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ROBERT SCHUMAN CENTRE

Regulatory Menu for Integration of Renewables

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Abhishek Ranjan	BSES Rajdhani Power Limited
Alberto Pototschnig	Florence School of Regulation
Amit Kumar	PwC India
Anand Kumar	Gujarat Electricity Regulatory Commission
Arnold Weiss	EPEX SPOT
Edwin Koekkoek	Delegation of the EU to India
Jagjeet Sareen	International Solar Alliance
Jean-Michel Glachant	Florence School of Regulation
Jenny Winkler	Fraunhofer ISI
K V S Baba	Power System Operation Corporation Limited
Laurent Schmitt	Digital4grids
Leonardo Meeus	Florence School of Regulation
Matthieu Craye	DG ENER, European Commission
Nicolò Rossetto	Florence School of Regulation
Norela Constantinescu	European Network of Transmission System Operators for Electricity
Paul de Wit	Alliander
Pierre Loaëc	DG ENER, European Commission
Pradeep Kumar Pujari	Central Electricity Regulatory Commission
Praveer Sinha	Tata Power
Prabhajit Sarkar	Power Exchange India Limited
Pradyumna Bhagwat	Florence School of Regulation
Raj Pratap Singh	Uttar Pradesh Electricity Regulatory Commission
Ravindra Kadam	Central Electricity Regulatory Commission
Rajesh Mediratta	India Energy exchange
Rajib K. Mishra	PTC India Limited
Sushil Kumar Soonee	Power System Operation Corporation Limited
Sutirtha Bhattacharya	West Bengal Electricity Regulatory Commission
Tim Schittekatte	Florence School of Regulation
Tomas Gomez	Comillas University
Vineet Mittal	Avaada Group

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Glossary

4MMC	4M Market Coupling
ABT	Availability Based Tariff
ACER	Agency for the Cooperation of Energy Regulators
AGC	Automatic Generation Control
AS	Ancillary Services
ATC	Available Transmission Capacities
BIMSTEC	Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation
BRP	Balance Responsible Parties
BSP	Balancing Service Provider
C&I	Commercial and Industrial
CBET	Cross Border Electricity Trade
CEA	Central Electricity Authority
CEP	Clean Energy Package
CERC	Central Electricity Regulatory Commission
CfD	Contracts for Differences
COP	Conference of Parties
CSS	Capital Subsidy Surcharge
CWE	Central Western Europe
DAM	Day Ahead Market
DER	Distributed Energy Resource
DISCOM	Distribution Companies
DSM	Deviation Settlement Mechanism
EBGL	Electricity Balancing Guideline
EC	European Commission
EU	European Union
EV	Electric Vehicle
FBMC	Flow-Based Market Coupling
FCR	Frequency Containment Reserve
FGMO	Free Governor Mode Action
FiT	Feed-in Tariff
FiP	Feed-in Premia
FRR	Frequency Restoration Reserve
GC	Green Certificate
gencos	Generation Companies
GHG	Green House Gas
GoI	Government of India
GTAM	Green Term Ahead Market
HXPL	Hindustan Power Exchange Ltd
HVDC	High Voltage Direct Current
IDM	Intra Day Markets
IEX	Indian Energy Exchange
IRA	Independent Regulatory Authorities
ISA	International Solar Alliance
ISTS	Inter State Transmission Systems
kWh	kilowatt-hour
LFC	Load-Frequency Control
MBED	Market Based Economic Dispatch
MNRE	Ministry of New & Renewable Energy
MoP	Ministry of Power
MRC	Multi-Regional Coupling

NECP	National Energy and Climate Plan
NLDC	National Load Dispatch Centre
NRA	National Regulatory Agencies
OTC	Over The Counter
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan
POSOCO	Power System Operation Corporation
PPA	Power Purchase Agreement
PRAS	Primary Reserve Ancillary Service
PX	Power Exchange
PXIL	Power Exchange of India Ltd
RCC	Regional Coordination Centres
RE	Renewable Energy
REC	Renewable Energy Certificate
RED	Renewable Energy Directive
RES	Renewable Energy Sources
RLDC	Regional Load Despatch Centre
RPO	Renewable Purchase Obligations
RR	Replacement Reserve
RTM	Real Time Market
SAARC	South Asian Association for Regional Cooperation
SAFIR	South Asia Forum for Infrastructure Regulation
SAFTA	South Asian Free Trade Area
SAR	South Asian Region
SAREC	South Asia Regional Energy Coalition
SEC	SAARC Energy Centre
SECI	Solar Energy Corporation of India
SERC	State Electricity Regulatory Commission
SLDC	State Load Dispatch Center
SNA	State Nodal Agency
SPV	Special Purpose Vehicle
SRAS	Secondary Reserve Ancillary Service
STATCOM	Static Synchronous Compensator
TAM	Term Ahead Market
ToD	Time of Day
ToU	Time of Use
TRAS	Tertiary Reserve Ancillary Service
TSO	Transmission System Operators
TYNDP	Ten Year Network Development Plan
UDAY	Ujwal DISCOMS Assurance Yojana
UI	Unscheduled Interchange
URS	Un Requisitioned Surplus
VRE	Variable Renewable Energy
XBID	Cross-border Intra-Day

Background

Electricity is one of the essential energy carriers in the transition to decarbonisation. Various world economies are undergoing energy transitions driven by ambitions to achieve energy access, strengthen energy security and environmental conditions depending on internal priorities and challenges (Gielen et al., 2019). The COP 26 Glasgow summit, in which countries pledged to limit global temperature change to under 1.5°C according to the Paris Agreement to achieve climate targets, further strengthened these resolves. The decentralisation and penetration of renewables brings unique challenges in the planning and reliable operation of power systems which influence the outcome of electricity markets. The complex energy transition requires technical, economic and regulatory knowledge to design the evolving electricity trade market. Therefore, countries should collaborate to share their experiences and expertise in market design (Bichpuriya and Soman, 2010).

In the European Union (EU), electricity from renewable energy sources (RES) is a significant part of various energy and climate policy strategies. The European Commission (EC) has taken the necessary steps to increase the renewable energy share in production and uptake. The figure below shows that the trend in different energy sources over the years is a decrease in fossil fuel energy sources and a rise in renewable energy sources.

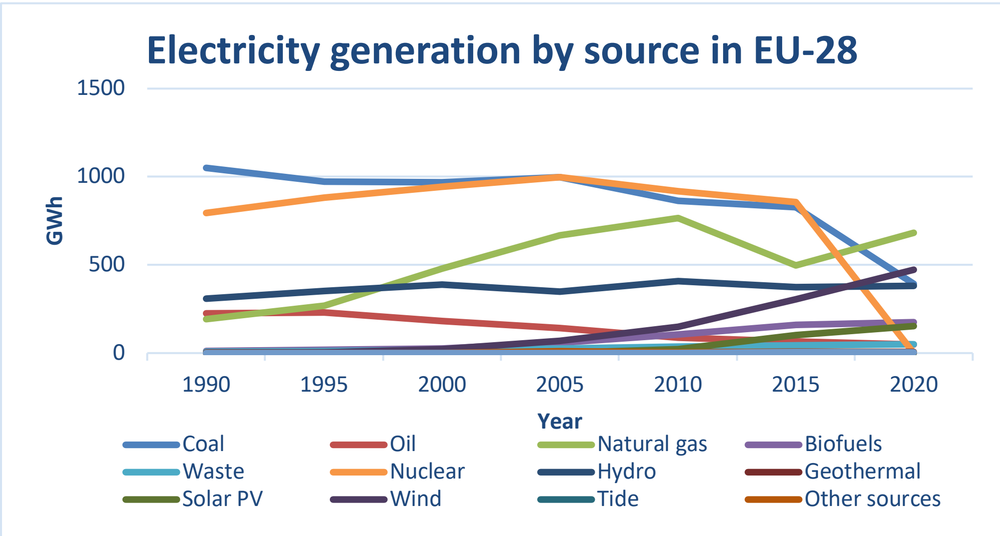

Figure 1: Electricity generation by source in EU-28 (IEA, 2020)

Before it was reformed, the EU electricity sector was a monopoly in which vertically integrated companies were responsible for the generation, transmission and distribution of electricity. These companies decided the electricity price and controlled the grid. Reforms which began three decades ago aimed to create an integrated internal European electricity market to reduce electricity costs and increase security of supply. The EU's internal electricity market has gradually integrated national markets in regional markets and then merged them into the EU market. As it transitions towards full decarbonisation, the European power market and system faces profound changes. With the deployment of decentralised renewable generation and demand response, consumers will play an important role in reducing the sector's carbon footprint (Rossetto, 2017).

A focus on India is crucial as it is among the top five countries with high greenhouse gas (GHG) emissions. Although India has low per-capita GHG emissions, with economic growth leading to increased energy use its per-capita emissions will possibly rise by 40 per cent by 2030 (Karstensen et al., 2020), with the power sector making the highest contribution to emissions. India's power system is also one of the largest globally. It has made significant achievements in its electrification target and provided over 252 million residential consumers with access to electricity as of 2020 (IEA, 2021a).

The Ministry of New and Renewable Energy (MNRE) has floated ample initiatives in accordance with national commitments and climate targets such as achieving net zero emission targets by 2070, as was announced at the COP-26 summit in Glasgow. Associated measures which were pledged during COP-26 include the installation of non-fossil fuel electricity capacity of 500 GW by 2030, sourcing 50 per cent of India's energy requirement from renewables by 2030, reducing emissions by one billion tonnes by 2030 and achieving a carbon intensity reduction of 45 per cent compared to 2005 levels by 2030 (WRI, 2021).The trend in electricity generation power sources in India is shown in the figure below (IEA, 2021a). Much electricity generation in India has been dominated by coal although hydro, wind and solar energies have slowly picked up.

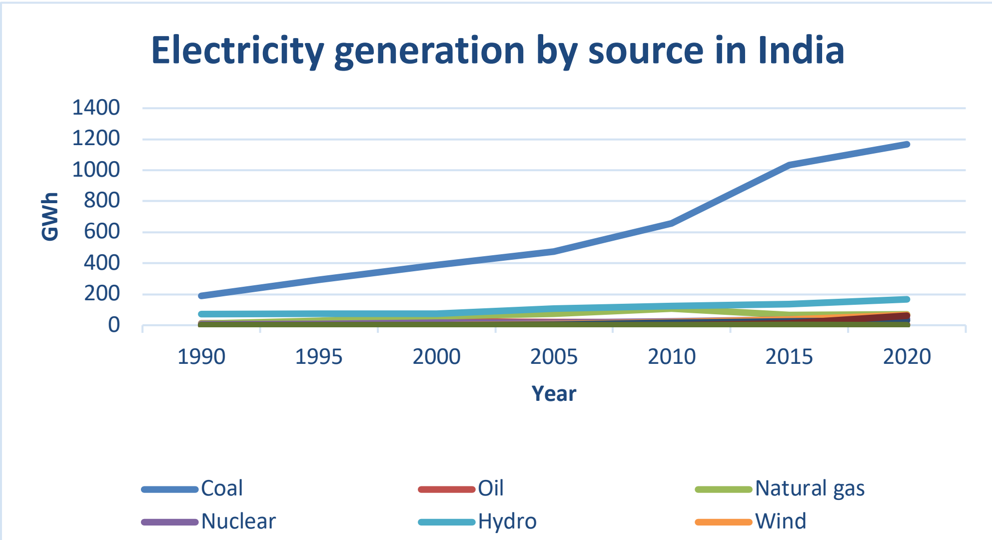

Figure 2: Electricity generation by source in India (IEA, 2021)

The energy market in India is evolving and there are several policy initiatives to enhance the share of renewable energy (RE) and capacity in the power grid. India has taken several steps in enabling regulation and policy to allow the renewable transition of the power sector. The key steps have involved introducing competition, encouraging regional trade and a more significant push for distributed energy resources. India has gradually introduced competition with regulatory oversight in different parts of the energy sector value chain, subsequently leading to the development of competitive wholesale markets for electricity.

This report is based on discussions in the fifth EU-India Regulatory Workshop Series in the framework of the 'India-EU Clean Energy and Climate Partnership' organised by the EU Delegation to India in collaboration with the Florence School of Regulation (FSR). The Partnership is supported by the Ministry of Power (MoP), the Central Electricity Regulatory Commission (CERC) and the Power System Operation Corporation (POSOCO).

The report examines and describes how electricity markets have evolved in Europe and India, and focuses on six topics: the wholesale spot market and the role of power exchanges; the role of decentralised energy resources; renewable energy resource support mechanisms; ancillary market balancing services; the retail electricity market; and cross-border electricity trade.

Chapter 1: Electricity Trade through Power Exchange

For decades electricity was provided by vertically integrated local or national monopolies, from generation to final supply and from transmission to distribution. These traditional arrangements helped achieve economies of scale, expand grids and ensure universal access to energy, but in recent years the system has been restructured and replaced with competitive wholesale markets, although not everywhere (Glachant et al., 2021). Like any commodity electricity needs to be bought and sold, and power trading may include buyers and sellers such as generation companies, distribution companies, consumers and traders etc. At both ends of power trading the electricity grid needs to be balanced i.e. demand needs to be met by timely supply. Power trading can not only be categorised by time horizons, i.e. long term, medium term or short term, but also according to how agreements are reached, e.g., through over-the-counter (OTC) trading, power purchase agreements (PPAs) or power exchanges. The specific nature of electricity affects electricity market design (Meeus, 2020). Different countries and regions have adopted different market designs, typically due to political factors and diverse initial conditions in the industry. Furthermore, uptake of intermittent renewables means market players will need to adapt to riskier environments and certain elements in current market designs will need to be adapted (Glachant et al., 2021).

In a short-term wholesale market or spot market, electricity can be traded in (i) day-ahead markets (DAMs), which usually close at noon for next-day delivery; (ii) intraday markets (IDMs), which are useful platforms to accommodate possible forecast errors (e.g. in demand or renewable energy generation) and are usually linked to the fact that deviations from programmes (imbalances) are penalised; and (iii) balancing and ancillary markets, which operate after gate closure when system operators must ensure system security. Short-term markets not only meet the objective of supply meeting demand but also help determine market clearing prices. These short-term prices are essential as they act as a reference for long-term markets, which help drive system expansion (IRENA, 2017).

Power exchanges (PXs) are trading platforms that facilitate anonymous trade between market parties and reduce the risk in market participation by acting as counterparties in all transactions and clearing all trades either themselves or through their clearing houses. Power exchanges also enhance market transparency as prices and volumes are published on their platforms. Power exchanges play a role in the day-ahead, intraday and balancing markets by organising continuous trading platforms, and in some cases also auctions (Meeus, 2020).

Electricity Trading in the EU

The European electricity market liberalisation process started more than two decades ago with the main aim of making the market efficient by introducing competitive forces where possible and regulation where needed. The process has also allowed for the development of an emission trading market, thereby encouraging integration of renewable energy sources and contributing to greenhouse gas emission reduction, which is important to combat climate change (Bojnec and Križaj, 2021). In 1996, the EU started to partially liberalise European electricity markets with the aim of creating a single integrated internal European electricity market across all the EU member states to reduce overall grid costs and benefit from synergies in security of supply. Unbundling electricity markets happened in steps starting with accounting unbundling in 1996 and followed by legal unbundling in 2003, ownership unbundling in 2009 and further market enhancement with an emphasis on consumers in 2019 (Meeus, 2020). The figure below presents the timeline of EU electricity market liberalisation.

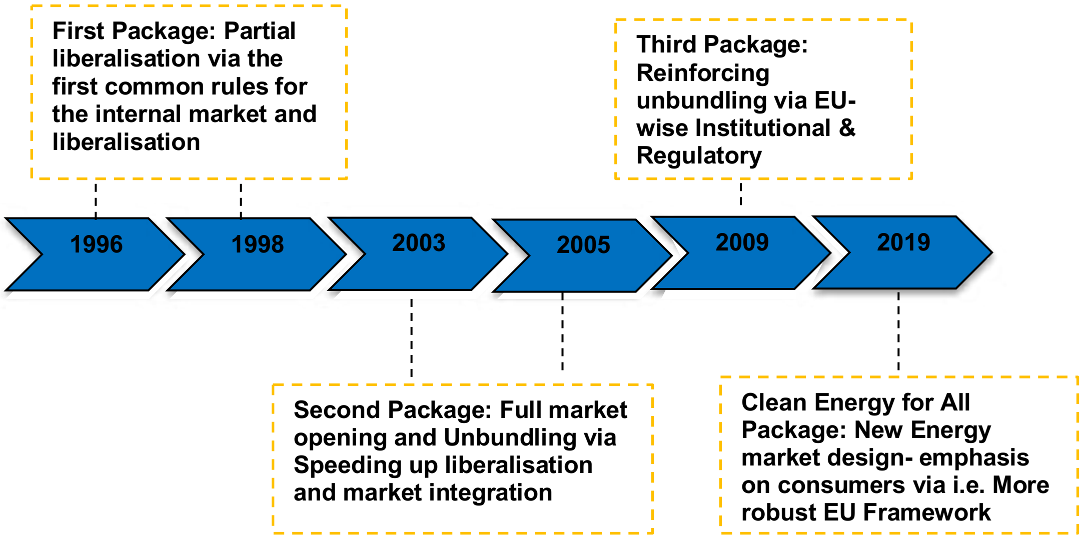

Figure 3: Timeline for EU electricity market liberalisation

At present, EU electricity market liberalisation is one of the most extensive cross-jurisdiction reforms, involving integration of many distinct state-level or national-level markets (Jamasb and Pollitt, 2005).

The sequence of electricity markets in Europe starts from years ahead to actual delivery and continues up to real time. Most European countries have a similar sequence of electricity markets. While some have evolved to form European markets, others remain national or regional (Meeus, 2020). The figure below provides a schematic overview of the electricity markets that currently exist in the EU.

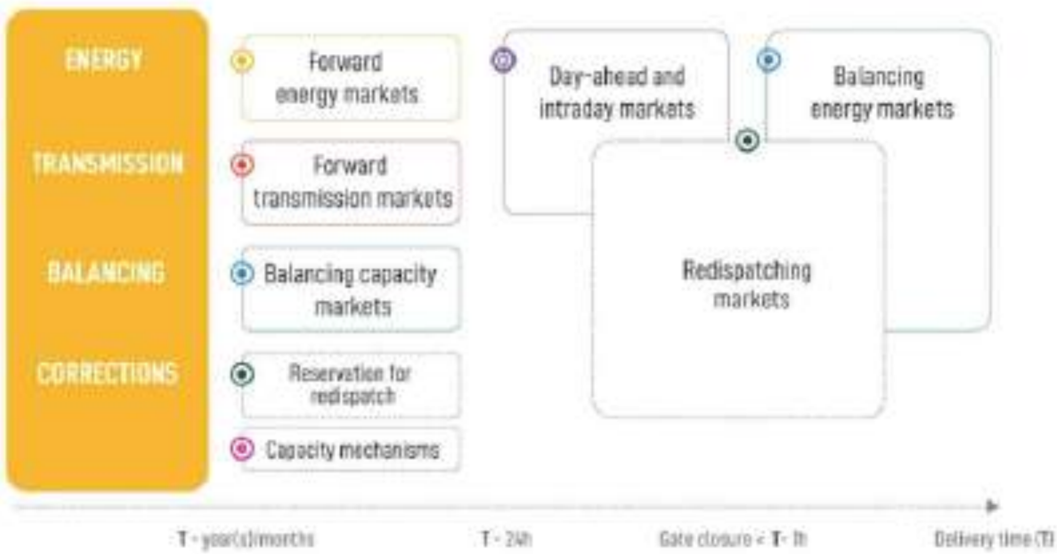

Figure 4: Sequence of existing electricity markets in the EU (Meeus, 2020)

The EU electricity markets can be categorised in four groups: long-term markets; wholesale and spot markets; balancing markets; and transmission re-dispatch markets (Meeus, 2020). Long-term markets comprise forward energy markets, forward transmission markets and capacity mechanisms while wholesale and spot markets include day-ahead and intraday markets. On the other hand, balancing markets include capacity and energy markets.

In Europe, power exchanges and OTC markets complement each other and compete for trading volume, which helps to reduce transaction costs for traders. Wholesale spot market trading is organised by one or several power exchanges in the various European member states. The evolution of power exchanges in Europe started in 1993 in Norway and took several years to establish in other countries, owing to which OTC continues to be the dominant form of electricity trade. Although most countries started off with their own PXs, they eventually consolidated into two large players, i.e. Nord Pool AS and EPEX Spot SE, through mergers and acquisitions. With the increased focus on PXs, it was important to have indicators to measure the performance of the exchanges, including the number of players, traded volumes, the price-setting frequency of certain generators, price volatility and price resilience. The day-ahead market consists of one pan-European auction at noon for the 24 hours of the next day. In DAMs power is traded for a dedicated hour or quarter-hour interval, and it can also be traded in blocks of combinations of time intervals. All accepted bids are paid the marginal offer based on the market-clearing principle of merit order. In the intraday markets, power trade is done in quarter-hour intervals via continuous trading bids in some countries and via auctions in others (Meeus, 2020). To support efficient integration of variable renewable energy generators, besides market coupling (inter-connected cross border markets promoting liquidity), the time horizons and gate closure times of the various spot products are being reduced to as short as five minutes, as in the case of EPEX Spot SE (EPEX Spot, 2022).

Electricity Trading in India

Liberalisation of the Indian electricity sector started roughly two decades ago. The Electricity Act 2003 reformed the power sector by enabling regulators to develop the power market by increasing competition while protecting consumer interests. In 2007, the Central Electricity Regulatory Commission (CERC) created a common platform for electricity trading through power exchanges. Currently, India has two active power exchanges, namely the Indian Energy Exchange (IEX) and Power Exchange of India Ltd. (PXIL), with a third one, Hindustan Power Exchange Ltd (HPXL), in the pipeline. Regulated under the CERC Regulations 2021, these power exchanges are the trading centres for suppliers and consumers. Suppliers submit their prices and quantity bids to sell energy or services, and potential consumers submit offers to purchase them (Bichpuriya and Soman, 2010).

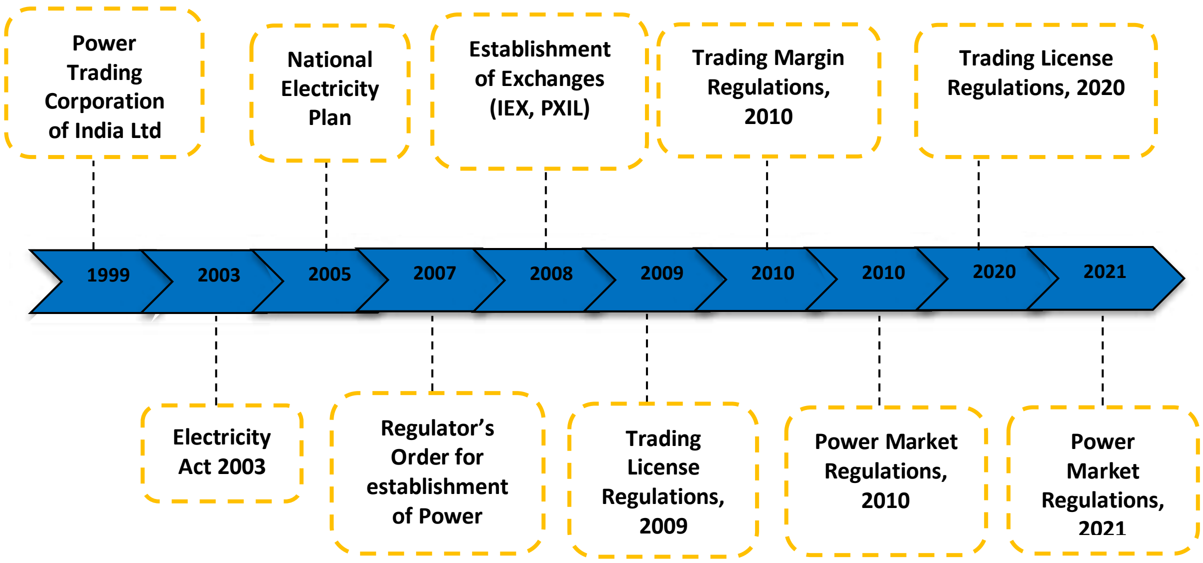

Figure 5: Timeline for Indian electricity market liberalization (Agrawal, 2022)

The sequence of electricity markets in India goes from years ahead to actual delivery and continues up to real time.

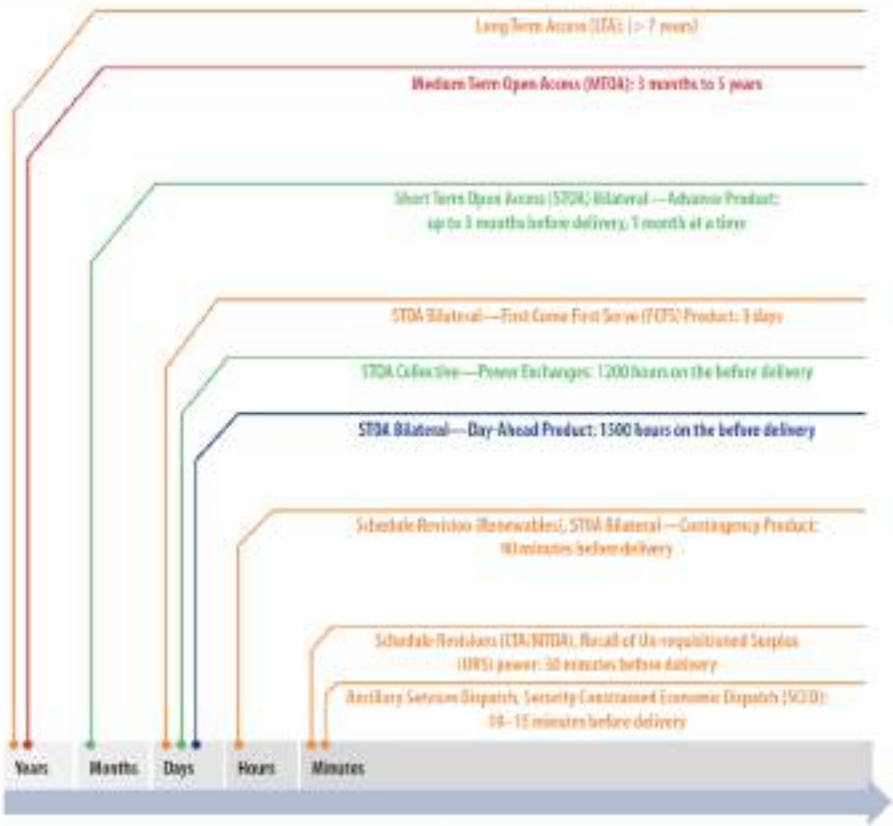

Figure 6: Sequence of existing electricity markets in the India (CERC, 2022a)

Various market options are presently available to market participants through bilateral transactions (advance, first-come-first-served, day-ahead bilateral and contingency) and collective transactions (day-ahead and real time markets) through the Power Exchanges (CERC, 2018a).

Most wholesale electricity trade in India occurs bilaterally through long-term power purchase agreements (PPAs). However, power trade through power exchanges increased from 0.4% in 2009 to 4.2% in 2019 and has seen a rapid growth of 23% annually (Regy et al., 2021). Today, the share of power traded via power exchanges is 6-7%, which is significantly less than in other advanced electricity markets (IEA, 2022). Over time, various short-term market product segments have been introduced, namely the day-ahead market (DAM), in which power delivery occurs the next day after transactions are contracted, the term-ahead market (TAM), in which the power transfer schedule can vary from 3 hours later the same day to 11 days in the future, and most recently the real time market (RTM), which brings together consumers and sellers just an hour before power delivery. In addition, India is in the process of establishing its first regulated over-the-counter market platform to facilitate direct participation by buyers and sellers to explore untapped sources of power to meet consumer needs (CERC, 2022a).

Almost 90% of the day-ahead scheduling is based on the principle of self-scheduling, in which the distribution company (DISCOM) specifies the quantity of power required a day in advance. The remaining 10% is traded by traders in direct bilateral trades between the DISCOMs and through power exchanges. The day ahead scheduling is followed by intraday energy requirement and system imbalances, which are generally managed through Deviation Settlement Mechanisms (DSMs) and Ancillary Services (AS) Mechanisms (CERC, 2018a). The Indian energy market is improved by introducing RTM and DAM schemes, which bring flexibility to the market. The objective of RTM is to get real-time balance while ensuring optimal utilisation of available surplus capacity in the system. The RTM contract specification is like that of the day-ahead market (DAM) as it is a half-hourly market price mechanism. However, its timelines are very narrow (Agrawal, 2022). RTM benefits RE integration in the grid, in which buyers and sellers meet their energy requirements through the organised market despite its intermittency. Other regulations to enable RE integration involve the green term ahead market (GTAM), which incentivises RE capacity beyond Renewable Purchase Obligations (RPOs) to promote renewable energy (IEX, 2022). With the aim of achieving ‘One Nation, One Grid, One Frequency, One Price,’ a proposed Market Based Economic Dispatch (MBED) framework is further expected to strengthen the DAM by optimising scheduling and economic dispatch of generation capacity on a day-ahead basis via a central pool. The framework aims to tap competition in the short-term market (including power tied up under legacy contracts to be transacted through power exchanges) and improve efficiency (CERC, 2022a).

Power Purchase Agreements

A power purchase agreement (PPA) is a power off-take agreement between two parties, an electricity producer and an off-taker of this electricity, such as an electricity consumer or trader. A PPA includes all the terms of the agreement, including the amount of electricity to be supplied, the negotiated price, who bears what risks, the accounting required and the penalties if the contract is not honoured (World Bank, 2021). PPAs are bilateral contracts that can be adapted to suit the needs of the parties and can take many forms. Typically, PPAs are long-term in nature covering a period of 10-25 years depending on the country. PPAs can be classified based on the type of buyer – either corporate or merchant – or on the mode of delivery – either physical or virtual. Physical PPAs can be further classified as on-site or corporate PPAs – in which power is delivered directly to the consumer without using the public grid – off-site PPAs – in which power is delivered to the consumer using the public grid but the focus is only on the physical quantity – and sleeved PPAs – in which power is delivered to the consumer using the public grid with a focus on both the physical quantity and balancing, which is usually done via an intermediary.

Virtual, or synthetic, PPAs decouple physical flows from financial flows, allowing for more flexible contracts. As in the case of physical PPAs, synthetic PPAs establish a price per kilowatt-hour (kWh) of electricity generated. However, electricity is not delivered to the consumer by the generator but instead it is traded on the spot market at the power exchange. The terms of such contracts are set as ‘contracts for differences’ (CfDs), which are essentially financial swap contracts. CfDs were first used in the UK to incentivise investments in new low-carbon electricity generation. The price guaranteed to the renewable energy generator, called the 'strike price,’ is determined in an auction and the PPA with the generator is executed at the strike price. If the market price is more than the strike price, the difference is paid by the generator. If the market price is lower than the strike price, the difference is paid to the generator (DECC, 2013). CfDs aim to protect the developer’s investment risk by ensuring a guaranteed long-term price, allowing investments to be made at a lower cost of capital, and scheduling through a power exchange ensures timely payment to generators, thereby improving their cash flow and reducing their need for working capital, which ultimately reduces the cost of generation and therefore also the cost to consumers (DECC, 2013; Grubb and Newbery, 2018).

In the case of India, which is trying to meet its ambitious renewable energy targets, CfDs can play an important role in helping reduce the volatility of market prices (Milligan et al., 2016). In addition, the CfD mechanism can offer flexibility by facilitating transfers of surplus renewable energy generation from renewable-rich states to renewable-poor states and help reduce exposure to deviation settlement mechanisms (DSMs) and compensation in unscheduled must-run status and thereby enhance grid balancing to ensure grid security (IEX, 2021).

Conclusion

Existing open wholesale markets are likely to be able to cope with currently evolving generation mixes in the short to medium term and accommodate increasing shares of intermittent renewable energy sources (RES). Short-term markets are one of the blocks to RES-proof wholesale markets, and power exchanges will play an important role in offering continuous trade at different time horizons and helping with price discovery. However, due to the variability of demand and supply, which introduces more price volatility, innovative market reforms are needed, particularly to integrate RES in the system. European markets are already offering a wide variety of products on energy markets, capacity markets and derivatives, including products for RES such as CfDs. Indian markets also offer a wide variety of products, particularly in the energy market and some derivatives with forward options. Given that most power trading is heavy on OTC or through PPAs, a transitional approach such as CfDs traded through a power exchange may be an option to reduce risk for renewable energy generators, improve system efficiency and reduce the cost to consumers.

Chapter 2: Role of Distributed Energy Resources in the Energy Transition

Distributed energy resources (DERs) are energy generation and storage technologies that can be deployed to meet the energy and reliability needs of customers (Ackermann et al., 2001). DERs may be connected to the local power grid or isolated from the grid as stand-alone systems. There are two subsets of DERs: distributed generation and demand side resources. Distributed generation is located within the distribution system or behind the meter whereas demand-side resources include load management systems required either for energy efficiency options or to relocate electricity use from peak to off-peak periods (Ackermann et al., 2001; Braun and Strauss, 2008). In other words, DER is a collective term used for a broad set of distributed generation for small scale electricity generation, electricity storage and controllable loads connected to distribution grids or directly at the customer's premises. DERs use RE source technologies such as microturbines, solar photovoltaic panels, small wind turbines, mini-hydro, energy storage systems and also fossil fuel-based cogeneration units (NREL, 2022).

The electricity supply in developing countries is typically characterised by inadequate generation capacity, poor system reliability and low levels of access to electricity. In the developing world, 789 million people lack access to electricity (Pérez-Arriaga et al., 2021). Many of these unserved communities are remote and sparsely populated, making grid extension complex and expensive. DERs are cheaper, modular and can be deployed more quickly to close the electricity access gap. DERs in mini-grids are crucial in providing last-mile connectivity to rural populations which are not connected to the main grid. According to an Energy Sector Management Assistance Program (ESMAP, 2019) study, compared to main grid extensions mini-grids offer certain favourable conditions such as demand levels, dispersion and distance to the existing grid and are economically competitive in supplying electricity in Asia (ESMAP, 2019). Access to reliable affordable clean energy promotes productive use of energy. Therefore, ending poverty is contingent on ending energy poverty, which will improve productivity and facilitate better delivery of public services such as education, healthcare etc.

DERs are also expected to play a vital role in decarbonisation of the Indian electricity sector through a transition from fossil fuel power generation (especially coal) (Poudineh et al., 2021). DERs can participate in wholesale electricity markets, ancillary service markets and capacity markets with benefits for market participants. Market integration of variable renewables and DERs can improve system operation with benefits for the entire power system (Damsgaard et al., 2015).

The Development of DERs in the EU

In the EU, policymaker awareness of the role of DERs in managing the grid at a reasonable cost has increased. The development and management of DERs are among the primary focus areas of the Clean Energy Package (CEP). The CEP promotes consumer empowerment and integration of DERs along with smart meters. In addition, the CEP emphasises the role of aggregators alongside energy suppliers in improving demand response. Emphasis is put on creating energy communities in which citizens can participate in the energy market with increased autonomy. The European Green Deal re-emphasises the focus on the energy transition through consumer engagement, including consumer rights and protection, data management and protection against energy poverty etc. (Piebalgs et al., 2020).

The following trends will become more evident in the future EU energy market landscape due to DERs:

- Decentralisation of energy systems with production, supply and exchanges being more locally sourced;
- Electrification of energy systems for heating, cooling and transport (replacing natural gas for heating in large parts of Europe);
- Increased digitalisation, with implications for future system operators to facilitate mutually reinforcing physical and digital infrastructure layers.

DERs are often deployed and 'operated' by small non-professional actors such as households, small businesses, manufacturing sites (such as solar rooftops) or through the involvement of a third party. DERs should be included in system planning and operation to achieve deep decarbonisation and low integration costs. Transactions in the energy market can be supported by the three pillars shown in Figure 7.

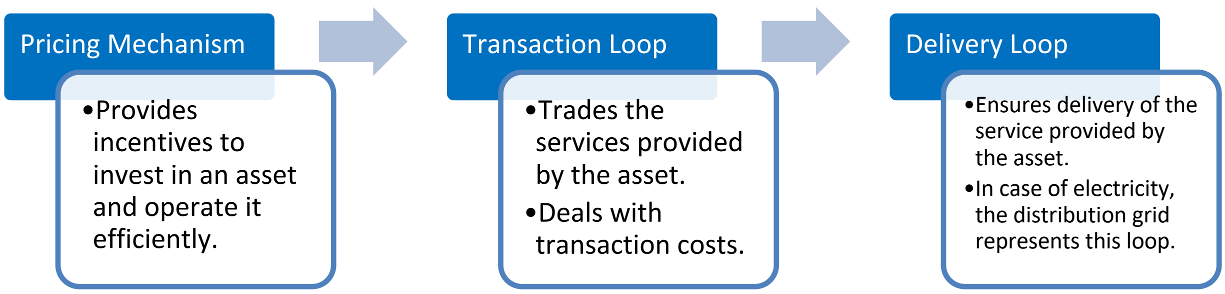

Figure 7: Transaction pillars in the energy market

The design of these pillars involves significant assets connected to the transmission grid and managed by prominent professional actors, such as energy utilities and wholesale traders. The specificities of DERs and small prosumers, however, have not been considered. In the EU, the first wave of change occurred around 10-15 years ago. It was driven by the decarbonisation agenda and led to the introduction of a series of support measures promoting the deployment of distributed generation from RE sources. Feed-in tariffs for solar PV, for example, provided a 'peer-friendly' scheme: households and small businesses deploying them could benefit from high export tariffs for 20 years or so. In addition, the support scheme typically foresaw a public off-taker in charge of marketing the electricity generated by the new prosumers in wholesale markets. Finally, grid companies were mandated to adopt simplified procedures and tariffs to connect the new small-scale generation assets (Glachant and Rossetto, 2021).

The Development of DERs in India

Electricity acts as an enabler to boost the economic development of a country (World Bank, 2019). However, a total of 64 million people located mostly in rural areas in India still lack access to reliable electricity (ESMAP, 2020). India's per capita power consumption is a mere 30 per cent of the world average (3265 kWh) and ranks 106th among 143 countries (IEA, 2019). Sixty-five percent of India's population live in rural areas. They are mostly dependent on agriculture and are far behind the urban areas in terms of various socio-economic indicators (Nathan, 2014; World Bank, 2019). In 10 of the 28 Indian states, the rural power supply is for less than 20 hours a day, indicating poor system reliability and quality of service in rural areas (PIB, 2019).

The incumbent distribution companies (DISCOMs) have failed to deliver an acceptable level of service to rural areas due to the sparse population, lower affordability and location disadvantages, as they are farther from the source of generation resulting in more transmission and distribution (T&D) losses (Das and Srikanth, 2020). In addition, DISCOMs face difficulties in billing and collection in remote locations (Nathan, 2014). A considerable gap exists between DISCOM tariff charges and the cost of supply in rural areas (nearly INR 5.40/unit) due to the high cost of service for utilities and the delay in subsidy and power tariff payments by the government, which were announced as part of its various social welfare schemes for rural areas (Das and Srikanth, 2020). DISCOMs therefore lack interest in creating and maintaining infrastructure in rural areas due to profit deficits, resulting in considerable load-shedding (Kumar et al., 2019).

In this context, India is targeting universal household-level access with an improved reliable supply of electricity (CEEW, 2020). India's policy mandates favouring DERs such as by including solar energy in irrigation pumps, with an initial target of 30.8 GW decentralised solar capacity under the Government of India (GoI) scheme known as *Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan* (PM-KUSUM). To achieve this, the country is promoting DERs which include rooftop solar, RE-based mini-grids and solar water pumps. The increased uptake of DERs in rural India will enable integration of variable renewables and has the potential to improve energy access and the quality of life.

In addition to government initiatives, several private players in India have established renewable mini-grids to electrify villages. Mini-grids in rural India are used not only for agriculture but also for commercial and industrial purposes, such as oil expelling, irrigation pumping, flour milling, milk chilling, rice hulling, etc. Non-agricultural production activities generate two-thirds of rural income and are also heavily dependent on access to reliable and affordable electricity (Chand et al., 2017). Technology innovations in micro-grids now enable remote monitoring of mini-grids. However, there is scope for continued business model innovation to ensure commercial viability in the rural context.

India is actively promoting measures to meet its target of 40 GW from rooftop solar as part of the 175 GW RE generation capacity target for 2022. The solar rooftop scheme has been provided with government subsidies and further simplified, allowing individuals to install solar rooftop panels by themselves or by vendors (MNRE, 2021).

In urban areas, DERs in the form of rooftop solar, battery storage and electric vehicles (EVs) can help to manage the load curves in the power grid, thus aiding better demand management. Moreover, battery support projects are useful for black start, frequency regulation, voltage regulation and power factor improvement and thus help avoid deviation settlement mechanisms (Poudineh et al., 2021). It is estimated that India will need 27 GW of grid-connected batteries by 2030. India has already started to run its first large-scale 10 MWh battery project in New Delhi to manage peak load during the evening hours (TPDDL, 2021). In addition, electric vehicles can also act as batteries by being plugged into the grid and offering grid services.

The DER Digital Breakthrough

The power system is facing many systemic changes, be it due to the high emissions from existing fuel sources or the gradually increasing share of renewables. Decarbonisation of power grids is an essential pillar to meet climate targets. DERs such as battery storage and electric vehicles can play an important role in providing the flexibility needed to integrate a high penetration of variable renewables. In addition, new digital technologies such as smart grids enable integration and optimisation of distributed and renewable generation and promote interaction between consumers and utilities, which will provide both with benefits. On the supply side, smart grids help improve grid efficiency, facilitate automation, reduce costs and improve the quality of the grid. On the demand side, advanced metering infrastructure enables consumers to become prosumers by either importing or exporting grid electricity based on price signals (Kumar et al., 2019). The two Ds of decarbonisation and digitalisation will unlock new business models such as time-of-use net metering, peer-to-peer trading, aggregators, etc. for DERs and thereby increase the number of DERs in the system. Integrating this growing number of DERs in existing markets and system operation becomes a necessity to ensure an economical and secure supply of electricity (Glachant and Rossetto, 2018).

Conclusion

Growth in the participation of DERs will make it less expensive for the rest of the system by helping avoid investments in cost-intensive grid expansion measures. India has embarked on an ambitious renewable energy plan, one that includes a focus on DERs. Measures to increase the share of RE through DERs in the energy mix will play a key role in not only providing energy access and affordable electricity, especially in off-grid places (generally rural areas) in India, but also help DERs (mostly in urban areas) to participate in the various electricity markets to offer grid services. The EU has been actively promoting DERs in its various policy and regulatory interventions, including putting consumers at the centre of its clean energy transition, which ensures their active participation, rights and protection of data management. New enabling and emerging technologies such as energy storage, electric vehicles and smart grids etc. strengthen the business case for DERs and digitalisation will further enable them to contribute in active ways. Therefore, regulation should be more dynamic in its response and bring on board active participation by all stakeholders. As the share of DERs increases in the system and they start to compete with other modes of generation in the energy mix, it will allow policymakers to plan energy investments in a more sustainable way.

Chapter 3: The Future of Renewable Support Mechanisms

Tackling climate change and the corresponding action to decarbonise our energy systems is one of the biggest challenges of our times. The COP 26 conference at Glasgow further boosted the resolve of countries around the world to set and achieve new targets. An IPCC 2018 report observed that to cap global warming at 1.5^{o}C above pre-industrial levels, global greenhouse gas (GHG) levels need to be curbed by around 45% by 2030 and reach net zero by 2050. Setting planned trajectories for GHG reductions by accelerating the phase-out of coal and subsequent utilisation of renewable energy (RE) sources with a natural gas transition could be one of the most cost-effective way to achieve climate neutrality (Piebalgs et al., 2020). Moreover, other RE vectors can be used like green hydrogen, electric vehicles and storage etc., thus improving the scope of cross-sectoral approaches.

India and the EU have their own sets of targets and approaches to reach these goals. At the end of 2021, global RE generation capacity, including hydro, reached 3061 GW. As of 2022, the EU has a cumulative 647 GW of RE and intends to achieve a 55% emission cut by its member states and a 40% share of renewables in its energy mix by 2030 (IRENA, 2022). India, on the other hand, aims to reduce its emission levels by 45% from 2005 levels and to meet 50% of its energy demand with RE and increase its non-fossil-fuel-based energy capacity to 500GW by 2030 (WRI, 2021). With targets to achieve net zero by 2050 in the EU and 2070 in India, the current RE capacities indicate the scale of the challenge ahead for both the EU and India to accomplish these ambitious targets. Support mechanisms are vital for countries to promote energy production from renewable sources to achieve these goals.

Renewable Support Mechanisms in the EU

In its long-term strategy to integrate more RESs, the EU has established several targets, measures and corresponding legislative initiatives, starting as early as the 1990s. These can be grouped according to the time horizon that they address, as is shown in the figure below. Directive 2001/77/EC set targets to reach 12% of energy and 22% of electricity sourced from RESs by 2010. For the 2020 horizon, the Renewable Energy Directive (RED) I (2009/28/EC) set collective targets to reach a 20% RES share in total EU energy consumption, provided a set of provisions and introduced and defined support mechanisms such as feed-in tariffs, network reinforcements and capacity mechanisms to promote energy production from renewable sources among its 28 member states (Nouicer et al., 2020; Piebalgs et al., 2020).

The 2019 EU Clean Energy Package (CEP) comprises eight pieces of legislation, i.e. four directives and four regulations. The National Energy and Climate Plan (NECP) defined under the Governance Regulation plans to ensure that the objectives of the Energy Union – the five dimensions of action, namely energy security, the internal energy market, energy efficiency, decarbonising and research, innovation and competitiveness – are considered by the member states. Another Directive, RED II (2018/2001/EU), renews goals from RED I, aiming at a minimum 32% share of renewables in final energy consumption by 2030. Additional steps to allocate RES support in a more competitive and cost-effective manner by requiring the member states to introduce market-based support mechanisms, legislation on prosumers, energy communities and revised sustainability and GHG emission-saving criteria for biofuels and biomass were other highlights of RED II (Nouicer et al., 2020).

The next initiative, the Green Deal, was first formulated by the EU Commission in December 2019 as a roadmap to reach net zero emissions of GHG by 2050, incorporating new strategies for energy system integration and hydrogen among other things. In the early 2020s, the European Green Deal Investment Plan and the Just Transition Mechanism were announced as the investment pillars of the Green Deal (Piebalgs et al., 2020). The freshly drafted RePowerEU Plan of May 2022 works further towards these objectives, also emphasising countering geopolitical issues of energy security with ambitious proposals to accelerate investment in RE electricity generation and value chain infrastructure (FSR, 2022).

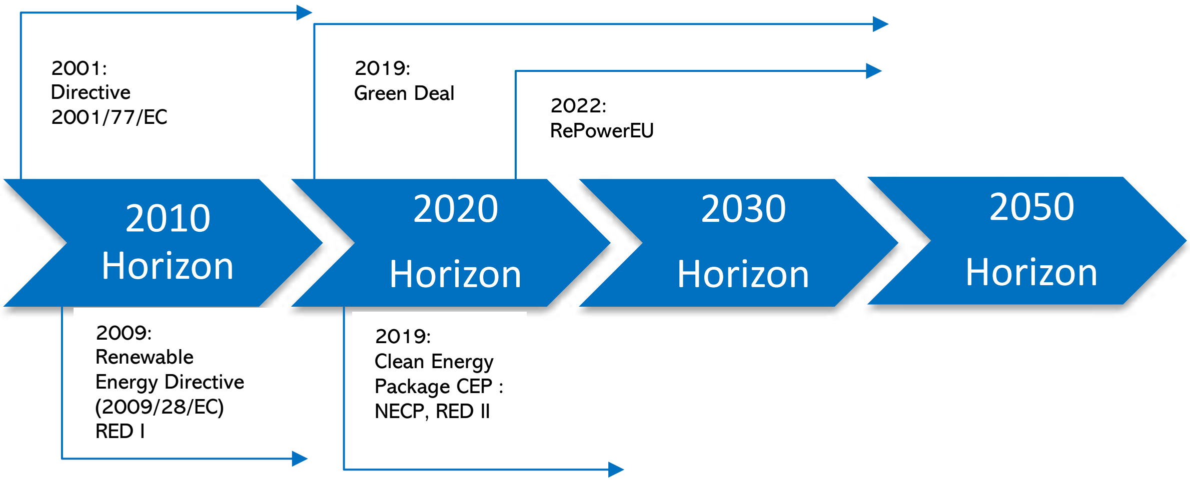

Figure 8: Evolution of EU measures and targets across time horizon

Different RES sources come with different technologies, output characteristics and market maturities. Therefore, they have different outcomes, and the support needed in terms of cost structure also varies accordingly. The RE support scheme can also be dependent on the policy objective and market failures, technology readiness and market requirements. The support can be in direct forms such as investment grants, tariffs incentives and tenders. For e.g. generation-based direct voluntary schemes such as green tariffs are based on the willingness of customers to pay premium prices for electricity from RES, whereas capacity-based direct voluntary schemes such as shareholder programmes are based on the willingness of certain companies and/or investors to have limited or no return on their capital invested in RES-based generation. Shareholder programmes are initiatives in which stakes in a RES plant are offered to the public (e.g. to the customers of an energy utility). In a donation, the RES developer asks the public for cost-free funding (Golnoush et al., 2022). Indirect forms of support are environmental taxes such as carbon pricing, taxation of electricity produced from non-RES resources and removal of subsidies on fossil fuels (Nouicer et al., 2020).

Overall, the main support schemes can be classified as is shown below. (Golnoush et al., 2022) analyse the schemes in terms of their effectiveness in attracting investments in RES-energy generation technologies and their efficiency. For instance, the FiT scheme in Germany from its onset in 1991 until 2019 helped install approximately 25GW of onshore wind, 12GW of utility-scale PV and 23GW of rooftop PV capacity. However, after the introduction of size caps in 2014 and 2016 new capacity installations decreased for utility-scale PV and onshore wind. Support schemes in Italy have been differentiated for PV and non-PV technologies. In particular, utility-scale and rooftop PV are supported with FiTs while Tradable Green Certificates, FiTs and FiPs have been used to promote onshore wind deployment. Solar PV and solar thermal in Spain are almost entirely financed by FiTs.

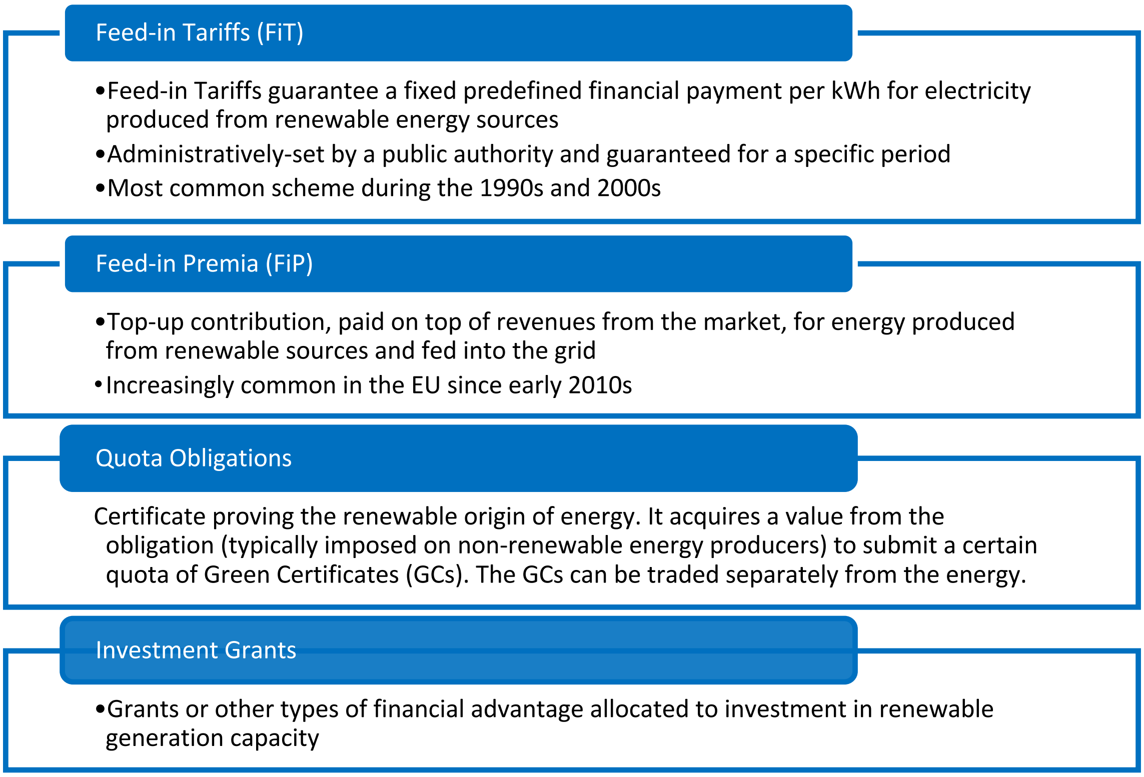

Figure 9: Classification of Renewable Support Schemes

FiPs with no capacity limits were introduced in Germany in 2012 to push direct participation by large-scale RES-E technologies with capacities above 500 kW in the electricity market. The level of support and financial incentives was decided by auctioning. Italy had FiPs allocated to new onshore wind installations through auctions. These, however, were not very competitive with Tradable Green Certificates (TGCs). Spain introduced a new specific remuneration mechanism providing support for both new and existing RES-E installations in the form of FiPs, from which onshore wind benefitted the most (Golnoush et al., 2022).

The EU electricity market focuses on achieving a state of increased security, flexibility and affordability of power supply. Cross border trade facilitates development of new infrastructure and transmission network interconnection capacities, thereby strengthening the internal market (Nouicer et al., 2020). Nine priority corridors covering electricity, gas and oil infrastructure across regions are expected to further contribute to stronger cross-border interconnections and integration of RE (EC, 2022). Electricity Regulation 2019/943 focuses on the future electricity market with measures such as setting core market principles, rules on trading, capacity mechanisms, network access charges, dispatching, re-dispatching and congestion solutions, and setting principles for balancing markets and the activities of transmission and distribution system operators along with Regional Coordination Centres (RCCs) focusing on bidding zones and network codes. RE electricity generators obtain a tradable Green Certificate (GC) for each MWh. This represents the ‘greenness of energy’ and can also be traded separately from energy. Non-RE producers are obliged to procure and submit a certain quota of GCs every year. Investment grants on the other hand are typically used to invest in non-mature RE technologies. ‘Banding’ is employed to avoid investment pooling in least-cost technologies (Verbruggen and Laes, 2021).

Renewable Support Mechanisms in India

Implementation of RE support schemes is done at two levels in India. The Ministry of New and Renewable Energy (MNRE) serves as the Government of India's central nodal agency promoting renewable energy for both grid-connected and off-grid services. And the State Nodal Agencies (SNAs) implement MNREs schemes at the state level, driven by factors such as RE resource potential, availability, supporting infrastructure and the will of the states to invest in RE (Aggarwal and Dutt, 2018; Bhushan et al., 2019).

The growth of RE in India is dispersed and is based on the RE penetration, which is highly variable across the states in India. The national average share of solar and wind in India is 8.2%, and the corresponding averages are higher in the ten renewable-rich states, i.e. Tamil Nadu, Karnataka, Gujarat, Rajasthan, Andhra Pradesh, Maharashtra, Madhya Pradesh, Telangana, Punjab, and Kerala (IEA, 2021b). As of 2022, the country's total installed solar power capacity is 56.95 GW. The installed wind capacity stands at 40.70 GW, biomass at 10.205 GW, small hydro projects at 4.88 GW and large hydro at 46.51 GW. In addition, India also has 223.14 MW capacity of grid-interactive waste to power projects and 253.61 MW capacity of off-grid waste-to-energy projects (MNRE, 2022). India has set itself ambitious plans for RE with a short term target of 175 GW (100 GW solar 60 GW wind, 10 GW biomass and 5 GW small hydro) by 2022 and a long-term target of 450 GW RE capacity by 2030. For offshore wind, MNRE announced a medium-term target of 5GW by 2022 and a long-term target of 30GW by 2030. Given that the current RE capacity is around 110 GW (excluding large hydro), much work needs to be done to meet the targets. Figure 10 shows the cumulative installed RE capacity of the different states in India.

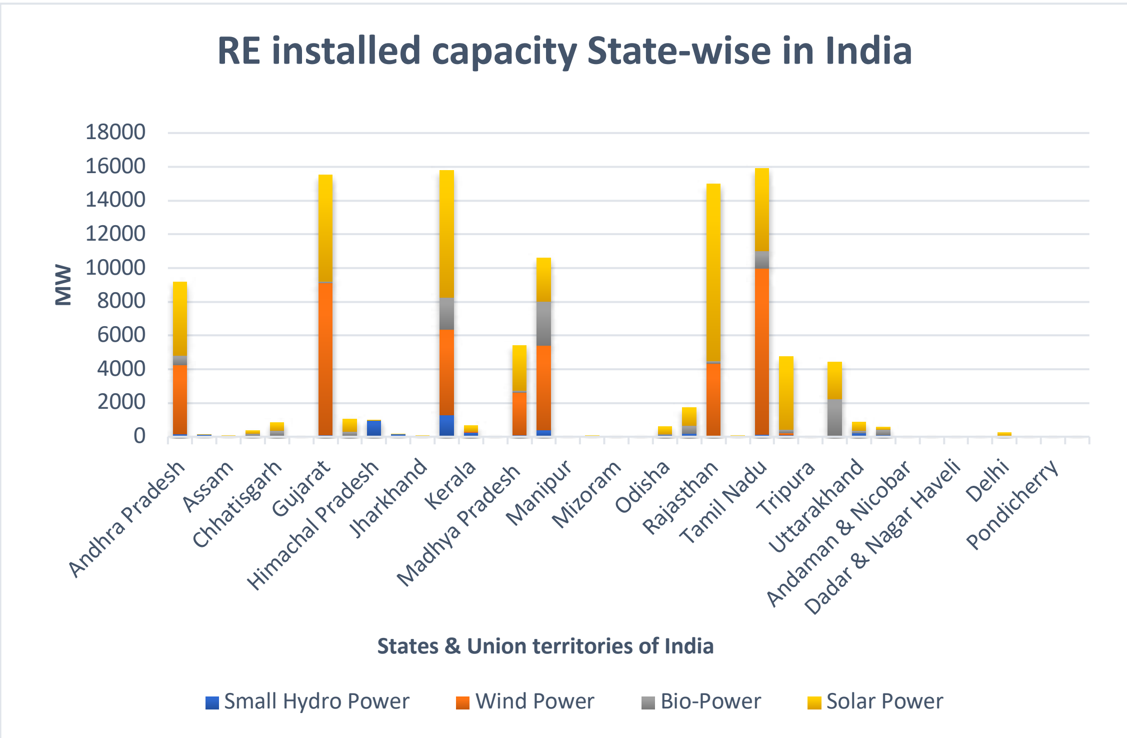

Figure 10: Cumulative RE installed capacity of States and Union Territories in India (MNRE, 2022)

Over the last few years, the Indian government has introduced several schemes and policies promoting the deployment and uptake of RE. The promotion of RE started as early as 2003 with the Electricity Act, which enabled anybody to set up a RE-based power plant and supply electricity to either a distribution licensed or captive industrial unit. The State Electricity Regulatory Commission (SERC) then further promoted RE integration with measures on grid connectivity and provisioning stand-alone systems in rural areas. The 2010 Jawaharlal Nehru National Solar Mission provided a basket of incentives to increase the share of solar, including viability gap funding, incentives for the development of solar parks boosting demand, the promotion of rooftop solar systems through capital subsidies and fixed tariff support which in spirit is nothing but a feed-in tariff (FiT). This paved way to lower the risk perception of RE, thus creating further favourable investment environments (Deo et al., 2021).

Policies have been greatly driving utility-scale wind and solar deployments. The procurement of utility-scale RE in the Indian context is conducted through a competitive reverse-auction process, where either central or state government agencies tender out capacity for utility-scale solar and wind. RE developers bid for the allocated capacity and the lowest tariff bidder is allocated the contract. In the case of central the Solar Energy Corporation of India (SECI) or National Thermal Power Corporation (NTPC) are the usual offtakers and also have a better credit profile, while in the case of the state, the offtaker is the state DISCOM. Utility-scale solar has had a much longer track record under the reverse-auction process, while wind energy was exclusively under the feed-in tariff (FiT) until reverse auction was introduced in 2017 (Aggarwal and Dutt, 2018).

Financial incentives were also provided for off-grid and decentralised RE systems, for example the PM KUSUM scheme for construction of decentralised grid-connected RE power plants, the installation of standalone solar pumps and the solarisation of grid-connected pumps. SECI, initially promoted rooftop solar by mandating installation of on-site solar in government buildings, public offices etc. As of November 2021, 6.1GW of the 40 GW of installed solar capacity was rooftop (Aggarwal and Dutt, 2018).

Some of the other major support mechanisms for RE include, fiscal incentives – where RE generators benefit from accelerated depreciation in the initial years which lowers the taxation and bolsters the financial viability of the projects; Renewable Purchase Obligations (RPO)- where state DISCOM and other major consumers are required to ensure a minimum share of solar and wind power in their power procurement; Renewable energy certificates (RECs) – tradable certificates that can be procured from the power exchange to meet the RPO requirement; Must run status – where RE is exempt from the merit order dispatch mechanism and scheduling regulations; Green Energy Corridors - strengthen the existing transmission and distribution grids to facilitate evacuation and smoother integration of RE; Inter State Transmission Systems (ISTS) waiver – where charges for the transfer of electricity from RE resource-rich states to resource-poor states via ISTS is waivered and last Technology Development and Innovation Policy (TDIP) - to promote research, development and demonstration (RD&D) in the RE sector (Aggarwal and Dutt, 2018; CERC, 2018b; Kumar. J and Majid, 2020).

Impact of RESs Transition

As the share of renewables are increasing, they are becoming more and more cost competitive aided by the support mechanisms induced in their early stages of deployment and uptake. Therefore, it is no more about bridging the gap in terms of economics, rather it is about making RE a core actor in the market. Conducive policies and variety of products offered in the wholesale spot electricity markets allow for RE to compete actively with other technologies. In addition to this, auction mechanism of RE has allowed for price discovery and competition. While the liquidity on the whole sale markets are higher in Europe compared to India, in the coming years India is expected to transition to a more market-based approach, migrating away from the PPA model which is currently the dominate form of energy trading (see Chapter 1) (Kumar. J and Majid, 2020).

The effectiveness of RE integration will depend a lot on the state of the grids and how it is managed. A lack of adequate infrastructure to transfer electricity from generation to demand sites is one of the main bottlenecks in the growth of RE. In addition, high ramping rates and the variability nature of RE brings in associated balancing costs for grid integration and fast response ancillary service requirements. Therefore, it is important to plan in terms of pace of generation and network deployment (Aggarwal and Dutt, 2018; Deo et al., 2021).

Conclusion

The journey of RE support both in the case of EU and India is quite diverse. Both geographies have set ambitious RE targets for themselves and have been laying out a host of support mechanisms to encourage RE deployment and uptake. In the initial phases on RE support, the focus was more on making RE more cost-competitive with other sources of energy, but as the share of RE has been growing they are naturally competing with the other technologies and are in fact cost-competitive. While there is lot of support for solar and wind, other technologies such as biomass, offshore wind etc will also need the kind of support bestowed upon solar and wind. As the share of RE increases in the system, support mechanisms must evolve beyond the RE market entry phase to a RE integration phase. Keeping in mind the particularities of renewable energy technologies, new rules and planning are needed for both networks and markets according to the level of maturity of various renewable technologies.

Chapter 4: Efficient Procurement of Ancillary Services

Electricity can be considered a commodity, just like copper, oil and grain. However, electricity markets differ substantially from other commodity markets due to physical characteristics such as time, location and flexibility. An increasing share of renewable energy in the energy mix can aggravate grid integration challenges. Therefore, ancillary services are required to balance and safely dispatch the system (Rancilio et al., 2022). Balancing relates to a situation closer to real time i.e. after the markets have closed (gate closure), in which grid operators (transmission grid operators and distribution grid operators) need to ensure that supply meets demand in a reliable way. Efficient balancing markets ensure security of supply at the least cost and can deliver environmental benefits by reducing the need for back-up generation. An important aspect of balancing is the approach to procuring ancillary services (ENTSO-E, 2022).

"Ancillary services are those functions performed by the equipment and people that generate, control, transmit and distribute electricity to support the basic services of generating capacity, energy supply and power delivery" (Hirst and Kirby, 1996). Ancillary services consist of a range of functions such as black start, redispatch, maintaining the load-generation balance (frequency control), maintaining voltage and reactive power support and maintaining generation and transmission reserves (Soonee et al., 2016). Proper operation of grids does not happen automatically and access to a broad range of services from various providers, including generators and demand response services gives grid operators flexible options to make efficient decisions. While there are many ancillary services, the most renowned one is frequency control, or balancing services.

According to ENTSO-E, balancing services are short term reactive measures that are needed to level out frequency deviations in the power grid. Balancing services include balancing energy – which is the energy used by grid operators to maintain frequency – and balancing capacity – which is a flexible capacity made available for a certain period to provide the balancing energy. Power grids need to maintain a certain frequency, which in the cases of the EU and India is 50 Hz. A deviation in frequency occurs when the power injected into the grid does not equal that withdrawn from the grid, so when there is more injection than withdrawal the frequency rises and if there is less injection than the withdrawal needed the frequency drops. If these deviations go beyond a threshold, then a blackout is imminent (Schittekatte and Pototschnig, 2022).

Balancing Services in the EU

To ensure cost competitive procurement of balancing energy, in 2017 the European Commission introduced the Electricity Balancing Guideline (EBGL), which sets the framework for stabilising the electricity grid throughout the European electricity market system (Meeus, 2020). In the ENTSO-E area, TSOs put in place load-frequency control (LFC) procedures, which are often referred to as 'electricity balancing,' to manage real-time power balances for each LFC area. There are several types of reserves that meet different operational needs, and they differ mainly in their response times and maximum durations of delivery. These reserves can be broadly classified as (i) Frequency Containment Reserves (FCR, R1, or primary control reserves); (ii) Automatic Frequency Restoration Reserves (aFRR, R2, or secondary control reserves); (iii) Manual Frequency Restoration Reserves (mFRR, R3, or tertiary control reserves) and (iv) Replacement Reserves (RR) (Meeus, 2020). The figure below shows the activation of the different reserves after a frequency drop or spike.

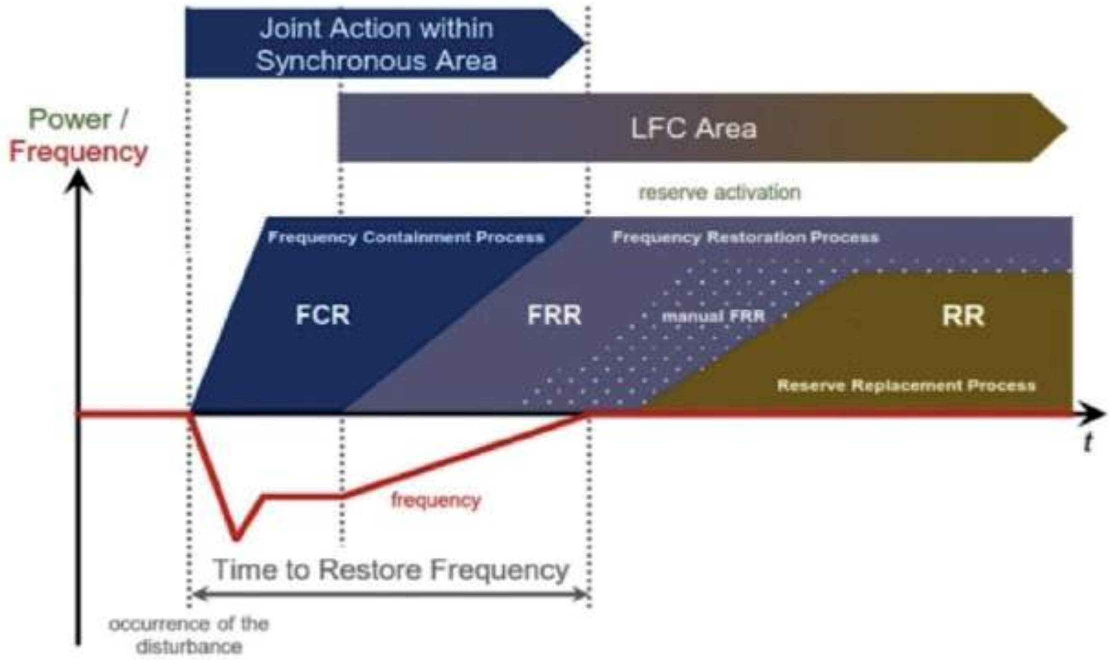

Figure 11: Frequency drop and the reserve activation structure (ENTSO-E, 2018)

FCRs are the fastest type of reserves. They are activated almost instantaneously and are operated using a joint process involving all TSOs in a synchronous area. FRRs kick in after a few minutes. First an aFRR is activated and it is followed by a mFRR. A FRR is operated for each LFC area and it aims to restore the frequency to its nominal value. Last, RRs are deployed after 15 minutes or more and can support or replace the FRR (Schittekatte and Pototschnig, 2022).

In Europe, the transmission system operators (TSO) act as a single buyer in each of their markets and operate the balancing capacity and balancing energy markets. On the supply side, balancing services are offered to the TSOs by balancing service providers (BSPs), market participants with reserve-providing units or reserve-providing groups. Balance responsible parties (BRPs) are market parties responsible for system imbalances, i.e. there is a mismatch between the energy volume declared to the TSOs at intraday gate closure and the attributed volumes. BRPs may include generators, industrial consumers, retailers or a portfolio of generators/consumers (balancing groups). They are subject to imbalance prices, which reflect activating balancing costs to address system imbalances (Schittekatte and Pototschnig, 2022).

Balancing Services in India

Considering the high variability and unpredictability of generation from renewable sources, efficient and economical grid operation becomes one of the critical challenges in India's power system (CERC, 2018a). Since 2002, the Central Electricity Regulatory Commission has been implementing a series of measures to ensure system reliability and security. System imbalances are addressed using a Deviation Settlement Mechanism (DSM), a commercial mechanism based on a frequency-linked incentive/penalty structure for intraday generation and withdrawal schedules to manage deviation either at the generation end or at the load-serving end. The DSM is an improvement on the previous Availability Based Tariff

(ABT), which addressed unscheduled interchanges (UI) (deviations from schedule) of power among the regions/states (Singh and Kumar, 2020). The figure below shows the evolution of the DSM in India.

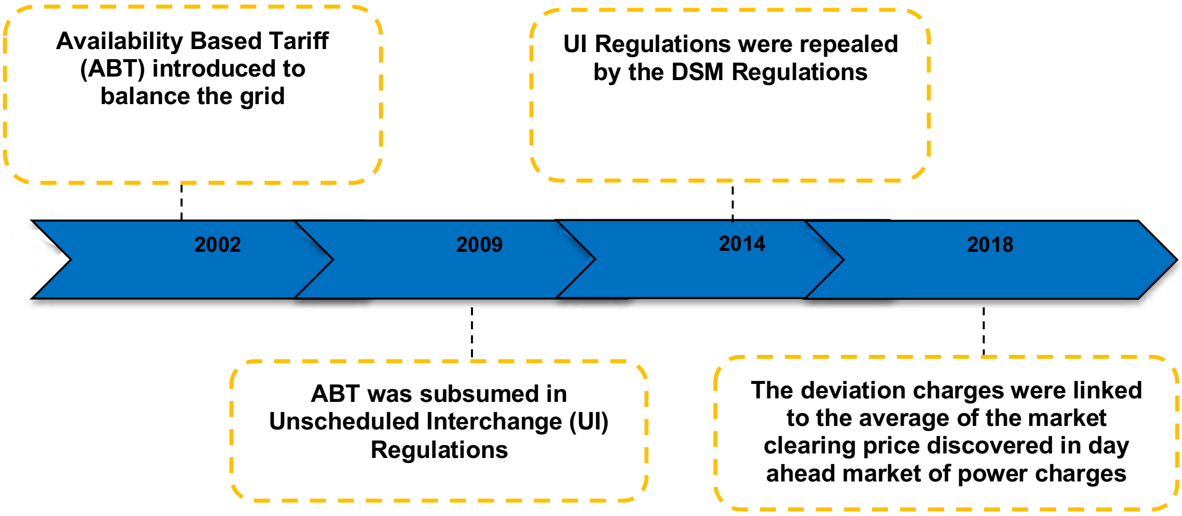

Figure 12: Timeline of DSM regulations development in India (Agrawal, 2022)

Presently, the DSM in India has narrowed down the operational frequency from 49.0-50.5Hz in 2002 to 49.9-50.05Hz in 2014 (CERC, 2018a). Although the DSM can bring about significant grid discipline and control frequency deviations, it does not completely meet the needs of the evolving Indian power sector (Singh and Kumar, 2020). To complement it, in 2022 the CERC brought into effect an Ancillary Service regulation which introduces various categories of ancillary services for frequency, voltage and black start functions, including capacity utilisation of un-requisitioned surplus (URS) generation, energy storage and demand response resources to provide ancillary services.

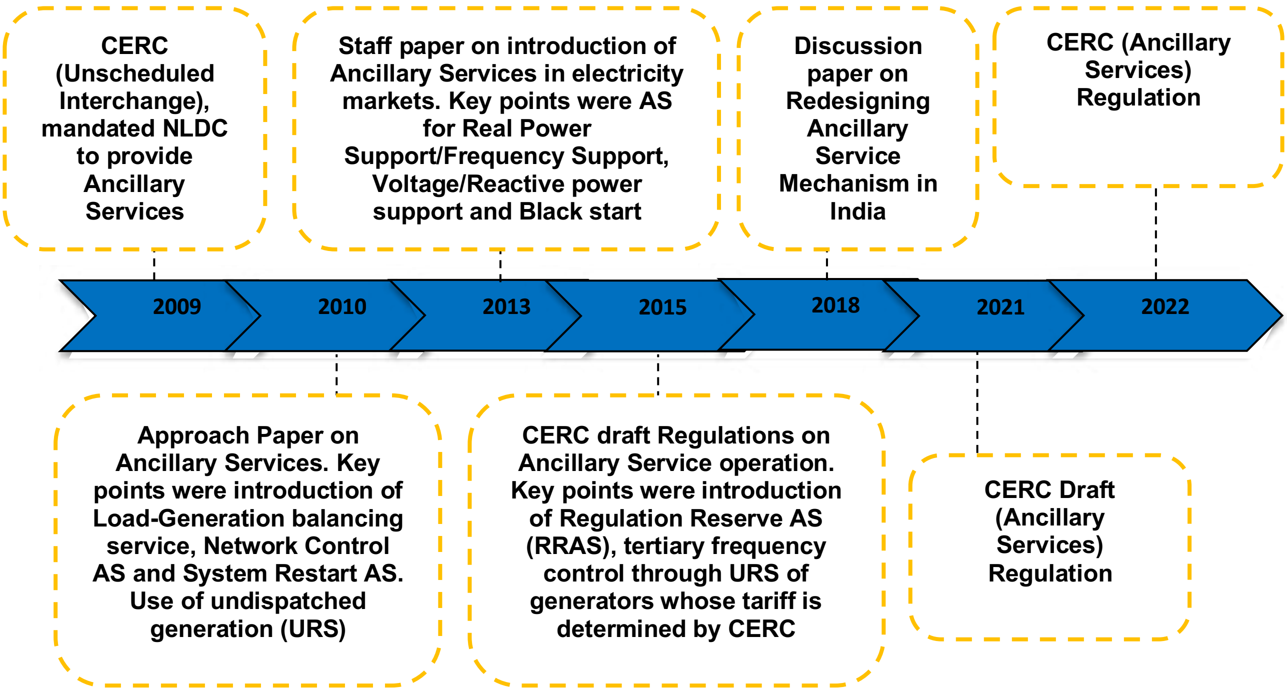

Figure 13: Brief timeline of evolution of Ancillary Services in India

The power grid in India is managed at the national level by the National Load Despatch Centre (NLDC) and at the state level by Regional Load Despatch Centres (RLDCs). The evolution of ancillary service regulation in India is shown in the figure above.

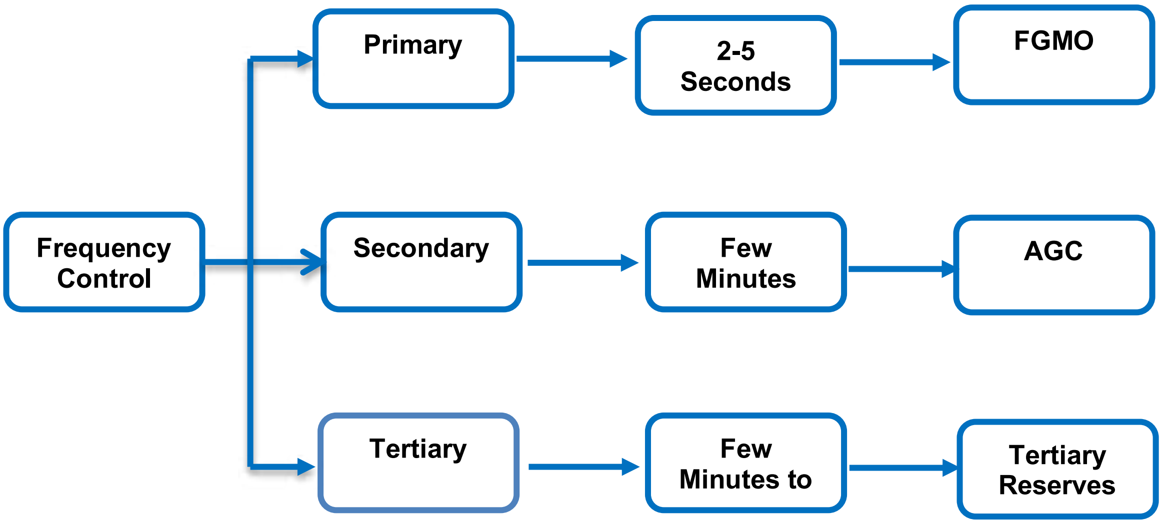

Figure 14: Classification of frequency control and response time in India (Singh and Kumar, 2020)

The market-based frequency control measures introduced in the ancillary service regulation are: (i) the Primary Reserve Ancillary Service (PRAS), which automatically responds within a few seconds and can contain the frequency up to 5 minutes; this is done through free governor mode action (FGMO) of the generator or through any other resource in the event of a sudden change in frequency; (ii) the Secondary Reserve Ancillary Service (SRAS), which is activated by the NLDC, has a response time of 30 seconds and can ramp up to 15 minutes and ensure frequency restoration up to 30 minutes; this is done through Automatic Generation Control (AGC); and (iii) the Tertiary Reserve Ancillary Service (TRAS), which is activated manually by the NLDC and kicks in after 15 minutes and can sustain up to 60 minutes (CERC, 2021, 2022b).

From Balancing Mechanisms to Balancing Markets

In Europe, in the beginning the emphasis was more on the balancing mechanism than the balancing market. Gradually due to national and European legislation, the market evolved and aided the harmonisation of EU electricity markets. As markets evolve it is important to note that the design of balancing mechanisms strongly influences trade in short-term spot markets. For instance, high imbalance prices encourage rebalancing by trading on intraday markets and high reserve requirements between balancing markets and other short-term markets may reduce volumes in the short-term markets. The cost of balancing is influenced by two main factors: (i) the volume of reserves – procuring and sharing capacity reserves across borders through intraday markets, improved imbalance settlement and imbalance netting across borders; and (ii) the price of reserves – improved market pricing and increased participation by the demand side acting as balancing service providers (Schittekatte and Pototschnig, 2022). In India, the nation already operates as 'One Nation, One Grid, One Frequency,' thereby making it more conducive to better grid management at the national level. However, given that the trade volumes are still growing in the short-term markets, with the support of other complementary regulatory interventions such as demand response and storage via ancillary markets the proposed MBED scheme and cross-border trade with neighbouring regions should unlock participation in the short-term markets and also enable a balancing market (see Chapter 1).

Conclusion

An important lesson noted by (Glachant et al., 2021) is that electricity market design around the world shows that the way that market mechanisms are used to dispatch and operate generation units is consistent with how the grid is actually operated. Balancing started as a technical measure to manage grids. However, with the evolving energy mix the approach to balancing is becoming more market-based. This is particularly enabled by digital tools. As the share of RES increases, coordination and competition are important to allow various technologies to offer balancing services to drive down the cost of balancing. However, it is important to ensure consistency across various market products from procurement to balancing. In the case of Europe, along with integrated energy markets balancing markets are also becoming more integrated. In the case of India, market-based balancing services have recently come into play. How they interact with the other markets has yet to be observed.

Chapter 5: Retail Electricity Competition

Competition in retail electricity markets started in the 1990s and is just three decades old. Globally, electricity retail markets emerged as a consequence of trade liberalisation and deregulation – particularly unbundling the previously vertically integrated electricity sector segments of state-owned utility providers into separate entities. Commercial and large industrial consumers were the first beneficiaries of competition in the retail sector. However, small residential consumers saw limited competition as few countries allowed competition, whereas some countries continue to follow regulated tariff regimes. The UK was the first European country to introduce electricity reforms. It was followed by the Nordic countries, Australia, New Zealand and a few other European Countries. Texas was the first US state to introduce competition in the retail sector. Later, 12 other US States and Washington DC allowed competition in the retail sector. However, these 12 states also ensured that incumbent network utilities must provide default supply tariffs. Six other US states initiated retail competition only for large industrial customers. The remaining 30 states in the US either did not implement or rolled back retail competition for residential customers (Littlechild, 2021).

The major rationales for societal benefits from retail electricity competition as discussed by (Littlechild, 2000) are as follows.

- Reducing market imperfections. The entrance of new players in the retail market helps decrease costs at different stages in the electricity supply chain. New entrants are expected to reveal the true costs of commercialisation of electricity rather than the previous arrangement of presenting a single block aggregating the cost of generation and transmission together with electricity supply. Furthermore, they were expected to reduce market imperfections by supplying electricity in territories where incumbent utility providers made extraordinary profits. Consumer engagement in selecting their electricity providers from the pool of providers increases the competition. Due to increased competition, retail suppliers reduce costs and increase efficiency in all the supply chain stages (NAO, 2008).
- New products and services to meet consumers' needs. Consumers' preferences drive retail suppliers to provide different retail service products, hedging products for risk management and other opportunities for tailored services according to their requirements.
- Informed choice among consumers against incumbent offers. Through promotion and advertisements, retail suppliers alert consumers about the potential advantages and prices of their alternative offers. Based on this information, consumers may evaluate their current offers from their incumbent suppliers and select offers that best suit them based on their informed choices, past experiences and evaluation.

In short, introducing competition in retail electricity supply improves products according to consumers' choices, decreases prices, encourages innovation, reduces the barriers to entry and increases competition in generation. Therefore, competition in retail electricity supply has a ripple effect beyond decreasing consumer tariffs and results in an overall improvement of the electricity sector.

Retail Competition in the EU

The deregulation of retail electricity started in the UK in 1990. After that, Nordic countries (Denmark, Finland, Norway and Sweden) were the first to open retail competition between 1995 and 1998 (Littlechild, 2000). Since the Nordic countries had light regulation and no price controls on retail electricity, high consumer switching rates were observed in these countries (Littlechild, 2021). Later, the 1996 Electricity Directive 96/92/EC persuaded the EU member countries to form a single European electricity market and open their retail electricity sectors for large users and distribution companies by 2003. After that, the 2003 EC Directive 2003/54/EC required EU member countries to allow their non-residential consumers and residential consumers to be free to select their retail suppliers by 2004 and 2007 respectively.

However, opening up the retail sector to competition had varied results in the EU countries. The consumer electricity provider switching rate reflects competition in retail electricity. It was observed to be as high as 21 per cent in Norway and Belgium but just one per cent in Hungary and Poland (ACER and CEER, 2021). This shows a lack of consumer engagement in the retail sector. Other reasons for low switching rates are regulated prices set by national regulators below cost levels and additional costs for consumers when they select new retail electricity providers. In contrast, inactive consumers have continued with their existing retail electricity suppliers at a higher cost (ACER and CEER, 2021; Littlechild, 2021). Furthermore, it has been observed that incumbent electricity suppliers occupy the main share of the retail market. Many critics began to question the benefits of competition because no price differentials in the products offered by retail suppliers represent a lack of competition. Moreover, these retail suppliers were not interested in serving vulnerable consumers. Therefore, regulators had to intervene by reintroducing price caps and regulating tariffs that the retail suppliers could offer consumers (Littlechild, 2021).

Dynamic Tariffs in the EU

A dynamic tariff is defined as the "*charging of different electricity rates at different times of the day and year to reflect the time-varying cost of supplying electricity"* (Faruqui and Palmer, 2011). Dynamic tariffs are based on real time, i.e. on the actual system conditions (Bhagwat and Hadush, 2020; IRENA, 2019a). The main kinds of dynamic tariffs are as follows.

- <u>Static Time of Use (ToU) tariff</u>. This usually applies to use of electricity for large time blocks of several hours, with the price for every time block specified in advance and remaining constant. Static ToU may use other time blocks, such as simple day and night pricing for off-peak and on-peak hours, or time blocks can be split into further smaller segments or according to seasonal consumption patterns (IRENA, 2019b).
- <u>Real Time Pricing</u>. Prices are set according to real time electricity consumption and are determined according to wholesale electricity prices.
- <u>Critical Peak Pricing</u>. Higher prices are charged during the day or on days when wholesale electricity prices are highest or the grid is unusually constrained.
- <u>Peak Time Rebates</u>. Consumers get a discount for reducing the load during peak times.

Dynamic tariffs is an emerging topic of interest in the retail electricity sector. Dynamic tariffs help retail suppliers differentiate between their products. Furthermore, dynamic tariffs as part of demand response were initially used to manage large controllable loads by incurring relatively low costs at each control point (Guo and Weeks, 2022; Roos and Lane, 1998). The increasing penetration of RE brings system stability and flexibility concerns due to its intermittent nature. Dynamic tariffs can play a crucial role in this regard by providing consumers with financial incentives as part of demand response to either reduce or shift the peak load to off-peak periods (Guo and Weeks, 2022). Also, dynamic tariffs are helpful for retailers as they can pass on their related risk to consumers as retail prices are aligned with spot market prices. However, most households in the EU are risk-averse and do not wish to take a chance with volatile electricity prices (Chamaret et al., 2020; Shirani et al., 2020). As a result, retailers stick to flat tariffs priced at a fixed rate for every kilowatt-hour of the consumer's electricity (Shirani et al., 2020).

Retail Competition in India

Enactment of the Electricity Act in 2003 opened the scope for introducing competition in the retail electricity sector in India, in two main ways. First, large commercial and industrial (C&I) consumers connected to the grid are allowed open access to electricity directly from the generation companies (gencos) of their choice after paying a Cross Subsidy Surcharge (CSS) and wheeling charges to the local DISCOM. Second, paralleled distribution licences are allowed, i.e. multiple DISCOMs are permitted to operate in the same area after obtaining a licence from the government. The third measure in the pipeline to further increase competition is unbundling content and carriage business from currently operating DISCOM in India (Singh, 2016). However, introducing competition in the retail sector has the following challenges in its implementation (Kumar and Chatterjee, 2012; SCE, 2015).

- Open access. India's initiative to allow open access for large C&I consumers has had limited success because State Load Dispatch Centers (SLDCs) has turned down most open access applications and imposed high CSS along with an additional surcharge to recover the fixed cost. The SLDCs had turned down most open access applications based on concerns and directives raised by the state governments and local DISCOMs. State governments have issued directives under Section 11 of the Electricity Act 2003 to restrict the import and export of power during power shortages (Singh, 2016). In addition to the state government's concerns, DISCOMs also have the following issues regarding granting open access to C&I consumers. First, electricity earmarked by the gencos and DISCOMs in PPAs has been found by DISCOMs to be exported through open access. Second, DISCOMs have been losing high-paying C&I consumers which subsidise low-paying consumers in the residential and agricultural categories. As a result, DISCOMs have been allowed to levy high CSSs on these migrating C&I consumers. Third, DISCOMs have not been able to recover the fixed charges due to the migration of C&I consumers to alternative suppliers. As a result, incumbent DISCOMs have been allowed to impose additional surcharges under Section 42 of the Electricity Act 2003. However, the imposition of high CSSs and additional surcharges makes the migration of C&I consumers non-viable as these consumers ultimately pay higher tariffs for open access (Singh, 2016).

- Parallel distribution licences. Parallel distribution licences are operational in a few areas in India, e.g. Mumbai and Adityapur in Jharkhand (Agrawal and Ghosh, 2021). However, implementation of a parallel licence, particularly in Mumbai, is marred by litigation between competing electricity suppliers, planning failures by the state government, inefficient regulation and excessive customer tariffs (Chitnis and Vaishnava, 2017). Consumers have moved back to their previous electricity suppliers when their existing tariffs have been increased. DISCOMs operating in Mumbai area have purchased electricity from their related gencos. These expensive power purchase costs have been passed to the consumers without adequate regulatory scrutiny (Singh, 2016).

- Unbundling of content and carriage. Currently, DISCOMs have not yet been fully unbundled into distribution and retail suppliers. DISCOMs in India are responsible for maintaining their cabling structures and supplying electricity to their customers. With an amendment to the Electricity Act 2003, India plans to further separate the cabling business from the supply of electricity to increase competition in the retail sector. However, the proposed amendment has been heavily criticised by various stakeholders. First, retail suppliers will choose large consumers rather than smaller ones, whereas lastresort providers will only have low-end consumers. Second, separating cabling from carriage will add to the cost of service as upgraded meters will be needed for metering. Third, accountability for poor-quality service is not demarcated between DISCOMs and retail suppliers. Last, obtaining a new electricity connection will become more cumbersome for new consumers as they have to contact both a DISCOM and a retail supply company (Singh, 2016).

Dynamic Tariffs in India

In India, ToU is known as Time of Day (ToD) tariffs. They are part of demand side management to incentivise consumers to shift a portion of their load from peak to non-peak hours. ToD tariffs apply to commercial and large industrial consumers in India. To a certain extent implementing dynamic tariffs has resulted in favourable outcomes for the overall power system in India. Furthermore, ToU tariffs have significantly reduced power purchase costs by lowering power consumption during peak hours. DISCOMs can increase their revenue by charging ToD tariffs during peak hours. As a result, power consumption during peak time has been reduced, whereas consumption has increased during non-peak hours. Last, ToD tariffs have helped better optimise the financial resources required for grid management and resolving congestion (PwC, 2010).

Future Products in the Retail Sector

The EU and India have seen two waves of reforms in their electricity sectors. The first wave consisted of structural reforms carried out by unbundling the state-owned electricity boards/companies and introducing competition in the retail electricity sector. The second wave ensured decarbonisation of the electricity sector through growth in RE not only at the generation level but also at the distribution level (e.g. solar rooftops). However, RE-based DER growth has already ushered in a third wave of reforms in the EU which is reflected in CEP, announced in 2019 (Nouicer et al., 2020). The EU is expected to reach 32 GW of residential solar PV capacity by 2030 (GfK Belgium Consortium, 2017). CEP explicitly identifies rights and responsibilities of the new entities formed due to the upsurge in DERs, i.e. prosumers, aggregators and energy communities (Nouicer et al., 2020).

Furthermore, the third wave of reforms by means of digital and other technological advances such as smart meters, DERs, EVs and storage will introduce new products and services according to consumers' needs (Glachant and Rossetto, 2018). Additionally, the rise in digital technologies will help energy services to move from traditional kWh at a prescribed price to customers buying energy as a service and service providers deciding the mode of delivery according to customer preferences, e.g. transport according to the number of kilometres travelled or maintaining room temperature at a particular level (IRENA, 2020; Rossetto and Reif, 2021). The emergence of data-driven technology will change the homogeneous nature of the products offered to consumers by retail electricity suppliers. Consumers can demand electricity according to their preferences based on multiple factors such as the cheapest offer, environmentally friendly energy and higher demand for EVs and batteries, etc. (Rossetto and Reif, 2021). Therefore, consumers will be able to make more informed choices among the pool of products offered by retail suppliers in the future.

Conclusion

Competition in retail electricity has had mixed results in the EU and India. Among EU member countries, competition in retail electricity has had limited success. This is reflected in the high consumer switching rate. Nevertheless, it has also been observed that fewer consumers switch to new retail electricity supply providers and the market is dominated by the incumbent retail electricity suppliers in a few EU countries. Competition in the Indian retail electricity sector is still in the preliminary stage. This is due to multiple hindrances in state governments and DISCOMs granting open access to C&I consumers. India has taken other steps to introduce competition in the retail sector by granting parallel licence operations to multiple DISCOMs in the same area. However, the implementation of parallel licences has failed because of tedious litigation between the competing DISCOMs, poor planning by state governments, inadequate regulation and costly PPAs between DISCOMs and their parent companies. As a result, despite the expectation of reduced tariffs due to the introduction of competition in the retail sector retail tariffs have increased.

Moreover, the new product offer of dynamic tariffs has had a limited impact due to the unwillingness of consumers to run the associated risk. Despite the above criticisms, it is necessary to experiment with introducing competition in the retail sector as it may benefit the sector. The growth of new technologies and digitalisation will create new entities such as prosumers, aggregators and energy communities. These entities will introduce new kinds of services in the retail sector.

Chapter 6: Electricity Trade Beyond Borders

Currently, RE technologies and services are transforming the electricity sector, creating a need for adaptable interconnected transmission lines between countries (Rossetto, 2017). The EU and India are diversifying their energy mixes by including more RE than traditional fossil fuel as energy sources. Cross-border trade through interconnected transmission lines between countries has the potential to harness distant RE resources. As a result, the various problems associated with RESs, such as their intermittent nature and variability in load and generation, etc., can be overcome (Bahar and Sauvage, 2013). Cross-border trade also helps make electricity more accessible and affordable, together with better reliability and supply. Moreover, cross-border trade will encourage competition by creating a large interconnected liquid market in the electricity sector (Meeus and Reif, 2020). This will allow gencos to compete across borders and lower supply costs for final consumers. Other spill-over benefits of inter-connected cross-border trade include promoting peace between trading countries and regional economic growth through local industry and job creation (Fischhendler et al., 2016).

Cross-border trade in electricity requires cooperation between various governmental and administrative bodies in a minimum of two neighbouring countries interconnected by transmission lines and cross-border interconnectors. This cooperation between neighbouring countries can be realised through intergovernmental meetings at the various ministerial, diplomatic and official levels. Additionally, the involvement of private industrial players such as private gencos, grid operators and DISCOMs will further boost cross-border trade. Apart from the physical dimension of electricity, the electricity marketplace, such as power exchanges, also fosters cross-border trade (Puka and Szulecki, 2014). Furthermore, the Global Commission on the Geopolitics (GCG) of Energy Transformation has pointed out that regional cooperation on RE and electricity will be as important as international trade in gas and oil in developing the energy system in the future. The GCG has stated that "*electricity trading tends to be more reciprocal" whereas "oil and gas flow in one direction, from an exporter to an importer*" (IRENA, 2019b).

Cross Border Trade in the EU

Cross Border Trade in electricity is a vital component of the common internal electricity market in the EU. The formation of an EU internal electricity market started with liberalisation of the electricity sector in the EU member countries three decades ago. EU legislative energy packages consisting of EU directives related to common rules for the internal market in electricity (Directives 96/92/EC, 2003/54/EC, 2009/72/EC and 2019/944) provided the groundwork for the establishment of the common internal electricity market (Meeus and Reif, 2020). Later, harmonising laws, rules and regulations led to the constitution of new institutions and organisations. The primary role of these new institutions and organisations was to regulate and facilitate cooperation among EU member countries, National Regulatory Agencies (NRAs), TSOs and DSOs on cross-border trade in electricity. The Agency for the Cooperation of Energy Regulators (ACER) and the European Network of Transmission System Operators for Electricity (ENTSO-E) are the most prominent institutions created in the EU. The roles and responsibilities of ACER include coordinating between the NRAs and facilitating the creation of EU network rules. ENTSO-E is entrusted with coordinating TSOs and DSOs and drafting network codes. These codes are essential as they are required for last-mile harmonisation and developing the common internal electricity market to achieve the EU energy and climate policy objectives (Jevnaker, 2015).

Apart from liberalisation, harmonisation and forming new entities for cross-border governance, market coupling is another key aspect of the integration process for the common internal electricity market. Coupling means that electricity can be exchanged between neighbouring countries, flowing from a cheaper to a more expensive one, ideally, until they are matched and price convergence is reached (Saez et al., 2019). The EU has enabled cross-border trade in all its member countries by improving procedures related to market coupling. Initially, cross-border trade (OTC or by power exchange) and transmission rights for electricity were dealt with in two distinct markets through an explicit auction (Meeus, 2011). However, implicit auctioning in a common internal electricity market has ensured that cross-border trade in electricity is more efficient by combining these two distinct markets, which is an important step towards a common integrated electricity market. Implicit auctioning with market coupling aims to streamline the cross-border trading of electricity and simultaneously grant cross-border transmission capacity in a single transaction through power exchanges. Furthermore, power exchanges make use of algorithms and the available transmission capacities (ATCs) of interconnectors as declared by the TSOs or flow-based coupling for better optimisation of capacity allocation for cross-border trade between coupled jurisdictions (Gomez et al., 2019).

The first market coupling started with a trilateral trade project for the day-ahead markets in three power exchanges (APX, Belpex, and Powernext) and three TSOs (Tennet, Elia and RTE) to increase market liquidity and adequately allot cross-border capacities in 2006 (Meeus and Schittekatte, 2020). Afterwards, volume coupling based only on electricity flows was carried out between Nord Pool (East Denmark) and EEX (Germany) in 2008. In volume coupling, the electricity market is coupled by "*linking the quantities offered and demanded in the two exchanges while keeping the price formation in these two markets separated*" (Glachant, 2010). The power exchanges used centralised calculation of cross-border electricity flows based on the available transmission capacities (ATCs) of interconnectors as declared by the TSOs according to their order books to carry out volume coupling.

Afterwards, price coupling was the next step in integrating EU day-ahead markets. This started in 2010. In price coupling, prices and flows are simultaneously determined in a single transaction by the countries participating. EU power exchanges and TSOs have developed procedures for price coupling which entail the following three steps. First, transmission capacity is calculated at the national level. Second, prices and electricity flows are decided based on exports, imports and available national flows. Third, local power exchanges execute the cross-border trade based on the volume of exports and imports and the price at which the trade has to be cleared (Schönheit et al., 2021). Currently, cross-border trade in the EU electricity market is carried out either by multi-regional coupling (MRC) with 47 bidding zone borders or by 4M market coupling (4MMC) with three bidding zone borders (ENTSO-E, 2021). MRC involves 19 EU countries and 85 per cent of EU power consumption (EPEX Spot, 2022). Both the 4MMC and MRC areas use the ATC approach to cross-border allocation (Meeus and Schittekatte, 2020).

Furthermore, central western Europe (CWE) started flow-based market coupling (FBMC) in 2015 (Meeus and Schittekatte, 2020). FBMC applies to CWE participating EU countries, including Austria, Belgium, France, Germany and the Netherlands (Bergh et al., 2016). In a departure from the price coupling approach, FBMC uses market-clearing and allocates transmission capacities simultaneously instead of deciding on the basis of ATC for capacity allocation before market clearing. FBMC further refined cross-border trade with better capacity allocation and integration of market activity. XBID, also known as cross-border intra-day, was launched for 15 EU member countries in 2018. Later, participants from eight more EU countries started to bid for XBID (ENTSO-E, 2021; Gomez et al., 2019). XBID allows all bidders in the participating countries to integrate in a single cross-border intra-day trade, provided the available cross-border transmission capacity is adequate to transport electricity (Meeus and Schittekatte, 2020).

Cross-Border Trade Infrastructure in the EU

Transmission lines are the only economically viable way to transport electricity (Meeus and Schittekatte, 2020). Therefore, establishing a regional transmission grid across borders is necessary for the functioning of the EU internal electricity market. In the EU, ENTSO-E overviews coordination and facilitates the development of the trans-national electricity grid. EC Regulation No. 714/2009 entrusted ENTSO-E with the development of a Ten Year Network Development Plan (TYNDP) on a two-year basis to provide a roadmap for the transnational EU high voltage transmission network to meet the EU energy goals, i.e. affordable, secure and sustainable energy for EU citizens (Scheibe, 2018). The TYNDP assesses the transmission and storage capacity of projects based on cost-benefit analysis and multi-criteria analysis authorised by ACER and the EC. Moreover, ENTSO-E has developed guidelines for the cost-benefit analysis and market, network and other interlinked methodologies for assessing grid development projects. The common internal electricity market further requires extension of the capacities of interconnectors to carry out cross-border trade in electricity (Puka and Szulecki, 2014).

Last, the EU has promulgated a Trans-European Networks for Energy (TEN-E) policy that focuses on interlinking the energy infrastructure among the EU member countries. TEN-E prioritises projects of great importance due to their non-economic benefits. However, these projects are not commercially viable. Therefore, they require public support. The aims of these projects include interconnecting isolated areas, buttressing cross-border interconnections and infusing more RE power in the electrical system. Nine priority corridors and three thematic regions are currently identified for development under the TEN-E policy (Meeus and Schittekatte, 2020).

Cross Border Trade in India

Regional cooperation on cross-border trade in electricity in the south Asia region (SAR) presents similar benefits to those in the EU. Cross-border trade will promote domestic investment, cost-effective expansion of RE resources and better reliability and supply availability. Cross-border trade in electricity benefits from time zone differences in electricity demand with seasonal variability patterns of supply and demand along with the various natural resources required to generate electricity across the SAR. For example, Nepal and Bhutan produce surplus hydropower during the monsoon season but this dwindles during the winter. The difference between surplus and insufficient electricity generation can be economically harnessed through cross-border trade in the SAR (IRENA, 2019b). It has been estimated that the potential gain from expanding regional electricity trade in the SAR is 9 billion rupees a year (Singh et al., 2018).

India is a member of two major regional intergovernmental organisations which envision promoting, inter alia, peace, national security and cross-border trade in the SAR. First, the South Asian Association for Regional Cooperation (SAARC) was formed in 1985. Its member countries are Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka. Afterwards in May 1999, the World Bank facilitated the formation of the South Asia Forum for Infrastructure Regulation (SAFIR), comprising infrastructure regulators, including electricity, in the aforementioned countries. The primary functions of the SAFIR include providing a platform for experience-sharing among regulators in the SAR, facilitating the regulatory process, running training programmes for SAR regulators and other stakeholders, research on regulatory issues and building a databank of regulatory reforms and processes (IRADE, 2016; SAFIR, 2010).

Later, in 2004 SAR countries signed a South Asian Free Trade Area (SAFTA) agreement with a vision of transiting towards a common market. Afterwards, they mutually agreed on regional energy cooperation. Additionally, the South Asia Regional Energy Coalition (SAREC) was constituted to coordinate between the various governments and private players to develop the energy sector across the SAR. Furthermore, in 2006 the SAARC Energy Centre (SEC) was established as a Special Purpose Vehicle (SPV) in Islamabad, Pakistan, to increase regional South Asia cooperation in the energy sector. Last, in 2014 the SAARC member countries signed a framework agreement to explore the potential of regional cooperation in the electricity market. Currently, Bangladesh, Bhutan, India, and Nepal are interconnected, but essential market elements like scheduling and dispatch, deviation handling, etc. have not been established by their respective power grid operators (Singh et al., 2018).

The second intergovernmental organisation is the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC), which was constituted in 1997. The BIMSTEC member countries are Bangladesh, Bhutan, India, Myanmar, Nepal, Sri Lanka and Thailand. Initially, a ministerial conference on energy was organised to promote cross-border trade in electricity among the BIMSTEC member countries and in New Delhi, India, in 2005 a plan of action on BIMSTEC grid interconnection was formulated. This action plan included the construction of new hydro projects, the interconnection of power grids, and the development of RE projects (Chaudhury, 2020). However, most cross-border trade in the BIMSTEC region has evolved due to bilateral agreements between India and Bangladesh, Bhutan and Nepal. The Indian Energy Exchange (IEX) launched a day-ahead market product called Cross-Border Electricity Trade (CBET) for Nepal on 17 April 2021. Furthermore, it is envisaged that participants from Bangladesh, Bhutan and other SAR countries will be able to bid in day-ahead and term-ahead markets at the IEX as part of the integration of the SAR electricity market (EPEX Spot, 2022). India and other member countries of the International Solar Alliance (ISA) have conceptualised '*One Sun, One World, One Grid*' as part of the interconnected solar energy infrastructure on an international scale (ISA, 2021). Cross-border trade will help achieve this aim. The timeline of policy development in cross-border trade in India is shown in Figure below.

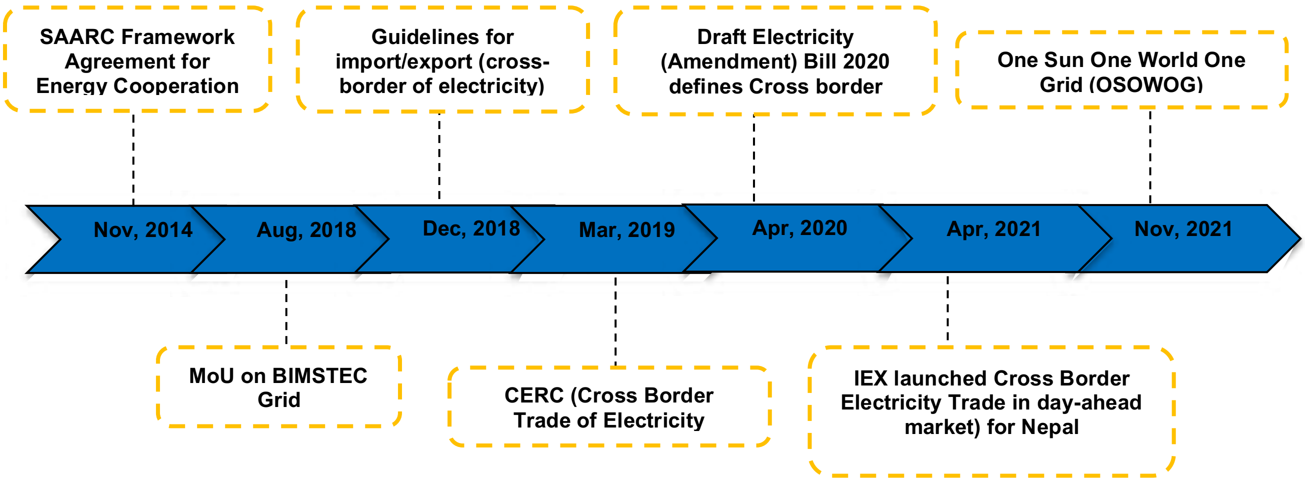

Figure 15: Timeline of Cross-border trade policy development in India

Cross Border Trade Infrastructure in India

India exports electricity to Bangladesh, Myanmar and Nepal and imports electricity from Bhutan. It also sells electricity to Bhutan during the scant hydro season (See Table1). Furthermore, India issued guidelines on the 'Cross-Border Trade of Electricity' in December 2016. These were replaced with the 'Guidelines for Import/Export (Cross Border) of Electricity' in December 2018. Additionally, the Central Electricity Regulatory Commission (CERC) issued CBTE (Cross Border Trade of Electricity) Regulations in March 2019. Moreover, India is planning to develop the following interconnections with its neighbouring countries. They are in different stages of implementation (PIB, 2020):

- Operation of Muzaffarpur (India)-Dhalkebar (Nepal) 400kV DC line (operated at 220kV)
- Baharampur (India)-Bheramara (Bangladesh) 2nd 400kV DC line
- Alipurduar (India)-Jigmeling (Bhutan) 400kV DC (Quad) line
- Gorakhpur (India)-New Butwal (Nepal) 400kV DC (Quad) line
- Sitamarhi (India)-Dhalkebar (Nepal)-Arun-3 HEP (Nepal) 400kV DC (Quad) line.

Table 1: Net Energy Exchange between India and Bhutan, Nepal, Bangladesh and Myanmar (in GWh) (POSOCO, 2022)

	Import	Export		
FY Year	**Bhutan**	**Nepal**	**Bangladesh**	**Myanmar**
2017-18	211.44	223.06	418.06	0.4
2018-19	92.9	290.83	284.97	0.46
2019-20	251.97	245.98	653.05	0.55
2020-21	260.07	61.15	408.56	0.72
2021-22	155.42	486.38	669.24	0.6
Total	**971.8**	**1307.4**	**2433.88**	**2.73**

Furthermore, India has already arranged regional power system integration with Bangladesh, Bhutan and Nepal through high voltage synchronous (alternating current) and high voltage asynchronous (direct current) connections. Last, India has deployed the latest technologies, including a Static Synchronous Compensator (STATCOM), Voltage Source Converter-based High Voltage Direct Current (HVDC) system, etc., in the Indian grid to facilitate cross-border trade with its neighbouring countries (PIB, 2020).

Barriers against Cross-Border Trade in Electricity for India

India faces significant challenges in initiating cross-border electricity trade for multiple reasons. First, an inter-regional institution to address issues related to cross-border trade in electricity with neighbouring countries is absent in the SAR. Although SAFIR has been constituted for the SAR, it has failed to yield any result in harmonising the rules and regulations related to cross-border trade in electricity across the SAR. The SAR needs institutions like ACER which can facilitate cooperation between important stakeholders such as NRAs, government bodies, gencos, power grid operators and DISCOMs. Second, the SAR does not have enough power exchanges in which bidders in the region can participate in inter-day and intra-day products. Furthermore, cross-border trade products are still evolving and are only available in India for Nepal. Third, more coordination and planning are required at the government-to-government level to build a cross-border transmission network. The countries in the SAR have to increase their investment in interconnectors and transnational grid lines, which is currently inadequate for the growth of cross-border trade compared to the EU common internal electricity market. Fourth, power systems across the SAR lack uniform operating codes and protocols for cross-border system operation to maintain grid integrity. This is primarily due to the lack of a uniform grid code as no institution similar to ENTSO-E has been constituted and mandated to oversee the harmonisation of codes. Last, pending sectoral reforms in the SAR constrain cross-border trade in electricity. These pending sectoral reforms include non-uniform unbundling of utilities, a lack of cost-reflective electricity pricing, weak financial performance of DISCOMs, a shortage of generation capacity and limited involvement of the private sector, which impedes cross-border trade in electricity (Singh et al., 2018).

Conclusion

Cross-border trade in electricity has multiple benefits, including increased reliability, accessibility, affordability, liquidity and competition in the electricity sector. The rise in intermittent and variable RE as a source of electricity requires an increase in cross-border trade for better optimisation across borders. Furthermore, cross-border electricity trade is impossible without regional cooperation and the participation of government and other important stakeholders in neighbouring countries. Constitution of new institutions such as ACER and ENTSO-E is required to facilitate the harmonisation of rules and regulations on cross-border trade. Additionally, power exchanges are required to provide platforms and products for cross-border trade. Last, infrastructure like interconnectors and a transnational transmission network is a must for carrying out cross-border trade.

The EU has already made leaps and bounds toward cross-border trade through market coupling and creating a common internal electricity market and market coupling. India also has taken steps toward cross-border trade in electricity through bilateral agreements with Bangladesh, Bhutan, Myanmar and Nepal. However, cross-border trade in electricity encompassing several countries in the SAR has yet to progress for various reason. These reasons include inadequate inter-regional institutions, marketing platforms and transnational network planning, and non-uniform sectoral reforms. Therefore, cross-border trade in the SAR requires cooperation at the government-to-government level along with other incremental measures such as the constitution of a new institution for governance, market platforms and additional investments in transnational infrastructure to increase cross-border trade in the SAR.

Conclusion

This report has presented a menu of regulatory options which will enable faster integration of renewables in the power system. We would recommend the full menu, but the choice is at the discretion of each country.

In a power system with a high amount of renewables, the value of electricity changes geographically, and by the hour. Market mechanisms are generally important to coordinate supply and demand in a system. An increased role of power exchanges and their various innovative product offerings will not only improve the uptake of RES in electricity systems but also help them operate efficiently. Keeping physical constraints like bottlenecks in the network in check, the scope of benefits is maximised when trade occurs across geographies.

DERs coupled with digitalisation can enable an increased integration of renewables, on a small scale at the local level and across vectors. They will be crucial in not only enabling access to energy in remote habitats but will also participate as active players in the electricity markets. Suitable rules and regulations need to be enforced to induce investors to explore the potential of DERs and enable DERs to play a responsible role in the system.

In the past renewables were not cost-competitive and therefore needed support to enable market entry. However now that we have significant cost-competitive renewables in the system, support mechanisms should adapt towards integrating these renewables. Keeping in mind the particularities of renewable energy technologies, new rules are needed for both networks and markets according to the level of maturity of renewable technologies.

The role of balancing is gaining more relevance due to the intermittency of renewables in the system; Therefore, we must ensure it is procured in an efficient manner. A well-designed market can provide the right incentives to offer balancing services, while ensuring consistency across the various market products. Balancing markets should be open, technology-neutral, unbiased and attract innovators to define new, beneficial ways to deliver these services. This is still at a nascent stage.

Introducing competition in the retail electricity market allows for new product offerings for the end consumer e.g. a service provider retailing only renewables etc. Retail competition has proven to be more beneficial for large commercial and industrial consumers and the benefits for small-scale consumers remain unclear. However, retail competition is likely to play an important role in maximising gains from a system with more renewables.

As renewable sources are not evenly distributed, trade across borders will help tap these resources in a given region. However, cross-border trade does not come easy as it requires a harmonised set of rules and regulations on the market, networks, operations and emergencies. This will require strong regional governance, coordination and political commitment. In Europe cross-border trade has benefited from the political framework of the European Union and its aim to set up an integrated electricity market. However, in the south Asian region, the challenge is more pronounced as the region does not have a common political framework binding the countries and therefore it is an uphill task, but one that holds good potential.

References

ACER, CEER, 2021. Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2020: European Union Agency for the Cooperation of Energy Regulators (ACER) & Council of European Energy Regulators (CEER).

Ackermann, T., Andersson, G., Söder, L., 2001. Distributed generation: a definition. Electr. Power Syst. Res. 57, 195–204. https://doi.org/10.1016/S0378-7796(01)00101-8

Aggarwal, M., Dutt, A., 2018. State of the Indian Renewable Energy Sector: Drivers, Risks, and Opportunities. Council on Energy, Environment and Water.

Agrawal, A., 2022. Real Time Market (RTM) at Indian power exchanges: Need, short term assessment and opportunities. Energy Policy 162. https://doi.org/10.1016/j.enpol.2022.112810

Agrawal, S., Ghosh, A., 2021. Making competition drive a consumer-centric power system. FinancialExpress.

Bahar, H., Sauvage, J., 2013. Cross-Border Trade in Electricity and the Development of Renewables-Based Electric Power: Lessons from Europe. OECD.

Bhagwat, P., Hadush, S., 2020. Dynamic Retail Electricity Tariffs: Choices and Barriers.

Bhushan, C., Bhati, Sreenivasan, P., Singh, M., Jhawar, P., Koshy, S.M., Sambyal, S., 2019. State of Renewable Energy in India 2019. Center for Science and Environment.

Bichpuriya, Y., Soman, S., 2010. Electric power exchanges: A review. 16th Natl. Power Syst. Conf. 115–120.

Bojnec, Š., Križaj, A., 2021. Electricity Markets during the Liberalization: The Case of a European Union Country. Energies 14, 4317. https://doi.org/10.3390/en14144317

Braun, M., Strauss, P., 2008. A Review on Aggregation Approaches of Controllable Distributed Energy Units in Electrical Power Systems. Fraunhofer IWES 4, 297–319.

CEEW, 2020. State of Electricity Access in India: Insights from the India Residential Energy Survey. Council on Energy, Environment and Water.

CERC, 2022a. Guidelines for Registration and Filing Application for Establishing and Operating Over the Counter (OTC) Platform.

CERC, 2022b. Central Electricity Regulatory Commission (Ancillary Services) Regulations, 2022.

CERC, 2021. Draft Central Electricity Regulatory Commission (Ancillary Services) Regulations, 2021.

CERC, 2018a. Discussion Paper on Re-designing Real Time Electricity Markets in India (No. RA-14026(11)/2/2018-CERC). Central Electricity Regulation Commission.

CERC, 2018b. Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) (Fourth Amendment) Regulations, 2018 (No. L-1/132/2013-CERC). Central Electricity Regulation Commission.

Chamaret, C., Steyer, V., Mayer, J.C., 2020. “Hands off my meter!” when municipalities resist smart meters: Linking arguments and degrees of resistance. Energy Policy 144, 111556. https://doi.org/10.1016/j.enpol.2020.111556

Chand, R., Srivastava, S., Singh, J., 2017. Changing structure of rural economy of India implications for employment and growth.

Chaudhury, A.B.R., 2020. Manifestation of SDG goals and scope for cross-border energy cooperation in BIMSTEC. ORF.

Chitnis, A., Vaishnava, S., 2017. In the Name of Competition: The annals of ‘cost-plus competition’ in the electricity sector in Mumbai.

Damsgaard, N., Helbrink, J., Papaefthymiou, G., Grave, K., Gentili, P., Giordano, V., 2015. Study on the effective integration of Distributed Energy Resources for providing flexibility to the electricity system.

Das, S.D., Srikanth, R., 2020. Viability of power distribution in India - Challenges and Way Forward. Energy Policy 147, 111882. https://doi.org/10.1016/j.enpol.2020.111882

DECC, 2013. Electricity Market Reform – Contract for Difference: Contract and Allocation Overview. Department of Energy and Climate Change.
Deo, P., Chatterjee, S.K., Modak, S., 2021. Renewable Energy in India: Economics and Market Dynamics. SAGE Publications, Incorporated.
EC, 2022. Trans-European Networks for Energy [WWW Document]. URL https://energy.ec.europa.eu/topics/infrastructure/trans-european-networks-energy_en (accessed 7.10.22).
ENTSO-E, 2021. ENTSO-E Market report 2021. European Network of Transmission System Operators for Electricity.
EPEX Spot, 2022. European Market Coupling | EPEX SPOT [WWW Document]. URL https://www.epexspot.com/en/marketcoupling (accessed 7.1.22).
ESMAP, 2020. Tracking SDG 7: The energy progress Report 2020. World Bank, Washington DC.
ESMAP, 2019. Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers. World Bank, Washington DC.
Faruqui, A., Palmer, J., 2011. Dynamic Pricing and Its Discontents. Regulation 34, 16–22.
Fischhendler, I., Herman, L., Anderman, J., 2016. The geopolitics of cross-border electricity grids: The Israeli-Arab case. Energy Policy 98, 533–543. https://doi.org/10.1016/j.enpol.2016.09.012
FSR, 2022. A first look at REPowerEU: The European Commission's plan for energy independence from Russia [WWW Document]. Florence Sch. Regul. URL https://fsr.eui.eu/first-look-at-repowereu-eu-commission-plan-for-energy-independence-from-russia/ (accessed 7.10.22).
GfK Belgium Consortium, 2017. Study on "Residential Prosumers in the European Energy Union." European Commission.
Gielen, D., Boshell, F., Saygin, D., Bazilian, M.D., Wagner, N., Gorini, R., 2019. The role of renewable energy in the global energy transformation - ScienceDirect.
Glachant, J.-M., 2010. The Achievement of the EU Electricity Internal Market through Market Coupling.
Glachant, J.-M., Joskow, P., Pollitt, M., 2021. Handbook on Electricity Markets. Edward Elgar, 2021. https://doi.org/10.4337/9781788979955
Glachant, J.-M., Rossetto, N., 2021. A New World for Electricity Transactions: Peer-to-Peer and Peer-to-X. European University Institute.
Glachant, J.-M., Rossetto, N., 2018. The Digital World Knocks at Electricity's Door: Six Building Blocks to Understand Why.
Golnoush, S., Dos Reis, P.C., Schittekatte, T., Piebalgs, A., Jones, C., Pototschnig, A., Glachant, J.-M., 2022. Review of different national approaches to supporting renewable energy development. EUI.
Gomez, T., Herrero, I., Rodilla, P., Escobar, R., Lanza, S., de la Fuente, I., Llorens, M.L., Junco, P., 2019. European Union Electricity Markets: Current Practice and Future View. IEEE Power Energy Mag. 17, 20–31. https://doi.org/10.1109/MPE.2018.2871739
Grubb, M., Newbery, D., 2018. UK Electricity Market Reform and the Energy Transition: Emerging Lessons. Energy J. 39. https://doi.org/10.5547/01956574.39.6.mgru
Guo, B., Weeks, M., 2022. Dynamic tariffs, demand response, and regulation in retail electricity markets. Energy Econ. 106. https://doi.org/10.1016/j.eneco.2021.105774
IEA, 2021a. World Energy Outlook 2021 – Analysis.
IEA, 2021b. Renewables Integration in India 2021. IEA Paris 93.
IEA, 2019. Key world energy statistics. International Energy Agency.
IEX, 2022. Green Market. Indian Energy Exch. URL https://www.iexindia.com/pdf/GTAM-leaflet.pdf
IEX, 2021. Achieving Renewable Aspirations: The CfD Model. Indian Energy Exch. URL https://www.iexindia.com/pdf/Innovation_March_21.pdf

IRADE, 2016. Prospects for Regional Cooperation on Cross-Border Electricity Trade in South Asia.
IRENA, 2022. Renewable capacity highlights 2022.
IRENA, 2020. Energy as a Service: Innovation Landscape Brief. International Renewable Energy Agency.
IRENA, 2019a. Time-Of-Use Tariffs: Innovation Landscape Brief.
IRENA, 2019b. Time-Of-Use Tariffs: Innovation Landscape Brief (No. 978-92-9260-115–7). International Renewable Energy Agency.
IRENA, 2017. Adapting Market Design to High Shares of Variable Renewable Energy (No. 978-92-9260- 025–9). International Renewable Energy Agency.
ISA, 2021. International Solar Alliance [WWW Document]. Int. Sol. Alliance. URL https://isolaralliance.org/work/osowog/ (accessed 7.1.22).
Jamasb, T., Pollitt, M., 2005. Electricity Market Reform in the European Union: Review of Progress toward Liberalization & Integration. Energy J. 26, 11–41.
Jevnaker, T., 2015. Pushing administrative EU integration: the path towards European network codes for electricity. J. Eur. Public Policy 22, 927–947. https://doi.org/10.1080/13501763.2014.1000363
Karstensen, J., Roy, J., Pal, B., Peters, G., Andrew, R., 2020. Key Drivers of Indian Greenhouse Gas Emissions. Econ. Polit. Wkly. 55, 46–53.
Kumar, A., Chatterjee, S.K., 2012. Electricity Sector in India: Policy and Regulation. Oxford University Press.
Kumar. J, C.R., Majid, M.A., 2020. Renewable energy for sustainable development in India: current status, future prospects, challenges, employment, and investment opportunities. Energy Sustain. Soc. 10, 2. https://doi.org/10.1186/s13705-019-0232-1
Kumar, J., Suryakiran, B.V., Verma, A., Bhatti, T.S., 2019. Analysis of techno-economic viability with demand response strategy of a grid-connected microgrid model for enhanced rural electrification in Uttar Pradesh state, India. Energy 178, 176–185. https://doi.org/10.1016/j.energy.2019.04.105
Littlechild, S., 2021. The evolution of competitive retail electricity markets, in: Handbook on Electricity Markets. Edward Elgar Publishing Limited, Cheltenham, pp. 111–155.
Littlechild, S., 2000. Why We Need Electricity Retailers: A Reply to Joskow on Wholesale Spot Price pass-through.
Meeus, L., 2020. The Evolution of Electricity Markets in Europe. https://doi.org/10.4337/9781789905472
Meeus, L., 2011. Why (and how) to regulate power exchanges in the EU market integration context? Energy Policy 39, 1470–1475. https://doi.org/10.1016/j.enpol.2010.12.019
Meeus, L., Reif, V., 2020. Why did we start with electricity markets in Europe?, in: The Evolution of Electricity Markets in Europe. Edward Elgar Publishing Limited, Cheltenham, pp. 2–15.
Meeus, L., Schittekatte, T., 2020. How to calculate border trade constraints?, in: The Evolution of Electricity Markets in Europe. Edward Elgar Publishing Limited, Cheltenham, pp. 48–59.
Milligan, M., Frew, B.A., Bloom, A., Ela, E., Botterud, A., Townsend, A., Levin, T., 2016. Wholesale electricity market design with increasing levels of renewable generation: Revenue sufficiency and long-term reliability. Electr. J. 29, 26–38. https://doi.org/10.1016/j.tej.2016.02.005
MNRE, 2022. Programme/Scheme wise Cumulative Physical Progress as on May, 2022 [WWW Document]. Minist. New Renew. Energy. URL https://mnre.gov.in/the-ministry/physical-progress (accessed 7.10.22).
MNRE, 2021. Amendment in Benchmark costs for Grid-connected Rooftop Solar PV systems.
NAO, 2008. Protecting consumers? Removing retail price controls. National Audit Office, London.

Nathan, H.S.K., 2014. Solar Energy for Rural Electricity in India. Econ. Polit. Wkly. 49, 60–67.
Nouicer, A., Kehoe, A.M., Nysten, J., Fouquet, D., Hancher, L., Meeus, L., 2020. The EU clean energy package: (2020 ed.). European University Institute, LU.
NREL, 2022. Distributed Energy Resources:A How-To Guide.
Pérez-Arriaga, I.J., Nagpal, D., Jacquot, G., Stoner, R., 2021. Harnessing the power of integration to achieve universal electricity access: the case for the Integrated Distribution Framework, in: Handbook on Electricity Markets. Edward Elgar Publishing Limited, Cheltenham, pp. 540–567.
PIB, 2020. Trade in Electricity [WWW Document]. Press Inf. Bur. URL https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1607177 (accessed 7.1.22).
PIB, 2019. Electrification of Villages [WWW Document]. URL https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1592833 (accessed 7.1.22).
Piebalgs, A., Jones, C., Dos Reis, P.C., Soroush, G., 2020. Cost-effective decarbonisation study. Florence School of Regulation.
Poudineh, R., Mukherjee, M., Elizondo, G., 2021. The Rise of Distributed Energy Resources:A Case Study of India’s Power Market.
Puka, L., Szulecki, K., 2014. The politics and economics of cross-border electricity infrastructure: A framework for analysis. Energy Res. Soc. Sci. 4, 124–134. https://doi.org/10.1016/j.erss.2014.10.003
PwC, 2010. Assignment on Implementation & Impact Analysis of Time of Day (TOD) tariff in India.
Regy, P.V., Sarwal, R., Stranger, C., Fitzgerald, G., Ningthoujam, J., Gupta, A., Singh, N., 2021. Turning Around the Power Distribution Sector: Learnings and Best Practices from Reforms (preprint). Open Science Framework. https://doi.org/10.31219/osf.io/xd2he
Roos, J.G., Lane, I.E., 1998. Industrial power demand response analysis for one-part real-time pricing. IEEE Trans. Power Syst. 13, 159–164. https://doi.org/10.1109/59.651628
Rossetto, N., 2017. Design the Electricity Market(s) of the Future, Florence School of Regulation; Energy; Electricity. Proceedings from the Eurelectric-Florence School of Regulation Conference 7 June 2017.
Rossetto, N., Reif, V., 2021. Digitalization of the electricity infrastructure: a key enabler for the decarbonization and decentralization of the power sector, in: A Modern Guide to the Digitalization of Infrastructure. Edward Elgar Publishing Limited, Cheltenham, pp. 217–265.
Saez, Y., Mochon, A., Corona, L., Isasi, P., 2019. Integration in the European electricity market: A machine learning-based convergence analysis for the Central Western Europe region. Energy Policy 132, 549–566. https://doi.org/10.1016/j.enpol.2019.06.004
SAFIR, 2010. South Asia Forum For Infrastructure Regulation,Country in South Asia - india,pakistan,sri lanka,nepal,bangladeshAbout SAFIR | South Asia Forum For Infrastructure Regulation [WWW Document]. URL https://www.safirasia.org/about-safir (accessed 7.1.22).
SCE, 2015. Standing Committee on Energy,: Electricity (Amendment) Bill, 2014 (No. Fourth Report). Lok Sabha Secretariat, New Delhi.
Scheibe, A., 2018. Utilization of Scenarios in European Electricity Policy: The Ten-Year Network Development Plan.
Schittekatte, T., Pototschnig, A., 2022. Distributed energy resources and electricity balancing : visions for future organisation.

Schönheit, D., Kenis, M., Lorenz, L., Möst, D., Delarue, E., Bruninx, K., 2021. Toward a fundamental understanding of flow-based market coupling for cross-border electricity trading. Adv. Appl. Energy 2, 100027. https://doi.org/10.1016/j.adapen.2021.100027
Shirani, F., Groves, C., Henwood, K., Pidgeon, N., Roberts, E., 2020. 'I'm the smart meter': Perceptions of smart technology amongst vulnerable consumers. Energy Policy 144. https://doi.org/10.1016/j.enpol.2020.111637
Singh, A., Jamasb, T., Nepal, R., Toman, M., 2018. Electricity cooperation in South Asia: Barriers to cross-border trade. Energy Policy 120, 741–748. https://doi.org/10.1016/j.enpol.2017.12.048
Singh, A., Kumar, T.B., 2020. Ancillary Services in the Indian Power Sector – A Look at Recent Developments and Prospects. Elsevier 149. https://doi.org/10.1016/j.enpol.2020.112020
Singh, D., 2016. Competition and Choice in Electricity Distribution in India.
Soonee, S., Baba, K.V. s, Barpanda, S. s, Chakraborty, G., Saxena, S., Singh, G., Dey, K., Pawan Kumar, K.V.N., Kumar, A., Rehman, S., Gaur, K., 2016. Ancillary services in India — Evolution, implementation and benefits. pp. 1–6. https://doi.org/10.1109/NPSC.2016.7858900
TPDDL, 2021. Delhi Power Minister visits South Asia's Largest Battery Energy Storage System [WWW Document]. URL https://tatapower-ddl.com/pr-details/199/1825286/delhi-power-minister-visits-south-asia%E2%80%99s-largest-battery-energy-storage-system;-appreciates-tata-power-ddl-for-innovative-project-in-delhi (accessed 7.10.22).
Verbruggen, A., Laes, E., 2021. Early European experience with tradable green certificates neglected by EU ETS architects. Environ. Sci. Policy 119, 66–71. https://doi.org/10.1016/j.envsci.2021.02.013
World Bank, 2019. Rural population (% of total population) - India | Data [WWW Document]. URL https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=IN (accessed 7.1.22).
WRI, 2021. COP26: Unpacking India's Major New Climate Targets [WWW Document]. WRI INDIA. URL https://wri-india.org/blog/cop26-unpacking-india%E2%80%99s-major-new-climate-targets (accessed 7.10.22).

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