main challenges now being faced by the residential sector are access to, and the availability of, energy sources and the efficient use of energy (TERI, 2015). Average per capita expenditure on cooking fuels has been increasing, on average, by 9% per year, in both rural and urban areas. Cookstoves need to have region-specific characteristics to meet needs (Dalberg, 2013). Depending on cooking habits, India can be classified into five broad food zones which determine heat density, the equipment required and key cooking activities.

A modern cook stove programme was started in India in the mid-1980s and reached a peak dissemination rate of about 2.9 million stoves a year in the mid-1990s. By 2003, 55.2 million modern cookstoves had been disseminated, mainly to rural households. Some restaurants, hotels and other businesses used biogasifier cookstoves that were as efficient as any cookstove. There are also biogas plants, which burn a mixture of methane and carbon dioxide. Biogas, as a modern form of biomass, offers socio-economic and environmental benefits (Minde, Magdum and Kalyanraman, 2013) and by 2006, nearly 4 million biogas plants had been built for cooking in

9 In 2011, the total population of India reached 1190 million – 834 million living in rural areas. In the same year, the urban population was 358 million. There are 167 million rural households and 79 million urban ones. This translates to 5 and 4.5 people per household in rural and urban areas of India, respectively (Census Info India).

households (Ravindranath and Balachandra, 2009). Comments by Indian officials, however, have pointed to only 2 million biogas plants -around half – still being in operation in 2014. A recent announcement by software giant Infosys, which plans to build over 7500 units in the Ramanagara district of Karnataka over a 10-year period, shows that the potential of biogas is starting to be recognised (Economic Times, 2016a).

There is only a marginal difference between solid fuel (firewood, charcoal) and modern fuel prices, with solid fuels being slightly more expensive. However, the cost savings are significant when the benefits of modern fuels are included (Dalberg, 2013). Biogas cookstoves are the most cost-competitive of all modern and traditional uses of fuels, with levelised costs for household and community-scale ones between 600-900 INR/GJ according to the CEEW (2015b). Firewood and LPG-based cookstoves generate heat slightly more expensively, at between 1000-1150 INR/GJ. Electric and induction stoves are more expensive still, with costs in the range of 1550-1650 INR/GJ. Clearly biogas-based cookstoves are cheaper and, in view of the availability of the resource, offer considerable potential in substituting traditional uses of biomass.

Biogas offers socio-economic and environmental benefits, and is a modern and clean alternative to traditional cookstoves with great potential

Per capita energy demand for cooking – based on 2004 values (Shukla, 2004) – is approximately 6.7 GJ in rural areas, meaning that a household of five people, would need total energy of some 34 GJ. Total energy demand for cooking is lower in urban areas at 3.5 GJ per capita or some 16 GJ per household of five. Useful cooking energy demand, however, is between 1.7 and 2.7 GJ per capita so the efficiency of cooking is 25-40% in rural areas and 50-75% in urban ones (van Ruijven et al., 2011).

Based on these capita demand values, the total energy demand for cooking in 2010 would be approximately 7 EJ. That would require 4.6-5.2 EJ of traditional uses of biomass in 2011, assuming that 66-75% of all households require it (Daioglou, van Ruijven and van Vuuren, 2012). That, in turn, is 80-90% of the reported total use of solid biomass use in the residential sector according to IEA energy balances (2015a); hence around 10-20% of total solid biomass use would be in modern forms. Traditional uses of biomass would be equivalent to 4-5 EJ in 2010. This report assumes the lower end of this range for the year 2010.

Heating and transport sectors

Most of the use of renewable energy in heating and transport is made up of biomass for cooking. Next in importance are solar water heaters in domestic and industrial processes. Their installed capacity in residential buildings reached 2790 MW in 2010 (about 4 million m^2) – mostly as flat-plate collectors (2413 MW; AEE-Intec, 2012), representing about 810000 systems. India, with new capacity of 622 MW, ranked fourth in annual installations worldwide in 2010, after China, Turkey and Germany, and capacity factors reaching 14%. The yield from solar thermal has reached 3.4 TWh per year, or 0.2% of the Indian building sector's

Box 3: LPG use and the role of subsidies

Domestic Indian consumption of LPG has grown strongly, with almost 45 million new connections installed between 2010 and 2013. However, the 2011 Census showed that only 70 million households out of the 110 million with connections use LPG as their primary cooking fuel. The subsidy for supporting this growth in LPG use stood at approximately USD 8 billion in the financial year 2013/14, but a study of who benefits from it shows that 50% of it goes to the top 30% of the population while the bottom 30% get only 15% (CEEW, 2014). With more than 70% of LPG distribution channels located in urban areas, about 50% of the urban population use LPG as their sole cooking fuel, as opposed to just 6% of rural people: yet 68% of the population lives in rural areas. While urban consumption of LPG and compressed natural gas for cooking has been growing, the use of electric kettles, electric water heaters, and induction stoves based on electricity has also been increasing. If gas subsidies are withdrawn, there may be a tendency to shift to using electricity in urban households, given the availability of such electrical products in an ever-increasing consumer market.

total fuel demand. For comparison, energy demand for water heating in India from all sources is about 1-2% of the building sector total (GBPN, 2014).

Residential buildings represent more than 90% of the total installed capacity of solar water heaters in India: the remainder is in applications in the industrial and commercial sectors, which made up approximately 30 000 m^2 of collector area representing more than 150 systems, including process heat. India's Arun dish-type installations provide process heat at temperatures around 120° C. Paraboloid dish systems in a drug manufacturing company generate heat at 280° C. Several other similar technologies are used in the country's manufacturing industry.

There were some 120 Indian distilleries in 2010 with a capacity to produce 1.8 billion litres of conventional ethanol production per year to meet the demand generated by 5% blending with petrol. Its production is mainly from sugar molasses: advanced bioethanol production is only in the R&D phase. Production of biodiesel (from jatropha) was small, at just 140-300 million litres per year: it is mainly used to replace replacement diesel in power generation and heating, instead of as a transport fuel (USDA, 2011).

3.4 Transmission and distribution grids

Reliable, affordable and secure electricity production is essential in ensuring the continued growth of industrial and commercial activities and in satisfying residents' rising demands. However, India's grid infrastructure is already strained and in need of major improvements. Its transmission and distribution losses are among the highest in the world, averaging 26% of total electricity generation, and rising as high as 62% in some states. When such non-technical losses as energy theft are included, total average losses are as high as 50%. Billing efficiency is 55% and collection efficiency only 41%. Power producers lose money as a result. Losses in distribution power lines also depend on the system's geographical spread: in extreme cases, such as in rural India, these may exceed 30%, even 45% during peak load periods.

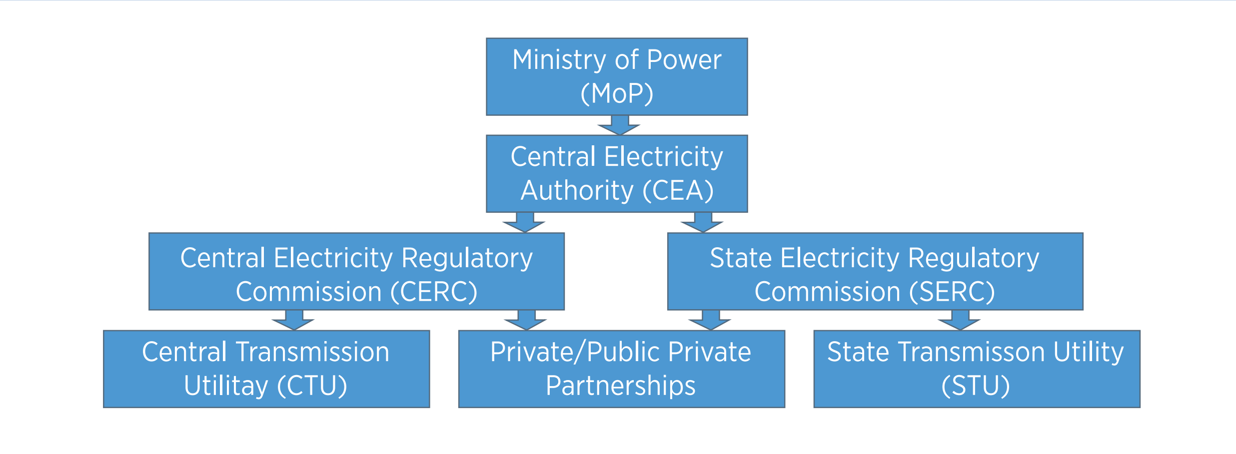
Power shortages resulted in a 0.4% loss of GDP in 2012/13. Load-shedding is common due to the peak power deficit, and businesses are put at a competitive disadvantage as a result of their need to pay for batteries and diesel generators for back-up power (Federation of Indian Chambers of Commerce and industry (FICCI), 2013).

Todays' grid infrastructure challenges stem from the high growth rates in electricity consumption by both industry and residents. The total length of transmission and distribution lines grew by just 50% in 2002-2013 period, while total electricity demand doubled. Over the longer term, peak load is expected to increase to 283 GW by 2022 and more than 600 GW by 2034 (CEA, 2015). The lag in transmission and distribution infrastructure is partly due to land acquisition or Right-Of-Way (ROW) issues, which led to more than 120 transmission projects facing delays in 2011 (FICCI, 2013).

Relieving grid congestion and improving the power grid infrastructure is a main priority for the central government, which will need to work with a variety of actors to achieve its aims (see Figure 13). The "green corridors" programme, which will allow electricity produced from renewables to be fed into the public grid, is one effort to address this issue while enabling the scale-up of renewable energy. Funding is being sourced for constructing transmission lines from international development banks, including KfW, the Germany's Development Bank, which recently concluded a USD 1.1 billion loan agreement to expand the grid with an Indian power transmission company (KfW, 2014).

The existing Indian Power system is divided into five regional grids (Northern, Southern, Eastern, North-eastern, and Western). By the end of 2013, all these grids had been interconnected through high-voltage transmission lines, but inter-regional transmission capacity is relatively low compared to installed capacity: in 2012, India had around 200 GW of power generation, but only 25 GW of inter-regional transmission capacity (Lall, 2012). In July 2014, total transmission capacity reached 250 GW (MoP, 2014a) and inter-regional transmission capacity is expected to reach around 65 GW in 2017 (PGCIL, 2012), by which time renewable energy capacity (excluding hydropower) is estimated to be 83 GW (MoP, 2014a). An estimated 135 GW of non-hydropower renewable generation is expected in 2022 by which time the Northern and Southern regions are expected to experience deficits up to 20 GW (MoP, 2014a).

Figure 13: Overview of India's transmission market structure



Source: Power Grid Corporation of India

Table 1: Estimated costs for the integration of renewables in India's power infrastructure

Solutions for renewable grid integration in India	Estimated costs (USD billion)	Relative share
Intra State Transmission System Strengthening	3.1	48%
Inter State Transmission System	2.9	44%
Dynamic Reactive Compensation	0.09	1%
Real Time Dynamic State Measurement Scheme as well as Communication Systems	0.07	1%
Energy Storage	0.3	5%
Establishment of RE Management Centre	0.03	1%
Total	6.5	100%

Source: Power Grid Corporation (2012)

Meanwhile, India is diversifying its power generation mix through growth in biomass-based power generation, CSP, wind power and solar photovoltaics. A Renewable Energy Purchase Obligation (RPO) has been introduced, requiring power distribution companies to buy 5-10% of their electricity from renewable sources, or to purchase renewable energy certificates (REC). Each REC, which can be traded across the various States, stands for 1 MWh of renewable power generation, and there is a separate market for Solar Renewable Energy Certificates (SREC). By 2014, some 15 million RECs had been issued: more than six million RECs had been traded since the implementation of the REC mechanism, whose nodal agency is the National Load Despatch Centre. Additionally, the Indian Energy Exchange that has been in operation since 2009, offers day-ahead and longer term markets for power providers, supplying around 5% of the country's electricity consumption. It also operates a Renewable Energy Certificate Market where RECs can be bought and sold.

Following the National Solar Mission, and the continued expansion of wind power, the Indian Government asked the Power Grid Corporation of India (POWERGRID) in 2012 to assess the transmission infrastructure and control equipment needed to achieve the added renewable power generation capacity outlined in the 12th plan. The result envisioned 164 GW of wind and 35 GW of solar in 2030. The so-called "Green Energy Corridor" report found that additional Intra-State Transmission networks would be required to facilitate transfer of renewable power from states[10] rich in it to

10 Renewable energy rich States examined were Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat, Maharashtra, Rajasthan and Himachal Pradesh.

others. It added that smart grid technologies – like forecasting methods, STATCOMs, synchrophasors, dynamic compensators and switchable/controlled bus reactors – would be required to maintain frequency and voltage, while renewable energy management centres would need to be established to exchange data and models to support the integration of renewables. The Indian Electricity Grid Code is the right venue for addressing such topics as low voltage ride-through – to provisions, voltage and reactive power (VAR) support, frequency and inertial response support, and reserves response (NITI Aayog, 2015). The Central Transmission Utility (CTU), the CEA, and the Power System Operation Corporation were identified as key stakeholders to examine the role of energy storage for renewable energy grid integration. Table 1 provides an overview of the estimated costs associated with different options for integrating renewable power generation (Power Grid Corporation, 2012).

Similar studies have been conducted at state level. The State of Gujarat, for example, assessed the policy and regulatory challenges needed to integrate up to 10 GW of solar PV and 35 GW of wind power into its grid infrastructure. It concluded that interstate trading of renewable energy would be needed to deal with the power surplus. On the policy and regulatory side, its report recommended exploring energy storage options in more detail (TERI, 2015).

Since then, the CEA has introduced connectivity standards for wind and solar PV generation plants with requirements for harmonics, direct current injections, flicker, fault-ride through, reactive power support, as well as active power injection for those wind generation stations connected at higher voltage levels (>66 kV) (CEA, 2013).

The CEA has also been examining additional strategies for integrating large scale renewable power projects and has suggested that states should set their renewable power purchase obligations according to their capacity to balance the combined variability of load and renewable power generation. States should examine technical and regulatory measures to enhance the flexibility of conventional generation to increase balancing capacity, and seek co-operation with the renewable energy management centres in renewable-rich states to make optimal use of transmission infrastructure (CEA, 2013). India has also increased its

Box 4: Telecom towers in India

The Indian telecom industry has grown at an annual rate of 28% in the last five years and the country now has about 740 000 mobile telephone towers – 60% of them in rural areas. Another 200 000 towers are expected by 2020. Rural areas are expected to drive telecom sector growth.

Of percentthe current towers, 70% have less than 16 hours of grid supply per day. Each consumes 6000 litres of diesel per year to cover the remaining 8 hours or so that are unsupplied. In all, telecom towers are consuming 5.12 billion litres of diesel per year.

The Green Telecom directive aims to address this challenge, and mandates:

- Making telecom operators as of 2015 run at least 50% of all rural towers and 20% of the urban ones on hybrid power (renewables technology or grid power);
- Increasing clean energy implementation to 75% of rural towers, and 33% of urban towers by 2020; and
- Enforcing a directive in line with the Government's priority of decreasing the fiscal deficit by cutting down the subsidy expenditure on diesel.

Various options exist for power supply to telecom towers, these include technologies such as:

grid + battery + distributed generation (DG);

grid + Solar PV + battery + DG; or

grid + Solar PV + battery + Fuel cell.

The cost of power for many of these systems would range between 20-40 INR/kWh (ICF, 2014).

ambition for renewable power generation since the 'Green Energy Corridor' report, and accelerated its implementation (MNRE, 2014a).

The Ministry of Power is implementing an Integrated Power Development Scheme (IPDS) with funds to strengthen sub-transmission and distribution networks in urban areas, to meter urban distribution transformers/feeders/consumers, and to provide for the deployment of solar panels, and smart grids (MoP, 2014a). Meanwhile the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) programme has been launched to strengthen sub-transmission and distribution networks, including metering, in rural areas (MoP, 2014b) Furthermore, the Cabinet approved the North-eastern Region Power System Improvement Project (NERSPSIP) in November 2014 to strengthen the Intra State Transmission and Distribution System (Business Standard, 2014): 19 GW of additional transmission capacity is under construction, with another 21 GW expected to be built before 2018.

Interconnector capacity with neighbouring countries will also play an important role in strengthening India's grid and improving reliability and load factors while accommodating higher shares of renewable energy: several neighbouring South Asian countries have abundant natural resources and operate their grids in common frequencies and similar voltages.

India has a total interconnector capacity of 1416 MW with Bhutan, creating major possibilities for importing hydroelectricity. Another 1200 MW capacity is planned, as is a 1517 MW interconnector capacity with Nepal. There is also, an important opportunity to expand it to use Nepal's hydropower potential. India has no installed interconnector capacity with Sri Lanka, but 1500 MW is planned for the future (NEA, n.d.)

3.5 Conventional fuel markets and short-term expectations

India both produces and imports fossil fuels. It has 10% of global coal reserves, the 5th largest of any country in the world (Krishnamoorthy, n.d.). They are mostly in the eastern side of the country, which is important since it necessitates transport links to other regions. Its coal production reached 14 EJ (more than 550 million tonnes) in 2012. It has the biggest coal demand after China and is expected, from 2020, to be the country most driving worldwide demand increases. India also imported 3.8 EJ of coal or 20% of its total consumption; it used 70% in power generation and 10% for steel and cement production. Demand is projected to double in the next decade, with the structure of the coal market remaining similar, but coking coal and power generation accounting for growth according to the Working Group for Coal and Lignite in the 12th FYP).

Demand for coal is expected to reach 1300 Mt/yr (35 EJ) by 2025, with 15% of it (200 Mt) met by imports. Some assessments expect this import volume to be reached as early as 2017 as domestic production is not likely to keep up with growing demand (Krishnamoorthy, n.d.). An energy system that increasingly relies on coal will be subject to energy security risks. Furthermore, a high demand for coal, and more imports, will bring India a larger energy bill. The high ash content of the type of coal used in India poses multiple problems. Its calorific value is typically low, resulting in the transport of large volumes and increased storage requirements. The efficiency of coal-fired power plants is also low compared to the world average. Renewables can help reduce both the growing dependency on importing coal and reduce problems related to its use.

In the Reference Case, India will consume one-third of global coal production in 2030

India's crude oil production has reached 1.6 EJ, and it imports an additional 7.9 EJ. Annual production has been stagnant at 0.83 million barrels per day (mbd) over past years. The import dependency of crude oil and refinery throughput are 76% and 84.7%, respectively. Imports are expected to increase by 50% between 2012 and 2017 according to the 12th FYP (Krishnamoorthy, n.d.).

The country's total natural gas production was 1.3 EJ, and it imported 0.3 EJ. The consumption of natural gas, including LNG, is growing the fastest of all fossil fuels, with demand increasing by 12% per year between 2007 and 2012. (Krishnamoorthy, n.d.). Its share in India's total energy system is expected to reach 20% in 2025, up from 11% in 2010. According to Natural Gas Vision 2030, demand is projected to more than triple from 242 million cubic metres per day in 2012 to 746 million by 2030. The fertiliser sector's present 25% share could drop to 15% as a result of increasing demand from other sectors, such as other petrochemical production and city gas, but mainly from power production. Domestic sources would account for half of the total supply, with LNG (45%) and cross-border pipelines (5%; e.g. from Turkmenistan and Trans-Afghanistan) accounting for the other half by 2030 (Petroleum & Natural Gas Regulatory Board (PNGRB), 2013).

The US Energy Information Administration estimates, India has more than 250 trillion cubic feet of shale gas resources in four basins, equivalent to more than 1000 years of natural gas consumption based on today's level of demand. National oil companies are allowed to explore and exploit such unconventional hydrocarbon resources (Krishnamoorthy, n.d.). India also has an installed nuclear capacity of 5 GW, with a plan to reach 60 GW by 2032 (Krishnamoorthy, n.d.).

Increasing demand and reduced domestic production is causing all fossil fuels to face import dependency in India. Crude oil has the highest share of imports, at three-quarters of total consumption in 2010. The share of imports of natural gas and coal were 22% and 13% of total consumption in 2013. A recent study by TERI (2015), concludes that the average import dependence of fossil fuels will increase from 40% in 2011 to 74% by 2030/31 under a business as usual scenario, mainly driven by the tripling of dependency in both coal and natural gas. A scenario that prioritises energy security through better energy efficiency involves switching toward natural gas and higher shares of renewables. This can help to limit the growth in import dependency to only 44% at the same time period. Crude oil and coal dependencies would remain the same as now, though that of natural gas would triple.

In the next 15 years, deployment of renewables will be key to securing India's energy supplies

3.6 Nexus issues

The interlinkage between water, energy and food supply systems is a major consideration in India. With its growing population and economy, demands for all three are increasing equally fast.

The electricity mix in India is dominated by coal-based power plants, followed by hydropower and natural gas (MNRE, 2014b). Coal will remain a key energy source in meeting rapidly expanding power needs despite the apparent water conflicts. India is a relatively water-scarce country, with only 4% of the world's freshwater resources. Worldwide, about 1200 new coal power plants are being proposed representing nearly 1000 GW of installed capacity: Three-quarters of the total number of plants planned are in China and India (Burt, Oris and Buchanan, 2013). About one-third of the total capacity is in India.

Seventy-nine percent of India's new energy capacity is expected to be built in areas that already face water scarcity or water stress. The country plans, for example, to build a cluster of 71 coal plants in the Vidarbha region of Central Maharashtra, a highly water-stressed area where lack of water for irrigation has been documented over the last decade. The Ministry of Water Resources predicts that the national demand for water in energy production will increase 16-fold by 2050. According to a study by an Indian electricity regulator, the most water efficient technologies (dry cooling) reduce consumption by 90% but result in an 8-9% increase in the electricity tariff.

Increasing the deployment of solar PV and wind turbines reduces the water-intensity of electricity generation, and a recent analysis for China demonstrates by how much. It shows that a combination of improving plant cooling technologies and increasing renewables, based largely on Solar PV and wind, can reduce the water-intensity of Chinese power generation by as much as 42% by 2030 (IRENA and China Water Risk, 2016). Though the study focused on China, its conclusions can generally be applied to other countries heavily reliant on coal for power generation, such as India.

There are about 26 million pumps in Indian agriculture. At least 12 million of them use grid-based electric motors and 10 million operate with diesel. The number of electric tube wells (pipes bored into the ground that pump water to the surface) has increased from 12 million in 2001 to nearly 20 million today. Nearly 20% of all India's power generation is used for agricultural water pumping. When rainfall is low, water stress increases. India spends over USD 6 billion on energy subsidies annually, and farmers pay only an estimated 13% of the true cost of electricity. With very low power prices, excess water use has even further impacts, especially on groundwater resources. India is the world's largest user of groundwater for agriculture: it accounts for nearly 80% of all freshwater use. As groundwater levels drop, more power is needed to retrieve it, thus increasing the energy intensity of extraction (IRENA, 2015b).

During 2014/15, the Government undertook to install 100 000 solar water pumping stations for irrigation and drinking water. In 2015/16, 22 000 were installed (MNRE, 2016a). The Government has also recently announced a piped water supply programme deploying 20 000 solar pumps in select tribal and rural districts (IRENA, 2015b). Replacing five million diesel pump sets with solar systems could lead to savings of nearly 18.7 GW worth of installed capacity, 23.3 TWh electricity, 10 billion litres of diesel and 26 Mt of CO_2 emissions. Renewables offer an important alternative for agricultural pumping with multiple benefits (IRENA, 2016c). The benefits of a large-scale deployment of solar pumps include expanding water services to underserved communities and unirrigated lands, while reducing dependence on grid electricity or fossil fuels. They also help to mitigate the local environmental impacts of using diesel, enhance overall grid stability in agrarian economies, and reduce the burden of electricity and fossil fuel subsidies. The technology is mature and has been successfully deployed at scale.

On the other hand, there is also evidence of risks posed by solar-based pumping. Since the operational cost of PV pumps is negligible, and the availability of energy is predictable, they could cause overdrawing of water. Many solar pumping promotion programmes package financial support with the deployment of drip irrigation technology so as to mitigate this risk. Drip irrigation technology can indeed improve the efficiency of water use, but it also is more capital and energy intensive, may not be suitable for all irrigation applications, and may reduce the replenishment of groundwater as a result of limited flow from seeps to aquifers.

The types of biofuel crops grown and their location in India, also makes a difference to overall water use. A litre of ethanol made from irrigated sugarcane in India, for example, needs more than 25 times as much water as one made from mostly rain-fed sugarcane in Brazil. Approximately 93% of India's sugarcane area is irrigated and there little availability of land for rain-fed sugarcane production.

In view of these resource constraints, sugar cane may have limited potential for large-scale biofuel production in India. Efforts to further increase its area and production would undoubtedly intensify already severe competition for land and scarce water resources. An alternative option, technologically similar and proven for the production of bio-ethanol, yet agro-ecologically much better suited to the Indian context, is producing ethanol from a feedstock of the stalks of sweet sorghum. Unlike sugarcane, sorghum can be grown with good success under rain-fed conditions in nearly all of the country, is drought tolerant and is much less demanding on soils (IIASA, 2014).

Another interesting issue is how the use of biomass in rural areas impacts food productivity and whether it can improve India's food security. Diverting cattle dung from farm manure to household cooking fuel, for example, can reduce the amount of time spent on collecting and preparing traditional biomass fuel. Additional research is needed on nexus issues like these.

4. DRIVERS FOR RENEWABLE ENERGY AND THE CURRENT POLICY FRAMEWORK

Key points

- India's widespread energy scarcity, and its vulnerability to energy price shocks, have led to a long history of initiatives to promote renewable energy. Also, reducing the environmental impacts of using fossil fuels and climate change are increasingly main drivers of renewables in India.

- India's recent target of 175 GW installed renewable energy capacity is indicative of its firm commitment to scaling renewables up. This ambitious target has led to much enthusiasm in the market, and recent efforts are bearing fruit – such as auctions for solar PV – but further efforts will be needed for its timely realisation.

- The drivers for renewables are different in India than in countries, which are advanced in their use, such as the US and Germany, and even China. Some of India's socio-economic characteristics are unique. Its population, income levels and, thus, energy demand are all projected to grow faster than in these countries. The growing demand will need to be met, and the trend shows that fossil fuels will meet more of it than renewables.

- India will be the world's most populous country towards the end of this decade. By 2017/2018 its population will equal China's and by 2030 it will be 18% larger than at present. More people will live in urban areas by then: some 610 million compared to today's 415 million, up from 32% to 40% of the population. That would mean building nearly 200 new cities of a million people each. Most of India's population, furthermore, is expected to be under the age of 30.

- Given its population growth rate, India needs to create ten million new jobs every year. Analysis carried out by CEEW and the Natural Resources Defense Council (NRDC) estimates that more than one million full time equivalent jobs will be created between now and 2022 by the solar deployment industry alone. Similarly, the wind sector would create 183 500 jobs by 2022, as its capacity increases to 60 GW. The job creation potential of the renewable energy sectors is therefore significant, but it is accompanied by an urgent, and currently unmet, need for training and skill development.

India's target of installing 175 GW of renewable energy capacity by 2022 was officially announced in the 2015 budget speech. As the country approaches the next budget announcement, the country's total installed renewable energy capacity is close to 43 GW, nearly 25% of this target (MNRE, 2016b). Historically India has paid much attention to renewables in its energy policy. In 1992, it was the first country to set up a ministry dedicated exclusively to renewable and new energy sources (previously it had been a dedicated department, which started operating in 1982). Wind and solar technologies have been promoted through various policies and measures in the past two decades, if with mixed success. Figure 14 below highlights the timeline of the various policy measures adopted, along with the growth of the country's renewable energy capacity.

Despite rapid strides in adding power capacity, India continues to be plagued by widespread energy poverty. A significant proportion of its population lacks access to clean and affordable energy. Estimates suggest that 80 million households, with more than 300 million people, have inadequate access to electricity. Advances have been made in extending the electricity grid across the country, but extending it to remote and rural areas is often economically prohibitive and faces the persistent problem of variable supply. Energy access is pivotal for holistic human development and economic growth across the agricultural, industrial and commercial service sectors.

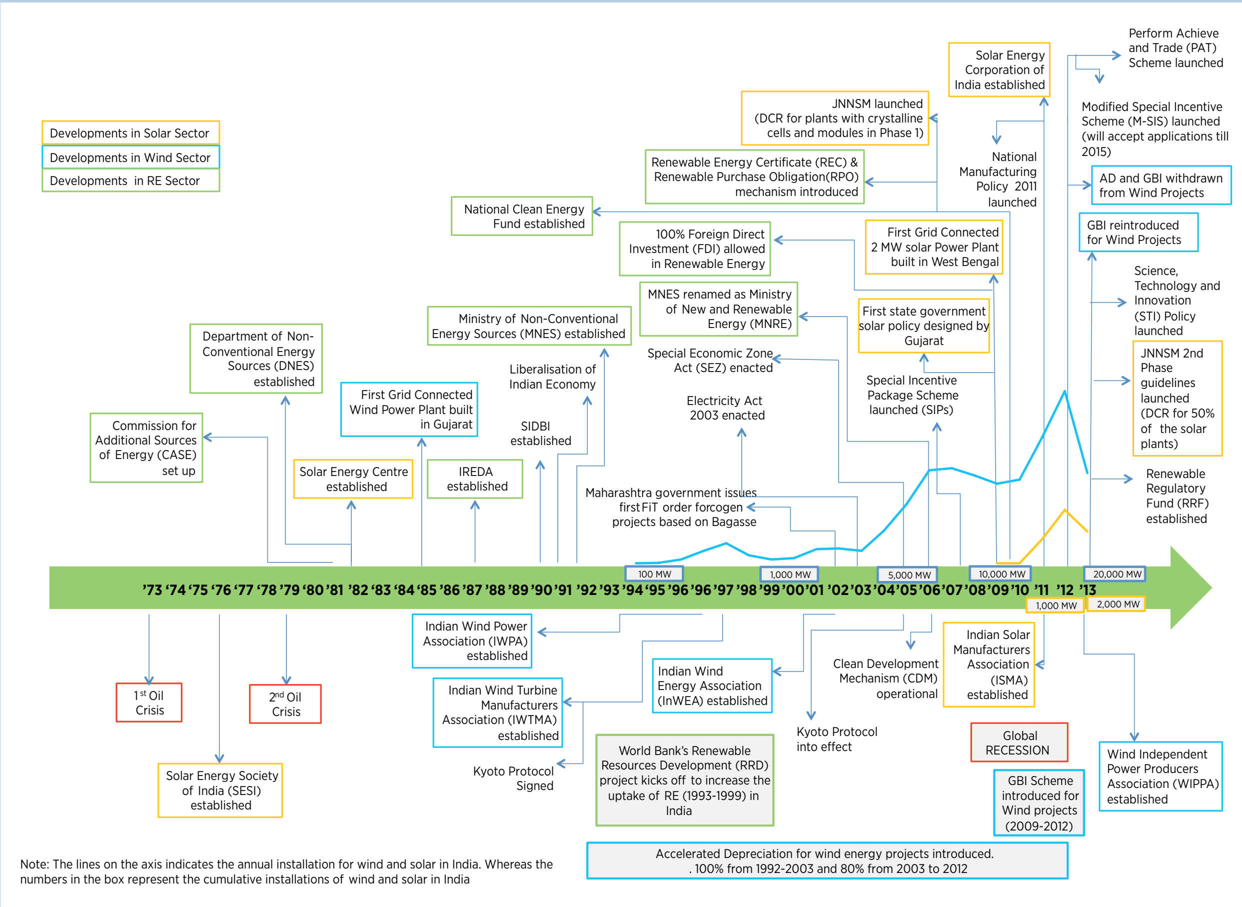
Renewable energy in India is seen as a supplement to energy supply from other traditional sources in meeting rapidly growing energy demand

India's energy policy is primarily focused on bridging ongoing supply and demand gaps, while bearing in mind the advantages from transitioning away from a mix highly reliant on fossil fuels. Despite several pro-renewables policies in place, however, the share of renewable energy has fluctuated between 13% and 19% over the past years and has yet to make a dent in the share of electricity generation from fossil fuels. In recent years, central and state governments have adopted programmes that give impetus to the wind and solar markets, including non-electricity driven applications. Efforts to use biogas effectively – and to extend the reach of the electricity grid to evacuate power and distribute it to people in remote locations – are being undertaken. There has also been a big push for decentralised energy systems powered by renewable energy in the last decade.

India's widespread energy scarcity – and its vulnerability to energy price shocks – have led to a long history of initiatives to promote renewable energy

India's growing trend of policy focus on renewables continues. In July 2015, MNRE released the draft National Renewable Energy Act (NREA), which specifies the need for large scale consumption of renewables. It also mentions that increasing the share of renewable energy would require changes both in domestic energy policies and in the planning guidelines for India's energy

Figure 14: Timeline of renewable energy policy developments until 2013



Source: CEEW analysis

Note: Additional developments took place in 2014-2016, including the announcement of India's 175 GW renewable power target, and the release of countries INDC.

system. The act promotes renewables in line with climate, environmental and macroeconomic objectives and aims to reduce India's import dependency on fossil fuels and GHG emissions. India released its INDC in October, 2015 with specific targets for deploying solar, wind and biomass energy, and a collective target of 40% of power capacity from non-fossil fuel sources. In early 2016, the country also amended its National Tariff Policy (NTP), which aims to promote faster adoption of renewable energy and sourcing of power through competitive bidding.

4.1 Drivers of renewable energy in India

Drivers for renewable energy vary from country to country. In China, the main ones have been air pollution and local job creation. Phasing out nuclear power is one reasonfor Germany's energy transition. In the US, improving energy security and cost-competitiveness were the main drivers for shifting to renewables. The drivers behind India's transition to a greater renewables energy system are different again: as discussed above, they include economic growth, energy access, energy security, and reducing the negative environmental impacts of increased fossil fuel use, such as air pollution.

Macroeconomic Drivers

Table 2 compares a number of socio-economic and renewable energy indicators for India, China, Germany and the US to show how their different population and economic drivers affect energy demand. The table shows that India's per capita income level is the lowest, but is expected to grow quickly. Around 20% of its population currently does not have access to electricity. Like China, it has a large share of traditional biomass, and has experienced significant growth in energy demand over the last 10 years. The table shows that India is unique among these major energy consuming economies in some of its socio-economic characteristics, as well as having different drivers than the US and Germany, and even China.

Despite its growing energy demand, India installs the least amount of renewable power generation capacity each year of the countries shown in Table 2 (if hydropower is excluded). China has installed very much more renewable power than any other country in the world, around 10 GW per year (excluding hydropower). With its ambitious targets, India is now aiming to use its rich renewable resource potential to catch up with other advanced countries.

Table 2: Socio-economic and renewable energy indicators for selected countries

	Data year	Data source	China	Germany	US	India
Population (million)	2014	UN	1 377	81	319	1 295
GDP/Capita (2014 USD)	2014	World Bank	7 593	47 627	54 629	1 630
Electrification rate (% pop)	2012	GTF	100	100	100	75
Total primary energy supply growth	2000-2011	IEA	135%	-7%	-4%	64%
Urbanisation (% Urban)	2015	UN	55%	75%	81%	32%
Urbanisation (% Urban)	2030	UN	69%	79%	84%	40%
Annual renewable power installation rate (GW/yr. average, excl. hydro)	2000-2014	IRENA	10	5	6	2
RE share (% TFEC, incl. trad. biomass)	2012	IEA/GTF	18.4%	12.4%	7.9%	39%
Modern renewable share (% TFEC, excl. trad. biomass)	2012	IEA/GTF	6.3%	12.4%	7.9%	10%[11]

Sources: GTF stands for the 'Global Tracking Framework" (World Bank, 2015); IEA (2015a); IRENA (2016g); UN (n.d.); World Bank (n.d.)

11 The modern renewable energy share is based on the 2015 SE4All Global Tracking Framework. IRENA analysis for the REmap base year 2010, two years' prior, shows the modern renewable share to be slightly higher, at around 17%, based on a different assessment of traditional biomass use and sourcing for energy consumption.

Table 3: Socio-economic and energy indicators for India to 2030

	Source	2030	Growth 2014-2030
Population (million)	UN (n.d)	1528	18%
GDP/Capita (2014 USD)	IMF, IRENA analysis	4409	170%
TPES (PJ/yr)	IRENA analysis	64498	106%
TFEC (PJ/yr)	IRENA analysis	42628	84%
Urbanisation (% Urban)	UN (n.d.)	40%	25%
Urban population (million)	UN (n.d)	611	47%
Electrification rate (% pop)	GOI (2014b)	98%	24%
Power capacity (GW)	IRENA analysis	663	141%

Table 3 looks forward to 2030 and some of the major changes India can expect, identifying the major drivers for the country's forecasted growing energy demand. India will be the world's most populous country towards the end of this decade. By 2017/2018 its population will equal China's and by 2030 will be 18% larger than today. More people will live in urban areas by then: some 610 million compared to today's 415 million, up from 32% to 40% of the population. That would mean building nearly 200 new cities of a million people each. Most of India's population, furthermore, is expected to be under the age of 30.

India's total primary energy supply has also been growing fast, increasing by 64% over the 2000-2011 period. By contrast, it has declined in both the US and Germany. China's growth was even higher, at 135%, but in recent years it has been slowing down and this is expected to continue in the short-term. By comparison, India's energy demand is expected to double over the 2014 to 2030 timeframe, driven by increasing population and per capita income, as well as the need to reach the goal of 98% electricity access. The growing demand for power in India will need to be met by a combination of fossil fuels and renewables. India is expecting to surpass China's coal demand over the next few years, and will require a power capacity of over 800 GW by 2030, up from around 275 in 2014. It is to raise non-fossil-fuel capacity from today's 84.5 GW (37 GW of renewable energy, 5.5 GW of nuclear and 42 GW of large hydro) to 320 GW in 2030. At present, non-fossil fuels contribute just over 30% of the total capacity of 277 GW. As India's total electricity capacity multiplies almost three times over between now and 2030, non-fossil fuel capacity will have almost to quadruple if it is to reach the target of a 40% share of the total.

India has already used most of its hydropower potential, and intends to add the bulk of this non-fossil fuel capacity in the form of solar and wind power. In China, large hydropower and nuclear together contribute 24% of its installed capacity mix. That is significantly more than the 7% contributed by solar and wind power, though their share is rising rapidly. In comparison, renewable energy (excluding large hydro) contributes 13% of India's installed capacity mix, with large hydropower and nuclear together contributing 17%. India will add 236 GW of non-fossil-fuel capacity, compared to China's 800-1000 GW, up to 2030, to reach a 20% share of total primary energy demand.

In addition, there are a host of policies which, if implemented, will enable the country successfully to pursue sustainable development. They include reforming building codes and rationalising prices in freight transport by eliminating subsidies (Bloomberg, 2014b) and would complement current policy support for renewable energy and energy efficiency.

Indian manufacturing is being given a boost – under the National Manufacturing Policy of 2011 and the "Make in India" programme pursued by the current Government – so that it can contribute 25% of GDP in the coming decade, up from 15% at present. This policy identifies focusing on 'greener and cleaner' technologies and local value chain creation as priorities. It recommends that the green manufacturing committee applies objective criteria to identify such technologies, consistent with the NAPCC. Similarly, the National Solar Mission (one of the eight missions under the NAPCC) aims to create a conducive environment for manufacturing in the solar energy sector, to reduce the dependency on imports and to develop India as a solar energy hub.

Box 5: Renewable energy jobs in India

Analysis by IRENA (2016d) estimates that 416 000 people work in the renewable energy industry in India. This excludes large hydropower which is estimated to employ another 104 000.

The solar PV industry employs an estimated 103 000 people in grid-connected (31 000 jobs) and off-grid applications (72 000 jobs). The biogas sector employs 85 000 people and the wind energy sector employs an estimated 48 000. India has the largest market for solar lanterns, with an estimated 700 000 – 800 000 units as of 2010. About 40% of the 110 companies active in the solar portable light manufacturing industry worldwide are headquartered in India and make up 30% of global sales. (IRENA, 2013a).

Table 4: Estimated direct and indirect jobs in renewable energy in India, 2013-2014

	Number of Jobs
Biomass	58 000
Biofuels	35 000
Biogas	85 000
Small hydropower	12 000
Solar photovoltaic	103 000
Solar heating/cooling	75 000
Wind	48 000
Total	416 000

Source: IRENA (2015c)

India has an installed total of 4.1 million family-size biogas plants (with 1-6 m^3 capacity), making it a distant second to China (MNRE and CII, 2010). MNRE has estimated that available dung could support some 12 million plants (Arora et al., 2010). Slightly more than 100 000 such plants were installed during the financial year 2008/2009, saving 120 000 tons of fuelwood. The Government estimates that some 200 000 jobs could eventually be created in the biogas sector, up from the present 85 000. An assessment concluded in October 2010 that Indian manufacturers of biogas plants were "steadily improving their technology and products, which has led to an establishment of Indian companies in the global market. Thus, foreign companies trying to break into the Indian market face strong competition from established Indian companies in the Indian market who have knowledge of local conditions and requirements." (IRENA, 2013a).

A report by Bridge to India and Tata Power Solar, concludes that there is a realisable potential of between 110 GW and 145 GW for solar PV in India, which could create 670 000 jobs (India Today, 2014). If India achieves its new target of 100 GW of installed solar energy by 2022, as many as 1.1 million full-time equivalent jobs could be created (IRENA, 2016d) – including over 210 000 skilled plant design and site engineering jobs, 18 000 highly skilled jobs in business development and over 80 000 annual jobs in performance data monitoring. Another approximately 183 500 full-time equivalent jobs would be generated if India were to reach its target of installing 60 GW of wind energy capacity by 2022. Looking ahead, solar and wind companies in India can support the clean energy market by reporting the numbers of jobs their projects create (CEEW, 2015c).

Furthermore, the Government has been developing international collaborations to enhance the transfer of clean technologies to India. All these efforts are aimed at spurring local value creation and growth in green jobs while pushing for local innovation.

Job creation is a major driver for policy makers around the world, and India is no exception. The country could have over one million solar jobs and over 180 000 wind jobs by 2022 (CEEW, 2016). Unlike in other developed countries, where a transition to renewables may result in job losses in the fossil fuel sector, the renewable energy sector in India is supplementary to it and so generates new employment rather than redirecting it, since renewable energy capacity is often in addition to that of fossil fuels. However, developers do not report job numbers voluntarily, as in other countries, so the absence of a clear mandate to do so by the

Box 6: The existing National Solar Mission

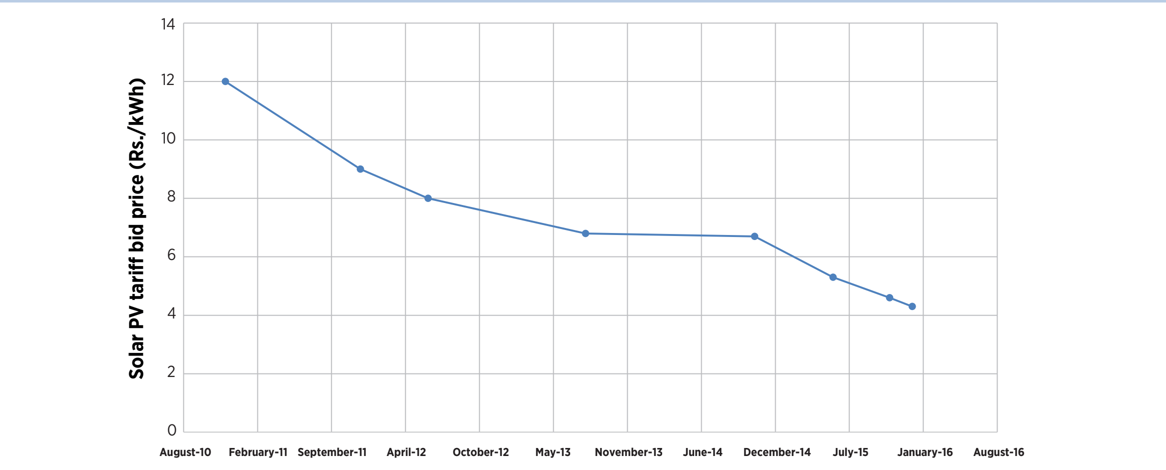
The JNNSM (often referred to as the National Solar Mission in this report) was launched in January, 2010 as one of eight missions under the NAPCC. It originally set a target of deploying 20 000 MW of grid connected solar power, and 2 000 MW of off-grid power by 2022, but this was recently revised up to 100 000 MW. The mission aims at reducing the cost of solar power generation in India in order to achieve grid tariff parity by 2022 through: long term policy; large scale deployment goals; aggressive R&D; and domestic production of critical raw materials, components and products,

The National Solar Mission follows a phased approach that allows the government to modify guidelines and policies based on the experiences gained and lessons learnt in earlier phases. It has, thus far, successfully driven investment, taking India from a cumulative installed capacity of grid connected solar photovoltaic of nearly 10 MW in early 2010 to more than 2 500 MW by May 2014.

During its first phase (2010-2013), more than 500 bidders competed for 63 projects allocated during two reverse auctions, driving prices to record lows. New solar energy investments in India increased to more than USD 2.5 billion in 2011. Phase 1 activities focused largely on achieving 1 000 MW of solar energy through an equal split between solar thermal and solar PV project technology.

Competitive bids for the National Solar Mission projects have rapidly driven down tariffs. Phase 1 bids revealed prices as low as INR 7.49 (USD 0.15) per kilowatt-hour for PV projects making it competitive with diesel-fired captive electricity generation. Phase 2 of the National Solar Mission has set tariffs even lower, to stand at INR 5.45/kWh (USD 0.09/kWh) with viability gap funding, and INR 4.75/kWh (USD 0.08/kWh) with accelerated depreciation. Bids in 2015 and early 2016 all came in at around INR 4.2-5.0/kWh (USD 0.06-0.07/kWh) indicating that prices are at the lower range of the Mission's target (Gambhir, 2016).

Figure 15: Solar PV bid price trend under the MNRE Solar Plan, 2010-2016

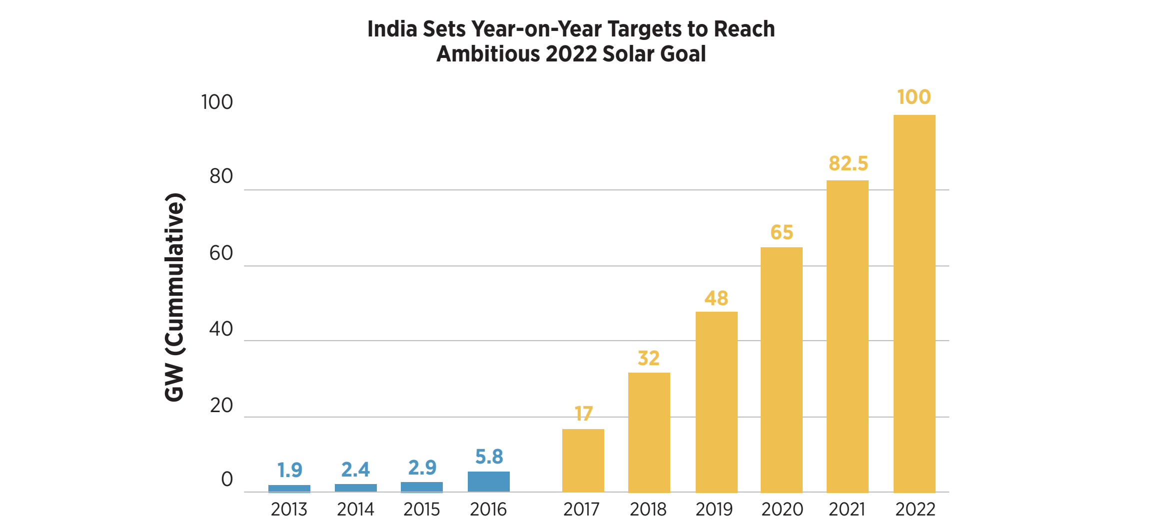


Note: Analysis based on MNRE, 2016c

Although Indian industries have responded positively to the Solar Mission, it faces several hurdles in moving ahead, if it is to scale-up solar energy. The central government — with co-ordinated action by states, developers, financial institutions, manufacturers, research institutes, and communities — needs to develop effective solutions for more credible project bids, enforceable RPOs and RECs, strong financial structures, increased domestic manufacturing, and reliable power evacuation and transmission.

The ambition of the programme has been scaled up significantly, with India now targeting 100 GW of solar capacity by 2022; 40 GW from rooftop solar projects, and the remaining 60 GW from utility scale ones. The next phase of the National Solar Mission aims significantly to increase annual installed capacity to reach the goal of 100 GW by 2022. Its annual target has increased from 2 GW in 2015 to 12 GW in 2016. By 2017 annual installations should amount to 15 GW, reaching 17.5 GW by 2021. (The targets under each phase count total progress in installed capacity under both the direct central government programme and the state programmes). The level of capacity installation growth is shown in Figure 16.

Figure 16: Solar PV installed capacity targets to 2022



Sources: World Resources Institute (2016)

central government creates a roadblock in analysing job creation.

In India, as in other developing countries, public support helps to drive the deployment of renewables and this, in turn, drives down their price and encourages job creation across the value chain, such as in manufacturing, installations, financing, and maintenance

A broad motivation for promoting renewable energy in India is to respond to a series of real and potential market failures, in energy access, energy security, climate change, and local environmental challenges

Security of affordable energy supply

Despite the competitive direct costs of fossil fuels, broad motivations for promoting renewable energy in India are provided by such factors as exclusion for the poor (who either do not have access to the energy markets or are unable to pay for energy services), the instability caused in the energy market by fluctuations in energy prices, and other real and potential market failures. Renewables are also increasingly emerging as the least-cost option for meeting the country's rising energy needs.

Ensuring access to energy is central to India's policy, which aims to address the underlying demand for energy services. The household sector consumes nearly

39% of the total energy supplied in the country: a significant proportion of this (around three-quarters) is provided by traditional biomass based fuels – like firewood, dung cakes, and charcoal – which are not accounted for in official statistics. This indicates the pressing need for increasing access to modern energy sources for millions of Indians.

The energy policy also aims to cater for India's growing energy demand and domestic supply gaps. Even under an aggressive scenario of global climate stabilisation, India would consume at least 60% more energy in 2035 than today. Varying output from domestic fuel sources, volatile prices of imports and uncertainty in geopolitical conditions, all lead to concerns about the predictability and stability of fuel supplies.

The pursuit of energy access and energy security enjoys considerable political support, and is recognised in the Integrated Energy Policy (IEP), which considers energy security as providing all Indians with an energy lifeline, regardless of their ability to pay for it. This is supported by a history of policies and programmes aimed at enhancing rural electrification going as far back as 1969 when the Rural Electrification Corporation was established. The Corporation promotes and finances a wide range of rural energy projects, including grid-connected, off-grid, renewables or conventional fuel driven power generation, power conservation and power distribution network initiatives.

India has limited sources of fossil fuels and is not geographically adjacent to any major sources of supplies, making it vulnerable to geopolitical and geo-economic shocks. The country's energy security policy, therefore, needs to be viewed through a wide lens, considering supply and demand issues from a planning and financial perspective at both the micro and macro scale (TERI, 2015). Renewable energy should be considered as a viable alternative that can mitigate this risk, at least in part, and offer the double advantage of allowing energy access to the poor and aiding energy security by diversifying the sources of supply.

Box 7: Climate Change

India now accounts for 6% of total global CO2 emissions, making it the world's third largest national emitter, after China (23% of the global total) and the US (16%) (this excludes the EU-28 which accounts for 11%). It will also play a key role in reducing the growth of global CO2 emissions. It released its INDC in October, 2015, pledging to reduce the emissions intensity of its GDP by 33% to 35% of the 2005 level by 2030.

It realises that its ambitious renewable energy targets will help to reduce emission growth, but is nevertheless simultaneously expanding its coal mining activities, the largest contributor to its increasing emissions (Reuters, 2015), mainly because it needs to grow its economy (CEEW, 2015a). India still needs to provide energy access to a quarter of its population, and will try to do this at the least cost, so as to provide affordable electricity. Renewables can play an important role in realising this objective if deployment starts now and their cost-effectiveness improves. Otherwise, there is a risk that coal will continue to be used for meeting the exponentially growing electricity demand.

So far, the contribution of manufacturing industry to India's economy is less 25% of GDP, much lower than in China, for example. It will have to grow at much higher rates if India is to overcome its development challenges, and will thus increase the country's energy demand and related emissions. Renewables offer industry an alternative to fossil fuels, and India is one of the world's frontrunners in deploying solar thermal energy and various forms of biomass for process heat. If such practices can be significantly expanded to cover increasing demand, emission growth can be reduced while the economy expands.

Various analyses (e.g. CEEW, 2015a) show that India could increase its renewable energy ambition significantly by 2030 to meet its growing energy needs, while reducing emissions. The country would, however, need to consider the related costs of realising such targets while ensuring it overcomes its development challenges. So any commitment to climate change must be built on technology partnerships and financial mechanisms.

Environmental Concerns and Climate Change

Climate change mitigation in India, as in most countries around the world, is addressed by such measures as end-use energy efficiency and pursuing renewables. The country's INDC includes a commitment to decrease the emissions intensity of its GDP by 33% to 35% from 2005 levels by 2030 (see box 7). India launched its NAPCC in June 2008, setting out eight 'missions' to support action: the most prominent are the National Solar Mission (see Box 7) and the Mission for Enhanced Energy Efficiency. The NAPCC was seen as a way to connect climate change mitigation and energy security, and to pursue both goals collectively. An analysis of Indian and global governance highlighted the availability of a vast market for future investment in clean technology and a corresponding need to deepen bilateral relations to develop, and secure access to, energy and climate related technologies.

Local environments, in a country greatly reliant on coal-based thermal power, are plagued with multiple issues beyond the challenge of climate change. These include air pollution (see box 8), related respiratory diseases and water pollution (New York Times, 2015). Renewable energy deployment has gained impetus from growing civil society opposition to the local environmental impacts of coal-based power. Environmental Impact Assessments (EIA) have been prevalent in India since the late 1970s and the Environmental Protection Act has been in place for 30 years (since 1986). An amendment to the act in 2006 excluded wind and solar projects from EIA requirements in order to accelerate renewable energy.

In late 2015, the Indian Ministry of Environment and Forests announced stricter standards for coal-based thermal power generation so as to minimise pollutants. These revised standards are to be implemented in a phased manner, based on the age of the coal power plant, with three groups: those installed before 2014; those installed from 2014-2016; and those installed after 2016. The new standards aim to reduce emissions of PM10 (maximum emissions of 0.98 kg/MWh), sulphur dioxide (maximum emissions of 7.3 kg/MWh) and nitrogen oxide (maximum emissions of 4.8 kg/MWh) (MOEF, 2015). Water consumption in new plants will be limited to 2.5 litre/kWh (Gambhir, 2016). The clean energy tariff on coal will increase from INR 50/tonne to INR 400/tonne (USD 6) in the 2016/2017 period (Economic Times, 2016b).

4.2 Key characteristics of the India's energy policy framework

India's target of 175 GW installed renewable energy capacity by 2022 is indicative of its firm commitment to scaling it up. This target has led to much enthusiasm in the market, and recent efforts are bearing fruit – such as auctions for solar PV – but further efforts will be needed for timely realisation of this ambitious target. Governmental policies need to be strengthened in order to tackle problems of policy uncertainty, governmental clearances, availability of finance, health of the transmission and distribution networks, and financial health of the state electricity boards, if the country is realistically to pursue the target.

The feasibility, efficiency and effectiveness of governmental policies depends on the characteristics of the national energy policy system of governance. Policies applied in China, Europe, or the US are not directly applicable to India. However, adopting general recommendations and lessons from countries at more advanced levels of renewable energy adoption is possible, helpful and ongoing. In setting its targets, India has drawn from the experience of countries around the world that have scaled up renewable energy by relying significantly on rooftop solar systems: thus the 100 GW solar target contains a 40 GW solar rooftop sub-target. This indicates how policy lessons are transferable, even if the modalities of implementing them with support policies like FiTs, net metering policies or financial support schemes are unique to each country.

The government's ambitious renewables target can easily be achieved if some of the key issues faced by the private sector are addressed. However, the process of doing this is complex, as in most countries, and is often drawn out over a long period. Policy initiatives have been put in place at the central and state levels for both grid-connected and off-grid renewable energy. Scaling up the renewable energy sector hinges on the combination of funding mechanisms, legislative frameworks, institutional arrangements, and other efforts which work together to support implementing strategies, policies and programmes.

Box 8: Economic impacts of fossil fuel combustion related air pollution in India

The economic cost of outdoor air pollution health impacts has reached 3% of India's GDP (World Bank, 2013b) and the estimated number of deaths from ambient air pollution (related to PM and ozone) reached 700 000 in 2010, up from 692 000 in 2005. The Global Burden Disease report has estimated that there are 620 000 premature deaths in India from air pollution-related diseases each year (Down to Earth, 2013). The Years of Life Lost (YLLs) from air pollution reached 18 million in 2010, while the DALYs reached 19 million (OECD, 2014). DALYs from indoor air pollution from biomass combustion stand at 5.5 million

Coal used in power generation is alone estimated to shorten life expectancy in India by 2.5 years on average, according to a study that modelled its effects (Burt, Oris and Buchanan, 2013). Changing climate trends and air pollutants also hit agricultural yields. According to Burney and Ramanathan (2013), they had reduced yields by 36% by 2010, and by as much as 50% in densely-populated areas.

Fossil-fuel based heat and power and transport results in outdoor and indoor air pollution. Emissions of fine particulates are some five times higher than the recommended threshold. Domestic sources and waste burning contribute 10-20% of total urban air pollution (Dalberg, 2013).

Traffic growth is the main driver of deteriorating air quality (OECD, 2014). India has been adopting Euro vehicle classes quite ambitiously – Euro 4 had been adopted in 13 major cities by 2009 (UNEP Risoe, 2013). Half of the 180 cities monitored in 2010, and 60% of their population, are exposed to critical levels of PM10 emissions. Air pollution is increasing in large and small cities alike, thanks to both transport and other emission sources like coal combustion for power generation and polluting industries such as ceramics next to densely-populated areas.

One reason that emissions are rising so fast is that rather old emission standards are still in force in India (New York Times, 2012), though new standards are coming into effect. Varying climatic and geographic conditions over India's large territory mean that the economic costs of health impacts vary from place to place. New Delhi, for example, has an air pollution problem when diesel heaters start operating, making it one of the world's most polluted cities in winter. A huge cloud of pollution cloud stands in front of the Himalayas, whereas the effects of coastal coal plants is rather limited since wind disperses their emissions. Burning biomass is a prime source of both indoor and outdoor pollution.

India, concludes a study by Yale and Columbia universities that assessed 132 countries, has the worst air pollution in the entire world. Its high PM2.5 levels are about five times above the threshold considered unsafe for human beings. PM causes acute respiratory diseases – the most common causes of deaths in children under five in India (NY Times, 2012) – and is linked to cancer. The benefits of cleaning up coal power plants are 25 times higher than the costs (Burt, Oris and Buchanan, 2013). Markandya et al. (2009) found much higher benefits from mitigating carbon dioxide emissions from the power sector in India (USD 46-49/t CO_2) than for the EU and China (in the order of 2-7 USD/t CO_2), but this includes savings from a switch to renewables, which also offer significant benefits.

A shift from burning coal to generate electricity will reduce both greenhouse gas emissions and fine-particulate air pollution. Several studies have estimated the probable health benefits. Roughly 90 000 premature deaths could be averted in India every year (Haines, et al., 2012).

A theoretical case study suggested that a programme providing 150 million low-emission household cookstoves over a decade would provide 87% of Indian households with clean combustion, either through advanced biomass stoves or through graduating to clean fuels. By 2020, some 240 000 children under 5 years would be saved from death from acute lower respiratory infections, and more than 1.8 million premature adult deaths from ischemic heart disease and chronic obstructive pulmonary disease would be averted. The total savings for the decade would amount to 55 million DALYs, an average of 5.5 million DALYs per year (Wilkinson et al., 2009).

The key legislation guiding the development of renewable energy in India is the Electricity Act, 2003, which, amongst others, mandates the State Electricity Regulatory Commissions (SERCs) to promote generating electricity from renewable sources by providing suitable measures for connecting to the grid and selling electricity to any person and also specify, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee. The Ministry of Power is responsible for the administration of this Act and the Energy Conservation Act 2001 and for amendments to them. The NTP of 2006 directs States to fix minimum percentages for purchasing renewable power and – as amended in early 2016 – to promote faster adoption of renewable energy and power sourcing through competitive bidding. Procuring renewable power for future requirements is to take place through such a bidding process. MNRE released bidding documents for grid-connected renewable energy in December 2012 after several rounds of consultations with stakeholders.

The allocation for solar power has already taken place through competitive bidding, under the National Solar Mission and state solar policies, but these guidelines seek to also cover all other renewable energy sources, such as wind, small hydropower, geothermal, biomass, and tidal energy. They seek to create competition in the grid-connected renewable energy sector, to bring transparency and fairness in allocation, to reduce information asymmetries among bidders, to achieve standardisation, and hence to reduce ambiguity in the whole process of project allocation (TERI, 2015).

Multiple agencies are involved in India's renewable energy sector. At the centre, the MNRE is the GOI's nodal ministry for all matters relating to new and renewable energy, with the broad aim of developing and deploying them to supplement the country's energy provision. It also conducts resource assessments for renewables and supports R&D in renewable energy technologies and has initiated programmes to support grid-connected power generation and off-grid standalone micro-grid generation, to demonstrate technology and to develop human resources.

The Ministry has also formed independent and collaborative institutes to promote the research and enhancement of renewable energy technologies in India. The National Institute of Solar Energy (NISE) – an apex national R&D institute – has testing facilities accredited by the National Accreditation Board for Laboratories (NABL) for solar PV modules, lighting systems, batteries, water pumping systems and small and large solar thermal systems. Similarly, MNRE set up the National Institute of Wind Energy (NIWE) for wind energy technologies. The Sardar Swaran Singh National Institute of Renewable Energy is focused on solid, liquid and gaseous bioenergy, biofuels and synthetic fuels for transport. Also the Alternate Hydro Energy Centre (AHEC) provides expertise in developing small hydropower in hilly areas.

State governments have nodal agencies and departments operating under their purview for effectively implementing all renewable energy and cogeneration schemes. These promote local renewable energy deployment by channelling subsidies from the centre. The MNRE provides them with grants for their recurring and non-recurring expenditure. Financial assistance to renewable energy projects is provided through the Indian Renewable Energy Development Agency (IREDA) – the financial arm of the MNRE, operating like a green bank – which provides loans and channels funds and other initiatives (TERI, 2014). It is registered as a non-banking financial company and arranges its resources through market borrowing and lines of credit from bilateral and multilateral lending agencies. The National Bank for Agriculture and Rural Development (NABARD) – a development bank set up by the Reserve Bank of India (RBI) – channels money received from Finance Ministry or MNRE to rural areas for developing off-grid solar power generation and applications related to rural development. Rural banking arms of various private banks also actively finance developing small and large scale renewable energy projects.

The Government of India has also get up a commission called NITI Aayog (formally the Planning Commission) which looks into various aspects of the Indian economy. In 2015 it released a Report on India Renewable Electricity Roadmap 2030 (NITI Aayog, 2015) which aims to accelerate renewable electricity deployment. While the report does not detail targets or an estimated energy mix for 2030, it does have a thorough discussion on policy, finance and grid integration issues related to vigorous deployment of renewable electricity.

Box 9: International Solar Alliance

The International Solar Alliance is a platform to bring together countries with rich solar potential, along with solar innovators, developers, and financiers. It aims to aggregate demand for solar energy across member countries, thus creating a global buyers' market, and thereby reducing prices, facilitating the deployment of existing solar technologies at scale, and promoting collaborative solar R&D and capacity.

Countries around the world are adopting and advancing their targets in order to transition to a solar-rich energy future while international, national and regional organisations are working to support governments to advance development and deployment. There are, however, three important roadblocks in the way of rapidly scaling up solar energy:

- The high cost of financing solar in many regions;
- The speed, scale, and skill requirements of deploying available solar technologies; and
- The 'solar technology trap' of becoming overcommitted to a particular technology.

The International Solar Alliance will accordingly focus on:

- Helping to coordinate action to lower the cost of finance for each type of solar energy, whether industrial captive power, commercial rooftop, residential rooftop, rural off-grid solar, or utility scale solar;
- Simultaneously experimenting with and replicating various business models and tailoring action to the needs of countries, so as to allow rapid scaling up with the most suitable business and financial model, and an easily available trained technical and managerial workforce; and
- Promoting the development of strategic and collaborative solar R&D so as to avoid getting locked into a single type of technology. Encouraging and rewarding R&D advancement in future and related technologies to improve the efficiency and integration of solar power, as well as to increase the number of available solar applications.

Encouraged by the success of the National Solar Mission, several states announced their own state solar policies and programmes (though Gujarat took a lead in announcing its solar policy a year before the Mission). State policies are broadly aligned with the Mission's objectives, though there are some differences: several state policies, for example, have not followed its approach of mandating domestic content requirements for projects. India has also spearheaded the creation of the International Solar Alliance, expected to begin operations in late 2016, to further promote solar energy in the country and worldwide (see Box 9).

4.3 Overarching power generation and transmission policies

India's Electricity Act of 2003 paved the way for regulatory interventions, which supported and accelerated the development and deployment of renewable energy. It mandates SERCs to fix quotas for the percentage of electricity being handled by the power utilities so as to procure power from renewable energy sources. It requires SERCs to determine the tariff for all renewable energy projects across their states and to ensure connectivity to the grid for project sites in remote locations and far from major load centres. The Act necessitates the preparation and notification of a National Electricity Policy, a Tariff Policy and, a Grid Code, so as to use the country's energy resources optimally. These are periodically amended and updated in order to stay relevant to the constantly changing energy portfolio.

The Electricity Act also stipulated that the CEA prepare a National Electricity Plan. The Plan would be for a short-term framework of five years while giving a 15 year perspective that includes: short-term and long-term demand forecasts for regions; suggested areas or locations for capacity additions in generation and transmission; outlining areas where improvement of the transmission system could occur and where development of a national grid, efficient generation, a better transmission and distribution could be implemented; and finally what types of fuels should be chosen based on economic, energy security and environment considerations. The first plan with five-year perspective was notified in 2007, and released several years later. The second plan (the latest) was notified to be in preparation in 2013, and the first draft volume focused on generation (the second volume focus is on transmission) was released in December, 2016 (MoP, 2016). It assesses the peak load and energy requirement for the period 2017-2022, and provides a perspective forecast for the 2022-2027 period.

The National Electricity Policy calls for better use of non-conventional energy sources, including solar and wind, for additional power generation capacity, and recognises the need to reduce the capital costs of renewable energy projects by promoting competition.

The NTP mandates SERCs to fix a minimum percentage of RPOs from renewable energy sources, taking into account their availability in the region and the impact on retail tariffs and procurement by distribution companies at preferential tariffs that the SERCs determine. The policy was amended in January 2011 to prescribe that solar-specific RPOs be increased from a minimum of 0.25 % in 2012 to 3% by 2022 – and was further amended in early 2016 to enable faster promotion of renewables to meet the country's recent targets.

The Indian Electricity Grid Code (IEGC) 2010 was developed by the Central Electricity Regulatory Commission (CERC), which lays down both the methodology for scheduling wind and solar energy and a basis for compensating the states with a large wind and solar energy potential for dealing with the potentially large degree of variability in generation. This is done through a renewable regulatory charge operated through the Renewable Regulatory Fund (RRF) mechanism. The Code stipulates that power system operators (state/regional load dispatch centres) shall make all efforts to evacuate the available power from renewable energy sources.

The IEP, formulated by the Planning Commission of India in 2006, provides a broad framework for all policies governing production, distribution and use of different energy sources. It emphasises the need to step away from capital subsidies towards performance incentives, such as a tradable tax rebate certificate (TTRC) that could be based on actual energy generated. It also suggests that power regulators create alternative incentive structures such as mandated feed-in laws or differential tariffs to support utilities in integrating power from renewable energy sources into their systems. Several states are moving in this direction with the development of net-metering policies and FiTs: at least 9 (of 29) states have announced net-metering policies in support of distributed renewable energy.

Other approaches that assist in supporting decentralised renewables (i.e. rooftop solar PV) by providing subsidies to lower capital expenditure are also being pursued, while policies that support self-consumption are also being implemented. The IEP envisions a limited role in power generation for renewable energy sources, with them only providing 5-6% of electricity in the grid as late as 2032 – a share that was already exceeded by 2010. The policy also suggests that they would only prove a crucial component to India's energy independence beyond 2050. However, other policies and recent initiatives by both the central government and some state governments like those in Gujarat, Rajasthan, and Tamil Nadu, indicate the growing role of renewables in the energy mix.

The NAPCC – announced by the GOI on 30 July, 2008 – outlined eight national missions to achieve a low-carbon growth path Missions on Solar Energy, on Enhanced Energy Efficiency, on Sustainable Habitat, on Conserving Water, on Sustaining the Himalayan Ecosystem, on creating a "Green India", on Sustainable Agriculture and, finally, on establishing a Strategic Knowledge Platform for Climate Change.

Government targets include the 100 GW solar PV and 60 GW wind energy goals to be achieved by 2022, plus targets for biomass (10 GW) and small hydropower (5 GW). However, the decade-long Remote Village Electrification Programme (RVEP) – under which solar home lighting solutions were distributed to about 10,000 villages – was discontinued in 2012. Some of its systems are suspected of having fallen into disuse, and batteries will reach the end of their useful lives and will need to be replaced. Whilst several policies have an impact on – and encourage – rural electrification, no replacement for the programme has yet been introduced.

As one of its strategies to combat climate change, NAPCC envisages renewable energy as constituting around 15% of India's total final energy mix by 2020. To achieve this, a minimum share of renewable energy is pegged in the national grid at 5%, starting in 2009/10 and this is to be increased by 1% per annum so as to reach 15% by 2020 (MNRE, 2016a). (As noted earlier in this section, the NAPCC targets are not in alignment with those already-realised in the IEP). Another clean energy initiative under the NAPCC includes promoting trade in RECs across states in order to increase compliance with RPOs.

4.4 Heating, cooling and cooking policies

A large proportion of the policies aimed at renewable energy integration in India are focussed on power generation, but renewables offer a suite of other applications, particularly for heating, cooling, cooking and mechanical operations, and these would greatly enhance the acceptance of renewables amongst the population of the country at large.

MNRE provides policy support for various renewables, bearing in mind the substantial scope of such non-electricity applications in providing energy to people on both small and large scales. Schemes run by both the central and state governments include a capital subsidy for solar water heaters as part of the NAPCC, subsidies under the national solar mission for solar desalination systems, and policy support to wind desalination systems through the MNRE programme on small wind energy and hybrid systems. India has local, state and regional programmes to support clean cooking, and is working with such international organisations as the Global Alliance for Clean Cookstoves to help promote greater adoption of modern and clean forms of cooking. Some important renewable sources have largely been overlooked: there are, for instance, no support policies for geothermal cooling systems.

4.5 Transport policies

India's transport sector is a major energy consumer, accounting for more than half of the country's total petroleum consumption and a quarter of its total energy. It accounts for about 13% of the carbon emissions from the energy sector. This indicates the urgent need for policy mechanisms to encourage the uptake of renewable energy in transport while reducing increasing reliance on imported petroleum fuels. India has the largest light-duty vehicle fleet in the world without efficiency or CO_2 emission standards. The country's Bureau of Energy Efficiency has, however, proposed instituting new Corporate Average Fuel Consumption standards, which could result in higher fuel efficiency for the light-duty fleet, mandating a 14% increase in fuel efficiency by 2016, and additional increases in discussion could require a further 38% increase by 2021/22.

While the use of renewable fuels for transport is still at a very nascent stage, the government has developed policies, through several different agencies, to support its uptake. The Indian Ministry of Railways launched a 'Vision 2020' plan in December 2009 proposing that a target of 10% of the total energy consumed by the Indian railways should be sourced from renewables. However, no significant progress has been made in reaching this target, though pilot projects at railway stations, railway signals and level-crossing gates are underway.

The Ministry has also entered into a joint venture with RITES Ltd., so as to set up a railway energy management company to undertake projects harnessing renewable power. These include solar and wind power plants, power trading activities, transmission lines and power evacuation planning, energy conservation initiatives, efficient co-ordination in power generation through captive power plant, and energy audits. The company will also facilitate faster execution of renewable energy and energy conservation works with the aim of reducing of Indian Railways' energy bill. Similarly, the Ministry of Heavy Industries & Public Enterprise launched a 'National Electric Mobility Mission Plan 2020' in August 2012. This includes interventions to reduce dependence on fossil fuels and promote the transition to electric vehicles powered by renewable energy. Advances on electrifying vehicles have so far been limited.

4.6 City and state level policy making for renewables

Some of the support framework required for up scaling renewable energy in India has to be provided at state level. State nodal agencies have been set up to implement the policy measures determined nationally by the MNRE and to decide additional state-specific policy that promote implementing renewable energy projects. The states, however, often tend to support incumbent energy actors and their state-level public utilities, and to subsidise power for consumers. They also determine how to implement national policies, and this can result in big differences in how programmes are administered. An overview of some states' renewable policies show how important, and dynamic, such local policy implementation can be.

So far ten Indian states have announced their own solar policies. The Rajasthan Solar Policy, adopted in 2011, is indicative of the type developed and implemented by various states. Targeting 700 MW of solar power by 2017, it is administered by the state nodal agency – the Rajasthan Renewable Energy Corporation Limited. It provides a preferential tariff, and promotes developing solar parks, setting up an infrastructure development fund, providing government land at concessional rates, it also provides exemption from the cost of electricity transmission and single window project clearance. Similar policies have been adopted by Tamil Nadu, Uttar Pradesh, Andhra Pradesh, Karnataka, Punjab, Madhya Pradesh, Chhattisgarh, Gujarat and Jharkhand.

Key provisions that states have made for solar and wind policies include topics relating to land acquisition. Conducive state land allocation policies can help it emerge as a favoured destination for renewable energy, while unfavourable acquisition policies can discourage investments in clean energy projects.

Examples of conducive land acquisition policies include the Rajasthan State government allotting land to wind and solar power developers either on lease, or at a concessional rate of 10% of the market rate, in 2011 and 2012. Gujarat introduced provisions for allocating the state's vast tracts of wasteland for wind installations in its Wind Power Policy of 2013. On the other hand, West Bengal's policy of allocating state-held land through competitive bidding, for example, has hindered attracting investments in wind-farm projects.

Solar Parks are another approach. State determined policies on large solar parks can be designed as a package deal, enabling project development timelines to be streamlined by allowing government agencies to undertake land acquisition and seek necessary permits, and also providing a dedicated common infrastructure (in the form of developed land, water, gas availability and access roads, and power transmission systems) to set up solar power generation plants by private developers. The advantages of solar parks include:

- Reductions in the cost of solar power by providing economies of scale in procurement, the acquisition of permits, and the development of power;
- Reductions in the risks of project implementation for developers and the expedition of project execution; and
- Preserving grid connectivity, which has not emerged as a major issue in Gujarat and Rajasthan (where the majority of solar PV is being deployed) partly because of the states' approach to using solar parks.

There is also a large push to promote solar in urban areas. Developing solar cities has been an active policy in India since 2008: over 60 cities and towns take part in the "Solar Cities" programme (see Box 10). Many programmes and financing options are available both centrally and at state level, as discussed earlier in this chapter. These can include income tax breaks, accelerated depreciation, tariff payments for renewable generation, import concessions, and other generation-based incentives. Many cities are also adopting approaches to support renewable energy and improvements in energy efficiency improvements through additional measures. Tax rebates are commonly offered by local authorities. Such cities such as Thane, Amravati, Durgapur and Navi Mumbai have property tax rebate programmes ranging from 5% to10% to promote either renewable energy or energy efficiency. Many municipalities also have green building incentives aimed at encouraging designs that include highly efficient building envelopes and integrate solar thermal and solar PV. (ICLEI, 2013). An Energy Service Company – a specialised service provider offering a range of energy solutions together with planning, designing and implementing energy efficiency projects – can agree to various types of performance contracts for projects. Besides improving energy efficiency, typical Energy Service Company projects can also include integrating solar water heating, or biomass/biogas steam generators. Finally, municipal bonds form one of the most common methods for local municipalities to support renewable energy. Issuers can include cities and regions, redevelopment agencies, districts, and publicly owned airports or other entities and the interest earned on the bonds is typically free from federal income tax.

Box 10: Solar Cities

Local politics drives much of the transition to an energy future with a greater renewable energy component in cities around the world. Peak electricity demand is sky rocketing as India continues to experience rapid urbanisation and migration to metropolitan cities, making it increasingly difficult for local electricity utilities to service it. In this context, MNRE launched a programme for the 'Development of Solar Cities' in February 2008. The recently revised programme aims, at the very least, at a 10% reduction in projected demand for conventional energy after five years: this can be achieved through combining energy efficiency measures and increased renewable energy supplies.

All types of renewable energy – such as solar, wind, biomass, small hydropower, and waste to energy – may be installed along with possible energy efficiency measures, depending on a city's need and resource availability. Sixty cities and towns are eventually to be enlisted in the 'Solar Cities' programme – with a minimum of one city, and a maximum of seven, per state. Specifications for being chosen as a solar city include population size, which must be between 500 000 and 5 000 000 people.

The programme consolidates existing local efforts to promote renewable energy – such as solar water heating systems, rooftop PV systems, and waste to energy systems – and proposes holistic energy management. Cities prepare a holistic master plan, which includes an energy consumption baseline, future demand forecasting and strategies per sector, and an action plan for implementing renewable energy projects on identified sites to reduce their fossil fuel consumption. (MNRE, 2015b). Finance, amounting to approximately USD 100 000 per city, is provided under the programme for developing the plan, identifying project sites and potential, and monitoring and promoting the deployment of renewable energy projects. By July 2014, 31 cities had been enlisted and had started the development of a master plan, while another 17 had got 'in principle' approval from the MNRE.

5. RENEWABLE ENERGY POTENTIAL AND COSTS

Table 5 provides an overview of MNRE and other organisations' estimates of the technical potential for power generation in India. The country has an estimated renewable energy potential of about 900 GW from commercially exploitable sources (1000 GW when large hydropower is included). It is endowed with very good solar energy potential. Most areas receive on average between 4-7 $kWh/m^2/day$ of solar irradiance. Assuming 3% of the country's wasteland is available for it there is a solar power potential of 750 GW.

The potential for wind is more differentiated. The National Wind Resource Assessment programme monitored 794 sites with heights ranging from 20-120 meters. At a hub height of 80 metres, there is at least 102.8 GW of potential at sites with a wind power density greater than 200 W/m^2 (MNRE, 2012). Other studies show considerable more potential, ranging from 300 GW to as much as 1000 GW (NIWE, n.d.). India has a vast 7600 km coastline and preliminary studies have indicated potential for deploying offshore wind power projects in its Exclusive Economic Zone (EEZ).

MNRE estimates the annual potential for biomass-based electricity at 18 GW, generated by 120–150 million tonnes of agricultural and forestry residues. There is also about 5 GW of possible power capacity from bagasse-based cogeneration in sugar mills. Sugar mills represent the largest share of industrial combined heat and power (CHP) potential in the country, equivalent to 14 GW. There is also 5 GW of additional potential from energy crops, taking current total biomass power generation capacity potential to 28 GW (MNRE, 2012; 2015c).

The potential of hydropower – small and large – is estimated by MNRE to be 20 GW (based on 6474 assessed sites) and 100 GW, respectively. The IEA assesses total hydropower potential at around 150 GW (IEA, 2011). According to an IREDA atlas of potential land for renewable energy assessment, there is 15 GW of potential for small hydropower for schemes up to 25 MW. The same assessment adds that the potential is actually much larger, as different states are offering sites for small hydropower for self-identification by prospective bidders.

Table 5: Renewable power resource potential of India

	2014 capacity	Technical potential in 2030		
		MNRE	IEA	Other
	(GW_e)	(GW_e)	(GW_e)	(GW_e)
Hydropower	40.5	100	150	
Hydropower (small)	4	20		15
Onshore wind (100m)				100
Onshore wind (80m)	22.5	102.8	45	
Onshore wind (50m)		49.1		
Offshore wind (at depth 5-25m)	-		15	
Solar PV (utility)	3	750		
Solar PV (rooftop)				
Biomass	4.3	28	20	
Geothermal			<10	

Sources: MNRE (2012; 2015c), NIWE (n.d.), IEA (2011) and IREDA

GW_e = Gigawatts-electrical

The technical potential for renewable energy in India is at least three to seven times higher than 2014 installed capacity for hydropower, wind and bioenergy. For solar its well over 100 times higher

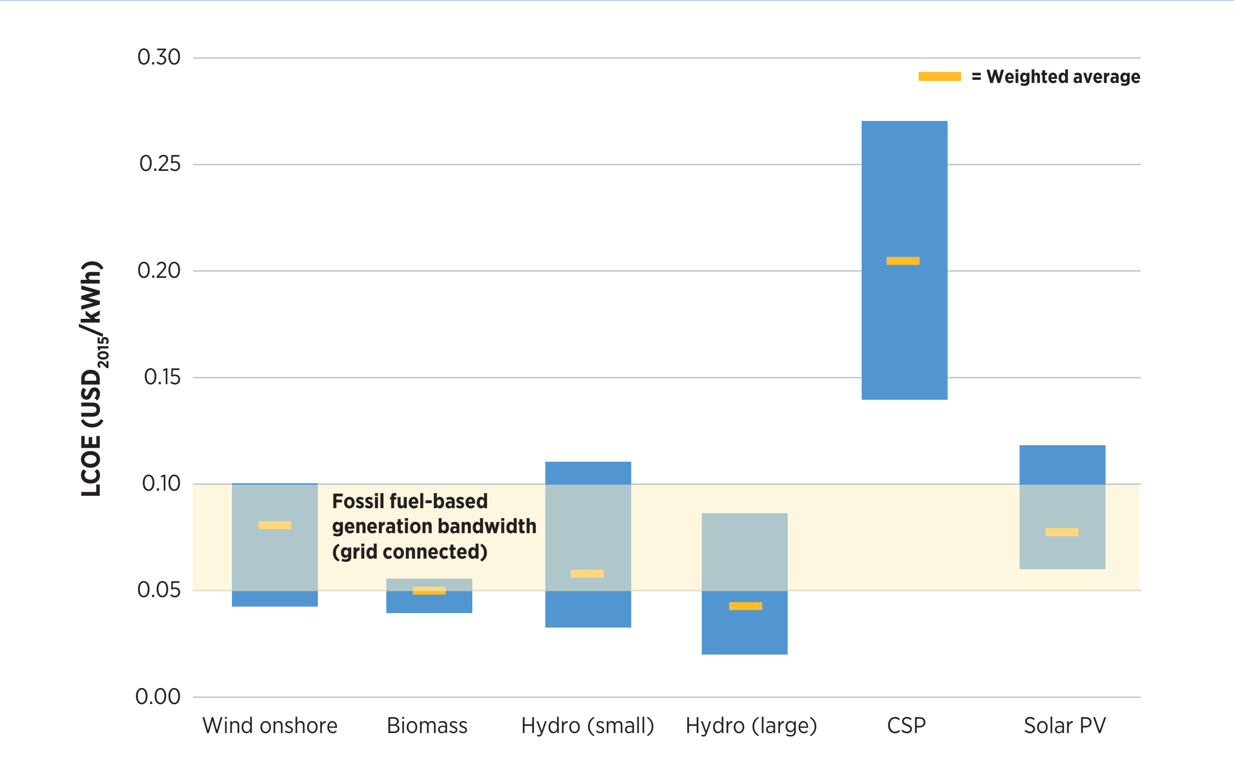
Table 6: Breakdown of total biomass supply potential in 2030

	Batidzirai *et al.* (2012) (EJ/yr)	IRENA (2014c) (EJ/yr)
Forest products incl. residues	0-1.7	0.6-2.2
Fuel wood		0-0.6
Wood residues		0.4-0.9
Wood waste		0.2-0.6
Agricultural residues incl. animal waste	0.5-7.9	7.0-8.1
Harvesting residue		2.4-4.3
Processing residue		0.9-2.4
Biogas		3.6-1.4
Energy crops	0.5-9.2	-
Total supply potential	1.0-18.8	7.6-10.3

Sources: Batidzirai et al. (2012) and IRENA (2014c)

Table 6 shows a breakdown of the total potential of biomass supply in 2030 by types. IRENA (2014c) estimated the biomass supply potential and related supply costs up to 2030, for seven types of biomass feedstocks (energy crops, harvesting residues, biomass residues, biogas, fuel wood, forest residues, and wood residues) for all REmap countries. By this estimate, India can expect a total biomass supply potential in 2030 of about 9 EJ. More than 80% of the total originates from agricultural residues, with a significant contribution from biogas: no potential for dedicated energy crops was estimated. These estimates are also in

Figure 17: LCOE range of commissioned or proposed renewable power systems in India, 2013-2015



Source: Based on IRENA (2015d) with updates to Solar PV and Wind from IRENA (2016f)

Note: Discount rate of 10% is assumed. The horizontal black bars show the weighted average for the 2013-2015 period.

line with a study by Batidzirai et al. (2012) that reviews biomass supply estimates for India from key literature, though this provides a wide range depending on how the availability of land and residues is accounted for.

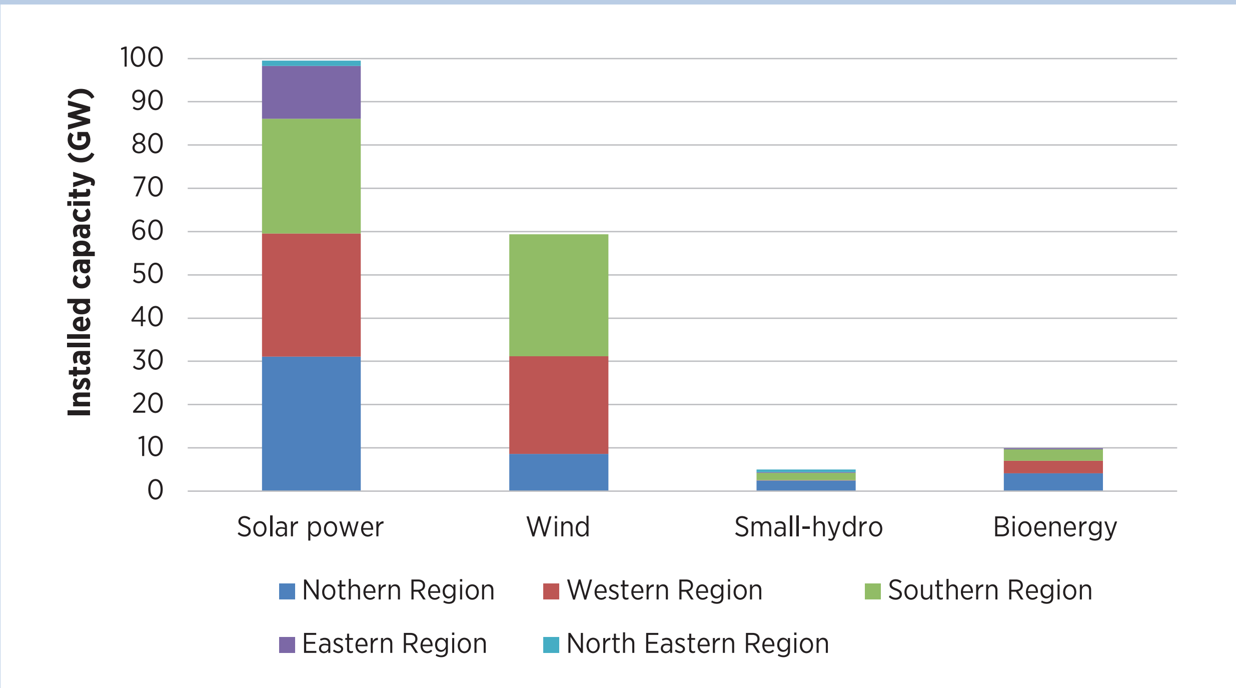
IRENA estimates that supply costs range from USD 1-12/GJ. The lower end of the range refers to agricultural residues (harvesting and processing), as well as to biogas, the higher end to forest products and residues, including fuelwood.

India has some of the world's most competitive levelised costs of electricity (LCOE), even for wind, where the quality of the local resource is lower than in other regions. Financing costs, however, are somewhat higher than in neighbouring countries like China, and this has an impact on the LCOE. Figure 17 gives an overview of ranges and weighted averages for renewable power technologies commissioned or proposed between 2013 and 2015. Hydropower is still the lowest-cost renewable power generation option, with weighted average costs of between USD 0.04/kWh and USD 0.05/kWh for small- and large-scale projects, respectively. Large-scale wind projects have average costs of around USD 0.08/kWh, with a range between USD 0.045/kWh and USD 0.11/kWh, with small-scale (<5 MW) projects having weighted average costs of USD 0.09/kWh. Biomass-fired power generation costs average between USD 0.045/kWh and USD 0.06/kWh, assuming feedstock costs of between USD 1.3-2.5/GJ. The weighted average LCOE of utility-scale solar PV fell to around USD 0.06/kWh in early 2016 and in early 2017 some PV auction have broken the USD 0.05/kWh mark, but there was still a wide range of costs, and projects with an LCOE of twice this average that are still being built.

Wind, hydropower, biomass power and solar PV all compete with fossil fuel power generation, with increasingly renewable energy being the least-cost generation option

The MNRE has also provided a tentative breakdown of which states and regions will experience the deployment of renewable energy capacity to meet the target of 175 GW by 2022 (Figure 18). It shows that over half of the 100 GW of solar power will be located in the Northern and Western Regions. Wind will predominantly be located in the Western and Southern Regions, while most regions will receive some bioenergy and small-hydropower.

Figure 18: Tentative regional breakdown of renewable power capacity under 2022 target



Based on analysis of MNRE (n.d.)

6. REFERENCE CASE DEVELOPMENTS FROM NOW UNTIL 2030

Key points

- India's TFEC is projected to increase from 17.4 EJ in 2010 to 42.6 EJ in 2030 in the Reference Case. Energy use trends, largely based on Planning Commission and CEEW estimates, show that its future energy demand will continue to be mainly reliant on fossil fuels.

- Total power generation is expected to increase by 3.5 times from 945 TWh/yr in 2010 to over 3 450 TWh/yr by 2030. Some 2 000 TWh of the expected increase will be met by growth in coal power generation. Total gross power generation capacity will reach an estimated 670 GW by 2030. Of this total, 40% – 262 GW installed capacity – will be related to renewable power generation.

- Coal power capacity will reach 385 GW, an increase of around 290 GW over 2010 levels. Total coal demand for power generation will increase by a factor of 3.5, from around 8 EJ to just under 28 EJ in the Reference Case.

- The increased renewable power capacity in the Reference Case is significant compared to historic trends, but still low compared to the growth in coal power capacity. Installed hydropower capacity will grow by around 25 GW to 48 GW, and biomass and biogas capacity from around 3 GW to 11 GW in total. Wind power capacity will experience the greatest increase to reach 145 GW by 2030, compared to 14 GW in 2010. Solar PV will also see strong growth.

- In total, the renewable energy share in TFEC will decrease from 40% to 23%, when traditional uses of biomass are included, and from 17% to 12% in terms of the modern renewable energy, which excludes such traditional uses in the building sector.

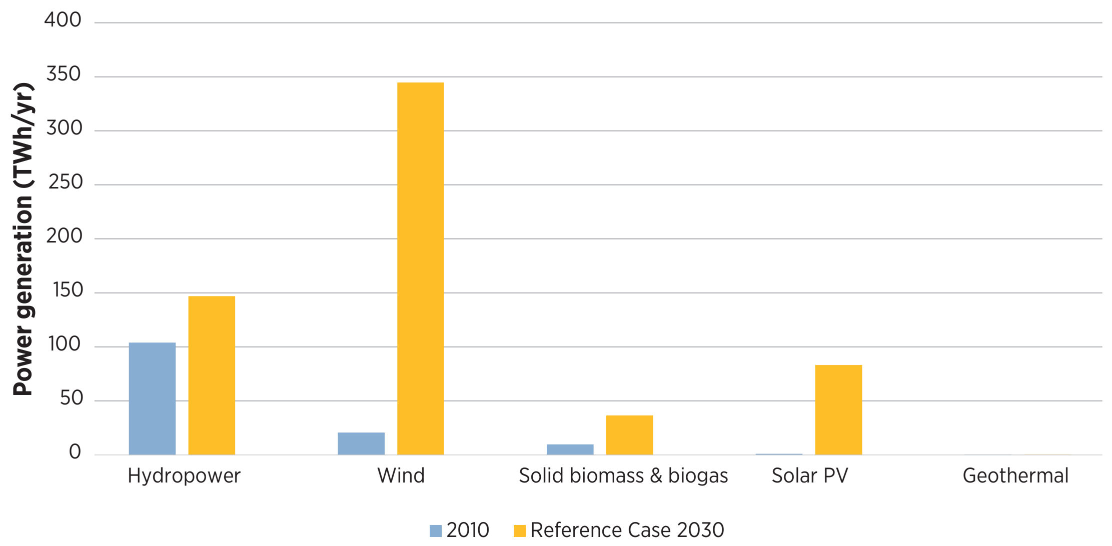
- Total renewable energy demand in end-use sectors (excluding renewable electricity) will see an increase from about 6.6 EJ/yr to 7.7 EJ/yr. In the building sector, which includes residential, commercial and government sub-sectors, developments in the traditional use of biomass are modest, with demand increasing from 4.1 EJ/yr in 2010 to 4.3 EJ/yr. In the industrial sector, the only renewable energy source is solid biomass use for process heat generation: this will increase by 50% from 1200 PJ/yr in 2010 to 1800 PJ/yr by 2030. Fossil fuels still dominate, and coal use doubles. The transport sector sees more than a doubling in demand, from 2 400 PJ/yr to almost 6 000 PJ/yr by 2030, almost all the increase is met by oil products.

- The results of the Reference Case show that fossil fuel growth largely dominates the period up to 2030. While the growth of renewable power generation accelerates, the use of coal in industry, of natural gas in buildings, and of oil in transport results in a decrease in renewables' overall share, particularly in the buildings and industry sectors.

The REmap analysis of India begins with an assessment of the uptake of renewable energy technology options between 2010 and 2030, based on current policies. Planning Commission (GOI, 2014b) and CEEW (2015d) estimates are used to a large extent to develop the Reference Case for this analysis, though IRENA estimates are employed in assessing biomass and LPG use in the building sector and some bioenergy technology breakdowns in the power sector, including off-grid power applications.

India's energy use has been growing rapidly and projections show that its TFEC is projected to increase from 17.4 EJ in 2010 to 42.6 EJ in 2030. The country needs to choose how this growth will be met. This chapter overviews the Reference Case energy use

Figure 19: Reference Case renewable power generation, 2010-2030



Source: IRENA analysis

trends in India between 2010 and 2030, which mainly rely on fossil fuels.

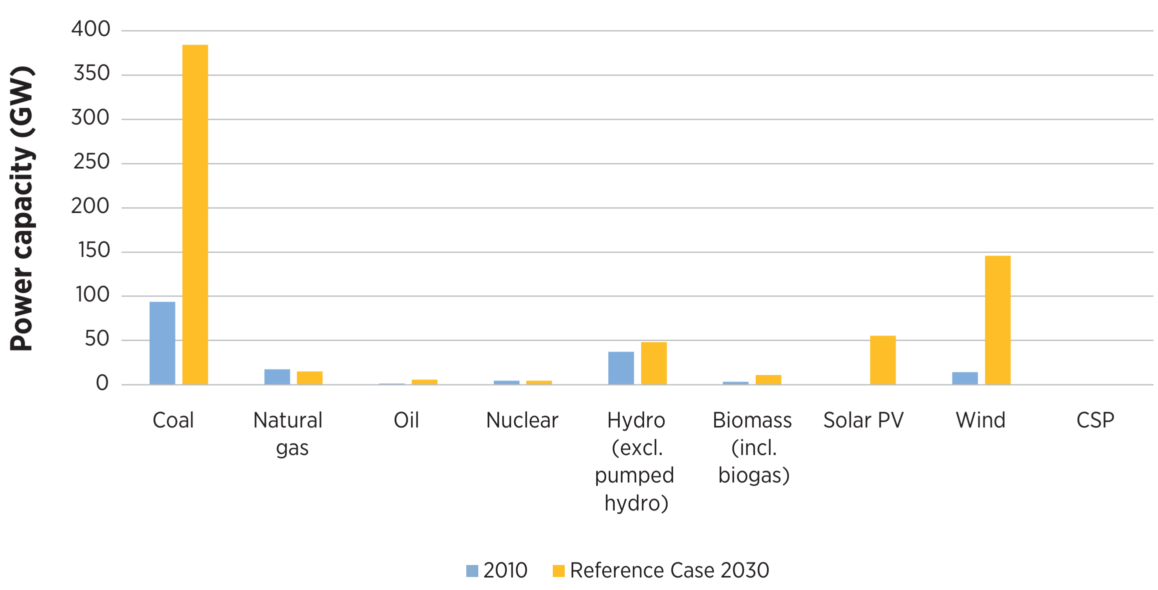
Between 2010 and 2030, the largest increase is in natural gas, which grows 20 fold, fuelled by surging LPG imports. Oil demand doubles due to large increases in demand from transport and buildings. Coal use also doubles in end-use sectors, while biomass use grows slightly, by around 10%. The increases in natural gas and oil are driven by an increase in economic activity and accelerated urbanisation, which takes the number of people living in cities and towns to 600 million by 2030. Urban populations consume more natural gas and oil, and – importantly in India's case – significantly more electricity. Though growth in end-use fuel consumption is significant, it is overshadowed by the very rapid increase in the consumption of electricity.

Total power generation is expected to increase 3.5 times over in the Reference Case from 945 TWh/yr in 2010 to over 3 450 TWh/yr by 2030. Some 2 000 TWh/yr of this extra 2 500 TWh/yr will be met by increases in coal power generation. Renewable power generation, meanwhile, is projected to increase from about 137 TWh/yr to 595 TWh/yr (Figure 19). Wind energy will form the largest component of this with around 345 TWh/yr in 2030, followed by hydropower with 131 TWh/yr. Power generation from solar PV will increase rapidly from under 1 TWh/yr to 83 TWh/yr by 2030, while bioenergy power (including biogas) grows from 10 TWh/yr to around 35 TWh/yr.

The total gross capacity of the power system will almost quadruple from 174 GW in 2010 to an estimated 670 GW by 2030. Coal power capacity will reach 385 GW in the Reference Case, an increase of around 290 GW over 2010 levels (Figure 20). Total coal demand for power generation will increase by a factor of 3.5 times over, from around 8 EJ to just under 28 EJ. As discussed in Chapter 3, heavy reliance on coal will require significant imports from world markets as domestic supply is limited and the quality of Indian coal is low (with a low heat rate). Power generation capacity from oil and nuclear will experience very slight growth, and natural gas capacity will remain flat.

Renewable power capacity in the Reference Case is significant compared to historic trends, but still low when contrasted with the growth in coal-fired power. Installed hydropower capacity will grow by around 25 GW to 48 GW, and biomass and biogas capacity will grow from around 3 GW to 11 GW in total. Wind power capacity undergoes the greatest growth in absolute terms to reach 145 GW by 2030 from 14 GW in 2010.

Figure 20: Reference Case power generation capacity, 2010-2030



Source: IRENA analysis

Solar PV grows even more proportionately, from under 1 GW to 56 GW[12] (of which 15 GW is distributed rooftop PV).

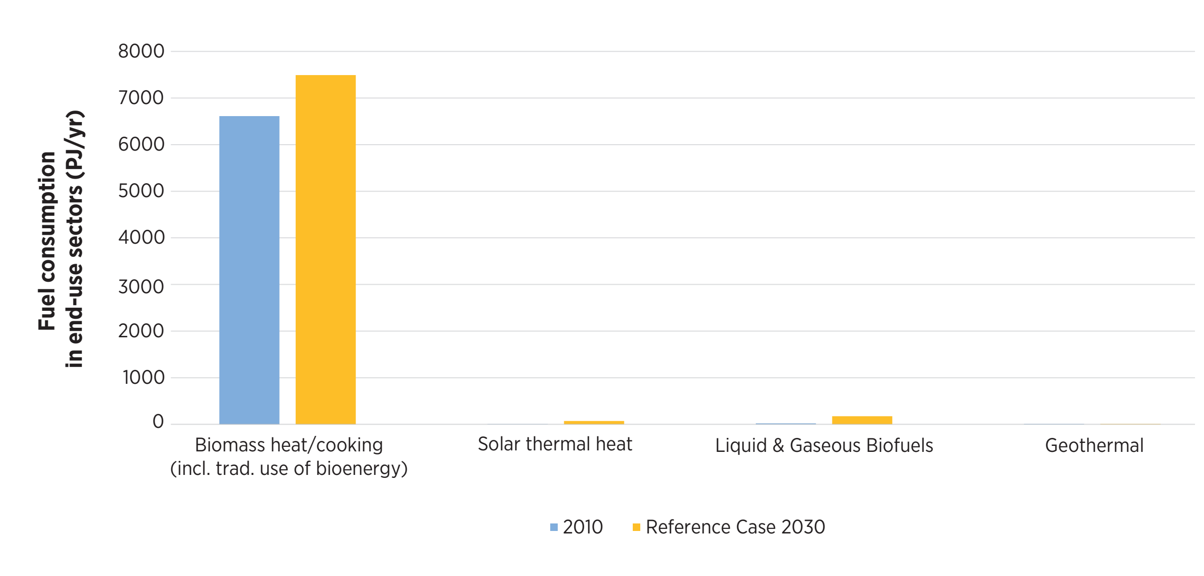
In the Reference Case demand for coal for both heating and power generation grows significantly. To meet this demand, measures will be needed to accommodate such a high coal demand. Current exploration and mining of coal needs upgrading; this, along with increasing demand, will be a major challenge if no action is taken. Infrastructure for coal imports will be required on India's western and southern coasts. Coal washing will need to become the norm requiring large quantities of water, and the fuels environmental externalities will need to be internalised (IEA, 2011). These investments could lock-in infrastructure that assure the country consumes large quantities of coal for decades to come.

Total renewable energy demand in end-use sectors (excluding renewable electricity) will increase in the Reference Case from about 6600 PJ/yr to 7700 PJ/yr (Figure 21). In the building sector, which includes residential, commercial and public sub-sectors, the traditional use of biomass only increases from 4100 PJ/yr in 2010 to 4300 PJ/yr, a very modest increase compared to the doubling of the sector's final energy demand. The doubling of the sector's demand is largely driven by significant growth in LPG and natural gas consumption. The increase demand for modern forms of bioenergy for cooking sees limited growth. Modern forms of solid biomass use increase by only 10% in the building sector, from 1400 PJ/yr to 1500 PJ/yr, but its use of biogas, though low, grows more than six-fold from 10 PJ/yr to 65 PJ/yr. The only other sizable renewable source is solar thermal, which increases 12-fold to 72 PJ/yr by 2030, but from a very low 6 PJ/yr starting point.

In the industrial sector, the only sizable source of renewable energy is solid biomass use for heat generation, which will increase by 50% from around 1200 PJ/yr in 2010 to 1800 PJ/yr by 2030. Fossil fuels still dominate: coal use doubles from 3200 PJ/yr to 6400 PJ/yr by 2030, as does oil consumption, from 1600 PJ/yr to 3200 PJ/yr. The largest increase – from 280 PJ/yr to just under 5000 PJ/yr – is in natural gas.

12 Solar PV growth in the Reference Case does not take into account the recently-announced goal of achieving 100 GW by 2022, this goal is considered accelerated renewable uptake and is incorporated into the REmap Options

Figure 21: Reference Case growth of renewable energy in end-use sectors



Source: IRENA analysis

Energy use in the transport sector more than doubles from 2 400 PJ/yr to almost 6 000 PJ/yr by 2030. Petrol and diesel consumption increases from 2 100 PJ/yr to 5 600 PJ/yr, with a small additional supply of liquid biofuel, largely based on biodiesel, increasing from 8 PJ/yr to 109 PJ/yr: that may be more than a thirteen-fold increase, but it still only provides under 2% of the sector's energy needs.

In the end-use sectors only bioenergy sees growth among renewable sources in the Reference Case; significant growth is, however, seen in fossil fuel demand

Table 7 gives an overview of the Reference Case's change in the share of renewables (including both modern and traditional uses of bioenergy) in India's TFEC between 2010 and 2030. The share of modern renewable energy in the industry and buildings sectors actually falls, due to large increases in their consumption of coal (in industry) and natural gas (in buildings).

Renewables' share in the power sector increases, however, from 14% to 18% in the same period – despite the high growth in coal power generation – as a result of the growth in solar PV and wind and, to a lesser

Table 7: Renewable energy share in the Reference Case of India, 2010-2030

	2010	Reference Case 2030
Power generation	14%	18%
Industry	18%	11%
incl. renewable electricity	18%	12%
Transport	0%	2%
incl. renewable electricity	2%	2%
Buildings (excl. trad. biomass)	21%	15%
incl. renewable electricity	21%	16%
TFEC – modern	17%	12%
TFEC – incl. traditional biomass	40%	23%

Based on IRENA estimates

extent, hydropower. The transport sector sees modest growth in renewable energy due to a small increase in biofuel.

Even though the share of electricity in India's TFEC is up from 12% to 25%, and the share of renewable power slightly increases, this is overshadowed by the growth in end-use fuels. As a result, the renewable energy share in TFEC will decrease from 40% to 23% in the Reference Case, when traditional uses of biomass are included, and from 17% to 12% if viewed in terms of modern renewable energy (which excludes traditional uses of biomass in the building sector).

The share of renewable energy in India's TFEC was around 39% in 2012 – split into 10% modern and 29% traditional forms – according to the Global Tracking Framework (GTF; World Bank, 2015). The IRENA analysis for the REmap base year of 2010 shows a similar share for total renewable energy (40%) but a higher one, of around 17% for modern renewables than in the GTF. Yet modern renewables are still less than half of all renewable energy consumed, with a large share still coming from traditional uses of biomass. These traditional uses are not sustainable and have negative social and environmental impacts and so need to be substituted with modern forms of renewables.

The results of the Reference Case show that fossil fuel growth largely dominates the period up to 2030. While the growth of renewable power generation accelerates, the use of coal in industry, natural gas in the building sector, and oil in the transport sector results in a decrease in the overall share of renewables particularly in buildings and industry. While much attention should be paid to the significant increases in electricity demand and the opportunities to increase renewable energy deployment in the power sector, there is also a need to look at increasing the growth of renewables in the end-use sectors. It is clear from this Reference Case that India is at the start of a period of a very high increase in energy demand, and government plans currently envisage the vast majority of it as being met by fossil fuels, despite little potential to supply them from domestic sources. Greater attention should be paid to meeting this demand with domestically produced renewable energy. The following chapters will address this challenge, and show how India can achieve significantly higher growth in renewable energy.

7. THE REMAP OPTIONS TO 2030

Key points

- Options have been identified that could raise India's renewable energy use to approximately 9.3 EJ by 2030, equivalent to a 25% share of TFEC. They include full substitution of traditional uses of biomass by modern renewables.

- Forty-two percent of the total renewable energy use in REmap is related to renewable power options. Various forms of biomass (such as for power, heat, and motor fuel) and solar (PV, CSP, solar thermal heating/cooling) would together account for 80% of total renewable energy use in 2030.

- Of the REmap Options identified in the power sector, 40% are related to solar PV, 20% to wind, 16% to hydro and 11% to biomass. The remaining is related to geothermal, solar CSP and rural electrification.

- Total wind capacity would increase 14 times over from its 2010 level. The increase in solar PV capacity is even higher and would reach an installed capacity of 200 GW by 2030 plus additional off-grid solar PV, more than double India's 2022 target of 100 GW. Renewable power's share of total capacity would increase to 39% in the Reference Case, and 60% in REmap. India's INDC pledged to reach a share of 40% by 2030.

- Primary biomass use would increase 20% over 2010 levels. While traditional use of bioenergy would be fully substituted by 2030, total primary biomass demand for its modern uses would more than double by then. Additional potential for biomass use is concentrated in the industrial, power generation and transport sectors.

- Solar thermal heat will play an important role. 20 million m^2 of low-temperature solar water heater capacity – and 12 million m^2 of medium-temperature concentrating solar collectors – have been estimated for industry. With these additions in REmap, solar thermal would account for about 0.7% of India's total industrial energy demand (excluding power). In the building sector an additional 125 million m^2 are considered as REmap Options. Most of this is for water heating, with a smaller share related to solar cooling substituting for air conditioning systems. The total installed solar water heating capacity in India's building sector would increase to 154 million m^2, delivering 370 PJ/yr, 2% of its total energy demand.

- REmap estimates a trend towards more electricity use in the transport sector through the increased use of electric vehicles and structural changes. An additional 100 TWh/yr electricity use is estimated for electric vehicles, with 20 million four-wheel cars and as many as 350 million two to three wheelers on the road in 2030.

- In REmap modern renewable energy's share of India's TFEC increases to 25% in 2030, more than double the Reference Case level of 12%. Renewable energy's share in power generation increases to 35% in REmap, from 14% in 2010, compared to 18% in the Reference Case.

- The energy intensity of India's economy was USD 6.9 per MJ in 2010 and will decrease in the Reference Case by 17% to USD 5.7 per MJ in 2030. In REmap, this is reduced further to USD 5.1 per MJ, a decrease of 26% over 2010 levels.

- Investment needs to rise considerably. The REmap options would require USD 26 billion in additional investment per year in renewable capacity, which – when added to the Reference Case investment need of USD 16 billion – would result in 42 billion of total investment needs for renewable technologies per year between now and 2030.

- Coal demand would decrease by 17% over the Reference Case, to around 30 EJ/yr, and oil demand by 23% to 8 EJ/yr.

- The total package of REmap Options identified would result in an incremental cost of substitution of USD 2.3 per GJ for consumers and result in additional costs of USD 3.8/GJ for society, making a total of USD 17 billion per year in additional costs. These exclude savings from the benefits of renewable energy from improved human health and reduced CO_2 emissions.

- These USD 17 billion total system costs would be outweighed by estimated savings from the effects of reducing air pollution, which amount to USD 46-161/yr, and from a reduction of 750 Mt of CO_2 emissions per year by 2030, saving USD 13-63/yr. Most of the savings related to air pollution are associated with the effects of traditional uses of biomass in the residential sector.

- The REmap Options would also have positive macroeconomic benefits for India across the board, resulting in higher GDP and significant net employment effects.

The Reference Case (i.e. business as usual) analysis for India uses an internally developed REmap tool. The data, assumptions and approach used were summarised in Chapter 2 while the results of the Reference Case are detailed in Chapter 6. Under the Reference Case, India is expected to experience a very significant growth in energy demand, in the order of around a two and a half times increase. Importantly most of this growth is to be met by fossil fuels, and the overall share of renewables actually decreases, despite a slight increase in the use of renewable power. So it is important to see where additional renewable potential is available, and IRENA uses the REmap tool to input this in the form of additional renewable energy options in the end-use sectors of industry, buildings, and transport, as well as for power and district heat generation. The process for identifying the REmap Options was as follows:

- The Reference Case for the period between 2010 and 2030 was created. The results of this projection are explained in Section 6,

- Commodities and fuel prices reflecting the national situation were prepared;

- Technology cost and performance criteria (e.g. capacity factors) were also prepared to reflect the national situation and

- Additional renewable energy options for all end-use sectors and the power sector were analysed, based on various studies and assessments.

The sources of the REmap Options for India originate from a range of research that includes:

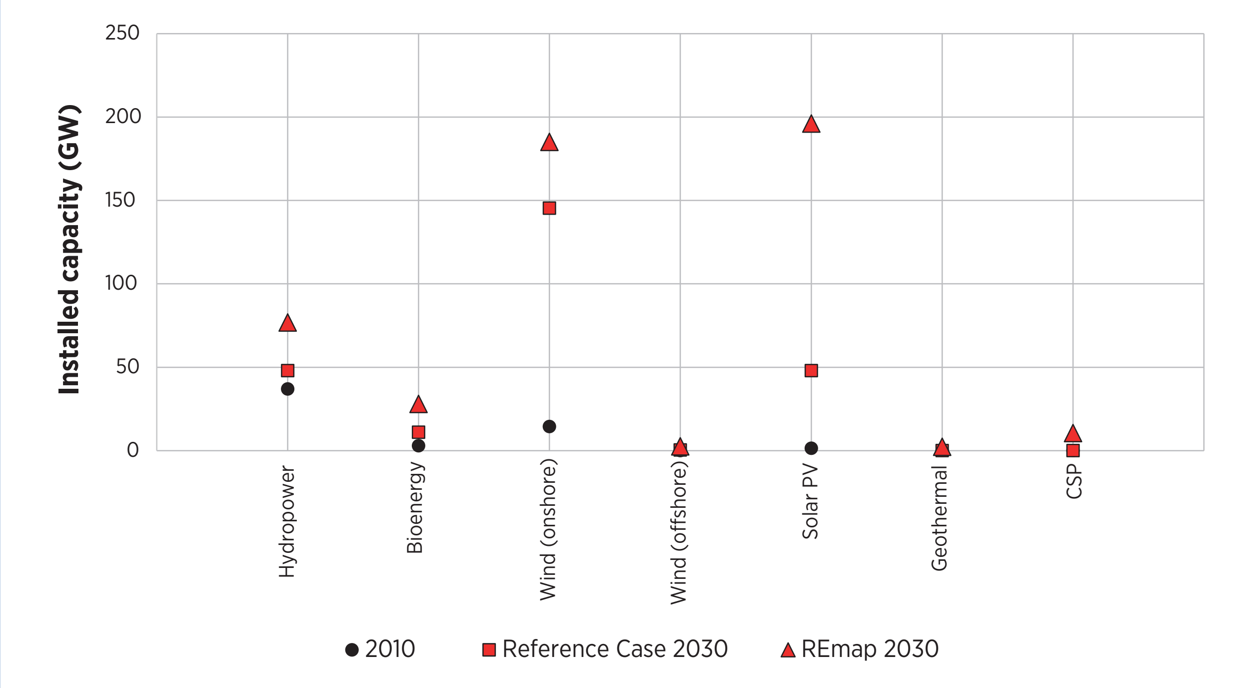
- For the power sector: The Planning Commission (GOI, 2014b) and Global Change Assessment Model (GCAM) estimates of the CEEW (2015d) were used, as well as internal assessments prepared by IRENA with input from MNRE. The Reference Case is broadly based on the Baseline Inclusive Growth Scenario, while the REmap Options are largely based on the Low Carbon Inclusive Growth scenario;

- For the heating (buildings and industry) sector: Solar Water Heaters in India (GOI, 2010) and a recent IRENA renewable energy in industry roadmap (IRENA, 2014b) with its accompanying data were used; and

- For the transport sector: A variety of sources were used, including CEEW (2015d), IRENA analysis, the Planning Commission (GOI, 2014b), Vision 2020 – A Blueprint for Railway Electrification Programme (GOI, 2011), and the National Electric Mobility Mission Plan 2020 (GOI, 2012).

In addition, expert opinions from MNRE, IRENA and external authorities were incorporated into the analysis to arrive at renewable potential. These were primarily the source of some biomass, off-grid and renewable power technology assessments.

Figure 22: Power capacity by renewable energy technology



Note: Figure only includes on-grid power capacity

Source: IRENA analysis

7.1 Renewable energy technologies in the power sector

The Reference Case showed modest developments in the power generation sector with a slight increase in the renewable share from 14% to 18%. There is significant growth in renewable power generation capacity (particularly wind, but also solar), but total demand for power in India grows equally fast, resulting in only relatively small increases in the sector's total renewable energy share between 2010 and 2030. The share of renewable power capacity reaches 39% of capacity in the Reference Case, just shy of the 40% INDC target. In fact, the fivefold increase in power demand creates a significant opportunity to realise India's large potential for renewables, and this needs to be considered. Figure 22 shows the change in renewable power generation capacities between 2010 and 2030, if the realisable potential of all renewable energy technologies waste is deployed beyond the Reference Case. In REmap the renewable share of capacity increases considerably, to 60%. The rest of this section explains this potential, technology by technology.

Solar

REmap Options can potentially take the installed capacity of on-grid solar PV to 200 GW and higher if including additional off-grid systems. This is over four times higher than is envisioned in the Reference Case, which assumes achieving 20 GW by 2022, and an installation rate of just over 3 GW/yr between then and 2030 to have 48 GW by that time. REmap Options include the recently proposed target of 100 GW by 2022 (as this constitutes an accelerated approach for renewables this is included in the REmap case). Achieving the REmap total of 200 GW would require an annual installation rate of 1 GW/yr from the 2014 level until 2022 and 15 GW/yr between then and 2030. Utility-scale solar accounts for 160 GW, and distributed generation – including grid-connected rooftop, for the remainder. An additional 20 GW of solar home systems and solar for telecom towers would also be in operation.

Solar PV has a capacity factor ranging from 16% to 19% and is estimated to produce around 350 TWh/yr of power, making up around 10% of India's power supply. So the impact of this addition on the grid will be limited (see Chapter 8 for a more detailed grid discussion).

This share is an increase from nearly zero at present, and represents significantly higher growth even greater than the very big increase expected in total demand for electricity.

Rooftops in densely populated cities are an important element in the availability of space for solar PV and thermal systems. By 2030 around 40% of buildings would have either a solar thermal or solar PV system on their roofs. The estimate is based on the availability of rooftops in New Delhi: at present they amount to around 31 km^2, which could take an estimated 2.5 GW of solar PV modules (Greenpeace, 2013). As Delhi makes up around 1% of India's total population, the total Indian rooftop potential may be around 250 GW. If it is assumed that there is around 50 GW of distributed rooftop solar PV (including solar home systems), around 20% of India's available rooftop area would have a solar PV system in 2030. With around 150 million m^2 of solar thermal residential and commercial systems, an estimated 20% of buildings would have them.

Besides this very significant growth in solar PV, REmap assumes an addition of 10 GW of solar CSP. The Reference Case assumes that there will be none of it. So, though a growth to 10 GW may seem modest compared to the increase in PV, it still implies building 20-50 large CSP plants within the next 15 years. The CSP plants included in REmap for 2030 have capacity factors up to 30% but no storage: though many CSP plants which include storage are being planned around the world, they result in higher costs. Besides, the fact that the increasing electricity demand in India is partly being driven by demand for cooling means the mid-day and afternoon peak load requirements fit well with CSP production, thereby reducing the incentive to build storage into them– at least before 2030. CSP plants commissioned in Rajasthan achieved capacity factors ranging between 19% and 26% in 2014. Gujarat and Maharashtra in the west of India, Jammu and Kashmir, Himachal Pradesh and Uttarakhand in the north, and Karnataka, Andhra Pradesh and Tamil Nadu in the south – as well as Rajasthan – are favourable locations with high direct solar radiation. The analysis assumes that the CSP plants are built in regions that ensure higher capacity factors than are presently achieved.

Wind

The capacity of onshore wind in 2030 increases from 145 GW in the Reference Case to 185 GW in REmap. The Reference Case assumes reaching a 60 GW target by 2022, and continued growth until 2030 with 145 GW installed wind power, resulting in just under 8 GW of capacity additions per year on average between 2015 and 2030. Recent wind capacity installations have averaged 2 GW per year, but rates have reached 3 GW/yr in several recent years, showing that more is possible. Realising the potential identified in REmap would require a significant increase over recent trends. REmap also assumes a limited growth in offshore wind, from just under 0.5 GW in the Reference Case to 3 GW. Total wind power generation would amount to 470 TWh, or just above 13% of total electricity supply. Together wind with solar PV would represent approximately 21% of the total power generation in India.

Bioenergy

Bioenergy used for electricity is differentiated in detail. In broad terms, the additions taking place in REmap are a mix of technologies that include 4 GW of biomass co-firing in coal power plants, 4 GW of solid biomass residue-fired CHP biomass plants in industry, 2 GW of gasifiers used in urban and rural applications, 2 GW of power-alone biomass fired power plants, 3 GW of waste-to-power systems, and 0.2 of GW off-grid biogas. REmap biomass use estimates are based on an overview of the assessments of potential prepared by the MNRE and other sources. Assumptions for each technology are discussed below.

- REmap assumes that around 4 GW additional power capacity from combustion of solid biomass in power-alone and co-firing – mostly in plants that at present burn coal – is added to this total. So just over 1% of the total coal power capacity of 310 GW still present in REmap, would be used to co-combust biomass for power production.

- For power-alone solid biomass combustion systems, MNRE estimates a total potential of about 23 GW, split between 18 GW from agricultural/forestry residues and 5 GW from energy crops. Yet IRENA's internal assessment of biomass supplies includes no dedicated energy crops, so it is assumed that none of the 5 GW capacity would be deployed by 2030. Based on today's residue generation factors, REmap assumes reaching 10 GW of the 18 GW potential (compared to 1 GW in 2010/2011).

- For waste-to-power systems, there is an estimate of about 4 GW potential. This is 3GW higher than the 1 GW in the Reference Case since waste generation potential will increase along with growth in population and the economy.

- For co-generation in industry, in 2010/2011, the total installed cogeneration capacity in India's sugar mills was about 1.9 GW (electric-capacity), generating about 6 TWh/yr, based on a 35% capacity factor (based on mills in Uttar Pradesh, and considering both on-season and off-season). This is equivalent to total generation of 85 kWh per tonne of bagasse.

- India produces approximately 80 Mt wet bagasse with a lower heating value of approximately 7-8 MJ/kg) each year, about 70 Mt of which is used for captive power generation.[13] According to Vision 2030 for the sugar industry, total sugar cane production will grow to 520 Mt/yr. by 2030 and would generate a total volume of 120 Mt wet bagasse per year. Based on today's level of wet bagasse use for power cogeneration (70 Mt out of 80 Mt), this provides the potential to install 5.1 GW in power capacity (at slightly improved efficiency levels and using 100 Mt/yr wet bagasse) in the Reference Case. The Reference Case assumes an additional 1 GW biomass-fired (non-bagasse) CHP capacity for distilleries, dairies and rice mills, which today have a combined CHP potential of 4 GW (Singh, Singh and Mahla, 2013), rising to about 8 GW by 2030 since total Indian industrial energy use will by then have doubled since 2010.

- In Remap, the efficiency of bagasse-fired CHP plants is twice today's levels, but less bagasse is available because some of it is used in producing advanced biofuels. This results in 4.6 GW bagasse-based power generation capacity in 2030. Another 4 GW is assumed for non-bagasse-fired capacity which results in a 2030 total of 8.6 GW.

13 Information about total heat production from cogeneration plants is limited. One source states that it is around 110 PJ per year (power-to-heat ratio of 0.2) but that, in actuality, it is likely to be lower (ISMA, n.d.). So an order of 150 compared to total power generation (so a power-to-heat ratio of about 0.15) is assumed.

Hydropower

India has limited potential to expand its large hydropower capacity. In 2015 around 42 GW total hydropower capacity was in operation, with around 10% of it considered medium and small hydropower. The Reference Case envisions increasing the total installed capacity by 11 GW, mostly in large hydropower. Based on the Planning Commission's Low Carbon, Inclusive Growth (LCIG) scenario, capacity will increase to around 77 GW in REmap, with a significant acceleration of small hydropower systems. Total hydropower generation will reach 246 TWh/yr, the third biggest renewable source after wind and solar PV. However, realising such a large increase in hydropower capacity would present difficulties. According to GlobalData (2016), 17 GW of hydropower capacity is under construction with an additional 2 GW in the financing phase. REmap would require this to almost double, with an additional 14 GW constructed. An estimated 50 GW is undergoing consideration and review for permitting in India. Considering the long permitting, planning and construction periods of many hydropower plants, many of these will not be built by 2030, but, a large number of projects are clearly being considered.

Renewable off-grid and electrification

In 2030, an estimated 1485 million people will live in India, 59% them in rural areas. This compares to 71% in 2005 when India's total population was 1131 million. At that time 55% of the rural population had access to electricity, but electrification had increased to around 75% of the total population by 2014. The Reference Case gives a gap to be closed of 240 million people by 2030 (assuming a 95% rate of electrification), whereas REmap – assuming 98% electrification – puts it a 280 million.

Electrification is possible either by grid-connection or off-grid systems. In the Reference Case, it is assumed that up to one-third of total rural electrification needs (related to household demand) can be met by off-grid/mini-grid systems. Assuming a total demand of 100 kWh of electricity in households of 5 people, the total needs of rural areas at present without access to power is equivalent to 8 TWh/yr, of which 2.6 TWh/

yr would be supplied by renewable energy off-grid systems. It is assumed that half of this can be supplied by solar home systems (1 GW, with a capacity factor of 1300 hours/yr), 40% by biomass systems that include gasifiers and biomethanisation (0.4 GW, both with a capacity factor of 3100 hours/yr), and the remaining 10% by wind (0.13 GW, capacity factor of 2000 hours/yr). With such developments, a total of 1.5 GW off-grid capacity would be installed in India by 2030, compared to today's level of about 120 MW. Biomass gasifiers also play a role in urban areas (0.9 GW), particularly in industrial systems.

For REmap, virtually full power access is assumed, raising total power needs to 8.4 TWh/yr. It is assumed that up to two-thirds of this total demand would be met by off-grid/mini-grid systems with biomass gasifier and biomethanisation accounting for 40% of them (0.7 GW installed capacity), solar home systems 35% (1.5 GW in total) and wind 25% (0.7 GW).

Solar systems can also play a role in the growing number of telecom towers in India. There are now about 740 000 of them, 70% in areas with less than 16 hours' grid supply a day. Many are entirely powered by diesel generators. By 2020, the number of towers is expected to increase by at least a third to just under one million. Already 5.1 billion litres of diesel is consumed annually to ensure continuous power supplies: by 2030 this could reach about 8 billion litres per year, generating about 30 TWh of electricity. About 70% of the towers' total power needs in 2030 could be met with 13 GW of off-grid solar systems, with capacity factor of about 1750 hours/yr.

7.2 Renewable energy technologies in the end-use sectors

Bioenergy for heating and transport fuel

REmap Options include various biomass technology options for heating, cooking and transport as well as solar thermal and electricity-based alternatives to thermal systems. The various forms of bioenergy make up the largest type of fuel used in end-use sectors.[14] In REmap biomass fuel demand for CHP[15] heat increases by 320 PJ/yr.

Estimates of biogas and biomass gasification are based on IRENA's manufacturing industry report (IRENA, 2014b) to increase from 25 PJ/yr in the Reference Case to 250 PJ/yr in REmap. No additional solid biomass use is estimated beyond the Reference Case for heat-only process systems in India's manufacturing industry. Total traditional and modern uses of biomass in the building sector increase only slightly by 10%, while the sector's total demand for fuel doubles between 2010 and 2030. A considerable share of the total traditional uses of biomass is substituted with LPG/kerosene and natural gas in the Reference Case. Remap assumes full substitution of traditional uses of biomass through a mix of modern biomass technologies and solar cookers. Gasifiers and biogas plants, already used in large amounts, would account for 45% of total modern biomass needs (at about 30% conversion efficiency), while another half would come from solid biomass use in modern cookstoves (at 25% conversion efficiency). In total, REmap assumes that around 1500 PJ/yr of modern biomass and biogas would be required to meet the cooking needs provided by the 4200 PJ/yr of traditional biomass still used in the Reference Case. This shift to modern forms of biomass cooking would result in a 2700 PJ/yr reduction of biomass use the building sector.

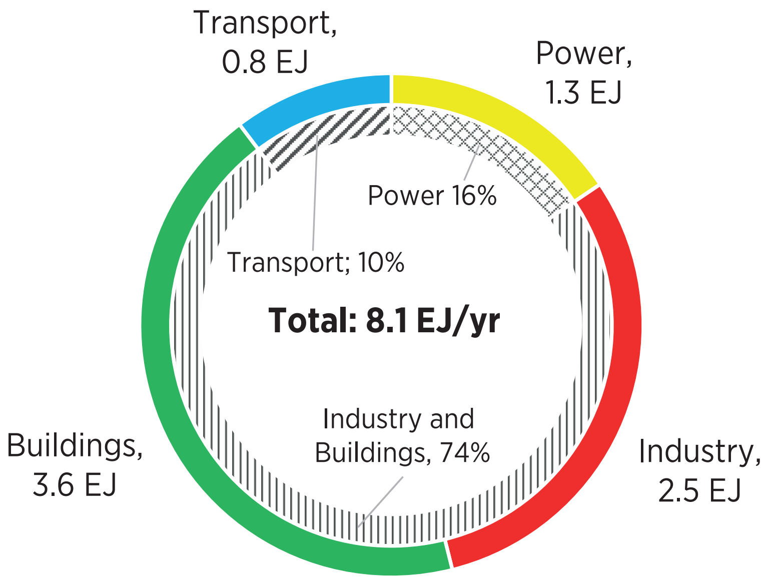
A total of 5.4 billion litres of ethanol (30% advanced, 70% conventional) and 8 billion litres of biodiesel was assumed for the transport sector in REmap. The Reference case also sees a strong, if smaller, growth of approximately 5 billion litres of ethanol and around 2 billion litres of biodiesel. In total, transport sector liquid biofuel demand reaches 20.5 billion litres (or 470 PJ) representing 13% of the sector's total energy demand in REmap.

With all these additions in various biomass technologies, India's total primary biomass demand reaches 8.1 EJ (see Figure 23) in REmap compared to approximately 6.8 EJ in 2010, but is higher at 8.2 EJ in the Reference Case. The decrease from the Reference Case total is due to replacing traditional uses of biomass with

14 The biomass used for industrial CHP is estimated based on the total CHP generation explained in the bioenergy power section.

15 This estimate of biomass use for industrial process heating is based on energy allocation of total fuel input to CHPs and their power and heat output.

Figure 23: Primary biomass demand by sector with REmap Options, 2030



Source: IRENA analysis

modern, more efficient alternatives. Demand for heating in buildings and industry would account for three-quarters of the total, with the remaining quarter divided between transport fuels and power generation. Total biomass demand in REmap would be 94% of the total 8.6 EJ supply potential of biomass in India in 2030 (the total is based on IRENA's bioenergy supply assessment (IRENA, 2014c))

Solar thermal in REmap assumes an additional 30 million m^2 of low-temperature solar water heater capacity for process heat in industry, along with an additional 12 million m^2 of medium-temperature concentrating solar collectors. The concentrating systems operate with capacity factors around 20%: for solar water heaters it is 13%. Solar thermal heating would therefore grow considerably from just 0.2 million m^2 in the Reference Case. With REmap's additions, solar thermal would account for about 0.7% of manufacturing industry's total energy demand (excluding power) in India.

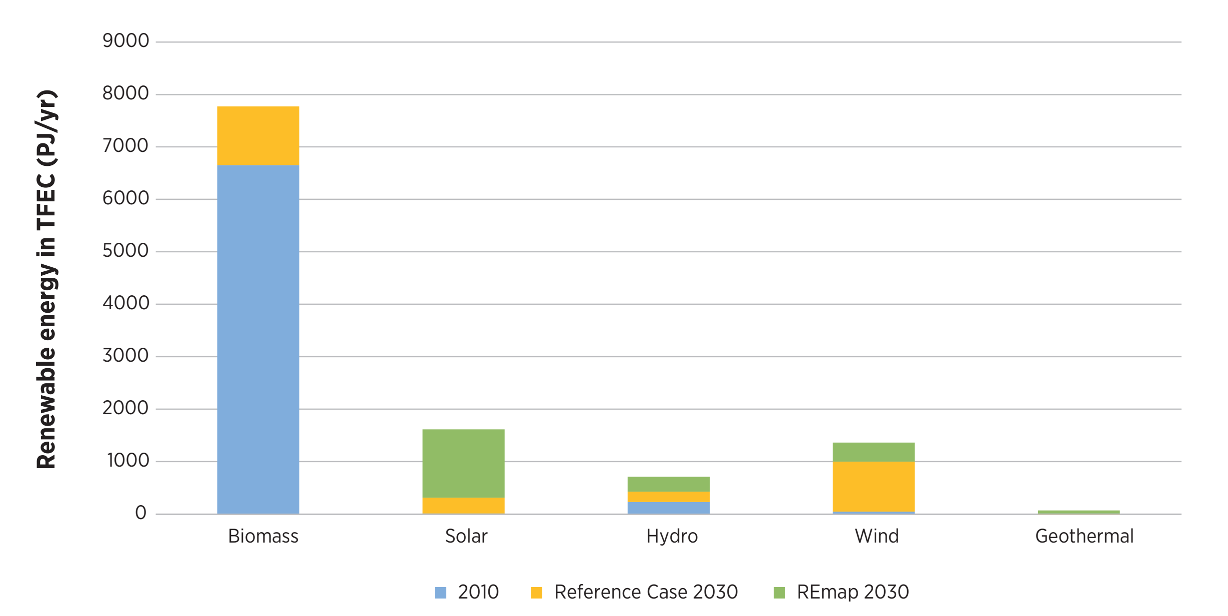
Remap Options also estimate much higher capacity additions -125 million m^2 – on top of the Reference Case for the buildings and services sector (including hotels). The majority of this is for water heating with a smaller share related to solar cooling substituting for air conditioning systems. Their capacity factors, at between 10% and 12%, are somewhat lower than those of industrial systems. Added to installed capacity of 29 million m^2 solar thermal capacity in the Reference Case, this would increase the total installed solar water heating capacity in India's building sector to 154 million m^2, or 2% of its total energy demand.

Electrification in the transport sector

REmap shows a trend towards more use of electricity in transport, through increasing use of electric vehicles, as well as structural changes or so-called modal shift. An additional 100 TWh/yr is estimated for electric vehicles – made up of four-wheel passenger cars (40% of the total additional demand), public vehicles (30%) and two-wheelers (30%). This would increase the total electricity demand of the transport sector by 150% in 2030, compared to the Reference Case.

Modal shifts to city trams from passenger road vehicles, and to high speed trains from aviation contribute further to the electrification of the transport sector and result in 60 TWh/yr extra electricity demand. The full 160 TWh/yr in additional demand is assumed to be supplied by new renewable power generation capacity, shared equally by new hydropower and solar PV. Electric vehicle

Figure 24: Increases in renewable energy consumption in TFEC by resource



Source: IRENA analysis

assumptions are based on 10 800 billion projected annual road passenger kilometres by 2030, 64% by two-to-three-wheelers, 18% by four-wheel automobiles, and 18% by public bus and mini-bus. The REmap options also assume a 30% penetration of battery electric two-to-three-wheelers, 20% of four-wheel battery electric vehicles (BEV) and 18% of public electric buses.

The Reference Case estimates 2 million electric vehicles to be in operation, 80% of them electric two-to-three-wheelers. In REmap this number increases greatly to 350 million, of which over 90% are assumed to be electric two-to-three-wheelers, with around 20 million passenger four-wheelers and buses.

Geothermal energy

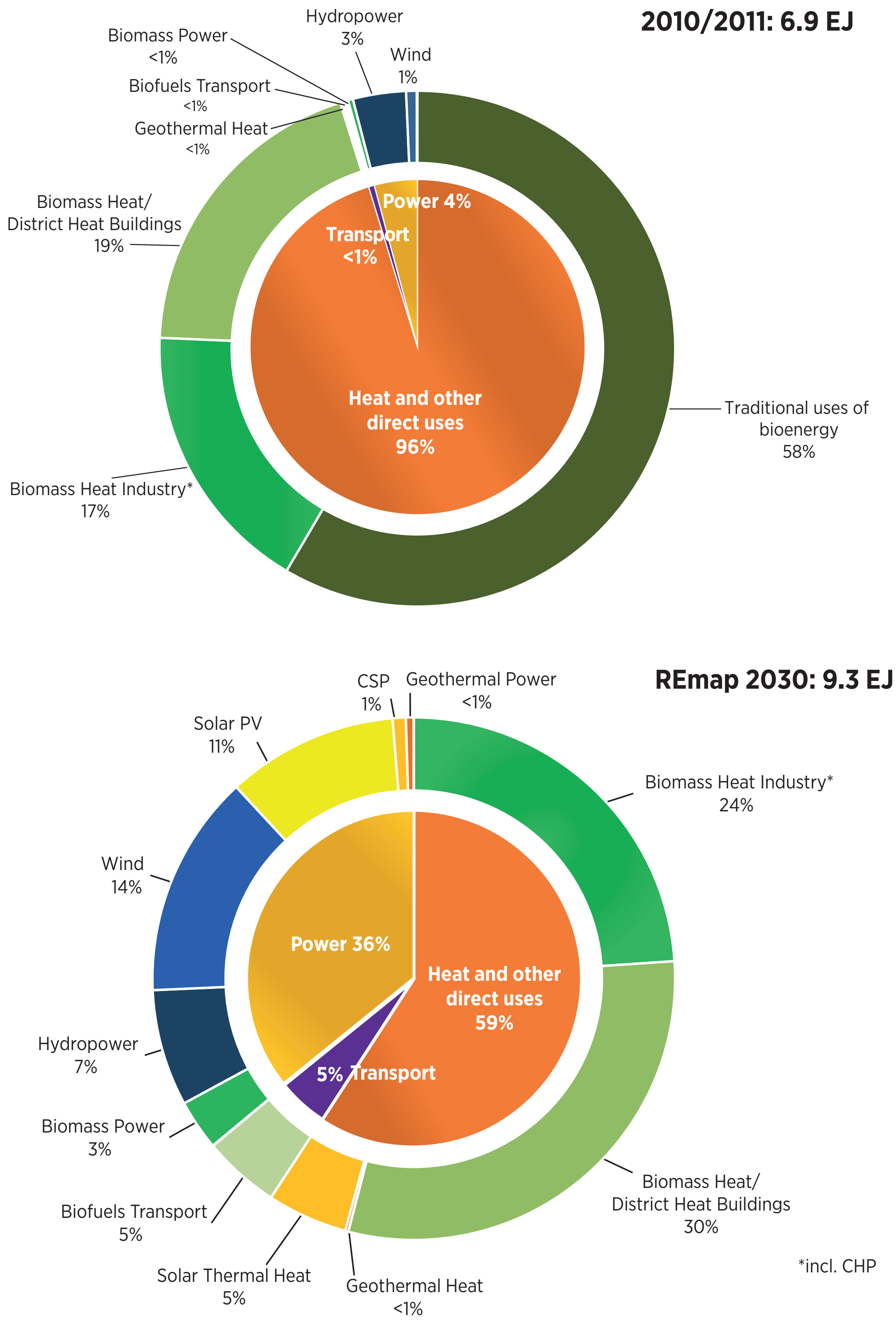
India's geothermal potential is very limited. The Reference Case envisages no addition of geothermal power, and a small share of geothermal heat, used largely in the building sector. The REmap Options assume a modest increase in geothermal power, based on assessments from CEEW's (2015d) GCAM. In total a capacity of around 2 GW, producing 16 TWh of electricity, could be in operation by 2030. There is also an assumption of a small amount of additional geothermal heat in industry based on an IRENA assessment for renewable energy in manufacturing (2014b).

7.3 Renewable energy capacity deployment and shares

Figure 24 shows the increases in renewable energy in TFEC for grouped renewable energy resources between 2010 and 2030, showing the growth occurring in both the Reference Case and REmap Options, and sheds light on the relative importance of each resource. Biomass use does not increase in REmap, as a result of substitution for its traditional uses, but it still remains the most important form of renewables in final energy terms. Solar energy experiences the largest percentage growth, because of significant growth in solar PV, as well as solar thermal systems in industry and buildings. Wind energy is the third largest source, but can only be used to produce power. It already experiences considerable growth in the Reference Case, so additions from the REmap Options are more limited. Hydropower is the fourth largest contributor, followed by minor additions of geothermal power.

Figure 25 shows the breakdown of renewable energy use by consuming sector in 2010 and under REmap. Biomass changes significantly, as its traditional use in the building sector is replaced with modern alternatives. Growth in biomass use is largely in the form of biofuels and residue combustion for CHP in industry.

Figure 25: Breakdown of renewable energy use by application and sector, 2010 and in REmap in 2030



Source: IRENA analysis

Table 8: Changes in the renewable energy share of India between 2010 and 2030 according to the Reference Case and REmap

	2010	Reference Case 2030	REmap 2030	Total renewable energy use (EJ/yr)
Power	14%	18%	35%	3.4
Industry	18%	11%	15%	2.4
incl. renewable electricity and district heat	18%	12%	19%	3.9
Transport	0%	2%	13%	0.4
incl. renewable electricity and district heat	2%	2%	16%	0.7
Buildings (excl. trad. biomass)	21%	15%	41%	3.2
incl. renewable electricity and district heat	21%	16%	39%	4.8
TFEC (excl. trad. biomass)	17%	12%	25%	9.3

Source: IRENA analysis

The other changes include a significant increase in solar thermal heating and solar PV power generation in both the building and industrial sectors. Solar PV and wind become the largest renewable sources of electricity, followed by hydropower. They achieve a significant share in India's final renewable energy use from nearly zero today. Biomass, but in modern forms, continues to dominate India's 9.3 EJ of total renewable energy use in REmap in final energy terms, accounting for two-thirds of it.

Of the 9.3 EJ of renewable energy consumed in REmap, approximately a third is electricity, up from 4% in 2010. About another third is fuel consumed in the building sector, largely for cooking – mostly modern forms of biomass but also some solar thermal heat. Most of the remaining third is biomass used in the industry sector for heating, with a small contribution from solar thermal and geothermal heat. Heating continues to be the largest market in REmap with a total 59% share and the use of biofuel in the transport sector makes up around 5% of renewable energy use compared to less than 1% in 2010. Transport fuels reach a 5% share compared to less than 1% in 2010.

With all these developments, the share of modern renewable energy shares in India's TFEC increases to 25% in REmap, more than double the 2030 Reference Case level of 12%. Renewable energy's share in power generation increases to 35% in REmap, from 14% in 2010, compared to 18% in the Reference Case. Despite an increasing amount of biomass and solar thermal being used in industry, the sector's renewable energy share remains at around 2010 levels in REmap: this is explained by the equally fast-growing TFEC of the sector as India becomes a more industrialised country.

The share of renewable energy in transport shows a significant increase from negligible in 2010 and only 2% in the Reference Case. In REmap 13% of transport fuel comes from biofuel, and the share climbs to 16% when renewable electricity is included.

The building sector's modern renewable energy share almost doubles to 39% in REmap from 21% in 2010, driven by the modern use of biomass and solar thermal.

Table 9 overviews development in physical terms between 2010 and 2030, showing how renewable capacity would increase from just above 50 GW in 2010 to over 520 GW in REmap, with a similar increase in power generation from renewables. The table also shows how direct uses of renewable energy – i.e. energy sourced from renewables for heating, cooling and transport fuels – significantly increase. A more detailed table showing a higher resolution of technology deployment, including rural and off-grid systems, is available in Annex F, including notes that describe some of the assumptions used to arrive at the REmap Options.

7.4 Costs and savings of renewable energy

Cost-supply curves

The previous sections have discussed technology options. This section aggregates them into an overall

Table 9: India's REmap overview

			Unit	2010/11	Reference Case 2030	REmap 2030
Energy generation and capacity	Power sector	**Total installed power generation capacity**	*GW*	**173**	**672**	**855**
		Renewable capacity	*GW*	55	261	523
		Hydropower (excl. pumped hydro)	*GW*	37	48	77
		Wind	*GW*	14	146	187
		Biofuels (solid, liquid, gaseous)	*GW*	3	11	28
		Solar PV	*GW*	1	48	196
		CSP	*GW*	0	0	11
		Geothermal	*GW*	0	0	2
		Marine, other	*GW*	0	0	0
		Off-grid and rural renewables (solar, wind, biogas)	*GW*	0.1	9	21
		Non-renewable capacity	*GW*	118	411	333
		Total electricity generation	*TWh*	**946**	**3 463**	**3 527**
		Renewable generation	*TWh*	136	628	1 223
		Hydropower	*TWh*	104	147	246
		Wind	*TWh*	21	345	471
		Biofuels (solid, liquid, gaseous)	*TWh*	10	35	105
		Solar PV	*TWh*	1	82	310
		CSP	*TWh*	0	0	28
		Geothermal	*TWh*	0	0	16
		Marine, other	*TWh*	0	0	0
		Off-grid and rural renewables	*TWh*	0	19	47
		Non-renewable generation	*TWh*	810	2 835	2 304
Final energy use – direct uses	Buildings and Industry	**Total direct uses of energy**	*PJ*	**13 055**	**27 567**	**25 256**
		Direct uses of renewable energy	*PJ*	6 639	7 638	5 966
		Solar thermal – Buildings	*PJ*	6	71	510
		Solar thermal – Industry	*PJ*	0	1	151
		Geothermal (Buildings and Industry)	*PJ*	9	9	19
		Bioenergy (traditional) – Buildings	*PJ*	4 063	4 259	0
		Bioenergy (modern) – Buildings	*PJ*	1 364	1 485	2 967
		Bioenergy – Industry	*PJ*	1 196	1 813	2 319
		Non-renewable – Buildings	*PJ*	1 023	4 740	4 740
		Non-renewable – Industry	*PJ*	5 116	14 553	13 914
		Non-renewable – BF/CO	*PJ*	278	636	636
	Transport	**Total fuel consumption**	*PJ*	**2 214**	**5 718**	**3 351**
		Liquid biofuels	*PJ*	8	109	468
		Conventional biogasoline	*PJ*	1	19	85
		Advanced biogasoline	*PJ*	0	1	37
		Biodiesel (conventional and advanced)	*PJ*	7	89	346
		Biomethane	*PJ*	0	0	0
		Non-renewable fuels	*PJ*	2 205	5 609	2 883

Based on IRENA estimates

cost and potential curve, and ranks them for cost-effectiveness. The cost-supply curve is an approximate representation of the realistic potential of renewable energy technologies – the REmap Options – which can be deployed by 2030 in addition to the Reference Case. The cost supply curve has not been used to develop the REmap, but is a representation of the REmap Options selected. This portfolio is not an allocation of the global additional potential based on the GDP of India and other REmap countries, nor does it represent extrapolations. Further technology portfolios can be generated, based on different understanding of the parameters that constitute REmap Options or other studies specifically looking at India.

Figure 26 and Figure 27 present two curves: the first is based on the business perspective, incorporating the local cost of capital (at a 10% discount rate), commodity prices (including local taxes or subsidies), the technology cost and performance characteristics: the second takes a governmental perspective based on standard international commodity costs and a fixed 10% discount rate. The former reflects factors likely to influence private investment decisions; the latter factors more relevant to government decisions on policy and spending. Decision makers will be tempted to pick low-cost options, from the left end of the curve, and skip high cost options on the right side, but the figure gives a perspective of the entire country. Decision makers may assume that options represented by individual blocks in the supply curve are homogenous in terms of substitution costs, but the blocks represent averages based on the assumed deployments in the REmap.

The curve should not be misinterpreted as a series of steps from left to right, in order of costs that can be chosen or avoided in isolation. In fact, there are synergies and interactions: all of these options need to be exercised together to achieve these levels of costs and their indicated renewable energy shares. Some options, for example, produce savings or efficiency improvements that help reduce the costs of more expensive ones. Focusing on the cheapest individual options will not result in the least expensive overall transition. That requires a holistic approach. And neither curve includes the benefits relating to improved human health or a better local environment that results from an increased deployment of renewables.

Observed from a business perspective, the average cost of substitution with Remap Options is USD 2.3/GJ of final energy. Viewed from the perspective of governments, this cost increases to USD 3.8/GJ of final energy. To put them in perspective, they represent around USD 8-11/MWh in additional cost if the entire portfolio of technologies is deployed. The costs would be borne across the entire energy system, by all energy services that are impacted by the renewable energy technologies, including power generation, heating, cooking and transport.

Substitution costs differ greatly by sector. They are cost-competitive in the building sector from both a business and government perspective, with a substitution cost of USD -5/GJ to USD-7/GJ, driven largely by the economics of replacing traditional uses of biomass with modern renewable energy. The transport sector has a very low incremental cost of USD 1.5/GJ from the business perspective, due to the effect of taxation on transport fuels, but increases to USD 6/GJ from the government perspective when these taxes are removed. The industrial sector has a narrow range of costs, from USD 2.5-3.0/GJ from the business and government perspectives, respectively, as a result of relatively low taxation on fuels used in industry. The power sector has the highest average cost of substitution at USD 6/GJ from the business perspective and USD 8/GJ from the government perspective, largely due to the substitution of coal. However, all costs presented here exclude any external cost reductions arising from the REmap Options.

Viewed on a technology level the cost supply curves give perspective on the competitiveness of individual renewable energy technologies compared to incumbent conventional ones. The substitution cost method and costs presented in the curves do not, however, take into account some factors than can influence costs, such as externalities relating to air pollution and climate change (which generally benefit renewable technologies), or some system-related costs associated with deploying either variable form of renewable power, or deployment and learning needs that may be required if local communities are to experience a significant amount of end-use renewable technologies. These costs are not limited to renewables, but tend to be prevalent when new technologies are entering the market.

Looking at some individual technology options, it is easy to focus on the left end of the curves. Here low-hanging fruit include technologies that are competitive without further consideration of external costs, such as solar thermal use for water heating in buildings. Inexpensive thermosiphon solar thermal systems can be used on many dwellings and – since there is a trend of increasingly using electricity for water heating in India – these systems are very competitive by comparison. Biogas for cooking is another

Figure 26: REmap Options cost-supply curve, business perspective

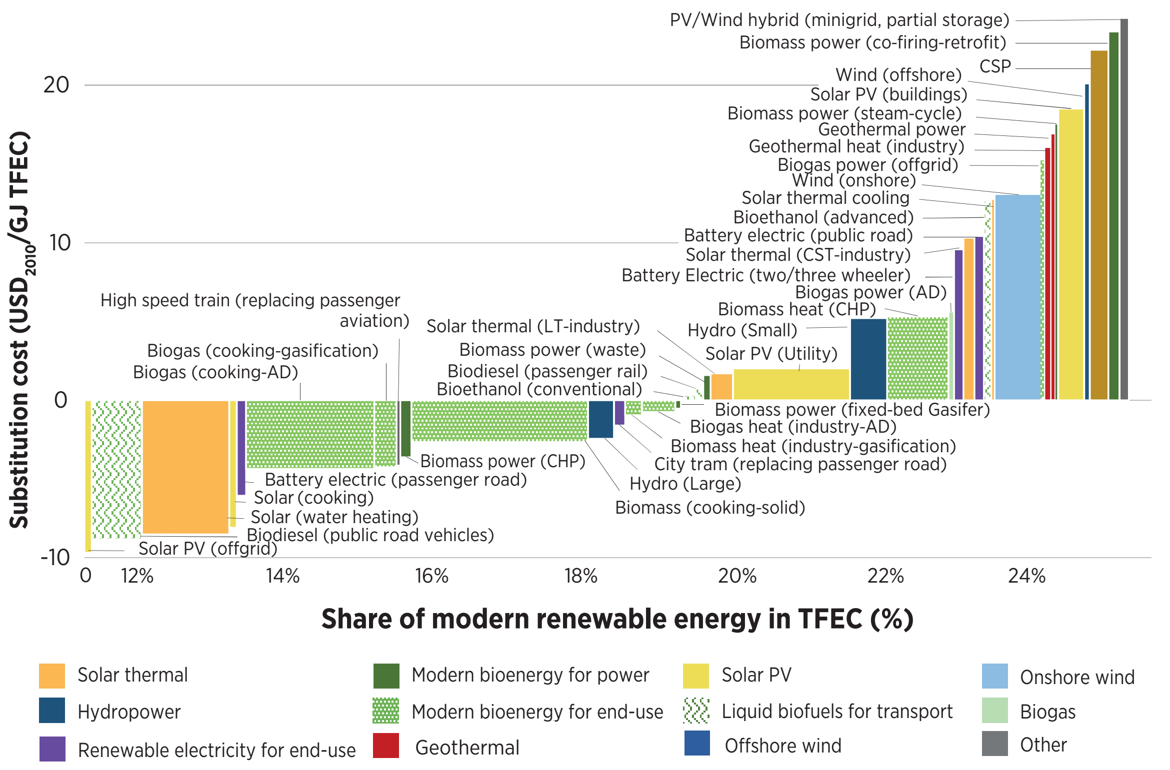
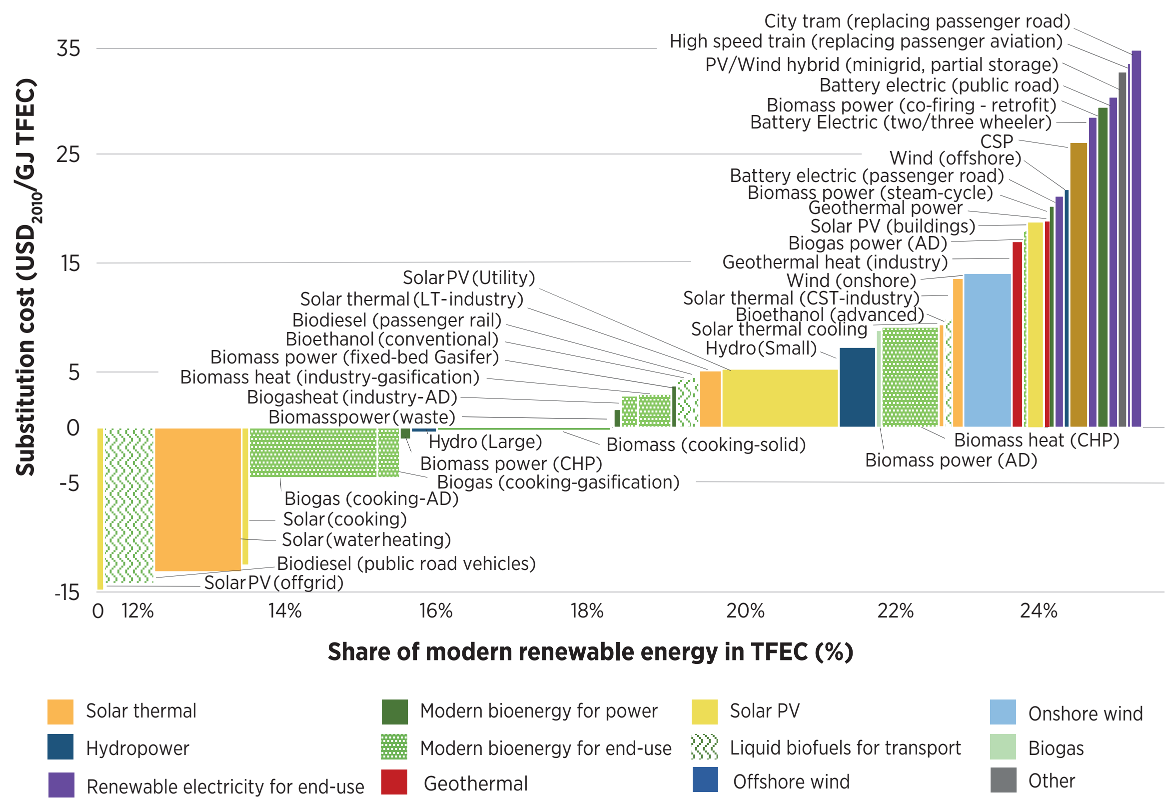


Figure 27: REmap Options cost-supply curve, government perspective



competitive option. If programmes are able to support the development of biogas systems, using anaerobic digestion, this competes well on cost both with LPG and with India's considerable use of traditional biomass in inefficient cookstoves Other technologies that fall in the competitive or near-competitive substitution cost range (negative to slightly positive) include biomass and biogas applications in industry. Biogas produced either from anaerobic digestion or fixed bed gasifiers is generally competitive, and biomass residues used for process heat or produced in CHP systems are also attractive, though cost slightly more than coal or natural gas alternatives.

Further to the right of the government perspective curve are the main power sector technologies. Even though many result in positive substitution costs, these do not include external benefits relating to reduced air pollution and climate change. The importance of including these is evident because all power sector technologies are assumed to replace coal fired generation. The very significant growth in coal power generation in the Reference Case means that most of the new renewable capacity will have to replace it. And, though much of the coal will be imported, the price is still very low. The result is positive substitution costs for most of the power REmap Options except a few off-grid and rural systems that replace diesel. Yet, despite this, many technologies still compete very well on costs. Solar PV on a utility scale is only slightly positive, and onshore wind is also slightly more expensive than coal. Rooftop solar PV is used both for rural and off-grid applications, resulting in savings. When on-grid is compared to the wholesale price of generation, it is positive, but would result in slight savings compared to retail electricity rates.

When considering costs and benefits, it is important to look beyond the technology substitution costs presented in Figure 26 and Figure 27 since, as Table 10: Financial indicators for shows, renewables provide important benefits to society. There would, be an incremental energy system cost of USD 17 billion per year, driven by positive substitution costs. Accounting for benefits resulting from better human health and from lower emissions of CO_2, however, means that a higher uptake of renewables could result in reduced external costs of USD 59 billion to USD 224 billion annually by 2030.

The benefits of modern renewables, therefore, far outweigh the slight increase in cost to the energy system. Most of the benefit, ranging from USD 46 to USD 161 billion per year, is related to reducedcosts associated with a lower detriment to human health, including indoor and outdoor air pollution. The remaining USD 13-63 billion relates to reducing costs associated with climate change.

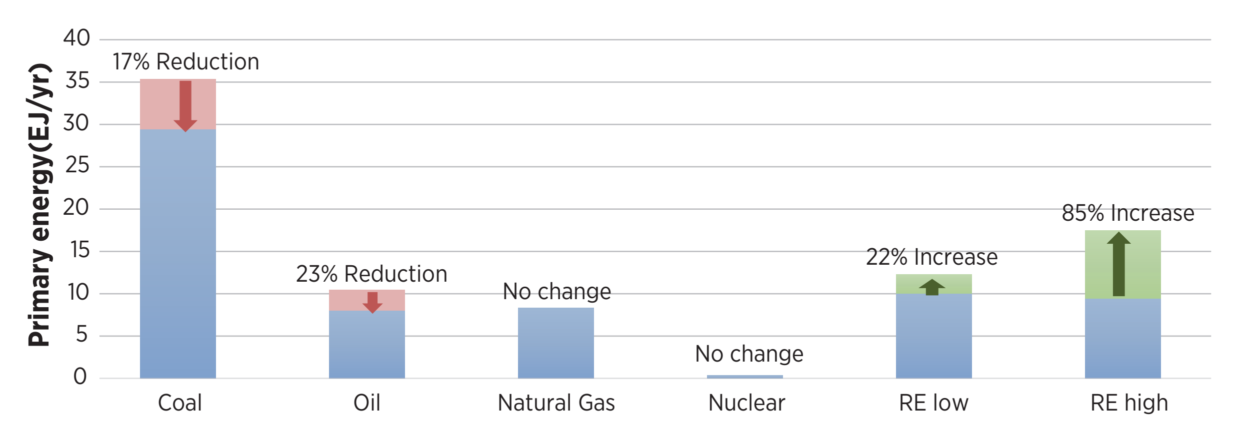
Total investment needs in renewable technologies in REmap would average USD 42 billion between today and 2030. This is made up of USD 16 billion annually taking place in the Reference Case, and an additional investment of USD 26 billion due to the REmap Options. Of this USD 26 billion, USD 21 billion would be necessary new investment (incremental investment)

Table 10: Financial indicators for REmap

	Costs in 2030 (USD billion/yr)
Incremental system cost	17
reduced health externalities	from -46 to -161
of which, indoor air pollution (residential)	-2 to -7
of which, outdoor air pollution	-44 to -154
reduced CO_2 externalities	from -13 to -63
Net cost-benefits	from -42 to -207
Incremental investment support needs in 2030	22
	Annual investment needs 2010-2030 (USD billion/yr)
Incremental investment needs	21
Investment needs Reference Case	16
Investment needs REmap Options	26
Total investment needs for renewables	42

Based on IRENA estimates

Figure 28: Changes in total primary energy supply in REmap



Note: The "RE high" calculation uses the US Energy Information Agency's partial substitution method while the "RE low" calculation uses the IEA's physical energy content method. These do not represent different cases, or levels of renewable energy consumption, but differences in converting renewable electricity and heat into primary equivalents.

Source: IRENA analysis

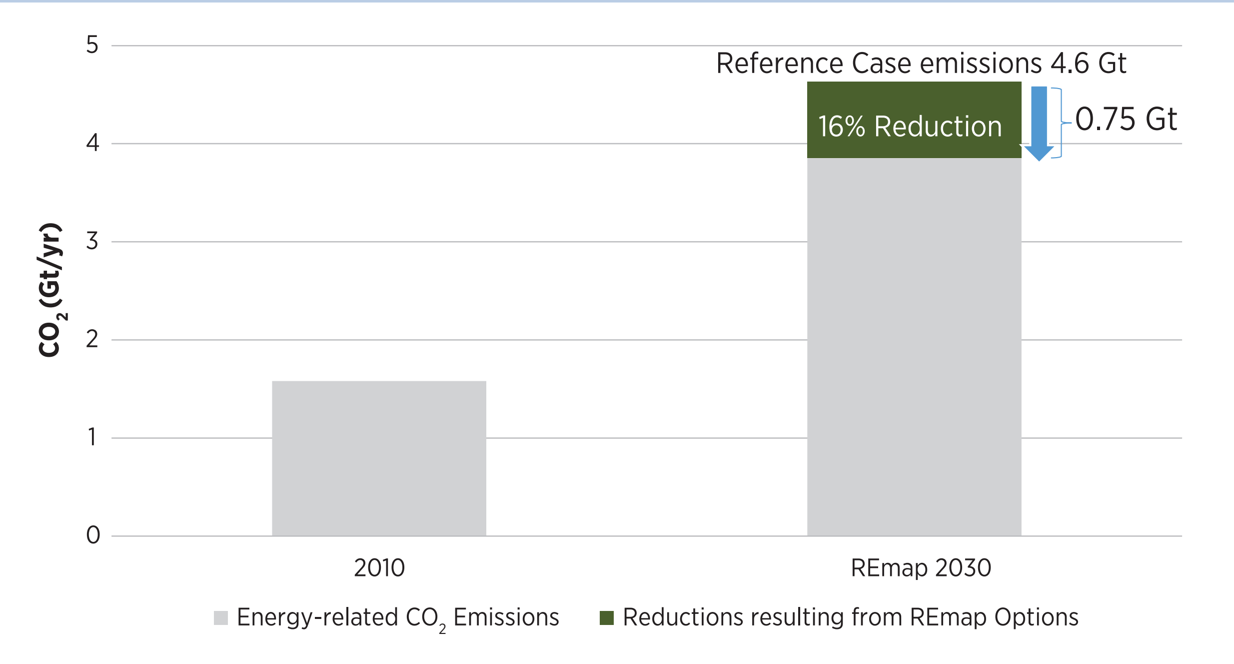
while USD 5 billion would be investment redirected from fossil fuel technologies into renewables.

Benefits of REmap Options

Figure 28 shows how the REmap Options would change the primary energy fuel mix in 2030. Renewables become the second largest contributor of energy services in total primary energy demand under both the methodologies used to convert renewable energy to primary energy.

Of the total coal and total oil use in the Reference Case, 17% and 23% respectively are substituted with the

Figure 29: Energy-related CO_2 emissions, 2010-2030



Source: IRENA analysis

Table 11: Development of India's CO_2 emissions, 2010-2030

	2010	Reference Case 2030	REmap 2030	Total Avoided
	(Mt CO_2/yr)	(Mt CO_2/yr)	(Mt CO_2/yr)	(Mt CO_2/yr)
Power generation	875	2713	2193	520
Industry	470	1188	1130	58
Transport	160	411	238	173
Buildings	76	319	319	0
Total energy-related emissions	1581	4631	3879	750

Source: IRENA analysis

REmap Options. No change in natural gas and nuclear demand is estimated, as they are not substituted in the REmap analysis. In comparison, total primary renewable energy supply increases by between 22% and 85% in REmap relative to the Reference Case, making it second only to coal. As most of India's oil is imported, and increasing amounts of coal are too, the REmap Option would result in reduced dependence on fossil fuel imports.

The reduction in fossil fuel use also has important environmental benefits. In addition to avoided costs from air pollution, valued at between USD 46-161 billion annually by 2030, there are also savings that result from reduced CO_2. India's total CO_2 emissions are estimated almost to treble from 1.6 gigatonnes (Gt) in 2010 to 4.6 Gt by 2030 under the Reference Case. The REmap Options would instead result in an estimated reduction of 0.75 (Gt) by 2030 (Figure 29). The largest decrease would occur in the power generation sector, followed by transport. If all REmap Options were fully deployed, India could reduce its CO_2-related emissions from energy combustion by around 16% from the 2030 Reference Case level (Table 11: Development of India CO_2 emissions, 2010-2030). The monetary benefit of these savings can be valued at between USD 13-63 billion annually by 2030.[16]

Such reductions in Indian CO_2 emissions would contribute just under 10% of the global emission reductions, which could be achieved if all Remap Options for doubling the share of renewable energy in global energy were implemented by 2030. India has the third largest potential – following China and the US – for an absolute reduction in emissions out of all 40 REmap countries. Together these three countries could account for half of the potential reductions in global emissions. Deploying renewables and reducing emissions in these countries are therefore essential for both bringing about a transition in the global energy system and for mitigating climate change.

CO_2 emissions savings resulting from the REmap Options would be 0.75 Gt annually by 2030, or a reduction of around 16% over the Reference Case level.

Important macroeconomic benefits would also result from greater deployment of renewable energy. IRENA has conducted an in-depth analysis based on REmap findings[17] looking into the effects of renewable energy on employment, GDP and welfare (IRENA, 2015e), which demonstrates that renewable energy would have positive macroeconomic impacts across the board in India. It shows, for example, that – if the REmap Options were deployed – GDP would be around 1% higher in 2030 than under the Reference Case. Most of the positive impacts on GDP can be explained by the increased investment required by renewable energy deployment, which triggers ripple effects throughout the economy. There are also important impacts on welfare, with India benefiting from some of the greatest improvements observed in any REmap country, primarily as a response to the reduced health impact of

16 For more information on how IRENA estimates external costs, please see the IRENA briefing note "The True Cost of Fossil Fuels: Saving on the Externalities of Air Pollution and Climate Change" and its accompanying methodology document (IRENA, 2016e).

17 The analysis mentioned in this section was conducted using REmap findings for India from the first REmap global report. The findings are indicative of the results when higher deployment of renewable energy occurs. It is important to note that, as the level of renewable energy deployment in India in REmap has been expanded by subsequent analysis, the findings presented in the report are likely to underestimate the level of positive macroeconomic effects.

air pollution and greenhouse gas emissions reductions. Developing economies are thus as likely as industrialised ones to benefit from economic changes from more substantial renewable energy deployment. Finally, there are important increases in employment. India now has around 500 000 people working in the modern renewable energy sector, and the study shows this could increase to 1.5 million in the Reference Case, and to as much as 3.5 million in REmap – a seven-fold increase over present levels. Employment in India is expected to increase substantially as it scales up its ambition for solar PV and wind deployment: meeting its 2022 target of 100 GW of solar alone is expected to create 1.1 million jobs (IRENA, 2015e).

8. BARRIERS TO A RENEWABLE ENERGY TRANSITION

This chapter goes into more detail about some of the barriers to the renewable energy deployment detailed in the last chapter, since accelerated deployment will present unique challenges that go beyond – or could exacerbate – typical issues arising in India's energy sector.

One challenge in the years to 2030 relates to issues associated with renewable power generation. Much of the technology deployed in REmap will be variable and often split into more decentralised generation units. Besides, increasing access to electrification will require more rural power production systems. The result will be an increased strain on India's already stressed power grid. Solutions will be needed to reinforce, expand and increase the flexibility of power infrastructure. REmap also directly addresses end-use sectors, and specifically the use of traditional forms of bioenergy for cooking and heating. Enabling a clean, affordable shift to modern forms of renewable energy for heating and cooking will require significant improvement of India's bioenergy economy, including better utilisation of residues and waste, and cleaner and more efficient combustion of bioenergy feedstocks.

Renewable energy systems tend to be smaller in size, and incur high up-front investment. As REmap shows, the incremental investment is needed for capacity, but savings result from reduced fuel costs. Higher capital cost and investment schemes that can value lower long-term operating costs resulting from smaller, or no, fuel demand and fuel price uncertainty will need to be developed and made available. They will be needed to expand access to the many rural communities and smaller businesses that have local renewable energy potential, but insufficient capital to develop their own capacity.

While this barrier is likely to impact the deployment of renewables up to 2030, there are already several existing challenges to deploying renewables in India. Installed renewable energy power capacity grew from a mere 3.9 GW in 2003 to 42 GW by the end of 2015 (excluding large hydropower that in 2015 amounted to an additional 40 GW). The Government, under its 12th Five Year Plan, aims to boost renewable energy capacity with ambitious capacity targets for solar, wind and other sources. The country also has targets for end-use energy technologies and the REmap Options outline how important many of these technologies are for meeting the country's long-term energy goals.

Some of the key barriers to enabling the renewable energy technology deployment identified above are listed in the following sections. They can be broadly categorised into several key areas:

- Mobilising investment, high upfront costs and the uncertainty of revenue generation;
- Difficulties in the business environment;
- Required solutions for decentralised energy production and storage; and
- Bioenergy challenges.

8.1 Mobilising investment

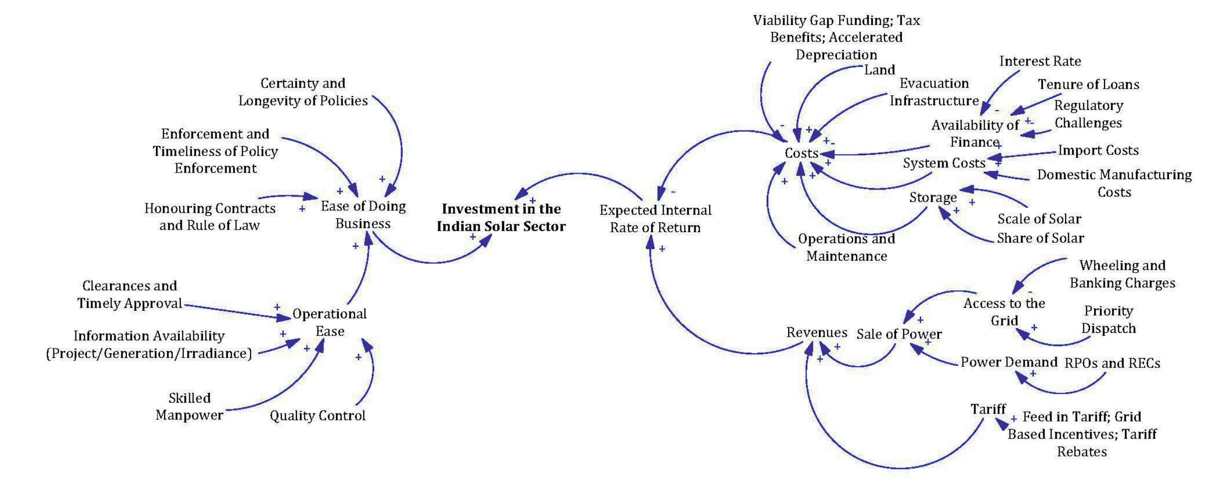
Investment in renewables needs to gain impetus if the targets are to be met and their great potential is to be tapped. The causal factors impacting investments are shown in Figure 30.

Investments are driven by the expected rate of return and the business environment. In the renewable energy sector, expected returns on investment are a function of the costs involved and the revenue generated.

Factors determining costs include:

- The capital cost of the system. The costs of the technological infrastructure impact investment, which is why government incentives like accelerated depreciation, viability gap funding and tax benefits are used to counter the effect of high system costs;

Figure 30: Framework to evaluate investments in renewable energy



Based on CEEW analysis

- The cost of finance – itself affected by regulatory incentives, interest rates and loan tenure – has a big impact on investment. Investment in renewable energy increases when finance is available at affordable rates for long tenures;
- The cost of land forms a large proportion of the total cost of a renewable energy project. As land costs are rising, investment continues to be adversely affected;
- The cost of evacuation infrastructure;
- The cost of storage, which is affected by the share and scale of renewables;
- Operations and maintenance costs, which, when declining drive down total costs and encourage investment.

Revenues from renewables can be driven by several factors, including:

- The extent and enforcement of renewable purchase obligations;
- The tariff at which renewable power is sold, which can be affected by FiTs, tariff rebates, and generation-based incentives; and
- Access to the grid, which is affected by wheeling charges and priority dispatch to the grid. When renewables are exempt from wheeling charges and/or granted first access to the grid, the revenue for producers increases, further encouraging investment. Investment grows if there is favourable business environment providing long term guarantees on policy measures, giving developers assurance of the enforcement of obligations and incentive schemes and ensuring a fast and fair legal framework to protect investments.

The business environment in the renewable energy sector is governed by such factors as:

- The certainty and longevity of policies, which build investor confidence and encourage investment;
- The timely enforcement of policies; the honouring of contracts and the strong presence of the rule of law. Legally binding contracts guarantee investors the option of legal recourse. This has a positive impact on investment as it makes the process more secure and
- Operational ease for the developer, which in turn is affected by several factors, such as
  - the approval time and the number of clearances required;
  - access to information (pertaining to projects, generation and irradiance);
  - the availability of skilled manpower; and
  - the country's standards of quality control.

Upfront costs

Initial capital requirements are significantly higher for renewable energy projects than for conventional power plants. The cost of wind projects ranges from INR 4.5 to 6.85 crores per MW, and that of solar projects now ranges from INR 6.5 crore per MW for utility scale ones to 10 crores per MW for rooftop and other decentralised applications. System costs account for about 85% of the upfront costs with the cost of finance, land and evacuation infrastructure together accounting for the remaining 15%.

Yet installed system costs are rapidly falling, particularly for solar PV. A recent bid in Rajasthan in January 2016 set a record low for a supply contract in India, offering PV produced electricity for under INR 4.34/kWh.[18] The lower electricity production costs are partly driven by lower equipment costs, but also by lower Energy Performance Certificate costs, and by improving terms for financing.

Funding renewable energy projects in India has become progressively easier over the past few years thanks to factors ranging from progressive fiscal policies to improved understanding of the intricacies of renewable energy financing. This has helped to overcome hurdles including the limited availability of financing options, a limited understanding of intricacies, and rigid and unfavourable debt contracts. Governmental policies specifically focusing on renewable energy and on access to finance for it have opened up a host of options for developers, ranging from government-backed banks to non-banking financial institutions. This has led to longer term tenures with additional refinancing options and favourable interest rates. So, a strong impetus from the government, coupled with an enhanced understanding of the sector, has given developers of renewable energy projects in India an improved outlook on financing (Bloomberg, 2015). Currency hedging remains a problem, however. Investments made with local currency add 6-8 percentage points to costs compared to those made with USD. So some types of projects can have prohibitively high financing costs of 13-14%, and this is viewed unfavourably by the many international financiers and investment companies interested in the Indian market. International equity and investors will be needed if India is to build significant renewable energy capacity, and the country has reiterated numerous times that it is looking for a global mechanism to help with some of the problems around hedging costs.

One way to address this is through issuing tax-free bonds. Three government owned agencies, including the Power Finance Corporation and IREDA, are to raise more than USD 600 million in such bonds, and use the funding to provide lower-cost finance to renewable energy project developers. Interest rates as low as 10.5% are said to be on offer (Cleantechnica, 2015b). The New Development Bank has also announced plans to issue bonds aimed at funding renewable energy development: their aim could be to provide a source of finance for the emerging set of projects resulting from auction programmes for renewable power (Cleantechnica, 2016). Financing can be particularly challenging for off-grid systems. Schemes to help have been developed. MNRE's flagship programme is the 'Solar Off-grid Refinance Scheme' (Figure 31), which is operationalised by IREDA through a network of banks and implementation partners identified by the Ministry through a separate process (NREL, 2012).

Uncertainty of revenue generation

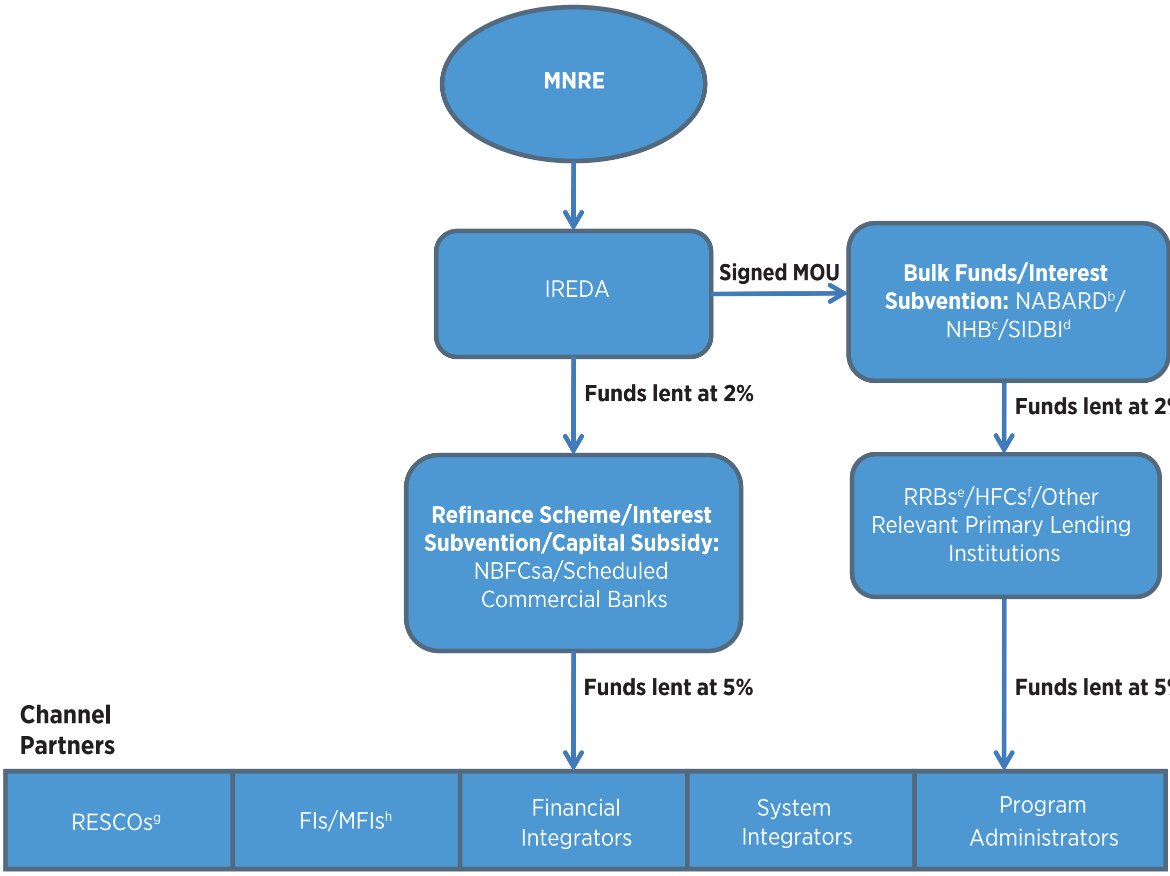
Uncertainty in generating revenues often results from inadequate or low demand for solar power, the gap between the LCOE and the prevailing tariff available on the market, and challenges associated with accessing the grid. Surplus demand on the power exchange, and the way the low-cost of thermal-sourced power is inhibiting states from procuring more renewable electricity, are also issues.

Lack of predictable demand for renewables

The comparatively high LCOE of renewable energy versus conventional fuels has previously caused low demand. RPOs are intended to increase generation in states with high solar irradiation, wind potential or biogasifier plants and to encourage trading with states that have less potential. However, poor compliance with RPO mandates has implied that the supply of RECs exceeds the demand on a monthly basis. As the stock of unsold RECs grows, the future outlook for renewable energy demand looks bleak unless robust enforcement of RPOs begins immediately. Auctions have addressed some of the issues over the lack of predictable demand

18 *http://pib.nic.in/newsite/printrelease.aspx?relid=134602*

Figure 31: Off-grid and decentralised solar financing framework



a. nonbanking financial companies; b. National Bank for Agriculture and Rural Development; c. National Housing Bank; d. Small Industries Development Bank of India; e. regional rural banks; f. housing financing companies; g. renewable energy service companies; h. financial institutions/microfinance institutions

Source: NREL (2012)

for renewable-sourced power, and will help to provide more revenue certainty for producers (see Box 11).

Gap between LCOE and prevailing tariffs

Until grid parity is reached and subsidies on fossil fuels are reduced, there will be a gap between the tariff that distribution companies are willing to offer to purchase power and the LCOE from some types of renewable energy projects. The gap can be filled via a variety of incentives such as preferential FiTs, generation-based incentives, or tariff rebates. Each is applicable or effective for different types of renewable energy applications.

Challenges in accessing the grid

Wheeling and banking charges, along with cross-subsidy surcharges, are levied on power producers who feed power into the grid and add to developers' project costs. Exempting renewable energy producers from these charges – as is already happening for solar energy in Karnataka – could increase expected returns on investment, However, this puts a burden on the utilities, so exemptions should only be given for short periods (it is 10 years in Karnataka). In the absence of storage technologies, renewable energy projects are vulnerable to variable power production unless they can access the grid and supply power on a priority basis.

Box 11: Auctions

Two types of mechanisms have been applied in India to reach its renewable energy targets. FiT were applied for projects on a first-come, first-serve basis: wind power has been the main beneficiary. The other mechanism has been auctions where tariffs were quoted that comply with technical and financial criteria. Solar power projects have been typically deployed through auctions.

The National Solar Mission has a committed systematic auction scheme. Between the scheme's first and second round the total capacity offered more than doubled, and the price dropped by 28% (IRENA and CEM, 2015). Under phase 1, batch I of the National Solar Mission, 150 MW of solar PV capacity was allocated in December 2010 (PPAs were signed for just 140 MW). Under Phase 1, batch II, 350 MW capacity was allocated in December 2011 (PPAs signed for 340 MW). Data from the period between 2010 and 2013, suggests that auction tariffs for solar PV are moving to market tariffs (Shrimali et al., 2015). Recent bids in 2015 and early 2016 have significantly increased capacity deployment, and costs are falling to around INR 4.2-5.0/kWh (USD 0.06-0.07/kWh), indicating that prices are at the lower range of the Mission's target (Gambhir, 2016).

There have been auctions in such developing countries as China, Morocco, Peru, and South Africa (IRENA, 2013b) and experience shows they are a cost-effective tool for deploying renewables by ensuring that projects are allocated fairly. However, deployment was often limited. A 2015 study the Climate Policy Initiative (Shrimali et al., 2015) suggests ways of designing new auction systems by managing risks for cost-effective and high deployment of renewables, especially wind power.

The three features suggested are : "(i) To increase cost-effectiveness, ensure sufficient competition by setting the volume of capacity auctioned well within the market's ability to supply; (ii) To improve deployment effectiveness, impose strong penalties for delays in commissioning projects, implement support policies to improve transmission infrastructure, and provide government guarantees to reduce off-taker risk; and (iii) Use auction design elements that can mitigate risks to achieve both cost-effectiveness and deployment effectiveness together. For the specific case of wind energy in India, introduce auctions in a controlled environment, in which the project site is already identified, transmission infrastructure is planned, and resource assessment studies are completed prior to bidding." (Shrimali et al., 2015).

8.2 Enabling business environment

India's renewable energy sector has suffered from delays in policy announcements (as in launching Phase 2 of the National Solar Missions), frequent changes in policy guidelines (including the type and quantum of incentives provided), and changes in the agencies overseeing the implementation of policy. The absence of a strong policy framework reduced investor confidence and led to a sharp decline in investment. It fell in the wind sector, for example, from USD 3.9 billion in 2011/2012 to USD 1.8 billion in 2012/2013, following the rollback of key governmental fiscal benefits including accelerated depreciation adjustments. Investors often cite such issues, such as limited availability of information about commissioned projects, and project-related data including regional resource assessments, as sources of rising perceived risk. The large number of clearances required, and time taken for them, also deter investors. Investment would benefit significantly from establishing single clearance windows and expedition channels. Skilled manpower is also essential as it impinges directly on the implementation and scale-up of projects: investors are cautious about the returns on their investment in its absence. This issue can be overcome by building local capacity development into renewable energy projects.

8.3 Challenges to decentralised energy

The Government of India runs several initiatives to increase distributed renewable energy in rural areas, including the Ministry of Power's Decentralized Distributed Generation Scheme, started in 2009, which covers deployment of renewable-energy-based mini grids. Similarly, the National Solar Mission, as stated in Box 6, includes an off-grid systems component and target.

Yet, despite these programmes, the decentralised energy market suffers from various challenges. One is posed by public perception, which believes grid electricity to be the only acceptable form of power, and this is compounded by the absence of strong regulatory frameworks to mainstream distributed renewable energy. The big challenge for distributed renewables is to develop business and financing models that trigger rapid deployment and ownership, particularly at the residential scale.

The decentralised renewable energy market also suffers from a wide range of differing subsidies and standards, which are often not monitored or implemented effectively. This, together with lack of finance for small distributed energy systems that do not enjoy investor confidence, further hinders the rapid uptake of distributed renewable energy projects.

Integrating large shares of variable power generation requires important consideration of the planning for, and development of, a future grid. Detailed system analysis and market design are key to enabling integration, and investment certainty needs to be provided to utilities and system owners so as to enable growth in generation assets and infrastructure. Integrating renewables into the power sector also has endogenous implications for using the capacity of complementary generation assets. Increased renewable penetration could lead to low capacity utilisation for complementary assets that could be required to enable flexibility.

The recently-announced Green Energy Corridor could help address some of these challenges. The project will fund improvements in electric transmission systems to facilitate the transport of power from areas rich in renewable energy to parts of the country where demand for power is high (ADB, 2015). Another interesting approach is the development of solar-wind hybrid parks that can use transmission infrastructure better by reducing the variability and production peaks of large renewable power projects and thus demand on the grid. India is also pursuing further development of mini and micro-grids: it issued a draft grid policy in early 2016 to allow for developing power capacity in smaller grid systems (Bridge to India, 2016).

8.4 Skills development

India will need to develop a skilled and knowledgeable workforce, if it is to realise a significant growth in renewable power capacity, enable a secure and strong future grid, and provide modern energy access to its population. The lack of employees trained in the skills needed to construct and operate decentralised renewable energy systems is an existing and ongoing challenge which is recognised as a barrier to realising renewable energy targets.

The country has made an effort to create qualification standards for its workforce. The Skill Council for Green Jobs and MNRE have been working to integrate renewable energy curricula into training and skill development institutions. Renewable energy coursework also has been promoted into India's Industrial Training Institutes (NRDC, 2016).

The government has plans to develop a "Solar Army", providing new jobs for installers and operators of solar PV plants. A specially-created association for renewable energy will help standardise and certify renewable energy technologies, with dedicated shops for solar products. Demonstration projects are planned, and India will strengthen its international co-operation activities for them and for research and development.

8.5 Electricity storage

The Government's increased solar PV target of 100 GW in 2022 will increase the share of renewables from 3% to 10.5%. MNRE is working with states to understand how such an ambitious target would impact their generation profiles, and what could be the possible challenges for evacuating power across the transmission network. India has also been considering an increase from installing 3 GW of wind energy a year to 10 GW.

India has many different geographical conditions ranging from deserts to long coastlines to the highest mountain areas, which means that energy storage technologies can be tested and explored in different scenarios. Its grid infrastructure has difficulties in keeping up with demand growth: load-shedding is coming, and peak prices have been introduced to reduce consumption. Furthermore, India has a large programme to provide electricity to the 43% of rural households without access to distributed renewable power generation, in the form of solar home systems or mini-grids. These can provide a quick solution for electricity access, but back-up systems in the form of diesel generators, bio-based power generation, or small hydropower or electricity storage would be required to ensure that power is available around the clock.

The Green Energy Corridor project focuses on strengthening interconnection across states, and there will be nodal agencies within each state supported by a national platform and the Ministry. MNRE recognises that deployment opportunities may differ substantially among states depending on their population density, the need for power sources in the agricultural sector, and requirements for rural electrification. It will also focus on the opportunities for deploying solar PV on city rooftops and close to existing power stations, as part of its ambitious plans. In total, 50-60 GW could be deployed in a distributed manner. MNRE is also considering a policy to oblige power producers expanding their fossil fuel fleet to pair it with at least 10% renewable power generation.

These recent developments show that India exemplifies many of the opportunities and challenges for storing electricity or integrating renewables. It has tremendous renewable energy resources and plans significant expansion of renewable capacity, especially for solar PV. However, challenges to a high-level of deployment of solar PV include the strength of local distribution grids, which may limit revenue streams for solar systems if incentives for feeding in excess electricity are available.

Electricity storage for integrating utility-scale renewables

India's transmission and distribution network faces a number of challenges simultaneously (India Electronics and Semiconductor Association (IESA), 2014). Firstly, it needs rapid expansion to keep up with the growing demand, but there are administrative hurdles and delays in the way. There has been a peak power deficit of around 9% (12 GW) (FICCI, 2013), and many cities have load-shedding and higher electricity prices to reduce peak demand. Secondly, electricity supply and demand are not evenly distributed across the country, requiring new inter-regional transmission capacity. Thirdly, around 60% of the existing power generation capacity consists of coal thermal plants, with limited capability to respond quickly to fluctuations in power demand and supply. Fourthly, India's distribution networks have reported average losses of around 26%, with the worst averaging 54%.

Renewable power generation from wind and solar PV are rapidly increasing, addressing the need for a more diversified power mix and additional generation capacity across the country. Yet, at the same time, they require additional measures to handle their variable generation patterns.

India is the world's fifth largest installer of wind power, and had a total installed capacity of 22 GW by the end of 2014 (IRENA, 2015d). The majority of which is in five states: Tamil Nadu (>7 GW), Gujarat and Maharashtra (>3 GW), Rajasthan (>2.5 GW), and Karnataka (>2 GW). These states are expected to add an additional 20 GW by the end of 2017. The problem for integrating wind power generation into the grid is that the peak wind season in some of these states (e.g. Gujarat and Tamil Nadu) runs from May to August, whilst peak power requirements are in October, when wind resources are low (CEA, 2013). So wind contributes up to 35% of overall electricity consumption per month in the wind peak season, but as little as 5% per month in the peak demand season. Grid balancing has been achieved through reducing generation in coal-based power plants in Tamil Nadu and gas-fired plants in Rajasthan. However, the coal-fired power plants are relatively old and their flexibility is constrained. Furthermore, using hydropower for regulation is limited to non-irrigation-based installations which, in the case of in Tamil Nadu, amounts to only 1.3 GW.

Solar PV production mainly takes place in utility-scale plants with a total installed capacity of around 2 GW (mainly concentrated in Gujarat, which reached around 1 GW in 2014). The government has opened a number of solar 500MW to 2500 MW parks, which will allow 20 GW of solar PV to be added to the grid between 2014 and 2019 through being connected to the state or central transmission networks.

Distributed renewable power generation can provide valuable system support to the grid: in Mahrashtra it is providing voltage support at weak points. Renewables can also support local reliability by allowing "islanding" of distribution networks when a surrounding grid is in fault/blackout (NITI Aayog, 2015).

Electricity storage, coupled to renewable power generation, can address any integration challenges that are associated with utility-scale wind and solar PV plants, and some of India's regulatory regimes provide favourable circumstances. There is a surcharge of INR 2.75/kWh for electricity production during peak times on the short term energy exchange and many businesses and villages have diesel generation (at a cost of over INR 18/kWh) to guard against black-outs. Furthermore, the Indian regulator uses Unscheduled Interchange (UI) and power factor incentives that could be used to support the deployment of electricity storage (IESA, 2014). The Power Grid Corporation of India (PGCIL) expects that 20 GW of flexible generation, including storage and supercritical thermal generators, will be required in 2016/2017 (Power Grid Corporation, 2012). It has three 50–250 kWh demonstration projects in place in the context of its Frequency Response Pilot Project, demonstrations include an advanced lead-acid, a lithium-ion, and a flow battery.

The cheapest option for storage is pumped hydropower. India has nine such schemes in place with an aggregated installed capacity of almost 5 GW, but only five – with an aggregated installed capacity of 2.6 GW – are actually working in pumping mode. The other four have problems with vibrations or tail pool dams that have not yet been constructed. Two more pumped hydropower storage plants, with an aggregated capacity of 1GW, were under construction in 2013, and another 2.5GW of pumped hydropower plans were being investigated. The CEA estimates the potential of pumped hydropower at almost 100 GW, 40% in the Western region (CEA, 2013).

USAID examined the ability of energy storage systems to reduce constraints in transmission capacity in Tamil Nadu, where it is underutilised for 9 months per year (USAID, 2014). Assuming capital costs of around INR 4 692/MW/day for the transmission network,[19] they calculated that current battery storage systems were not cost-effective and that their capital costs would need to come down by 80%.

Electricity storage for decentralised and off-grid deployment of renewables

In 2012, over 43% of rural households did not have access to electricity, but the country has extensive plans to rapidly increase electrification and is extending distribution networks to connect rural villages.[20] Under the DDUGJV scheme, the Ministry of Power has sanctioned the electrification of 124 786 villages, and the expansion of the electrification in 602 910 more. Connections to 108 913 un-electrified villages and intensive electrification of another 314 160 villages has already been completed (MoP, 2014a). At the same time, India is also supporting decentralised distributed generation to villages which cannot be cost-effectively connected to the grid or where there are only limited hours of supply. Decentralised distributed generation projects receive 90% subsidies towards capital expenditure, and connections to Below Poverty Line (BPL) households are financed with 100% capital subsidies at INR 3 000 each. (MoP, 2013).

The household load for an individual village is assumed to be 200 W, and most electricity demand is for lighting or businesses after sunset. Both individual solar home systems and micro grids could be used to provide electricity, but storage systems or back-up power would be required to provide electricity at night.

Most decentralised distributed generation is based on diesel generators, which can provide electricity at a nominal cost of INR 30/kWh. According to USAID, solar PV coupled with advanced electricity storage systems produce electricity cheaper than these diesel generators. IESA estimates that there is a market for energy storage of around 1.4 GW for rural micro grids and 1 GW of grid connected rural electrification.

Electricity storage for other applications

There are a number of other markets for electricity storage in India. Many industrial and commercial users (including clusters of small and medium-size enterprises) are already deploying lead acid batteries or diesel generators to provide back-up power. Advanced electricity storage systems could be used to replace traditional back-up power sources, and to reduce the costs of peak pricing to industrial and commercial users (USAID, 2014). IESA estimates a market of around

19 This estimate is at least a factor of three lower than the costs of the transmission network in the US (USD 65-390/kW/day for the US, compared to USD 27/kW/day in the case of India).

20 A village is deemed electrified if 10%of all the households of the village has electricity access and if electricity is provided to public spaces such as schools, panchayat officers, health centres, community centres and dispensaries.

1.3 GW for this application. Another option is to couple advanced electricity storage systems to utility-scale renewable power generation plants on site, allowing for smoothing the power generation mix (IESA estimates a market of around 1 GW in 2022). Finally, there is a large market for electricity storage systems coupled to solar PV panels or small wind turbines for powering telecom towers: only 2% of India's some 740 000 such towers, are provided with renewable power. (IESA expects a potential market of around 700 MW in 2022).

8.6 Bioenergy challenges

Biomass would account for a significant share of India's total final renewable energy use in 2030 if the potential of all the technology options identified in REmap were deployed. The estimated demand for primary energy in REmap is 7 EJ, less than IRENA's supply potential estimate of 8.6-9.1 EJ in 2030. The country has the potential to supply its demand domestically with its own resources.

There are challenges in realising this potential. One is the market environment for rural sustainable bioenergy use compared to fossil fuels, which still receive subsidies in parts of the energy system, particularly for rural energy needs (see Box 12). It will be important to develop government programmes to increase awareness and local and regional modern cook stove initiatives that can ensure affordable and reliable equipment.

If feedstock is available, biogas can be a cost-effective option. The Government has funded many household biogas installations – running, for example, on cattle waste – over past decades, but many have fallen into disuse. Government funding resulted in beneficiaries not always being motivated to maintain systems financially, or lacking the knowledge to do so. Training in maintenance and requiring a financial stake in systems will help ensure they are kept running for years. Household programmes can be expanded to the commercial scale, and there is significant potential for biogas development if commercial scale plants can be set up in large hotels, sewage treatment plants, and industry.

Today's bioenergy market focuses mainly on household cooking, with smaller amounts used for industrial process heating. No change in total demand for primary biomass (about 7 EJ) is expected between 2010 and 2030, but – according to REmap – the 2030 market structure is extended toward uses beyond cooking. Biomass use in 2030 is expected to have notably increased in process heat generation (from 1.2 EJ to 2.4 EJ), in power generation (from 0.1 EJ to 0.8 EJ) and in the transport sector (from negligible to 0.9 EJ).

Supplying the considerable increase in biomass demand for such different applications will require planning in the entire supply chain. Power and manufacturing industry sectors will require the security of continuous supply. Planning for the uptake of this biomass potential can accelerate deployment. Meeting the demand for power and heat generation will mean that plants will need to be located in areas with access to local biomass feedstocks, as will ethanol and diesel production plants. Feedstocks can, of course, be transported, but estimates show that – under unfavourable conditions – storage and transportation costs can represent two-thirds of total biomass costs in India. Hence it will be essential to assess biomass supply by region and to link this potential to meeting demand. Available biomass feedstocks at present have several competing uses beyond energy applications where practices vary from state to state. Such uses of biomass will also need to be considered in planning for the increased demand, and the use of feedstocks that do not compete with these applications should be prioritised (Ravindranath, 2005; Natarajan et al., 2015).

While managing biomass feedstocks is a serious challenge for bio-energy projects, there are also others. Concerns were raised in the 1980s and 1990s about the growing practice of head-loading firewood to cater for needs in small towns and large cities with flourishing firewood markets. As such markets become an important source of income and livelihoods, the questions arise of whether there will be a tendency to exploit biomass resources unsustainably and even illegally. There have been reports of women in some rural areas having to walk even greater distances than usual to collect firewood, or having to switch to inferior fuels such as shrubs, roots, weeds, or loose crop residues (AIREC/SSEF, 2014).

Box 12: Fossil fuel subsidies

Another important and major challenge hindering the growth of renewable energy – and financial investment – is the way and level at which traditional energy is priced. Administered pricing and associated subsidies create a situation where subsidised fossil fuels – or energy derived from them – tends to be significantly cheaper than the market price, leading to a skewed marketplace in which renewables have to compete. Government spending on subsidies for petroleum products — which was as high as INR 139 869 crore (USD 2.3 billion), or about 1.2% of GDP in 2013/14 — limits the government's spending elsewhere, including increasing the capital investment in renewables. Investment in renewables can yield significantly greater returns than such purely consumptive spending as with subsidies. This issue is high on the agenda both in India and in international forums like the G20, which has made fossil fuel subsidies a topic for discussion and action. In India, the issue is exemplified by:

Subsidised kerosene – competing with decentralised renewables

The subsidy associated with kerosene, widely used as a primary lighting source in rural India, is exorbitant. Subsidised kerosene is priced at INR 14/litre, and is not available anywhere in the country at market price. India imports almost 80% of its petroleum (crude and products) consumption, and kerosene is subsidised by more than 70% in terms of import price parity. So the final consumer pays less than a third of the actual cost of the fuel. This has two implications for decentralised renewables. First, subsidised kerosene competes with the decentralised lighting solutions based on such renewables as solar. Second, since it is so cheap, it is heavily black marketed and adulterated into 'subsidised' diesel to use as auto-fuel and to run irrigation pumps in areas with poor electricity availability – leading investment in renewable energy based options like solar pumps being unviable.

Subsidised electricity, in a generation mix with an 80% contribution from thermal sources

Another way in which some Indian states heavily subsidise fossil-fuel-based energy is by subsidising electricity to the end consumers, especially domestic and agricultural ones. Thermal, essentially coal-based, plants contribute as much as 80% of the country's generated electricity. Hence any subsidy to electricity invariably subsidises coal consumption to a significantly higher extent than renewables.

9 SUGGESTIONS FOR ACCELERATED RENEWABLE ENERGY UPTAKE

Developing and using renewable energy is a priority. It helps to address the growing challenge of energy demand and to enhance the security and diversity of energy supplies. Based on the existing policy framework discussion and on barriers to renewable energy in India in the previous sections, this chapter provides suggestions with following five themes:

1. Establishing transition pathways for renewable energy
2. Creating an enabling business environment
3. Integrating renewable energy
4. Managing knowledge; and,
5. Unleashing innovation.

9.1 Establishing transition pathways

Like most countries, India has national plans and targets, indicating its long term commitment to renewable energy. Onshore wind, solar PV, small hydropower and biogas cogeneration are the most active renewable energy technologies, with wind contributing the lion's share of the total capacity and other technologies still in their infancy. Initiatives planned for the coming years include a greater focus on solar PV, offshore wind, CSP and cogeneration from bagasse for distributed renewable power. Assessments of these technologies' potential indicate that policy and R&D support will ensure the deployment of all types of renewables, avoid any technology lock-in, and accelerate the overall renewables contribution to the energy mix.

This section includes recommendations that propose coherent and economically feasible policies. The relatively high cost and low availability of debt in India significantly increases the cost of renewable energy projects. Thus the financing woes of the renewable energy sector could be mitigated by:

- Maintaining the longevity and credibility of policy support: prematurely cutting off support for projects leads to plummeting investor confidence and apprehension for project developers, often prohibiting new ones from entering the market. India's renewable energy projects respond to postitive incentives, such as accelerated depreciation and generation-based incentives, which need to be stable and not revised mid-term;

- Increasing outreach to banks and establishing a Green Bank: domestic banks should be encouraged to see renewables (especially wind and solar) as credible business opportunities. Policies driving the creation of a Green Bank are critical for injecting new liquidity and reducing the cost of capital for renewable energy projects. Green banks offer low cost capital at lower interest rates than is available in private sector transactions. Multilateral financing and self-financing provide the majority of the funding of ongoing renewable energy projects. With international funding expected to decline, it is critical to have policies to abate the risks perceived by domestic banks and to increase lending;

- Using infrastructure debt funds for investment in renewable energy: long-term debt lines and lower interest rates offered by such debt funds can enable the renewable energy market to expand. Infrastructure debt funds can act as a conduit for debt financing into infrastructure projects with more favourable terms. An appropriate project authority, such as IREDA, could provide guarantees to make this tool effective; and

- Establishing priority sector lending for renewables, by which they are unbundled from other power projects, thus boosting low-cost financing for them. Installations of distributed renewable energy systems already benefit from having access to priority sector lending status, and this could be extended to grid connected renewable energy. Unbundling renewables from the existing power sector, with independent lending limits for the renewable energy sector, would increase the availability of domestic financing.

Other policies can also catalyse the transition to a higher renewable energy future:

- Improving the enforcement of RPOs to signal renewable energy demand clearly. Uncertainty over RPO enforcement and over the future of RECs reduces lender confidence. The states of Rajasthan and Tamil Nadu have already made moves towards improving RPO enforcement;

- Creating conducive land acquisition policies: land acquisition policies like those in the states of Gujarat and Rajasthan are essential to give a boost to renewable energy projects. As discussed in this report, the cost of land imposes a significant cost on solar and wind projects. State government policies, which designate land for the development of such projects, while taking local conditions and sensitivities into account, could counter the problem of land acquisition and the high cost of land;

- Introducing net metering policies to tap into the large potential for decentralised (rooftop) renewable energy production in India. Net metering systems would allow households to feed excess power back into the grid, thus increasing the use of renewables;

- Encouraging farmers to grow biofuel crops under rain-fed rather than irrigated conditions. Such a policy would boost agricultural returns in rain-fed areas, and provided competition with food crops can be avoided, would minimise the risk of inducing food insecurity;

- Shifting to alternative (and more energy-efficient) chemicals to reduce HFC emissions in the residential air-conditioning sector; and

- Developing a national biomass mission.

9.2 Enabling business environment

Policy frameworks that provide a level playing field for renewable energy and facilitate the formation of markets must be developed. The lack of ease in doing business poses a great challenge for up scaling renewables in India. Policy instability, delays in clearances, clearance malpractices and the absence of clear information all deter the move towards increasing the share of renewables in the country's energy mix. Policy efforts to counter these problems include:

- Timely implementation of policies and incentives, these will be essential in encouraging investor confidence. Existing policies, shackled by tardy bureaucratic procedures, significantly hamper investor and project developer interests. Policies to counter red tape are critical;

- Transparent bidding processes with rigorous selection criteria are crucial for overall stakeholder participation, and especially for attracting serious players. This would ensure that projects are allocated to actors who have the ability to ensure project completion and attract financing. These projects must be monitored to make certain that they operate at the contracted capacity, feed power into the grid, follow mandates for quality standards etc.;

- A single window clearance facility with time-bound clearances for new projects should be established, as has been done by state regulatory agencies in, for example, , Rajasthan and Chhattisgarh. Single clearance and time-bound clearances enable project developers to anticipate accurately the time and effort required to get project clearance, and improve investor confidence by providing a greater degree of certainty and ease of operation in the renewable energy market;

- A nationwide training programme for renewable energy technologies should be designed and instituted under the National Skills Development Council. The transition to an energy future with a significantly larger share of renewable energy is partly contingent on the availability of a skilled and trained workforce. The Government has announced that around 11 000 solar technicians were trained in 2015 – to be joined by another 50 000 between 2016 and 2019 – to build a 'Solar Army' to meet the ambitious solar energy targets. The workers will receive training under the government's national skill development mission at such organisations as the industrial training institutes (ITIs).

- Costs and benefits must be considered when developing new policies. Cleaning up power plants, for example, results in health benefits worth twenty-five times the cost.

9.3 Smooth integration of renewable energy

Significant delays in deploying renewable energy are caused by the high costs of evacuation infrastructure, wheeling charges etc. Project developers need to be given incentives, like first access to the grid in the form of priority dispatch schemes etc., if renewable energy is to be scaled up. The sector still requires significant support and facilitation to ensure timely and adequate evacuation infrastructure. Policies to this effect include:

- Exempting renewable energy projects from wheeling, banking and cross-subsidy charges, as already happens in states like Maharashtra and Karnataka. A policy to this effect would provide exemption for a fixed period, usually 10-15 years from commissioning of the plant. This reduces the cost of the PPA for industrial and commercial consumers alike;

- Establishing a roadmap for setting up sub-stations and transformers. Policies to systematically upgrade grid infrastructure for power evacuation are specifically needed to improve energy access and electrify villages without power. Several states, including Bihar, are already developing plans for additional sub-stations and transformers;

- Ensuring priority dispatch for renewable energy. This would mean that power from all grid-connected renewable energy projects, is guaranteed grid access, irrespective of project size or the load at the time;

- Encouraging the use of information and communication technology (ICT) to manage peak load, especially in metro cities. This can be used for demand management, thus enabling consumers to modify their use of power based on the load on the grid. Similarly, the utilities can use it to manage loads, congestion and shortfalls. ICT initiatives would also reduce the cost of stand-alone energy storage;

- In systems where losses are high because of the geographical spread of the grid system, a larger number of lower-capacity substations, together with the conversion of single-phase supply to three-phase supply, would reduce these losses substantially. Designing systems with "slack capacity" is also important by considering the trade-off between upfront investment and distribution costs; and

- Improving the grid as a top priority in mitigating constraints in power supply.

9.4 Managing and creating knowledge

Data on renewable energy is often incomplete and difficult to collect, posing a significant challenge both for investors and for policy makers. The need for up-to-date, comprehensive data is well understood, and initiatives to collect it continue. Yet additional efforts are required to provide it inexpensively to project developers and financiers in order to reduce their perception of risk. This includes data on existing and potential projects, various actors in the market and government policies. Thus, renewable energy deployment will benefit from policies to:

- Improve data collection from developers on the status of projects, capacity added per year and jobs created. This would enable policy makers to formulate better support frameworks and investors to have a better understanding of the market, which, in turn could drive up investment;

- Establish information platforms for lending institutions to encourage partnerships between banks to syndicate loans, share experiences, etc.

Box 13: A proposal for a National Biomass Mission

Biomass from agricultural residues and from forests and wastelands presents a huge potential for energy generation in India. Preliminary estimates for the potential of power from biomass – based on agricultural production levels for 2012/2013 and the biomass surplus available from forests and wastelands – suggests that the total untapped potential was close to 41 GW, in addition to the energy generated and used in cogeneration plants. This estimate takes into account all the competing uses of biomass – including as a traditional fuel for cooking and heating, and fodder for livestock – and has mapped the resource potential from surplus biomass alone. As agricultural output increases in the years ahead, the biomass available for power production is also set to rise. Thus, an aggressive target of 25 GW of biomass power (electricity and co-generation) by 2020 would be achievable even though power and cogeneration from biomass now stands at a mere 2.7 GW.

Proposed National Biomass mission

- Term: 2015-2020
- Capacity target: 25 GW
- Investment required: USD 8.75 billion
- Average size: 5-6 MW plants (5000 plants of 5MW each)
- Land requirement: 1 acre/MW
- Land footprint: 2.14% of India's total wastelands
- Employment generated: approximately 62 500 full time jobs in operations and maintenance and several additional jobs in construction, fuel collection, processing and transportation

Moreover, cogeneration – most applicable in industries – has a large potential in India's sugar industry, which has traditionally practised it using bagasse as fuel. With advanced biomass cogeneration units for generation and using steam from cane residues at high temperature and pressure, the sugar industry can produce electricity and steam to meet its entire energy demand, as well as surplus power in the range of 80 kWh/t of cane crushed. The capital cost of installing a bagasse-based cogeneration project is almost identical to the cost of a biomass power plant, in the range of USD 718 000-798 000/MW (INR 45 million-50 million/MW). The cost of generation varies between USD 0.05-0.06/kWh (INR 3.25-3.75/kWh), depending on the plant's load factor (PLF) and the interest rate on term loans. The average life of a biomass power plant is close to 20 years, but can be extended to 30 with major restoration work.

While India's potential for biomass-based energy is large, one of the major practical obstacles is the availability and acquisition of land. At least 5 acres (2 hectare) of land is required for approximately 5 MW of installed capacity of biomass power generation. Biomass power plants are most economically viable when they have a capacity of between 5 MW and 10 MW: a 5 MW plant requires an average input of 50 000 kg of biomass per day. Unlike other renewables, biomass requires large tracks of land for fuel storage. Yet just 2.14% of India's total wastelands would suffice for 25 GW of biomass power.

However, collection, transporting and storing biomass often imposes significant added costs, and an absence of readily available input fuel and adequate storage space raises transport costs, further compounding the challenge of fuel linkages and transport. Our proposed mission suggests establishing multiple decentralised small scale biomass plants – which require relatively lower investment in both land and fuel – to counter these challenges.

Biomass power generating units provide significant economic benefits in addition to the electricity they produce. A 10 MW project could create employment for about 100 workers during its 18-month construction phase, 25 full-time workers in operating the facility, and 35 people in collecting, processing, and transporting biomass material.

The recommendations below are made in the context of a proposed National Biomass Mission, with a target of 25 GW of biomass power, including both cogeneration and power plants (The challenges to renewable energy scale-up identified in chapter 8 and the recommendations made in chapter 9 are also applicable to biomass).

Promote the distributed biomass market to improve procurement. There is an abundant surplus of biomass available in India. However, high collection and transport costs often become a hindrance in executing biomass power generation projects effectively. Instituting district biomass markets, to which agricultural residues and biomass collected from wastelands and forests can be brought for sale, would go a long way in addressing this gap. Such formal markets could enable larger producers to source their biomass easily from many of them at a time. Furthermore, easy access to biomass could encourage entrepreneurship and allow decentralised producers to set up plants. Pilot projects should be initiated in such key agricultural states, as Punjab, Haryana, Himachal Pradesh, Bihar and West Bengal, to test the viability of decentralised procurement and production of biomass-based energy.

Develop an information portal to catalogue and update biomass availability. Cataloguing can be done by crop type, region, season, calorific value, quality and price. Such information could be collected at a district level, with MNRE collating it within a usable platform. This could go a long way to increasing confidence in market dynamics for what is still a nascent sector.

Mandate biomass cogeneration in certain industries, such as the sugar industry. MNRE already provides several incentives for bagasse cogeneration plants such as accelerated depreciation, tax holidays, and exemption from excise duty. Such incentives, if combined with a minimum enforced requirement to meet captive demand from biomass, could drive growth in biomass cogeneration plants deployment.

Offer a FiT specific to biomass generation. Biomass power plants are lucrative only if a FiT is provided to the producer for units of energy fed into the grid. Estimates suggest that the cost of production stands at USD 0.06/kWh, so utilities must buy each unit of power for more than this. Reverse auctioning could be used to determine the lowest cost outlay from public funds. The National Clean Energy Fund could be used to finance the FiT, although state utilities could also contribute by including biomass cogeneration towards fulfilling their RPOs.

Rigorous project selection criteria. In order to draw serious players able to source and store biomass, attract financing and ensure project completion; the proposed National Biomass Mission should have stringent guidelines for choosing projects in a reverse auction bidding process. Such guidelines are especially applicable for independent biomass power plants where the input has to be externally sourced, as opposed to the cogeneration units in the sugar industry where bagasse is available on site. The developer's proposed provisions for the purchasing, transport and storage of biomass should be borne in mind when projects are allocated.

Offer government land (wastelands) or lease it at concessional rates for the lifetime of the project. Land availability poses a significant challenge, but it could be overcome if such schemes as leasing government land were instituted, similar to Rajasthan's policy solar projects. The sale of a small proportion (e.g. a minimum of 5 acres) of wastelands to the developers of biomass projects should be mandatory in each administrative block of every state.

Establish renewable energy parks. Given the shortage of land available for harnessing renewables, mixed land use could be promoted. The same site would have multiple operating renewable energy systems – such as having biomass storage units with solar PV panels on their roofs – thus using the land in the most efficient way.

Research and Development of innovative gasification technology and hybrid crops. Funds allocated by MNRE to encourage research into gasifiers that have improved the efficiency or development of biomass polygeneration units could go a long way to boosting the biomass' share of power in the Indian energy mix. Research into hybrid hardy seed types that can be grown in wasteland plantations should be encouraged, as this could solve the input fuel challenge faced by independent biomass plants. Grants worth USD 100 000 could be instituted to assist researchers in such an endeavour.

This would be particularly helpful for co-financing projects;

- Particularly focus on nexus issues (water and energy); and
- Improve air pollution emission standards to the level of those in developed countries.

9.5 Unleashing innovation

Renewable energy deployment around the world is continuously benefiting from innovation, whether in technological improvements, new applications of existing technologies, new business and financing models, or innovative and inclusive policy mechanisms. India, with its endemic problem of access to energy, has seen much innovation in low cost renewable energy applications and constantly evolving distribution and financing models. It should:

- Develop building codes in cities to include renewable energy standards for all new buildings developed as part of a housing complex. Guidelines could include mandatory district cooling systems, solar water heating, energy efficient lighting etc.;
- Promote technological development in energy storage, water saving technologies for CSP plants, energy monitoring and devices for system balance. Policies that promote and incentivise technological advances in these fields, both domestically and in the form of joint research, are crucial for the long term scaling up of renewable energy in India;
- Reward innovation and domestic manufacturing. In the light of the Government's Make in India campaign, an effective mechanism to support domestic manufacturing and innovation in renewable energy technology, distribution and financing mechanisms could be rewarded with a monetary prize and certification of excellence. Prizes could be targeted, on, for example, increasing the efficiency of solar panels or the durability of wind turbines, lowering the cost of balancing systems (including storage), or of distributed energy in areas that are hard to reach. Such targeted prizes could stimulate innovation in technologies and business models with the ultimate aim of increasing access to clean energy;
- Support partnerships: Policies that support north-south and south-south co-operation in the form of joint research and development, international funding of domestic research, tied project funding for piloting new technologies etc. help in furthering the available renewable energy technology. Partnerships like the Joint Clean Energy Research and Development Centre between India and the US lead to a significant commitment to research and development. This partnership committed USD 50 million, equally shared by the two countries, for research on efficient buildings, second generation biofuels, and solar energy. The government funding was augmented by joint research consortia contributing the equivalent of USD 75 million;
- Develop a government approved crowdfunding platform. Such a platform for distributed renewable energy projects ratified by MNRE would help project developers raise finance and would build investor confidence, as the projects would have government clearance. Such a portal could bridge the gap between financiers and small developers; and
- Additional measures can include: instituting an energy access prize to drive innovation in decentralised generation; the government partnering with energy efficient economies to develop best-practices to reduce growing demand; exploring additional partnerships on energy storage R&D, energy service company business models; and developing a coalition for low-carbon rural development (including for agriculture, water, climate and livelihoods facing climate risks).

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ANNEX A:

Technology cost and performance data in 2030

	Capacity factor	Overnight Capital Cost	O&M* Costs	Conversion efficiency	Production cost
Power sector					
Renewable energy technology (RET)	**(%, cap)**	**(USD/kW)**	**(USD/kW/yr)**	**(%)**	**(USD/GJ$_e$)**
Hydropower (small)	37	2000	40	100	24
Hydropower (large)	43	1500	30	100	16
Wind onshore	26	1600	80	100	34
Wind offshore	44	2870	186	100	39
Solar PV (residential/ commercial)	16	1400	15	100	33
Solar PV (utility)	19	1000	12	100	20
Solar CSP no storage	30	3300	33	100	46
Biomass co-firing (retrofit)	70	500	12	38	35
Biomass steam cycle (non-OECD)	40	1200	30	38	46
Biomass fixed-bed gasifer	80	700	17	35	38
Biomass anaerobic digester	85	3300	82	35	53
Biomass steam cycle (waste)	40	2000	50	32	61
Biomass gasifier/ biogas anaerobic digester, off-grid	35	900	18	37.5	12
Solar PV – off-grid, partial storage, mobile towers	22	2000	20	100	42
PV/wind mini-grid – partial storage, households	25	3500	35	100	64
Geothermal	80	5500	220	10	35
Conventional technologies					
Coal (non-OECD)	80	1300	52	35	19
Diesel (Gen-set)	40	1500	37	42	88
Unserved Energy					105
Buildings sector					
RET	**(%, cap)**	**(USD/kW)**	**(USD/kW/yr)**	**(%)**	**(USD/GJ$_{th}$)**
Space Cooling: Solar	12	1100	27	80	47
Water heating: Solar (thermosiphon)	11	215	7.5	100	11
Cooking: Solar	10	150	5	100	8
Cooking biogas (from anaerobic digester)	15	22	0.5	30	17
Cooking biomass (solid)	15	19	0.48	25	48
Cooking biogas (gasification)	15	22	0.5	30	41
Conventional technologies					
Space cooling: Electricity	10	90	2.2	75	44
Water heating: Electricity	10	90	2.2	75	44
Cooking traditional biomass	10	10	0.25	10	37

	Capacity factor	Overnight Capital Cost	O&M* Costs	Conversion efficiency	Production cost
Industry sector					
RET	**(%, cap)**	**(USD/kW)**	**(USD/kW/yr)**	**(%)**	**(USD/GJ_{th})**
Autoproducers, CHP electricity part (solid biomass)	50	692	17	70	23
Solar thermal	15	250	4	100	8
Geothermal	40	2 000	50	100	23
Biomass gasification	80	200	5	85	15
Solar thermal (CST)	20	450	45	100	16
Biogas heat industry (from anaerobic digester)	50	150	4	85	7
Autoproducers, CHP heat part (solid biomass)	50	692	17	70	24
Conventional technologies					
Coal (steam boiler)	85	300	8	90	6

Transport Sector						
	Unit activity of renewable-driven vehicle	**Overnight Cap. Cost**	**O&M Costs**	**Fuel demand**	**Production cost**	**Power demand**
RET**	**(p or t km/ yr/ vehicle)**	**(USD/ vehicle)**	**(USD/ vehicle/yr)**	**(MJ_f/p or t-km)**	**(USD/p or t-km)**	**(MJ_e/p or t-km)**
First generation bioethanol (passenger road vehicles)	15 000	28 000	2 800	0.9	0.52	0
Second generation bioethanol (passenger road vehicles)	15 000	28 000	2 800	0.9	0.52	0
Biodiesel (public road vehicles)	60 000	100 000	10 000	0.2	0.39	0
Biodiesel (passenger rail)	500 000	500 000	50 000	1.04	0.28	0
Battery electric (passenger road vehicles)	15 000	29 000	2 900	0	0.52	0.69
Battery electric (public road vehicles)	60 000	84 000	8 400	0	0.35	0.27
Battery electric two-wheeler (passenger road)	5 000	4 020	442	0	0.25	0.07
City tram for passenger road vehicles	500 000	1 260 000	126 000	0	0.57	0.37
High speed train for passenger aviation	500 000	1 255 000	125 500	0	0.56	0.37

	Unit activity of renewable-driven vehicle	Overnight Cap. Cost	O&M Costs	Fuel demand	Production cost	Power demand
Conventional technologies						
Gasoline (passenger road vehicles)	15 000	28 000	2 800	0.8	0.53	
Diesel (passenger road vehicles)	15 000	30 000	3 000	1.54	0.60	
Diesel (public road vehicles)	60 000	100 000	10 000	0.2	0.39	
Diesel (freight road vehicles)	110 000	120 000	12 000	1.16	0.30	
Diesel (passenger rail)	500 000	500 000	50 000	1.04	0.28	

* O& M = Operations and Maintenance

** *in this row the "p" stands for "passen*ger" and the "f" stands for "freight"

ANNEX B:

Energy prices, business perspective

	Cost
Crude oil (USD/GJ)	19.1
Steam coal (USD/GJ)	3.8
Electricity Household (USD/kWh)	0.1
Electricity Industry (USD/kWh)	0.06
Diesel (USD/GJ)	31.1
Gasoline (USD/GJ)	43.4
Biodiesel (USD/GJ)	31.6
First generation bioethanol (USD/GJ)	38.9
Second generation bioethanol (USD/GJ)	49.5
Fuelwood (USD/GJ)	11.9
Energy crop (USD/GJ)	22.3
Agricultural residues (USD/GJ)	4.7
Biogas (USD/GJ)	2.5
Traditional biomass (USD/GJ)	3.6
Municipal waste (USD/GJ)	1.2
Carbon price (USD/GJ)	0.0

ANNEX C:

Details of REmap costing and external cost assessment methodologies

Two examples are provided to explain how the substitution costs are estimated:

- Biomass boiler substituting LPG-based boiler: The difference between the annualised capital, operation and maintenance and energy costs of the two boiler systems to deliver the same amount of heat are estimated, thereby taking into account the conversion efficiency, size of capacity, lifetime, capacity factors, etc. This is divided by the total final biomass demand of the boiler required to deliver that heat.

- Wind power substituting existing coal-based power: The difference between the annualised capital, operation and maintenance and energy costs of the two power systems to deliver the same amount of electricity are estimated, thereby taking into account the conversion efficiency, size of capacity, lifetime, capacity factors, etc. In the case of existing coal-based power, there are no capital costs as the capacity is assumed to be depreciated already. This difference is divided by the total renewable electricity generated from the wind power capacity.

For the business case, energy prices were estimated based on a number of methods. For some multipliers, expected developments in energy prices for the period between 2010 and 2030 were used based on the IEA projections and these were applied to national 2010 prices. For the case of coal, import prices were used; for natural gas, Asian regional import prices were used; for oil products, IEA crude oil import price projections were used (IEA, 2012). For conventional liquid biofuel prices, growth in price was matched to expected development in petroleum prices; advanced biofuel estimates originated from IRENA's own estimates. All biomass feedstock prices are based on IRENA bottom-up analysis (IRENA, 2014c). Electricity prices were assumed to increase 30% over 2010 levels, which is based on the average price increase of conventional energy carriers, but also taking into account the changes in the fuel mix of the power sector with renewables.

In the government case, for coal, India was assumed to largely remain a domestic producer, therefore the lower price option was used. Electricity prices are based on national prices as described in the business case, but with the effect of taxes removed. For natural gas India was assumed to be an importer of natural gas and the higher price was used. Natural gas and coal prices were based on import/export price estimates from the IEA (2012). Petroleum prices are standardised for the world and indexed to expected developments in the price of crude oil based on IEA (2012). Liquid biofuel prices are IRENA estimates with the effect of taxes or subsidies removed. Biomass fuel prices are regionalised to the Asia (non-OECD) region.

Two detailed methodology document are available online detailing the approach used to calculated external cost and substitution costs, system costs, and investments:

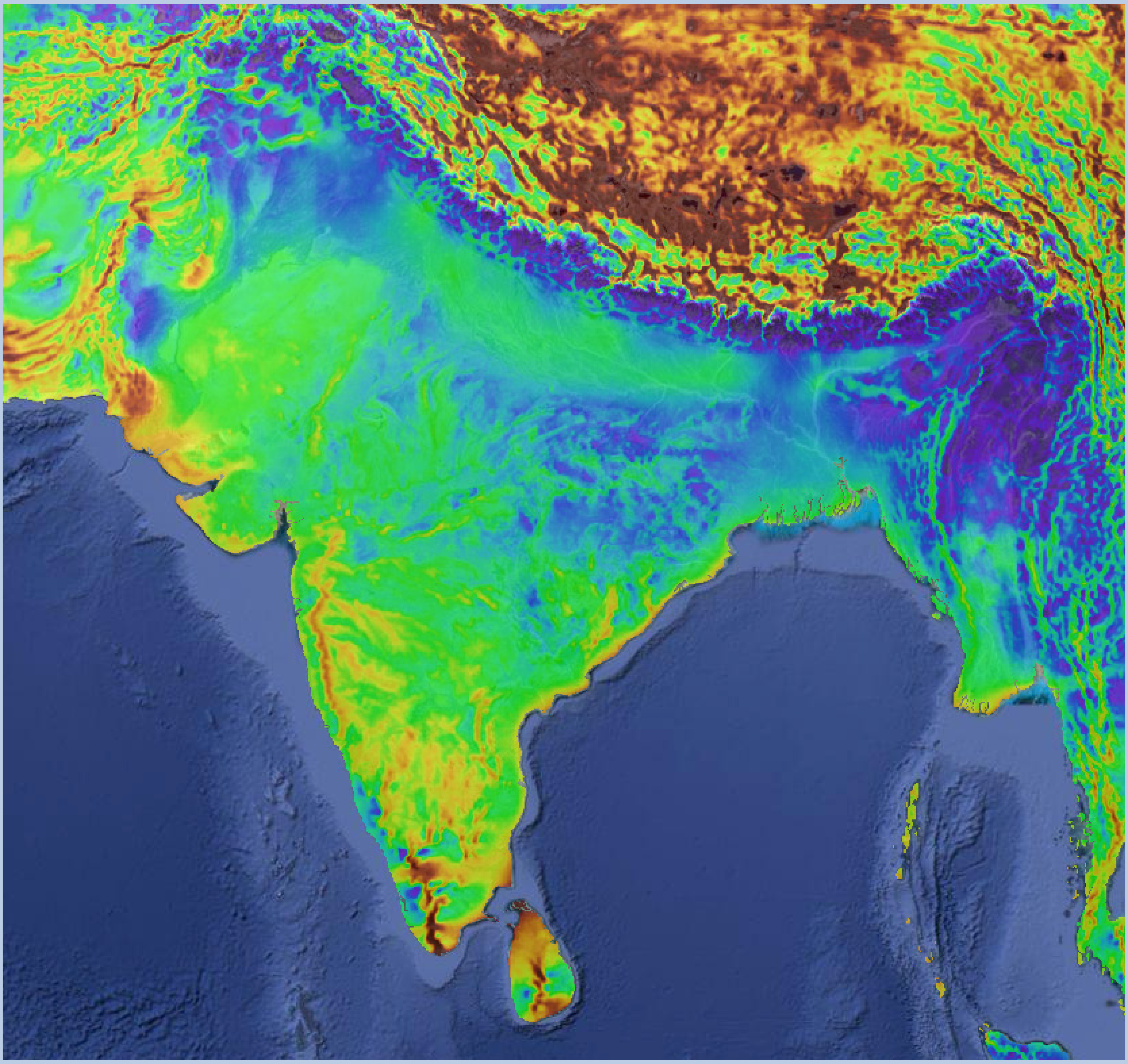
- REmap cost methodology: *www.irena.org/remap/IRENA_REmap_cost_methodology_2014.pdf*

- REmap external cost assessment methodology (IRENA, 2016e): *www.irena.org/DocumentDownloads/Publications/IRENA_REmap_externality_methodology_2016.pdf*

ANNEX D:

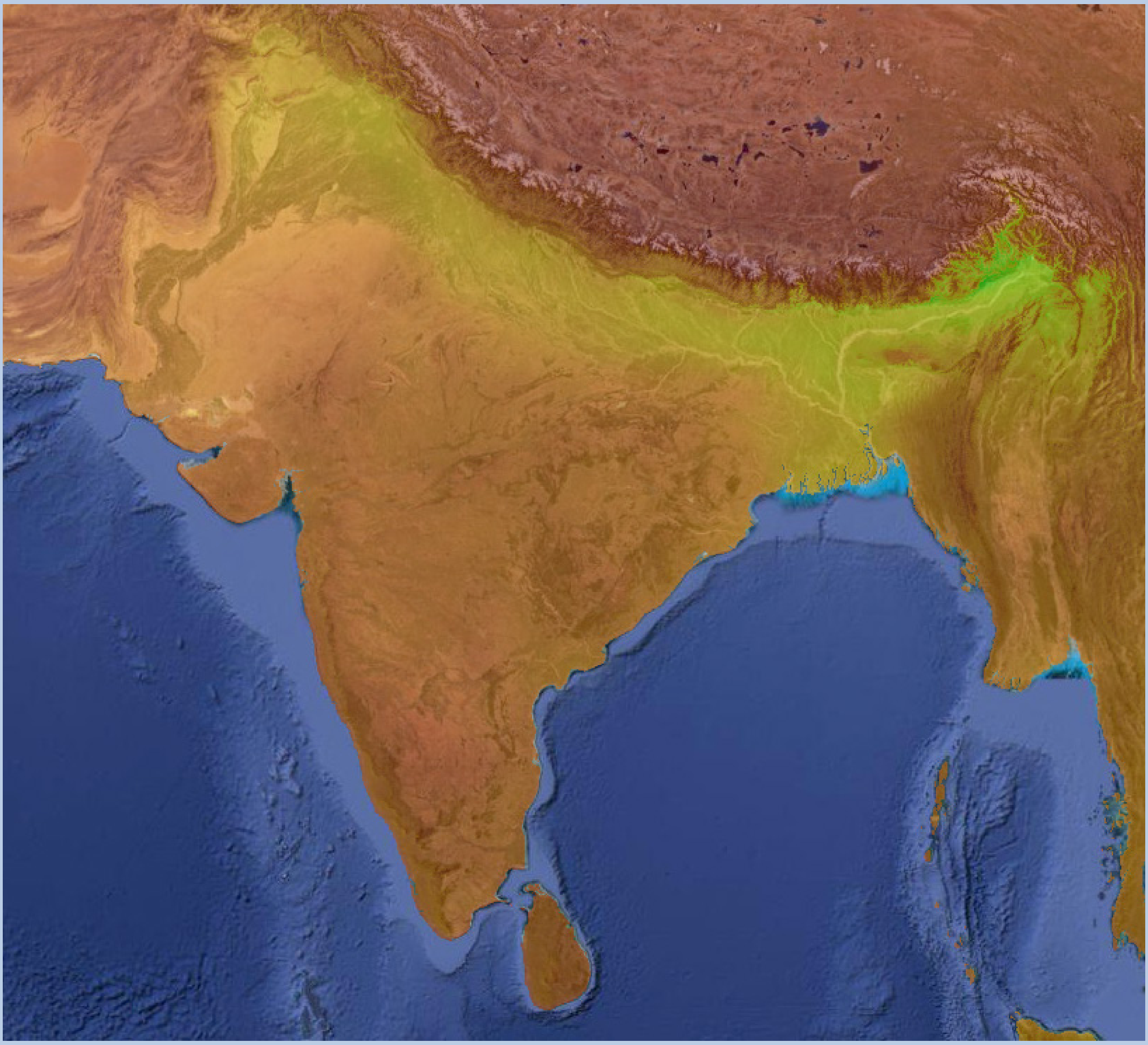
Resource map

Wind



Source: IRENA Global Atlas, 3TIER Global Wind Dataset 80 m height

Solar



Source, IRENA Global Atlas, 3TIER Global Solar Dataset 3 km, in W/m²

ANNEX E:

India's clean energy support measures

Types of instrument	Instrument	Capacity addition/ power production	Duration/ tenure	Interest rates/ cost of capital	Risk mitigation	Leveraging existing government programmes or market instruments
Tariffs and contracts	FiTs	Potential to drive renewable energy capacity addition	10-25 years	-	Increased investor confidence due to investment protection and equal access to energy market	Globally: standard global practice in power sector; In EU countries and US: being used for renewable energy.
	PPAs	-	Generally, for 25 years	-	Increased investor confidence due to assured revenue stream (assumes robust contracts)	In India: exists in conventional power sector; In US, United Kingdom (UK): being used for renewable energy.
	Power bundling	-	Contingent upon availability of unallocated power	-	Reduces cost of renewable power for customers	In India: leverages existing unallocated capacity (successfully employed in Phase 1 of JNNSM).
	Payment Security Mechanism	-	-	Possibly can reduce the cost of capital by reducing risk premium	Increases investor confidence by covering for defaults by distribution companies	-
	Generation Based Incentive	High potential to incentivise power production	For 4-10 years in India; Need for certainty during contract period	Incentivises easy access to finance	-	In India: Being used in wind and grid connected roof top solar sector in India
	Priority dispatch	Can help leverage capacity beyond the contracted amount	-	Can decrease capital costs by reducing storage costs	-	In Denmark and Germany: given to renewable energy sector
	Remuneration rates	Can foster growth of market as it allows passing the costs to consumers	-	-	Increased opportunity to recoup investments	In Germany: promotes growth of renewable sector on market principles

Types of instrument	Instrument	Capacity addition/ power production	Duration/ tenure	Interest rates/ cost of capital	Risk mitigation	Leveraging existing government programmes or market instruments
Debt	Priority sector lending	Intended to promote off-grid capacity addition	-	Increased availability of funds at lower costs (earmarked funds)	-	In India: Available for off-grid solar, SMEs etc.
	Multilateral funds	-	Longer term loans (up to 18 years)	Lower interest rates (10.7-12%)	Capacity building; market strengthening (e.g. R&D); enhanced due diligence	Consortium lending
	Bilateral funds	Tied support which can increase capacity addition	Longer term loans (up to 18 years)	Lower interest rates (10.7-12%)	Increased risks related to technology choice; enhanced due diligence	Consortium lending
	Credit guarantees	Limited impact	Up to loan duration	Did not reduce capital cost; mechanism adds to borrowing cost	Can increase investor confidence	In India: for small and medium industries, for exports, etc.
	Infrastructure Debt Funds	Can boost capacity addition by making cheap funds available	Longer term loans	Lower interest rates	-	In India: IDF scheme; L&T Infra debt fund; tax free infrastructure bonds (by IIFCL)
	Green Bonds	Can promote capacity addition by release of equity capital and refinance option	Longer tenure	Increased access to capital pools; low cost of funds	-	Globally: Bonds by World Bank, IFC, ADB
	Securitisation	Can help in scaling up capacity through access to public market	Can help early exit of initial investors	Lower cost of capital and increased access to capital pools	Spreads risk widely and increases investor confidence	In India: General securities market including power sector; SolarCity (California) issued its first solar IPO
	Green Banks	Focused on renewable power capacity addition	-	Low cost finance (as it obtains low cost capital)	Acts to reduce risk perception amongst investors	Being implemented in states in the US
Direct financial transfers	Viability Gap Funding	Alternative to power bundling mechanism; impact yet unknown	Disbursal over 5-year duration	Reduced cost of capital due to upfront subsidy disbursal		In India: VGF scheme for PPP in infrastructure, New manufacturing policy
	Central Development Fund	Central fund to spur renewable energy investment in China	-	-	Can be used for multiple purposes	In India: NCEF yet to gain major traction

Types of instrument	Instrument	Capacity addition/ power production	Duration/ tenure	Interest rates/ cost of capital	Risk mitigation	Leveraging existing government programmes or market instruments
Tax exemptions	Accelerated depreciation	Attracted developers with large balance sheets to avail of tax benefits	-	-	-	In India: Offered to several industries and infrastructure sector
	Tradable Tax certificates	Can bring IPPs at par with captive investors and help raise additional finance	-	-	-	In India: tradable duty free import credits; In US: transferable tax credits in RE
	Excise duty exemptions	Worked successfully in phase I of JNNSM	-	Reduces cost of capital by reducing equipment costs	-	In India: Given across various sectors (manufacturing, export promotion, captive consumption etc.)
	Master Limited Partnerships; Real Estate Investment Trusts	Attracts investors by allowing IPPs to raise capital at public exchanges, monetise tax credits or AD, etc.	-	Lowers cost of capital	-	In US, Singapore, etc.: for conventional power sector
Regulation	RPOs/RPSs	Creates demand and attracts capacity addition	-	-	Risk reduction contingent upon enforcement of RPOs	In China, California: for RE
	RECs/ Green certificates	Has attracted capacity addition but market for RECs is declining; mechanism needs strengthening	RECs lapse in 730 days from date of issuance	-	-	In Norway: Green certificates:
	Carbon markets (CDM)	Attracted investments initially but plagued by regulatory and price uncertainties	-	-	-	-

Types of instrument	Instrument	Capacity addition/ power production	Duration/ tenure	Interest rates/ cost of capital	Risk mitigation	Leveraging existing government programmes or market instruments
Infrastructure support	Wheeling & transmission charges	-	Need to be constant over contract period	Exemption reduces O&M and capital costs	-	In Andhra Pradesh and Tamil Nadu (Indian states): Exemption to solar sector
	RE Infrastructure Development Fund	-	-	Reduces overall capital cost by reducing the burden of last mile infrastructure costs	Reduces evacuation risks	In India: IDF scheme for infrastructure sector, Rajasthan's REID fund
Trade policy	Domestic content requirement	May hinder capacity addition due to lack of prompt equipment supply	-	Increases overall capital cost of project	Risks related to after sales service, equipment quality and trade disputes	
Others	Equity investment	Low access to debt locks up equity in few projects	Potential mismatch in expectations	High share and cost of equity increases overall capital cost	Equity investor assumes larger risks	Globally: well-known instrument
	Risk insurance instruments	Can attract risk averse investors and help scale up solar		Cost of capital increases due to high premium for such products	Can cover risks related to technology, off-taker, PPA and project development	In India: ADB and the World Bank have partial risk guarantee schemes available for renewable energy projects; US, Japan: well developed market

Source: Ghosh and Himani (2012)

ANNEX F:

Detailed REmap overview table and list of assumptions

	Renewable Energy	Unit	2010/2011	Reference Case 2030	REmap 2030
1. Electricity					
Power Capacity	**Renewable Power (incl. hydropower)**	***GW***	**55**	**261**	**523**
	Hydropower (excl. pumped storage)	*GW*	37	48	77
	Large hydropower	*GW*	34	43	54
	Small hydropower	*GW*	3	5	23
	Renewable Power (excl. hydropower)	***GW***	**18**	**213**	**446**
	Wind [2]	*GW*	14.5	146	187
	Onshore	*GW*	14	145	185
	Offshore	*GW*	0	0.4	3
	Bioenergy [3]	*GW*	3	11	28
	Biogas [4]	*GW*	0	0.4	1.5
	Biomass gasification (urban & rural) [4]	*GW*	0.13	0.1	1.3
	Solid biomass co-firing	*GW*	0	1.0	1.0
	Solid biomass combustion (power alone) [5]	*GW*	1	2	9.0
	Waste to power [6]	*GW*	0.1	1	4.2
	Industrial CHP (bagasse & non-bagasse) [7]	*GW*	2	7	11.3
	Solar PV [8]	*GW*	0.4	48	196
	Utility-scale	*GW*	0.4	41	161
	Distributed generation (grid connected)	*GW*	0	7	35
	Solar CSP [9]	*GW*	0	0	11
	Geothermal [10]	*GW*	0	0	2
	Off-grid and rural electrification [20]	*GW*	0.1	8.7	21.3
	Solar home systems	*GW*	0.1	2.5	8.7
	Solar for telecom towers	*GW*	0	5	10
	Small-scale wind	*GW*	0	0.33	1
	Biomass gasifiers	*GW*	0	0.85	1.2

	Renewable Energy	Unit	2010/2011	Reference Case 2030	REmap 2030
Electricity Generation	**Renewable electricity (incl. hydropower)**	***TWh***	**136**	**627**	**1224**
	Hydropower (excl. pumped storage)	*TWh*	104	147	246
	Large hydropower	*TWh*	93	131	171
	Small hydropower	*TWh*	11	16	75
	Renewable electricity (excl. hydropower)	***TWh***	**32**	**480**	**978**
	Wind	*TWh*	21	345	471
	Onshore	*TWh*	21	342	463
	Offshore	*TWh*	0	2.5	8
	Bioenergy (incl. CHP)	*TWh*	10	35	105
	Biogas	*TWh*	0	1.3	9
	Biomass gasification	*TWh*	1	1	9
	Solid biomass combustion (power alone and co-firing)	*TWh*	3.5	10.5	35
	Waste to power	*TWh*	0.3	3.5	15
	Industrial CHP	*TWh*	6	19	38
	Solar PV	*TWh*	1	82	310
	Utility-scale	*TWh*	1	71	270
	Distributed generation (grid connected)	*TWh*	0	11	40
	Solar CSP	*TWh*	0	0	28
	Geothermal	*TWh*	0	0	16
	Off-grid and rural electrification (total of technologies for this section above)	*TWh*	0	19	47
2. Heat					
Solar heating/cooking/cooling (buildings) [11]		*million m²*	2.5	29	210
Solar thermal (buildings)		*PJ*	6	71	510
Solar heating/cooling (industry) [11]		*PJ*	0	1	151
Solar water heater collectors (flat-plate collectors, evacuated tube collectors etc.)		*million m²*	0	0	30
Concentrated solar thermal		*million m²*	0	0.2	12
Geothermal heat [12]		*PJ*	9	9	19
Biomass buildings (modern) [13]		*PJ*	1 364	1 485	2 967
Solid biomass		*PJ*	1 354	1 420	2 220
Gasification		*PJ*	1	15	115
Biogas		*PJ*	9	50	632
Biomass buildings (traditional) [13]		*PJ*	4 063	4 259	0
Number of improved biomass cookstoves [14]		*million*	NA	63	125
Biomass industrial [15]		*PJ*	1 196	1 813	2 319
Industrial CHP (incl. biogas)		*PJ*	411	760	1 041
Solid biomass-fired boilers		*PJ*	785	1 028	1 028
Gasification		*PJ*	0	25	100
Biogas (AD)		*PJ*	0	0	150
Modern renewable heat/cooling/cooking		*PJ*	2 576	3 379	5 966
Total renewable heat/cooling/cooking			**6 639**	**7 638**	**5 966**

Renewable Energy	Unit	2010/2011	Reference Case 2030	REmap 2030
3. Transport				
Electric vehicles (EV 4+ wheel, PHEV) [21]	*million*	0	1.9	23
Electric vehicles (2/3 wheeler) [21]	*million*	0	0	343
Electric vehicles, electricity demand [21]	*TWh_e*	0	0.56	106
Modal shift, electricity demand [16]	*TWh_e*	0	0	58
Biofuels [17]	*PJ*	8	109	468
Conventional bioethanol	*PJ*	1	19	85
Advanced bioethanol	*PJ*	0	1	37
Biodiesel	*PJ*	7.3	88.9	346
4. Total primary biomass demand / supply [18]	***PJ***	**6 764**	**7 890**	**6 534**
5. Ratio of electricity generation				
Gross power generation	*TWh*	946	3 428	3 466
Generation ratio of renewables (incl. large hydro)	*%*	14%	18%	35%
Generation ratio of renewables (excl. large hydro)	*%*	5%	14%	30%
6. Total final energy consumption (TFEC) [19]				
TFEC	*PJ*	17 431	42 628	38 689
Industry (incl. CO/BF)	*PJ*	7 124	21 030	21 693
Transport	*PJ*	2 432	5 920	4 141
Buildings (residential & commercial)	*PJ*	7 085	15 679	12 856
Agriculture	*PJ*	791	?	?
Renewable gas, heat and fuel (modern)	*PJ*	2 584	3 488	6 434
Renewable Electricity (incl. large hydro)	*PJ*	489	2 259	4 405
Ratio-renewables to TFEC (modern)	**%**	**16.6%**	**12.5%**	**25.8%**
Traditional biomass	*PJ*	4 063	4 259	0
Ratio-renewables to TFEC (incl. trad. biomass)	**%**	**40%**	**22.5%**	**25.8%**

Note: Reference Case 2030 + REmap Options = REmap 2030

1) Reference case is based largely on Planning Commission 2014 (BiG scenario). The reference case for the power sector incorporates targets based on the Twelfth Five-Year Plan to 2017; exceptions are for Solar PV (see note 8), wind (see note 2), and biopower (based on IRENA assessments).
2) The Reference Case assumes reaching a 60 GW target by 2019, and continued linear growth until 2030. This would result in just under 8 GW capacity additions per year between 2015 and 2030. Recent wind capacity installations have exceed 3 GW per year, so a significant increase. For REmap yearly capacity additions increase by 25% to 10 GW year. REmap Options also include 14 GW additional to meet the increased electricity demand in end-use sectors in REmap 2030
3) Reference case and REmap Options are based on a mix of sources compiled by IRENA which are explained in more detail for each technology in footnotes 4-7.
4) Based on van Ruijven, Schers and van Vuuren (2012), it is assumed in Reference Case that by 2030, more than 95% of all rural electrification needs (representing about 390 million people in 2030) are met compared to about 50% in 2010 levels. While all of this is possible by grid-connection. Various renewable energy-based off-grid technologies can also play a role. Their potential and cost-effectiveness depends on the demand load and the capital costs relative to the grid & transmission costs. Potential of solar PV off-grid and wind/diesel mini-grid systems range from 1-100% according to the results of this study. In Reference Case, it is assumed that one-third of the total rural electrification needs can be met by off-grid/mini-grid systems. Assuming 250 kWh/household (5 capita/household), total power need of rural areas that do not yet have power access is equivalent to 19.5 TWh/yr, and 6.4 TWh/yr to be supplied by renewable energy off-grid systems. It is assumed that half of this total can be supplied by solar home systems (2.5 GW, capacity factor of 1300 hours/year), forty percent by biomass systems that include gasifiers and biomethanation (0.8 GW, both with capacity factor of 3100 hours/year), and the remainder ten percent by wind systems (0.3 GW, capacity factor of 2000 hours/year). With these developments, a total of 3.6 GW off-grid capacity would be installed in India by 2030, compared to today's level of 117 MW (end of March 2014) that is dominated mainly by solar home systems. Biomass gasifiers also play a role in urban areas (0.2 GW), in particular, in industrial systems, but in the Reference Case, about half of what their potential would be in rural areas.
   For REmap 2030, full power access is assumed that raise the total power needs to 21 TWh/year compared to 19.5 TWh/year in the Reference Case. It is assumed that half of this total demand would be met by off-grid/mini-grid systems with biomass gasifier and biomethanation systems accounting for forty percent of this total (1.4 GW installed capacity) and wind a quarter (1.3 GW). The remainder 35% would be provided by solar home systems (7.8 GW in total).
   Solar systems also play a role for telecom towers that are growing in number in India. Today there are about 740 000 tower of which 70% are in areas of less than 16 hours grid supply. Total diesel consumption to ensure continues power supply today has reached 5.1 billion litres, and by 2030 it can reach about 8 billion per years to generate about 30 TWh per year electricity. There is a potential to substitute about 70% of the total power needs with off-grid systems that would require about 17 GW solar systems in 2030 (with capacity factor of about 1750 hours/year).

5) For power-alone solid biomass combustion systems, a total potential of about 23 GW is estimated, with 18 GW from agricultural/forestry residues and 5 GW from energy crops (*http://mnre.gov.in/schemes/grid-connected/biomass-powercogen/*). However, for India's total biomass supply in 2030, IRENA has estimated no dedicated energy crop potential. Of this total 18 GW potential (based on today's residue generation factors), a total of 10 GW is assumed for REmap 2030, compared to 1 GW capacity in 2010/2011. For the Reference Case, total installed capacity is assumed as 3 GW.
6) For waste-to-power systems, the potential today is about 4 GW (based on today's waste generation factors). For REmap 2030, 4 GW is assumed that would be much less than the potential in 2030 given India's increasing population and economic growth that would result in a higher volumes of waste being generated.
7) In 2010/2011, total installed cogeneration capacity in India's sugar mills was about 1.9 GW (electric-capacity). These plants generate about 6 TWh/yr, based on a capacity factor of 35% (considering both on-season and off-season, and based on mills in Uttar Pradesh), total power generation of 85 kWh per tonne of bagasse. A total of 80 Mt/yr wet bagasse is produced (with a lower heating value of approximately 7-8 MJ/kg), of which 70 Mt is used for captive power generation. Information about total heat production from cogeneration plants is limited, one source (*http://www.cercind.gov.in/2009/July09/Presentations-by-22-07-09/Presentation-Indian-SugaR-Mill-Associations.pdf*) states around 5 (power-to-heat of 0.2) but that in the actual situation it is likely lower, so an order of 7 compared to total power generation (so a power-to-heat ratio of about 0.15) is assumed.
   According to Vision 2030 for sugar industry, total sugar cane production would grow to 520 Mt/yr by 2030. This would generate 120 Mt/yr wet bagasse. Based on today's level of wet bagasse use for power cogeneration (70 out of 80 Mt wet bagasse), this would have a potential to install 5.1 GW power capacity (at slightly improved efficiency levels and using 100 Mt/yr wet bagasse) in the Reference Case. An additional 1 GW biomass-fired (non-bagasse) CHP capacity is assumed for distillery, dairies and rice mills which today have a combined CHP potential of 4 GW (Singh, Singh and Mahla, 2013), or about 8 GW by 2030 with total industrial energy use doubling in India between 2010 and 2030. In REmap 2030, efficiency is double compared to today's levels, but less bagasse is used since a share of the total generated is allocated to advanced biofuels production (80 Mt/yr with the remainder 20 Mt being used for advanced biofuel production); this results in 6 GW power generation capacity in REmap 2030. Half of the potential in non-bagasse sectors (4 GW) is assumed in addition that take the total industrial biomass-fired CHP capacity to 10 GW (running with a capacity factor of about 4 300 hours/year, and a power-to-heat ratio of 0.25).
8) Reference Case assumes achieving a 20 GW target by 2022, and an installation rate of just over 3 GW/year in the 2022-2030 timeframe. It does not include the recently proposed 100 GW target by 2022, which is accounted for instead in the REmap options, which then assumes growth rate increase from 12 GW/year to 15 GW/year for the time period 2022-2030. This would result in yearly capacity additions of just over 13 GW. Share of utility-scale (80%) and distributed generation (20%) are estimated based on an IRENA assessment. REmap Options include an additional 14 GW additional capacity of utility-scale solar PV to meet the increased electricity demand in end-use sectors in REmap 2030.
9) REmap Options based on IRENA Assessment.
10) REmap Options based on CEEW.
11) Reference Case and REmap 2030 estimates for the building sector are based on CEEW. For the industry sector, estimates are based on IRENA's Renewable Energy in Manufacturing report and assume that some low and medium temperature heat (less than 400 °C) can be met with solar thermal that would account for about 1% of the total energy needs for process heat generation. Compared to total demand this may be a low number, but given the growing size of India's manufacturing industry, the absolute volume of solar thermal heaters installed is significant.
    For buildings, solar cookers account for 5% of the total substitution of traditional use of biomass in the Reference Case that would require 10 GW (14 million m^2 or 3-4 million solar cookers, based on 10% capacity factor) capacity in REmap 2030. By 2017 the target is to have 3.5 million home units, 0.5 school units, 0.05 community cooking units. The remainder of solar thermal is additional capacity for heating (83 GW) and cooling (1.7 GW) that represents about 4% of building sector's TFEC. Heating is predominantly for water heating whereas solar cooling substitutes 0.03% of the total power use of air conditioning systems in 2030 (700 TWh/yr compared to total building power demand of 1 450 TWh/yr).
12) Reference Case is estimated based on 2010 IEA energy balance with no increase in heat production in the Reference Case. REmap option is based on IRENA RE in manufacturing assessment.
13) In Reference Case 2030, total traditional and modern uses of biomass increase only slightly by 5% compared to total fuel demand growth of the building sector of 63% between 2010 and 2030, with no change in their share of the total building biomass use. Hence, a considerable share of the total traditional uses of biomass are being substituted with LPG/kerosene. In REmap 2030, full substitution of traditional uses of biomass is assumed with a mix of modern biomass technologies and solar cookers (see footnote 11 for solar cookers). Gasifiers and biogas plants that are already used in large amounts would account for 45% of the total modern biomass needs (about 30% conversion efficiency) and another half would come from solid biomass use in modern cookstoves (25% conversion efficiency).
14) To substitute 4.2 EJ of traditional uses of bioenergy REmap assumes 0.58 EJ modern biogas cookstoves, 0.8 EJ modern solid biomass cookstoves, and 0.1 EJ of biomass gasification. Based on these fuel demand, total cookstove capacity is calculated assuming a 15% capacity factor and 25-30% stove conversion efficiency. Then this total capacity is divided for each category of cookstove by an average cookstove unit capacity to arrive at the number of cookstoves shown in the table.
15) Biomass (total of bagasse and non-bagasse) used for industrial CHP is estimated based on the total power generation explained in footnote 7, based on the power-to-heat ratio assumptions. Total biomass use for industrial process heating is estimated based on energy allocation of total fuel input to CHPs and the power and heat output. Biogas and biomass gasification is estimated based on IRENA's manufacturing industry report. No additional solid biomass use is estimated beyond the Reference Case that provide process heat for a wide range of process heat applications in India's manufacturing industry (covering 12% of India manufacturing industry's total fuel demand in REmap 2030).
16) Model shift is a structural change in the transport sector. Two options are considering: Electrified city trams instead of personal passenger diesel/petrol automobiles accounting for around 400 billion passenger kilometres per year (5% of road passenger kilometres); and high speed rail instead of passenger aviation accounting for around 160 billion passenger kilometres per year (XX share of passenger domestic flight kilometres).
17) Reference case based on 2% blending requirement by 2030; REmap 2030 based on 15% blending requirements in both diesel & gasoline.
18) IRENA own estimates of supply based on IRENA (2014)
19) TFEC growth in the Reference Case is based on the Planning Commission BiG Scenario for all sectors and energy carriers except biomass (based on an IRENA assessment) and oil product use in buildings (based on IEA WEO)
20) Power capacity for rural electrification includes off-grid and mini-grid systems. Capacity shown here is in addition to capacity in the grid connected categories above.
21) Electric vehicle assumptions are based on projected annual road passenger kilometres by 2030 of 10 800 billion. Of this 65% is served by 2/3 wheelers, 18% by 4 wheel automobiles, and 18% by public bus and mini-bus. For these segments the REmap options assume a 30% penetration of battery electric 2/3 wheelers, 20% of 4 wheel BEV, and 18% of public electric buses.

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