Transformation of the Power Sector and Its Framework in Developing Countries

vRE Discussion Series – Paper # 07

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Technology Cooperation in the Energy Sector

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The GIZ TechCoop vRE Programme

Over the past decade, a '1st wave' of National Subsidy Programmes for variable (i.e. fluctuating) Renewable Energies (vRE) has (i) led to impressive growth in global cumulative installed capacity of wind and PV power and (ii) dramatic RE cost reductions. However, due to their typical 'technology push' focus, most of these **1st wave national vRE programmes have not aimed at achieving an economically optimal pathway for national wind and PV development over time.** Naturally, this has led to suboptimal national RE deployment, resulting in (i) unnecessary losses of Government budget and credibility (subsidy schemes were too expensive or too slow, RE technologies were scaled up too early or applied at the wrong network nodes, lack of planning resulted in avoidable transmission losses or dispatch problems), and/or (ii) excessive private sector profits and/or massive insolvency waves after subsidy-driven vRE bubbles. None of this is intrinsic to vRE technologies or economics: it was simply ill-advised planning.

Increasingly, OECD and non-OECD governments want to move beyond simple vRE technology-push policies, and shift to a new, 2nd wave of optimised national vRE pathways, by applying the same fundamental economic, financial, and political target functions that are used successfully for standard power system planning. To this end, vRE need to be analysed as an integral part of the national energy system and its growth in time and space, by applying methods which readily fit the toolkit already used by dispatchers, regulators, and utilities.

vRE integration has advanced in numerous power sectors and these have experienced a steep learning curve with respect to changes in system operations and expansion, business models and planning, policies and institutions, and further transformation will require more innovative approaches. At the same time, some global trends such as rapid innovation deployment, policy, and finance are and will be changing the power sector profoundly and in every aspect, all over the world. This requires advanced adjustment, in some cases even a disruptive change in respective planning, policy, business models, and institutional framework. **Institutional response, however, is discussed so far mostly for industrialised countries, but indeed only for very few emerging economies. Therefore, the GIZ Technology Cooperation vRE Programme is compiling solutions and transmitting them to developing countries, which face the challenge of change sooner or later.**

The GIZ vRE Discussion Series

Under the 'vRE Discussion Series', we put forth emerging results and issues of special interest to GIZ partners, along the main fields of our work: vRE policy, economics, finance and technology issues. As the series' title indicates, these are often based on work in progress, and we strongly encourage suggestions and ideas by mail to the contact below.

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Executive Summary

The global power sector faces profound change, driven by rapid technology innovation, renewable energy deployment, decentralisation, digitalisation, shifting policy, new financial tools, and other trends. This requires adjustment and sometimes causes even a disruptive change in planning, policy, business models, and institutional frameworks. While many authors and studies have discussed the need for institutional response to profound changes in the power sector, such studies have mainly examined industrialised countries (ICs) or a few large developing economies such as Brazil, South Africa, China, and India. In the present paper, we review the state of this literature and draw attention towards these issues in the Global South. We also open the discussion of how power sector institutions in developing countries (DCs) including emerging economies (EEs) can adequately respond to the challenges from profound change and accelerate the transition to clean, reliable, and affordable power systems.

The profound changes mentioned above have already arrived and posed a new challenge for many ICs, whose power sector institutions had undergone a reform between the 1980s and the first decade of this century. These earlier reforms were typically characterised by market liberalisation, which created a variety of institutional setups in the power sector, typically involving competitive wholesale and retail markets. In contrast, the institutional setup in many DCs is still based on integrated and nationalised supply systems, increasingly supplemented by long-term agreements (often power purchase agreements – PPAs). Only a few DCs have implemented competition in power markets.

For all the variety, the institutional setups in the Global South can roughly be assigned to five general categories (labelled I.a, I.b, II, III.a, III.b, as shown below), revealing regional patterns.

I.a **Monopoly:** The archetype of a fully vertically integrated system is common in many sub-Saharan African as well as in several Middle Eastern and Central Asian countries, apart from small island states. Countries within this group have implemented regulations and corporatisation, but not PPAs.

I.b **Monopoly & IPPs:** Integrated systems with some participation of Independent Power Producers (IPPs) based on PPAs are concentrated in western and northern Africa, central America, and South-East Asia, plus few South American, East and South African countries. Regulation, corporatisation, and partial disaggregation are frequent in this group. Typically, PPAs cover fossil fuel power plants, and in some cases also include renewable generation.

II. **Unbundled & IPPs:** Further unbundled power systems with IPPs, i.e. vertically disaggregated in generation, transmission, and distribution but still under regulated or state-fixed prices, are found in Pakistan, India, and China. IPPs and incumbent generators alike deliver to a single buyer or trader. Whereas India and China are moving towards wholesale market competition (see III below), some other countries including Nigeria are moving from I.b to this category.

III.a **Wholesale market:** Some large countries in Latin America, plus the Philippines have implemented competitive wholesale power markets. However, grid functions remain regulated monopolies.

III.b **Wholesale & retail market:** Wholesale and retail competition is implemented partially in Colombia and under preparation in the Philippines.

The institutional setup governs the interconnected power system of a country. Thus, it determines also the policies and rules of access to electricity by grid extension, if not those for off-grid access.

Compared to the situation some decades ago, the diversity of countries across categories suggests that the expected institutional reform is shifting gradually towards more competitive power sectors also in the Global South. However, in view of a perpetuation of the type I.a and the inertia of change in most DCs, it is possible that the reform process has stalled in many areas. The prevailing element in power system configurations in numerous countries is long term contracts (PPAs) with independent third-party power producers (IPPs).

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Even the few systems that already have introduced wholesale competition (thus belonging to group III.a), such as Brazil, Chile, and Mexico, have deviated from textbook version of such markets, and have forced long term contracts into the system to ensure sufficient and sustainable energy and capacity. Thus, a new variety of hybrid power markets is appearing in the institutional categories, where short-term wholesale markets coexist with long-term contracts mandated by the government. Power capacity markets implemented in some ICs constitute a different type of hybridisation.

Drivers and Impacts of Change

Power sectors, including in the developing world, face extremely rapid change, which can become a self-reinforcing process. There are three groups of interrelated drivers:

i) **Global and national policies** targeting decarbonisation, access to electricity, and democratisation all give preference to renewable energies and decentralisation, such as the use of DERs. In addition, the political push for RE has imposed further complexity and detailed regulations into the functioning of the power systems in many industrialised and DCs. Whether governments opt for renewable support schemes via Feed-in Tariffs (FiTs), net metering and renewable portfolio standards or RE obligations, all these regulations modify the incentives, risk-reward, and decision scope of actors in the power systems.

ii) In volatile **global markets** for energy, RE technologies offer cost stability. Availability of capital at low cost in global financial markets favour capital cost intensive technologies, such as RE.

iii) Diverse **innovations** change the relative economics of energy and transport technologies, benefitting variable Renewable Energy (vRE), solar and wind power, distributed generation (DG), storage and power-to-X applications, as well as electric vehicles (EVs). Information and communication technologies (ICTs) – sometimes termed digitalisation – enhance the deployment of vRE and DG with smart metering, intelligent grids, system flexibility, demand-side management (DSM), and coupling with thermal and transport sectors. Particularly important for DCs, ICT reduces the cost of operation, management and maintenance of remote mini-grids and taps a completely new mode of small-scale solar power supply.

In particular, the impacts on the power sector of aforementioned drivers are tangible through the following developments:

- In view of these trends, global investment in generation shows increasingly preference for low-carbon technologies and steps gradually away from conventional generation infrastructures, favouring vRE instead of coal and nuclear energy. **vRE deployment** impacts the bulk power part subsystem and system operation. That is, higher vRE generation capacities are forcing subsequent adjustments in the operation of all generating units in an interconnected system. An increasingly volatile residual load must be matched with a higher flexibility of conventional power plants and other flexibility-enhancing measures. Supply efficiency and reliability can be maintained and facilitated by RE as well, although this requires specific measures. In addition to temporal supply profiles, also the spatial distribution of vRE-generation must be better reflected in planning to optimise load management and transmission planning and operation.

- The **emergence of DERs** and digitalisation strongly affect power distribution systems, given the potential for reverse flows of electricity. The shift from electricity consumers to active prosumers poses operational challenges and commercial threats to distribution system operators (DSOs).

- **New players in liberalised markets**, attracted by DG and digitalisation are entering the markets: new suppliers gain access to retail and wholesale markets, aggregators bundle small generating capacities as well as flexible loads to offer flexible supply, small generators and aggregators offer ancillary services. In addition, communities of consumers and self-generators form micro- and mini-grids – small local networks based on third-party DG or mutual exchange of energy, facilitated by ICT.

- **Digitalisation** is an integral part of this transformation, which can also become self-reinforcing. Smart grids allow for more prompt and efficient system operations on many levels. This strengthens coordination among central actors such as TSOs and DSOs while facilitating communication with consumers or prosumers. In addition to the collection and transmission of data, price or other scarcity signals may help optimise processes across the whole power system, including grid and ancillary services. However, digitalisation does pose privacy risks and therefore entails strong protection rules.

- Innovations in energy and communications have the potential to **accelerate electrification**, in part through decentralised renewable energies. Mini-grids, solar home systems (SHS) as well as pay-as-you-go (PAYGO) systems and other basic supply systems are available at lower cost, even with storage. However, their deployment requires suitable institutional arrangements, which consequently may need some adjustment to achieve the goal of universal energy access by 2030.

Inevitable but Uncertain Future Transformation

In the next few decades, the power sector around the world has the potential to undergo a transformation broader and more rapid than any experienced before. The future power system will have more levels, with different relative weights, interactions, and technologies. The details, though, are highly uncertain and different in each country, as are the timing and shape of the transformation. The transformation will have the following common components:

- Consumer/prosumer level: internet-of-things appliances, controls of electrical and thermal systems, intelligent homes, commerce and services, EVs with charging stations, energy storage, rooftop photovoltaics (PV), connection to and exchange with local or distribution grids, SHS with storage, PAYGO;
- Local network level: mini-grids in stand-alone mode or with exchange to secondary distribution grid, interchange of energy and services, platform (e. g. blockchain) and local grid independent or operated by a third party;
- Secondary distribution level (low to medium voltage): connected to local grids or individual consumers/prosumers, supplying EV charging stations, operating or connecting to energy storage, thermal (heating, cooling) supply coupled to power (power-to-heat), flexible switchgear to allow upward flow;
- Primary distribution level (medium to high voltage): connecting transmission to secondary (local) distribution grid or industrial consumers, receiving feed-in from utility-scale generation from RE and other (including combined heat and power), exchange with industrial consumers and self-generators, flexible switchgear in transformer stations, large to intermediate storage (hydro, chemical), possibly power-to-heat/power-to-gas;
- National transmission level (high voltage): interconnecting central generation including large hydro with storage capacities, long-distance direct current transmission lines, interconnection to island grids and neighbouring grids (border coupling), international (regional) transmission cooperation, feeding into primary distribution, and receiving upward flow;
- Cross-border transmission: international cooperation and control of flows;
- Overall ICT systems to assure interoperability and enhance flexibility.

There is great uncertainty around the degree and concrete shape of decentralisation, and which of these system components will be predominant and how they will interact. In the most likely scenario, the power system will remain a hybrid of central and decentralised forms. Even where most of the power transactions will happen decentralised on a local level, the regional, as well as central level grids and generation, will continue to support the needs for energy, reliability, and capacity.

Many new technologies within the levels of the future power systems are already emerging and permit a vision of a decentralised low-carbon power sector. However, there are still uncertainties about which elements will prevail, e.g. where exactly the main part of storage will take place. We cannot foresee the full potential of today's technologies, let alone how they might evolve.

In some countries, a version or variation of an entirely transformed power sector may exist as early as 2030. Due to the disruptive character of emerging energy technologies, the transformation may take place more rapidly than

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many observers expect. The speed of change will be diverse, depending on the policies of the respective country – namely whether a country is proactive, neutral, or defensive. A mature and stable configuration may prove more persistent than power systems already undergoing growth and change, and there remains still strong resistance by stakeholders perceived as losers in the transformation process.

Lessons on Institutional Adjustment from Industrialised Countries

ICs facing increasing wind and solar shares have tended to extend competitive power markets from energy towards capacity and ancillary services. However, these adjustments are not uniform throughout different systems. In Germany, the power system's flexibility has become one of the main issues in the power market design. Within the U.S., the adjustment of distribution grid charges to compensate income losses from net metering and the modification of the net metering rules themselves are an issue. In the U.K., a performance-based regulation has replaced the cost-of-service regulation on the distribution level.

Solutions to energy transformation included diversifying unbundled systems through the creation of new market mechanisms, facilitating market access and competition, and revision of regulatory schemes. In most cases, these changes adapt and adjust rather than overhaul existing systems. Consequently, regulation might play a stronger part also in ICs, not restricted to the grids, in form of hybrid institutional elements, such as capacity markets or regulations.

One principle in ICs is that markets should compensate energy and ancillary services by the value of the service instead of by cost. Another principle is to expand markets to allow participation by a wider variety of actors, such as compensating prosumers for participating in ancillary services and system flexibility. New regional marketplaces for energy and ancillary services allow distribution companies to act as a buyer of services from prosumers and other actors facilitated by innovative ICT applications. Many power sector experts also suggest expansion of power markets to cover larger regions, as has been done in the EU, where the government and regulatory authorities act as meta-coordinators, matching the adaptation of market-based coordination modules where DERs coexist with centralised generation, while decentralised market participants trade with one another and with incumbents.

Given the different status and trends of institutional development between industrialised and most DCs, it is worth considering whether the institutional responses to profound power sector changes of the ICs offer lessons for others. Additional differences such as the stagnating versus growing electricity demand should be taken into account. Furthermore, some countries in the developing world have original solutions such as the hybrid institutional and market designs for long-term contracts and short-term wholesale markets. These may serve as models for other DCs.

Mapping of Challenges and Institutional Frameworks in Developing Countries

Taking a country-by-country look at the developing world and matching the current power sector institutional frameworks with the intensity of challenges in the Global South, we observe that all countries in the developing world already face some kind of challenge from the change in question.

Countries with competitive power markets face challenges in all areas, including some that face challenges off-grid. These challenges are:

For the **bulk power area**, challenges are intense in countries with competitive power markets but are not limited to these. Mexico, China, Brazil, and India – the largest developing economies – are among the countries challenged most. By 2020 these are expected to see wind and solar reach approximately a 10%-share of power generation. Some constituencies (states, provinces) within these countries are even reaching a very high vRE share in their respective generation and dispatch zones. Some countries that allow for IPP-access also hit ceilings of easy integration, namely Uruguay, Cape Verde, and other island states. Other countries with 2020 targets of over 10%-share in generation from solar and wind power include Egypt, Ethiopia, Jordan, and Morocco. South Africa is an example where RE development is already forcing IPPs into the previously fully integrated institutional system. In some countries such as Costa Rica, IPPs are limited to RE generation.

For the **retail and distribution area**, the biggest challenges are found in EEs with advanced regulatory frameworks. This is caused by a combination of policy support for DG and the introduction of intelligent grids. Countries where the power sector lacks competitive markets, face an intermediate level of challenge. Apart from RE- and/or ICT-support policies, many such countries also have high consumer electricity prices, such as in African, Caribbean, Central American as well as some Asian countries. The combination of high consumer prices, unreliable supply, and decreasing cost of solar PV and storage provokes an increasing number of residential and commercial consumers to self-generate.

Many countries have adopted net metering and net billing schemes to promote DG. However, scarcely anywhere in the developing world, the penetration of distributed vRE in the power sector has reached levels of Germany with its FiT or California with net metering yet. Utilities in many EEs are introducing smart metering systems to reduce the so-called technical and commercial losses and to achieve cost savings and rapid communication in metering and billing.

In China, experiments with smart grids are ongoing in cooperation with the grid operators and IT companies. Intelligent grids are also considered in so-called 'smart cities' schemes implemented by cities with national support, again rather found in Asia, where also the propensity for ICT application is high.

Many smaller countries with fully integrated systems and no PPAs confront major electrification challenges, as is the case in both South Asia and to a lesser extent South-East Asia. The electrification process is close to being completed in Latin America and North Africa. Sub-Saharan countries, however, appear almost all in this list of access challenges, with the notable exceptions of South Africa, Gabon, and Cape Verde. In most countries that are facing challenges in terms of lack of electricity access, the power sector is either fully integrated, or somewhat disaggregated and allows IPPs in the interconnected system. However, India, Pakistan, and Nigeria, as well as Bangladesh and Indonesia, have advanced IPP participation under single buyers.

Many of the challenges these countries face were present before the current transformational changes began to affect the power sector. Indeed, grid innovations, renewable energy, and distributed energy technology have the potential to help countries overcome longstanding access issues.

Options and Recommendation for Institutional Change and Regulatory Response

To cope with power sector transformation, some general recommendations for the institutional framework of power systems are valid in all countries:

- A political will, which has to manifest in high level and broad support from government leaders and policymakers, to shape the power sector according to the development objectives in the face of the inevitable change.
- Energy policy executives and regulators need legal and capacity strengthening in view of increasing challenges. Policy and regulation should act independently from large business interest.
- Legislation must provide the appropriate framework for energy and other regulations, including codes for technical and operational requirements (grid codes, licenses, standards for respective products and services, apart from tariff levels and systems for grid and other charges, such as charges for ancillary services), custom and tax laws, and other.
- Institutional frameworks should provide thoughtful incentives for higher dynamics toward transformation and sustainability, maintaining efficiency and security of supply, removing existing obstacles and turning to performance and incentive regulation principles of operators instead of strictly cost-based regulation; value-of-the-service should be recognised as pricing criteria.

The sequence of power sector reform from integrated unbundled monopoly towards full competition also referred to as the standard model of liberalisation is, not anymore, the paradigm to be pursued vigorously. Instead, many countries may opt for an adaptive realignment of the existing framework, advancing the unbundled & IPP system with a well-structured single buyer, strengthened self-generators, or hybridisation of wholesale competition with long-term contracts. Such changes leave open an option of continuing an evolution towards other degrees of liberalisation or competition, while still enabling profound transformation towards a cleaner and more decentralised power system.

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A specific objective for the **bulk power area**, thus the generation, transmission, and wholesale markets, is to ensure sufficient and clean power supply. Several options are suitable to achieve this goal.

Interconnection and increased cross-border exchange of electricity are effective technical supply expansion and balancing options, which depend on domestic political support as well as international or interstate commitment and regulation. To ensure appropriate transmission expansion and restructuring a close cooperation but also independence is required between the regulator and government, as well as grid operators, owners, and investors. Among other tasks, the regulator should ensure that transmission system development is based on planning that accounts for new spatial and temporal shifts in supply and demand.

PPAs or long-term contracts are key elements of power supply in most DCs and deserve particular attention. PPAs must be structured to allow flexibility and avoid obstructing integration of low-cost vRE. Procurement of new PPAs for low-carbon generation, technology specific (promoting RE-IPPs) or not, should be structured to reduce risks for incoming players while not subsidising. PPAs can help ensure adequate capacity and other services, but it is important to carefully design the interface between centralised and decentralised processes. Regulators must also plan capacity and energy needs and the respective grids, in spatial and temporal dimensions. In any case, the competitive bidding process for PPAs is preferable to negotiating unsolicited PPAs.

Open access or third-party access are other means of promoting new generation and removing barriers to renewable energy and go along with the general requirement of open non-discriminatory grid access in competitive systems. To unleash self-generation, appropriate standard contracts for cooperation between the self-generators and system operators should be offered and regulated.

To increase flexibility, integrated utilities or system operators can draw from a suite of technical options in different areas: power system management, DSM, increased supply flexibility, network flexibility, storage, and power-to-X. For these options to succeed, regulatory measures are needed such as expanded balancing areas, shorter dispatch and trading intervals, platforms for flexibility-related services, and technical standards.

Policymakers and regulators must push the system operators to prepare for rapid change, while also allowing and promoting necessary investment and cost coverage. Elements of a strong regulatory framework include performance-based regulation, price signals on the bulk power level that reflects grid capacity shortages (zonal or nodal pricing) and mechanisms for system service procurement and remuneration.

At the **distribution and retail level**, a strong and guiding participation and cooperation by legislators and regulators, but also independent expertise is required.

The digitalisation of metering and grid ICT in grid management raises further regulatory issues. These include standardisation, competition, transparency, information treatment, communication, and privacy protection.

ICT-supported control options for grid management can also help power systems cope with high penetration of vRE in the low-voltage distribution grid, principally from rooftop solar PV. If these options are not viable, regulators may opt to cap production from small solar systems or require they be equipped with peak-shaving storage.

Mini-grids at the distribution level have already been piloted in many countries and may become widespread in the future. Like larger grids, these local networks also require regulation and an institutional framework. Mini-grid issues include the connection to the distributor for the temporary exchange of power and ancillary services and clearing platforms to connect multiple prosumers and enable mutual power exchange.

While the power systems may become further disaggregated, this increases the complexity of their informational connections as regards both markets and operations. Disaggregation requires improved coordination between system operators and regulators, which involves substantial regulatory supervision.

This, in turn, may require remuneration of distribution companies based on active grid management, also known as performance regulation of distribution network operators. To ensure regulated distributors remain economically viable while also incentivising solar and possibly storage, regulators may need to modify or evolve net metering regulation, such as through value-of-solar tariffs, dynamic tariffs for distributed energy services, and greater aggregation of distributed energy. Greater penetration of small DG challenges the traditional supply business of distributors. To adapt, distribution companies may pursue new business lines, which in turn may require attention from regulators. The distributor may also obstruct the deployment of DERs by imposing excessive charges or procedures, which also requires regulatory intervention to ensure both market access for DG and fairness to distributors. Policymakers must design a good balance of rights and obligations between distributors and future prosumers, leaving room for innovation and new business models. Policymakers should seek to avoid grid defection, and also promote officialization of self-generators. Distributors should have a complete picture of DG in their service areas and share this information with the authorities and the regulator. Furthermore, regulation should allow DERs to better participate in the upstream energy and ancillary services markets.

Regulators of power, other energy and network sectors, as well as competition and privacy protection, need to cooperate. The legislators should redesign a framework open for innovations and search of solutions rather than restrictions and the regulators should act to enable the sector's preparation for the new era.

End-user pricing should be fine-tuned for efficient allocation of services according to value (temporal as well as local value) and thereby increase overall system efficiency. Another issue in pricing is the matter of charges and taxes for consumption of power drawn from the grid or self-produced, and whether these should be charged differently. In our view, taxes or fees imposed on self-consumed low-carbon electricity are counterproductive, especially since these prosumers may not receive subsidy support.

Specific regulatory challenges and options in **electrification** include general coordination of grid expansion and the off-grid approaches as well as specific regulations for the different off-grid technologies.

Utility-driven planning of grid expansion and densification tends to ignore existing non-utility infrastructure and energy options. This approach neglects the option of connecting mini-grids bottom-up to the interconnected grid. A coordinated planning approach, however, can reduce overall cost and improve system operation.

Regulators also need to accept mini-grid business models (small IPPs) within the established regulatory framework. Such decentralised renewable backup power schemes may also be run by non-profit actors and benefit from grants from international cooperation and non-governmental organisations. Nonetheless, schemes based on RE and storage will likely become increasingly cost-competitive and reduce the future need for financial support.

Implementation of mini-grids involves intensive changes in licenses and tariffs. Though each mini-grid project is unique and has a unique set of public and private investors and operators, unified regulations can smooth the introduction of such projects.

Since stand-alone systems, like SHS, are operated by private individuals, their regulatory requirements are low. One important issue is product and service quality. To cope with this issue, quality certification by the respective authority is needed, corresponding to international standards. Further means are the supervision of imports at customs as well as ensuring competitive markets for products with sufficient suppliers for quality products.

The availability of communication by wireless telephone network allows inexpensive remote control and monitoring of small, distributed units for basic energy services. The PAYGO model has opened new opportunities to cheaply transfer even small amounts of money. This facilitates new energy-related business models and the spread of low-level electrification. The business practices of these companies must be fair and transparent. This is a matter of regulatory or antitrust supervision.

High Relevance for Development Cooperation

Profound changes in DCs' power sectors regulations, operation, planning, and institutional reform all require support from international development cooperation. For German and wider European international development cooperation, which actively supports energy transformation related to environment and climate goals, cooperation must increasingly consider institutional implications of the energy transition. For any DC considering greater renewable integration and possibly energy sector transformation, cooperation should include technical and advisory assistance regarding power sector institutions.

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Abbreviations

CHP	Combined Heat and Power
DC	Developing Country
DR	Demand Response
DER	Distributed Energy Resource
DG	Distributed Generation
DSO	Distribution System Operator
DSM	Demand-side Management
EE	Emerging Economy
EV	Electric Vehicle
FiP	Feed-in Policy
FiT	Feed-in Tariff
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
IC	Industrialised Country
ICT	Information and Communication Technology
IEA	International Energy Agency
IoT	Internet of Things
IPP	Independent Power Producer
ISO	Independent System Operator
LAC	Latin America and the Caribbean
OECD	Organisation for Economic Co-operation and Development
PAYGO	Pay-As-You-Go
PPA	Power Purchase Agreement
PV	Photovoltaics
RE	Renewable Energy
RTO	Regional Transmission Organization
SB	Single Buyer
SHS	Solar Home System
TSO	Transmission System Operator
VPP	Virtual Power Plant
vRE	Variable Renewable Energy

Terminology and Glossary

International development cooperation in general and in the energy part, in particular, is highly multidisciplinary, so that talking at cross-purposes is intrinsic. In order to reduce the probability of misunderstanding, we disclose the concepts and glossaries we try to adhere to in this paper.

In general, terms concerning so-called framework conditions, we use concepts of new institutional economics where "institutions are the rules and organisations are the players" (Douglas North) and refer to the glossary of the Coase Institute.[1]

Recently, the term 'market design' is being used also for the power sector, with reference to specific functions (providing capacity, energy, ancillary services) and its competitive arrangement within the power sector.[2]

For power market terms the glossary in a 2006 World Bank paper on power sector reforms is still a useful reference. In ten years since publication, however, new terms have emerged. Therefore, we recommend also the glossary by the Federal Energy Regulatory Commission (FERC).[3]

For energy and renewable energy terms we refer to the glossary of the REN21 Global Status Report.[4]

Under developing countries, we include all countries in the OECD list that receive official development assistance.[5] We sometimes use the term emerging economies for a sub-group.

[1] See www.coase.org/nieglossary.html.
[2] For an overview, see Cramton (2017).
[3] See www.ferc.gov/market-oversight/guide/glossary.asp.
[4] See www.ren21.net/gsr-2017/pages/glossary/glossary.
[5] See www.oecd.org/dac/financing-sustainable-development/development-finance-standards/DAC_List_ODA_Recipients2014to2017_flows_En.pdf.

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1 Introduction – Rationale, Objectives, and Overview

The power sector is rapidly evolving. More, in some parts of the world the changes even occur disruptively. These changes are primarily driven by technological innovation, namely the increased deployment of renewable energy on various levels (e.g. ranging from large-scale ground-mounted installations to rooftop solar systems) and an advancing decentralisation in energy generation, facilitated by digitalisation. Whilst certain innovations are merely influencing a small sub-sample, other trends are widely observed in a large number of countries. Especially in industrialised countries (ICs), the emergence of new modes of operations is challenging conventional hierarchies and reverting power flows in the grid, thereby resulting in a transformation of national power sectors.

However, these changes do not only affect power sectors in ICs that are often characterised by unbundled and liberalised markets. Their influence extends to developing countries (DCs) and emerging economies (EEs) in particular, where different institutional set-ups prevail, ranging from vertical integration to partly unbundled market structures. While the implications of technological advances in ICs are already apparent, it is questionable whether solutions that have proven successful in ICs constitute models that are directly transferable to DCs, in view of underlying differences in energy sector capabilities and dynamics.

Research and advocacy organisations have – with increasing frequency – published analyses, discussion papers and reports on this matter, particularly on the design of power markets with a high share of variable renewable energy (vRE) generation. However, little has thus far been published on the challenges faced by DCs. The paper at hand aims to contribute filling this research gap.

This paper addresses the institutional challenges for DCs[6] in transforming their power sectors, with a special focus on countries that are facing significant changes already or expecting to do so in the near future. It further intends to raise awareness for the implications of these profound changes in the power sectors and the importance of adequate regulatory frameworks in paving the way for a successful and systematic sector transformation. In addition, the paper stresses the need for international energy cooperation in paying more attention to this matter.

With the objective of providing orientation and support to organisations, technical staff and partners, the paper maps the intensity of challenges resulting from currently observed trends against the institutional set-up prevalent in a selected number of countries. Furthermore, the paper discusses a range of options to respond to challenges and provides recommendations for regulatory adjustments in the areas of generation and transmission, retail and distribution, and access to electricity.

After this introduction, we firstly give an overview of the present institutional arrangements of the power sector (Chapter 2) by outlining different regions of the developing world and corresponding dynamics in institutional adjustments.

In Chapter 3 we describe the upcoming profound changes in power sectors by means of reflecting on various political, global, and techno-economic drivers.

In Chapter 4 we analyse responses of ICs as a potential reference case for the developing world.

[6] According to OECD, developing countries are countries that receive official development assistance, including emerging economies. See www.oecd.org/dac/financing-sustainable-development/development-finance-standards/DAC_List_ODA_Recipients2014to2017_flows_En.pdf.

In Chapters 5 and 6, we turn our attention to the developing world. Firstly, we analyse the intensity of challenges in DCs against the background of currently existing frameworks and market structures. For that purpose, we distinguish the challenges according to subsectors or areas: bulk power, retail and electrification and further attempt to create a mapping by country.

In Chapter 6, we consequently identify important challenges resulting from the observed changes and discuss options for institutional response, including adjustments of framework conditions for each of the three areas (bulk, retail, electrification). Thus, this chapter constitutes the main contribution to the existing body of literature on the topic as it provides concise recommendations for embarking on a successful power sector transformation pathway.

Chapter 7 in conclusion stresses the fact that while changes and adjustments in the developing world will be inevitable, addressing the latter will require support from international development cooperation. This support is closely related to environment and climate matters, which are of special concern to Germany.

2 The Status of Power Sector Institutions and Reforms

2.1 Principle Types of Arrangements

The institutional and organisational arrangements of power sectors worldwide vary significantly. As a matter of fact, there are rarely two countries possessing the exact same power sector design. Nonetheless, by defining some key criteria, we can distinguish principle types of arrangements and classify countries. Based on the presence of market competition and the vertical integration of the power sector's value chain, we are able to differentiate between three basic types as well as several subtypes, resulting in five power sector arrangements:[7]

I. Vertically integrated monopoly
   a. Fully integrated
   b. With procurement from Independent Power Producers (IPPs)

II. Partially unbundled but regulated power markets with IPPs and Single Buyer (SB)

III. Competitive power markets
   a. Limited to wholesale
   b. Wholesale and retail

The five (sub-) types can be described and depicted as follows:

2.1.1 Fully Integrated and Bundled System

Type I: The traditional power sector is organised as a fully integrated and bundled system. This organisational structure is prevalent in the build-up phase of a country's power system to assure electricity supply as a public service.[8]

Two subtypes can be differentiated, based on the existence of IPPs:

Subtype I.a (Monopoly): The interconnected power system is operated by a stable, vertically integrated organisation; i.e. generation, transmission and distribution are fully integrated or operated by subsidiaries of the same corporate parent as interdependent corporations. Distribution companies may be disintegrated and operated by distinct monopolies as regional demarcated entities. Except for the latter, all functions and services are bundled.

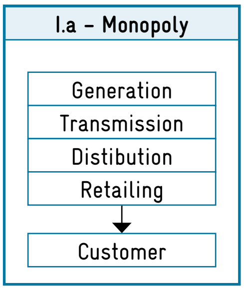

Figure 1

Subtype I.b (Monopoly & IPPs): The defining characteristic of this subtype is market access for IPPs on the basis of power purchase agreements (PPAs). This opening up to the private sector is a means to attract capital for investment in power generation. Howev-

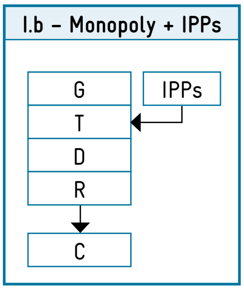

Figure 1

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[7] Following the categorisation by Besant-Jones (2006) as well as Gratwick et al. (2008), which are based on Hunt (2002).

[8] Another earlier type of public power supply arrangement emerged from decentralized electrification initiatives and subsequent interconnection on higher voltage level as well as centralisation of generation. In Germany e.g., this led to a multitude of utilities as well as layers of local, regional and interconnected monopolies. They were not competing but demarcated against each other, horizontally as well as vertically. They were subject to investment approval and price regulation, as well as anti-trust supervision. With liberalisation and introduction of wholesale and retail competition in OECD countries, this type of public power supply arrangement practically disappeared.

er, IPPs still need to be contracted with the vertically integrated company, acting as a monopolistic purchasing agency, which commonly is the state-owned, integrated utility or its transmission affiliate. There may be separate distribution companies for demarcated regions. Prices are regulated.

2.1.2 Partially Unbundled System

Type II (Unbundled & IPPs): A partially, vertically disintegrated, and/or functionally unbundled system is established by at least separating generation and transmission/distribution. In addition to the customary, state-owned generation company, supply is assured by IPPs on the basis of PPAs. A separate procurement agency may be established as the SB, typically but not always associated with the transmission company. The SB or regulator may organise competitive bidding for the PPAs. Yet, there is no short-term (wholesale) market competition between power producers. Moreover, transactions are mainly bilateral. The SB (or grid company) sells or supplies electricity to one or various distributors. In absence of a market, regulation extends to generation and grid services, including pricing in general.

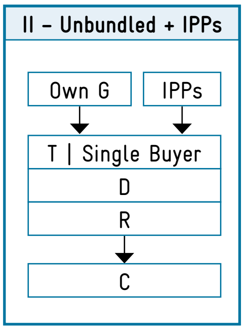

Figure 1

2.1.3 Fully Unbundled and Competitive System

Type III: A vertically disintegrated and functionally unbundled system allows for competition and open market access. Nevertheless, grid operation remains a regulated monopoly. In addition, some system tasks, e.g. ancillary services, are imposed by law onto grid or market operators in order to assure reliability. This concept of system operation has been introduced in the late 20th century. It is based on the theory that only grid operation – but not power system operation as a whole – is a natural monopoly. The decisive motive here has been to pursue higher cost efficiency through open markets.

Two subtypes can be distinguished:

Subtype III.a (Wholesale Market): This subtype is defined by a completely unbundled system with competition on the bulk power level only. The participants in wholesale markets are generators, distributors, and large users. Only the regulated transmission company develops and operates the transmission system.

Subtype III.b (Wholesale & Retail Market): In contrast to the subtype mentioned above, subtype III.b is characterised by the introduction of competition also on the retail level. Regulated distribution operators (DSO) are in charge of the basic supply of electricity to the end-consumer. The customer may choose between competing non-DSO suppliers.

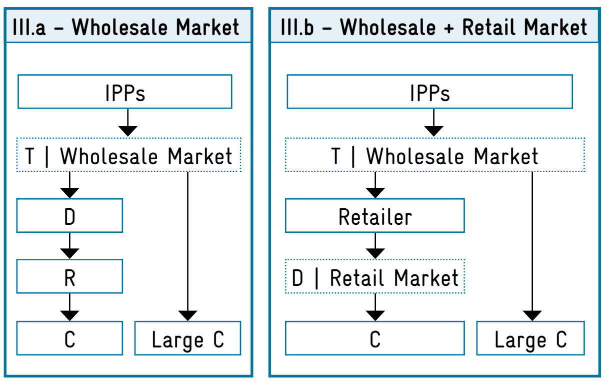

Figure 1: Types of power sector institutional arrangements (source: by authors, Gratwick (2008))

2.2 Global Implementation Overview

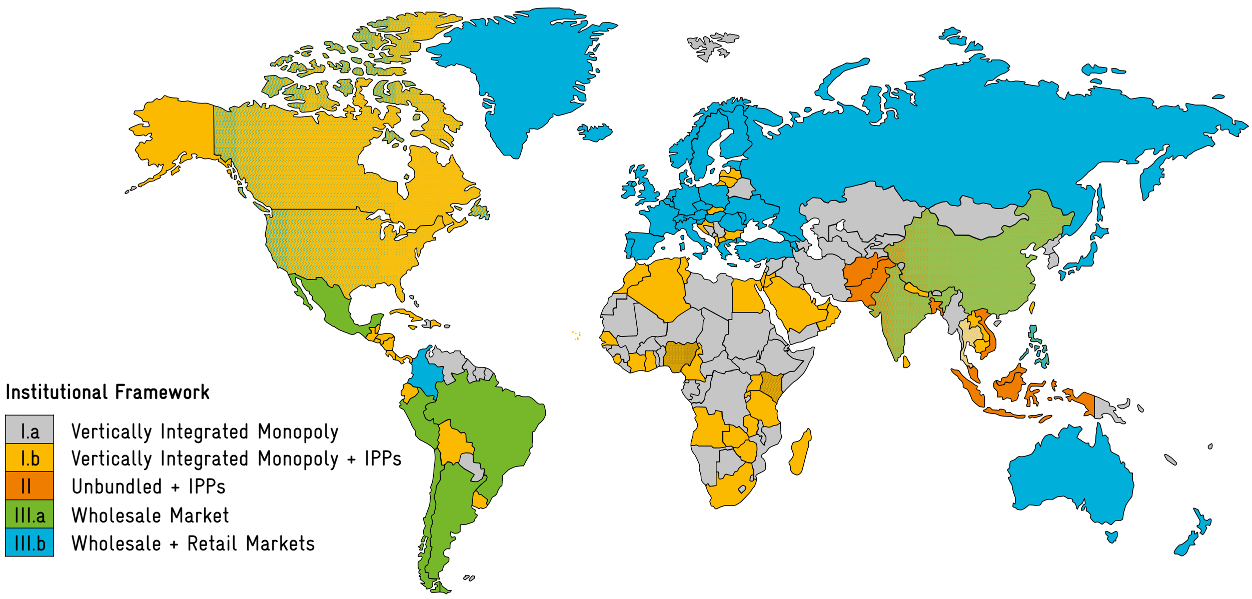

Figure 2: Current status of the electricity sector (source: by authors, IEA (2017a))

A mapping of the power sectors' institutional arrangements[9] shown in Figure 2 indicates that in terms of the number of countries and constituencies, the type I.a and I.b prevails.

Moreover, the map reveals a clear distinction between the industrialised and developing world:

- ICs predominantly introduced the competitive power market design including retail markets (type III.b), with the noticeable exception of some regions in the western and south-eastern US and most provinces of Canada, where regulated monopolies prevail; besides the control areas of Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) where wholesale competition has been introduced, and in some cases also retail competition.
- Only a few countries from the developing world have introduced or are in the process or planning to introduce an arrangement with wholesale and retail markets. Examples are Colombia for large consumers and the Philippines.

In addition, the map shows striking regional differences within the developing world:[10]

- Several large countries in Latin America have wholesale power markets. That contrasts with other parts of the developing world, such as Africa, where a competitive (type III) arrangement is not found, and Asia where competitive arrangements are nascent.
- In developing Asia, limited liberalisation is predominant; i.e. IPPs are present within monopolis-

[9] The source map of this figure was published in IEA (2017a). The IEA RETD working group published a slightly different map in IEA RETD TCP (2016), where some countries were categorized differently in 2016.
[10] For an analysis of regional differences see also Vagliasindi, M. and Besant-Jones, J. (2013).

tic institutions (type I.b) as well as in unbundled setups (type II) and in nascent competitive (type III) arrangements.

- The central Asian countries are mostly sticking to a fully integrated arrangement without any IPPs (type I.a).
- The Middle Eastern countries remain with state-controlled, fully integrated arrangements. Some countries of the Arab peninsula though introduced IPPs.
- In Africa, all countries' power systems are still organised monopolistically, whereby some countries - including the larger economies - are working with an IPP-model (type I.b).
- Non-OECD Europe shows a high diversity in its institutional setups, from type I.a and intermediary arrangements (e.g. some countries on the Balkans) up to the full competition type III.b (e.g. in Russia and countries in the Caucasus; Ukraine is set to introduce retail competition soon).

2.3 Implementation Status in Developing Countries

The following paragraphs aim at highlighting further differences between DCs and EEs within larger geographic regions. A distinction is made between (i) Asia, (ii) Africa, (iii) Latin America and the Caribbean (LAC) as well as (iv) countries with deficient energy access rates.

2.3.1 Africa

Taking into account the organisational structure (separation of sector organisations and participation of IPPs), all countries in sub-Saharan Africa fall under category I.a and I.b. However, further differentiation within the region can be made based on a more detailed analysis of power market characteristics and institutional set-ups.[11] Ten distinct arrangements (shown in Figure 3) are found, further allowing one to divide the two previously defined arrangements I.a and I.b into five sub-categories each.

- The classical, fully monopolistic type I.a is found in 20 countries.[12] Therein four specific arrangements (Namibia, Mozambique, Ethiopia, and Sudan) differ from full integration because of some vertical or horizontal disintegration. The vertically integrated monopoly & IPPs model is found in 12 countries. Some countries (South Africa, Zambia, Kenya, Zimbabwe, Ghana, Nigeria, and Uganda)[13] developed their institutional set-up further and exhibit vertical or horizontal separation of organisations.
- Nigeria is a distinct case where the system has been unbundled, the distribution level reorganised and privatised, and a national bulk electricity trader created. However, the electricity trader acts neither as a wholesale market operator nor as a typical SB but rather enables and secures transactions from generators to distributors. The distribution system was reorganised in regional demarcated monopolies and was privatised. The regulator determines prices.

[11] Thereby, this differentiation follows Eberhard et al. (2016).
[12] One may observe that these countries are mostly former French colonies, and have applied the public service concept of French energy supply.
[13] One may observe that these countries are mostly former British colonies, coming from a mixed or private power sector organisation of power supply.

- Except Libya (type I.a), all North African countries' arrangements fall into type I.b, i.e. allowing IPPs to participate even if details vary: Tunisia still possesses a fully integrated utility, in Algeria a formal disintegration (vertical unbundling) has been implemented, although under control of the incumbent utility. In Morocco, historic distributors operate alongside an integrated state company that controls the system as a whole. In none of the three countries an independent regulator has been established (as of now) in contrast to of Egypt, where also separate distributors operate.

Although power sectors in Africa are characterised by monopolistic competition, the mentioned countries have introduced some

- corporatisation, thus transforming power sector organisations from state agencies to autonomous corporations (away from being an integral part of the state);
- privatisation of previously state-owned corporations, i.e. operation of power sector corporations according to commercial guidelines instead of state budgeting;
- third-party access or open access for newcomers to energy markets as well as independent regulators in the power sector.

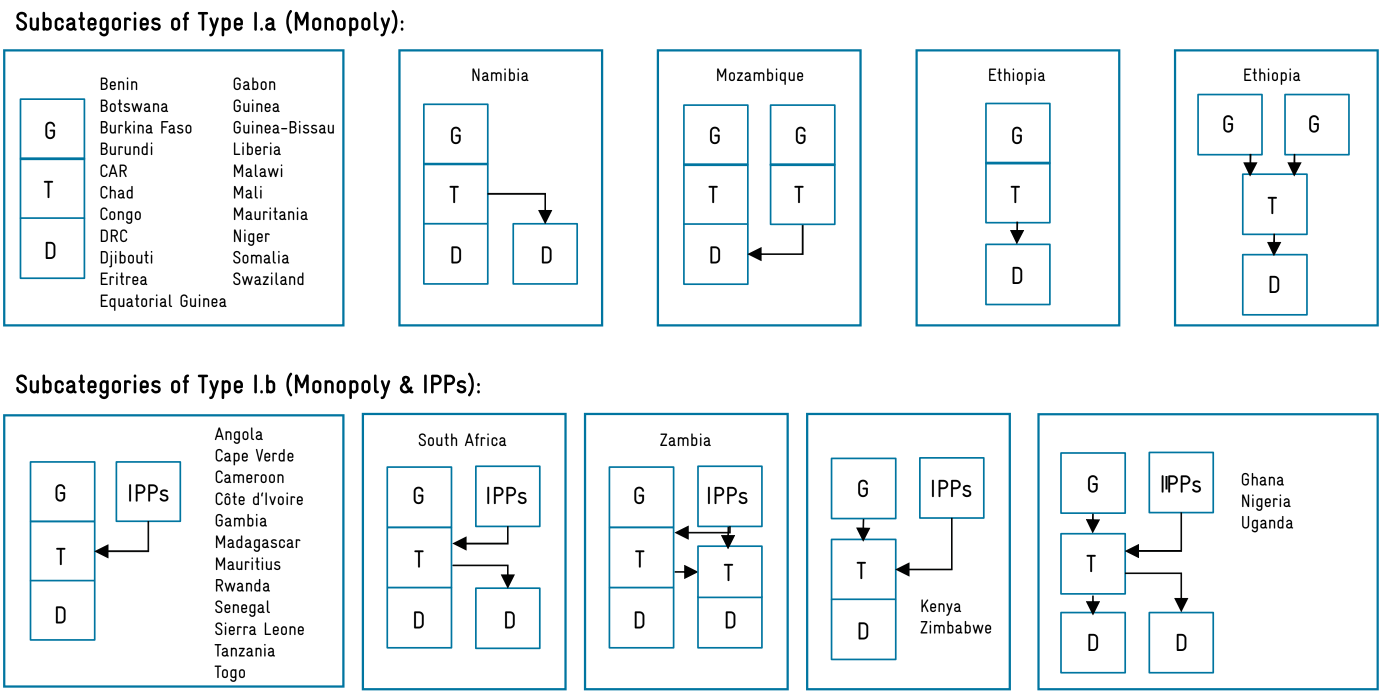

Figure 3: Power sector structures in sub-Saharan Africa 2014 (source: by authors, Eberhard et al. (2016))

2.3.2 Asia

Turning our attention to developing Asia, the prevalence of IPP-related models can be observed (Table 1). However, power sector arrangements are continuing to evolve further. And some countries are preparing moves from one type to another.

India, the Philippines, and Singapore have officially adopted all elements of an electricity market reform, but India was still lagging behind in implementation in 2017. China is planning a wholesale market. The Philippines have a wholesale market operating but also important IPPs. The country is about to start retail competition.

2.3.3 Latin America and the Caribbean

In LAC, both ends of the spectrum in terms of power sector arrangements (namely type I and III) are present. However, the SB type (II), the prevailing category in non-OECD Asia, is missing in LAC.

On the one hand, we observe

- type III.a - wholesale market competition in Chile, Argentina, Brazil, Peru, and Mexico but also in smaller markets of Guatemala, El Salvador, and Panama, as well as

Table 1: Electricity reforms in non-OECD Asia, 2013 (source: by authors, data from OIES (2016))

Country	Type	IPPs	Whole-sale Market	Regulator	Disintegration	Corporatisation	Open/Third-Party Access	Distribution Privatisation
Bangladesh	I.b	X		X	X	X		
Bhutan	I.b	X		X	X	X		
Brunei	I.a			X				X
China	II	X		X	X	X		
India	II	X		X	X	X	X	X
Indonesia	I.b	X			X	X	X	
Laos	I.b	X						
Malaysia	I.b	X		X	X	X		
Maldives	I.b	X		X		X		
Myanmar	I.a	X		X				
Nepal	I.b	X		X	X	X		
Pakistan	II	X		X	X	X		
Philippines	III.a	X	X	X	X	X	X	X
Singapore	III.b	X	X	X	X	X	X	X
Sri Lanka	I.b	X		X				
Thailand	I.b	X		X	X	X	X	
Vietnam	I.b	X		X	X	X		

POLICY

- type III.b - fully developed competition in wholesale and retail markets.

On the other hand, we find

- type I.a still prevailing in Paraguay, Nicaragua, Venezuela, Guyana, and small Caribbean island States, and

- type I.b in Uruguay, Bolivia, Ecuador, Costa Rica, Honduras, Dominican Republic, Jamaica, Cuba, Belize.

Brazil, Chile, and Mexico have effectively created hybrid arrangements forcing wholesale market participants to conclude long-term power supply contracts. This seems to become a new institutional hybrid, and model for other countries (see Section 2.4.2).

2.3.4 Countries with Deficient Energy Access Rates

In terms of the state of sector developments well as coverage of the grid, we find countries where electricity access is still far from universal. Figure 4 shows the rate of electrification in DCs across the globe.

In these countries, mini- and micro-grids are operated besides the interconnected national grid. Additionally, there is electrification occurring on household or purpose level by the utilisation of solar home systems (SHS) or even smaller basic supply systems.

The frameworks and types of organisations responsible for electrification are diverse. In many countries, a specialised authority is entrusted – such as a rural electrification

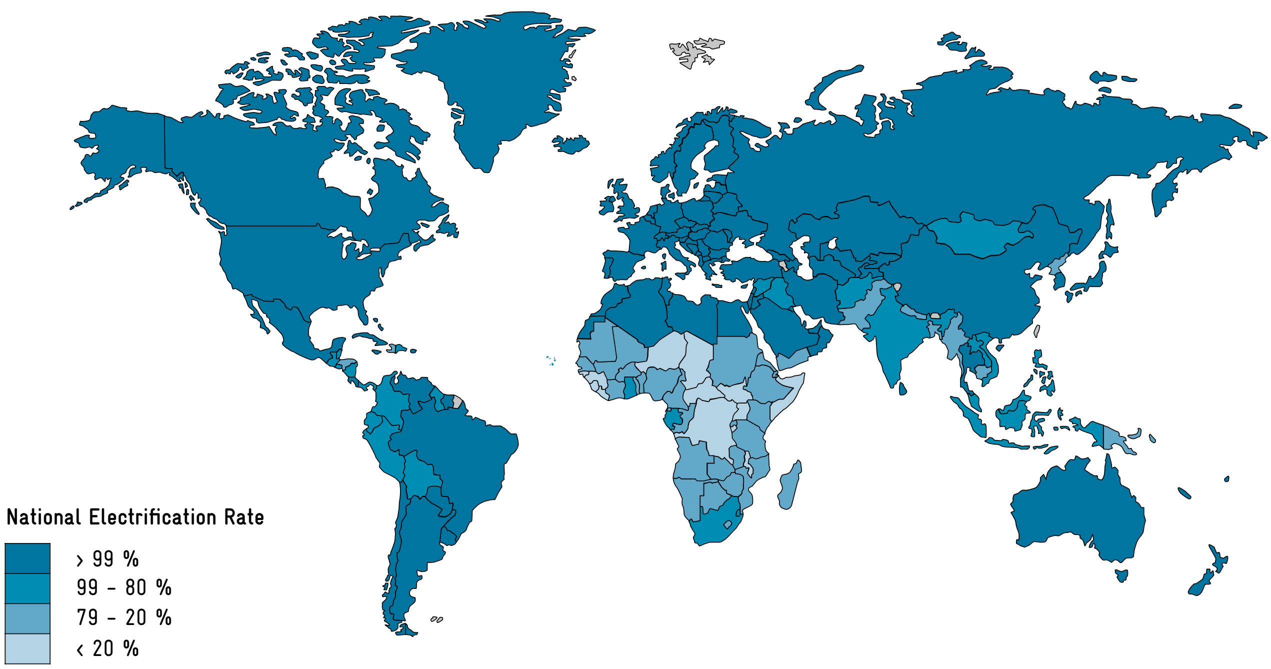

Figure 4: National electrification rate (percentage), 2014/2016 (source: by authors, IEA (2017b), IBRD (2017))

agency – that holds the mandate to implement publicly financed programs. Furthermore, responsibility for on-grid expansion and supply is usually transferred to a utility, i.e. the distribution company or a fully integrated power company. In contrast, for isolated mini-grids, four operator models can be identified: i) utility, ii) private, potentially centred around a large user/operator, iii) community-based including cooperatives, or iv) a PPA-based hybrid model. Aside from the mentioned operator models, stand-alone home or task-size systems are mainly promoted by private companies.

2.4 New Reform Dynamics

The dynamics and forces to reform and restructure the power sector were very strong in the 1990s. It was expected that in the long-run most countries would vertically disaggregate the integrated system. It was believed that they would unbundle functions, divest state-owned corporations, permit market access for IPPs, and establish power and ancillary service markets as well as grid regulation with long-term concessions. This was then considered the standard model of liberalisation in the power sector. Figure 5 illustrates these dynamics as a sequence of the previously introduced principle types for the organisation of the power sector.

In reality the dynamics have been different and diverse, slowing down or departing from the models.

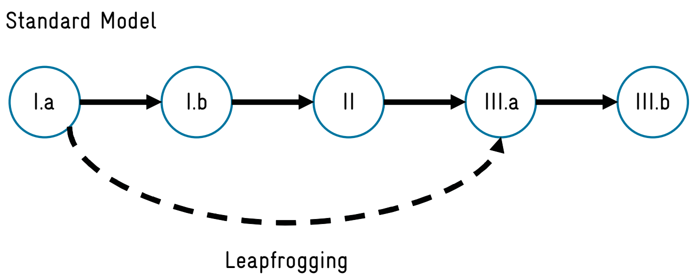

Figure 5: Standard model of liberalising the power sector and alternative historical development path for EEs and DCs (source: by authors, based on IEA (2017a))

2.4.1 Demise of the Textbook Liberalisation Model

It was believed that most countries would advance in this manner, at least in those countries with larger power sectors. The expectation was that countries would either follow the standard approach of reform, evolving from type I.a (where existing) to I.b, to type II and finally to type III.a and III.b. Alternatively, a country could move directly from type I to III, i.e. leapfrogging the IPP-SB phase as e.g. the very early-mover Chile did. These dynamics, supported by multilateral development banks, were felt strongly in the first years of reform, including in non-OECD countries (particularly in Latin America). However, since the turn of the century they have mostly subsided. In a critical assessment of the effective results, analysts already in 2008 recorded a 'demise of the standard model'.[14]

Ten years later, this appreciation affirmations remain true, although in the last decade some advances towards the competitive market design have been made or are about to be made in some countries, particularly in EEs.

As seen in the sections above, most of the more than 100 non-OECD countries are still characterised by a type I setup. More in particular, only small measures have been taken within type I.a arrangements, such as introducing corporatisation, commercialisation, and regulation. However, a significant number of countries has moved to subtype I.b. by introducing IPPs.

Some countries have moved further, by e.g. reorganising the sector, allowing privatisation, and enabling access for IPPs, though without introducing effective competition. These countries did therefore not proceed further than type II. However, the number of EEs and DCs in this category does not exceed the number of 20. In contrast, the number of countries from the developing world having introduced effective competition has not even reached ten.

2.4.2 Emergence of Hybrid Models

Furthermore, the enormous variety of institutional arrangements and the combination of elements from different models resulted in the introduction of the term 'hybrid models'.

The hybridisation of markets through government sponsored IPPs has become a new feature. Competitive procurement, e.g. through auctions, now commonly exists parallel to wholesale power markets. An International Energy Agency (IEA) working group has suggested distinguishing four prototypes of power market arrangements that differ from the systematisation above.[15]

- Vertically integrated systems: investment choices are made upon central planning and dispatch decisions, based on costs and other drivers; many countries, e.g. South Africa.
- Energy only markets: investment as well as dispatch choices are made locally, based on wholesale market prices; e.g. Australia, Texas, a selection of EU countries.
- Prosumer markets: investment as well as dispatch choices are made on the basis of retail market prices; e.g. Germany and California.
- Hybrid systems: dispatch choices are made upon wholesale market prices. Yet, investment decisions are centralised, based on planning and risk sharing mechanisms; e.g. Brazil.

[14] See Gratwick et al. (2008).

[15] See IEA RETD TCP (2016). This categorisation focuses on differences in industrialised countries' and emerging economies' power sectors. It is somewhat neglecting the role of IPPs, fundamental in developing countries.

These hybrids emerged when governments and regulators forced wholesale market participants to conclude long-term power supply contracts. The contracts are awarded after competitive procurement, selected by auctions, and imposed by the government instead of single tender or unregulated contracting between the supplying and buying party. The main argument for this arrangement is assurance of future supply security.[16] Moreover, sometimes it is argued that auctions more efficiently foster the increased deployment of low-carbon energy carriers.

The competitive bidding of long-term PPAs in hybrid systems requires more than indicative planning of generation in order to define what is to be procured (i.e. energy, capacity, supply time profile).

Overall, the power sector arrangements in DCs have become increasingly distinguished from one another and thereby idiosyncratic. Some of the specific RE promotion policies of the last 15 years have increased the complexity and have made power sector institutions more specific from country to country.

2.4.3 Renewable Energy Policies Modify Framework Conditions

The framework conditions of the power sector are not only determined by the specific power market design, but are also affected by other sector regulations and policies, such as environmental command and control policies. In the past 15 years, renewable energy policies have become a particularly strong modifying element.

The most important policies are listed below:

- Feed-in policies (FiPs) do not only determine tariffs or premiums for RE generation but often also provide for a prioritised RE dispatch. In several countries, this combination resulted in far larger investment in RE technologies than it would have otherwise been the case. As a consequence, vRE are dispatched most of the time, displacing other forms of power generation, which follow in the merit order at higher variable cost. About 110 countries or states have adopted FiPs, among them more than 30 DCs.[17] In many cases, FiPs are limited to a determined volume or a specific range of project size and technology.

- RE-specific tendering to provide a long-term PPA is another policy favouring RE. While FiPs are stagnating, tenders have become increasingly popular in recent years to promote larger RE capacities. Instead of focusing on individual projects with long-term contracts for specific energy quantities, auctions are increasingly geared towards capacity and/or supply profiles. The Renewable Energy Policy Network for the 21st Century (REN21) has counted more than 20 countries using auctions in 2016, among them 10 DCs.[18]

- Renewable portfolio standards or RE obligations are additional policies that interfere with the normal functioning of the power market. Here, power suppliers are obliged to have a minimum share of RE energy in their portfolio. Since this policy fits better to unbundled and competitive power sector arrangements, e.g. in US States, it has so far only been applied in very few DCs.[19]

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[16] In power markets with stagnating demand, e.g. in Europe, the supply security concern is addressed by capacity markets (e.g. in France and UK), or by capacity regulations (when a regulator disallows closure as in Germany).

[17] See REN21 (2017), p 203. If individual States (e.g. of India) and provinces within countries are counted the number for DCs would be somewhat higher.

[18] See REN21 (2017), p. 206.

[19] See REN21 (2017), p. 205.

- Finally, net billing and net metering has been used alongside other policies to support the deployment of small-scale, distributed RE systems. It enables generators to receive credits or payments for electricity generated but not consumed on site. Net metering and net billing change the transaction between the self-producing consumer and the supplier, in particular the distribution company. If adopted in high price countries, this policy has a strong impact on the income and profitability of the supplier, namely the distribution company. Therefore, they usually call for adjusting the tariffs. Net metering started in Japan and is common in US States, but has also been introduced in several DCs. However, the adoption of new net metering policies slowed down in 2016.[20]

Other policies promoting RE, e.g. tax credits, also provide incentives, but do not pertain to rules and regulations in the power markets.

[20] See REN21 (2017), p. 123.

3 Transformation of the Power Sector Towards a 'New Era'

In this chapter we identify drivers and enablers of change in the power sector. Subsequently, we describe current developments as well as impacts thereof and focus on changes in the institutional set-up of the power sector. Finally, we outline what a future power system in a 'new energy era' may look like, although the timing of it coming into existence is still uncertain.

3.1 Global Trends and Drivers of Change

After a few decades of policy-driven increase of RE which led to challenges of integrating significant vRE generation into the power sector, a whole range of drivers and enablers are now active, which induce change that will fundamentally transform the power systems. We can distinguish three groups of drivers and enablers: policies, markets, and innovation. They are interrelated, mutually reinforcing or – less frequently – contradicting each other.

3.1.1 Trends in Global and National Policies

Most importantly, policies that aim to decarbonise economies and societies will continue to promote and support RE. They form part of the framework established by the international climate regime and finance.

Likewise, electrification policies supported by international organisations as well as multilateral and bilateral cooperation will continue to bank on RE. This trend is further strengthened by innovation in the field of digitalisation and DERs (see below), and their auspicious economics.

The institutional development of the sector is not mainly geared towards RE technologies, but rather to supply efficiency and reliability. In some countries, democratisation may further decentralise the power system. This is again facilitated by RE, in particular by solar energy.

3.1.2 Trends in Global Energy and Financial Markets

World energy markets are and will continue to see uncertain and volatile prices, also in response to changes in carbon policies. Global financial markets are currently favourable for investment in technologies with high upfront expenses as markets are demonstrating high liquidity, low cost of capital and a general lack of suitable high return investment alternatives. Globalisation continues to play an important role and has resulted in greater wealth and hence investments also from non-OECD countries, although not only in low-carbon technologies. One of the most important new players is China, investing heavily in infrastructure projects in Asia, Africa, and Latin America.

3.1.3 Innovation

Innovation in the power sector is more and more driven by economics and business opportunities. Technical and industrial progress and competition have led to continuous cost reduction for solar and wind energy (vRE) as well as to cost advantages for RE vis-à-vis fossil power. Another consequence of this trend is that the overall generation cost in flexible and hydropower-based systems can be reduced by further RE deployment. In addition, distributed generation (DG) on the consumer level (self-generation) – mainly comprised of rooftop solar systems – is arriving at or even below grid parity in some power systems.

Moreover, the cost for storage technology (notably batteries) is falling. Consequently, expectations are fuelled that vRE in combination with storage may become economically competitive. After all, solar power with or without storage is becoming increasingly affordable also in off-grid areas.

Aside from storage technology, several other technology fields are explored regarding their ability to better integrate vRE in power systems. Furthermore, in order to cope with vRE's intermittency, fossil power stations are engineered to operate more flexible. In view of future temporary power surpluses in the customary premium markets when vRE shares are high, power-to-X applications (heat, gas, hydrogen) are under development. In addition, electric vehicles (EVs) and systems are being tested and produced with the perspective to become a huge e-mobility sector, driven by direct EV promotion policies in some countries, and anticipation of stricter environmental and climate regulation in the automotive industry competition, and competition by newcomers.

Independent from developments in the energy sector, information and communication technologies (ICTs) are progressing at a fast speed, which in turn fosters innovation in the energy industry. By reducing energy demand, for instance through the smarter control of energy appliances, cost reductions are achieved. That often happens by employing price-based incentives as control signals.

Innovations in ICT impact existing system operation as well as routines and market structures on numerous levels. ICT applications on the consumer level constitute smart homes or the internet of things (IoT). Furthermore, consumer-supplier communication is enhanced by intelligent meters. In terms of intelligent grids, ICT enables vRE integration, facilitates dispatch, helps to manage interoperability, and supports the allocation of ancillary services such as re-dispatch in the power supply. In addition, ICT facilitates demand-side management and the introduction of virtual power plants (VPPs) by new or existing platforms. Another possible ICT application is the coupling of the energy with the transport and thermal sector. ICT innovations for instance enable flexible car sharing systems that are – amongst others – suitable for EVs.

Lastly, recently developed blockchain technology has great potential to help in the operation of mini-grids by enabling communication between (and within) mini-grids, and thereby introducing an efficient and direct means for individual households to trade electricity with one another.

Specifically, in DCs and systems with incomplete grid interconnections and lack of access to electricity, ICT offers promising opportunities for small-scale solar power supply, such as pay-as-you-go (PAYGO) systems, as it reduces the cost for the operation, management and maintenance of mini-grids, e.g. remote island systems.

[21] Words such as 'revolution' are used frequently, notably by consulting companies. They tend to emphasize the disruptive character of the changes and the novelty of the challenges, in particular for the conventional business models. See McKinsey (2018) for EU und US utilities, EY (2016) worldwide, PWC (2018), and Accenture (2014).

3.2 Current Dynamics and Impacts of Change

Many of the drivers, enablers and trends mentioned above can be observed causing change already nowadays. In the long run, these changes will lead to an entirely new system, resulting from the on-going evolutionary or even revolutionary processes[21] (see next section) that have taken place. Before getting to the long-term effects, however, it seems useful to analyse their current and immediate impacts by looking at some exemplary power systems. We therefore focus on the three main factors changing power systems, namely (i) vRE, (ii) DERs, and (iii) digitalisation. We discuss the challenges for the stakeholders, which need to face the threats and seize opportunities.

There are several subsystems of the power sector that are affected by these profound changes: the bulk power system, the distribution and retail system, as well as newly electrified regions.

Although all three drivers of innovation come into play in the mentioned areas, some influencing factors dominate a given subsystem. The bulk power system is mainly influenced by vRE deployment, since it has to deal with large- and small-scale vRE generation and its impacts. The power distribution system is strongly affected by DER and digitalisation. Electrification of areas with no energy access, on the other hand, is predominantly achieved, and thus influenced by a combination of vRE in the form of DERs and digitalisation.

3.2.1 Challenges Associated with Variable Renewable Energy

The rapid rise of vRE, such as wind and solar power, imposes a number of challenges concerning their integration and the transformation of the electricity system.

Increasing vRE generation capacities require adjustments in all other generating units, because the system is interconnected. Once significant vRE shares are installed and securely dispatched,[22] the traditional base load of conventional power plants is losing space and relevance. Due to varying demand and intermittent vRE generation, less residual load has to be covered by conventional power stations.[23] Furthermore, the residual load in itself, that may at times of high vRE generation even fall to zero or become negative, is becoming increasingly volatile, making the operation of a secure and stable system a much more sophisticated task. Inflexible plants may still be needed for operational and capacity reasons in a medium-term perspective, but they do not generate enough income to cover their operating cost (e.g. fuel and maintenance) under existing conditions in liberalised markets. In addition to more flexible conventional power plants, efficient storage technologies and new ‘smart’ (and hence responsive) electric appliances are needed. Furthermore, innovative approaches contribute to finding efficient solutions by aggregators, which aim at incorporating contributions from various but many smaller players in the sector on the supply as well as on the demand side, storage and also grid management, who can increase or decrease generation, or reduce, delay, relocate consumption, store etc.

Existing grid configurations do not yet reflect the availability and distribution of vRE resources, and transmission grid planning and expansion have only begun to account for these aspects. In fact, the regional concentration of renewable energy generation capacities does not necessarily coincide with demand centres and/

[22] Dispatch for vRE generation may be based on regulated priority or due to close-to-zero short-term marginal costs in the merit order, which is the usual mechanism that determines the operation of power generators in liberalised markets.

[23] The residual load is defined as the load that has to be offered to match the demand after subtracting those generators that have to produce electricity for operational reasons (‘must runs’) and those that generate with low or zero marginal cost (such as wind and solar PV) from total power supply.

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or existing grid infrastructure. vRE generation capacities are often weakly connected to the distribution grid at medium-voltage level, as well as high-voltage transmission and demand centres. Congestion occurs frequently. As a result, existing generation assets cannot be operated in the most economical way.

3.2.2 Challenges Associated with Distributed Generation

Distributed energy resources, i.e. DG on consumer level (in addition to large units or utility-size generation including ground-mounted wind or solar parks), have grown rapidly in some places. Small-scale generation is often based on vRE such as rooftop PV installations or combined heat and power (CHP) solutions. Consequently, on the downstream side of the power sector's value chain, DG and end consumers have recently attracted more attention, also regarding operational issues.

- In power systems where the share of decentralised generation is rising based on privileged feed-in rights and tariffs (FiTs), many commercial and residential consumers have become both producers and suppliers to the grid. However, they remain consumers at the same time, metered and remunerated under distinct contracts. FiTs typically incentivise small investors to install as much capacity as possible. Operating these assets temporarily inverts the electricity flow in the distribution network.

- Where net metering is the measure of choice to increase the share of DG, the consequences for the supply-side as well as the grids are more complex. Net metering has allowed the 'rise of the prosumer', i.e. a term referring to households acting as producers and consumers at the same time. The power flow in the grid may not be much different as when a FiT applies. However, the incentives for the prosumers are different which consequently impact investment and operation decisions.

- Whether induced by FiT or net metering, DER will confront the DSO with a different demand curve and distributed injection. In case the penetration of PV generation is high, the DSO is facing a lower demand during sunshine hours and a steep increase at twilight hours towards the evening peak (resulting in the so-called Californian duck curve).

- In case of net-metered consumption, the remuneration of grid-services based on net billing causes the DSO to lose revenue. That in turn may require an increase of the general network service tariff. In effect, consumers who do not generate themselves essentially cross-subsidise distributed generators.

- With rapidly falling costs for solar energy, similar operational and regulatory issues are expected to occur more frequently, even when neither net metering nor FiTs are offered. This is likely to be the case particularly in countries or regions where end user prices are high, and/or load shedding and supply instabilities frequent. Consumers then turn to self-generation and use less energy from the grid. If end-user prices are substantially higher than FiTs, small generators may prefer self-use.

- Prosumers may also start to use the electricity for new appliances, such as for the charging of car batteries or heating requirements. In effect, demand may rise, alter load profiles, and overstrain the distribution infrastructure. This problem could intensify if advanced regulations are already in place and customers operate these inherently flexible loads, such as EVs, according to real-time retail prices. In case of low energy prices, flexible loads may ramp up in a correlated manner and cause congestion of the limited distribution grid capacity. This poses the question of how a technically and economically efficient infrastructure system should look like; which institutional framework (including pricing) should be in place and how flexible load management mechanisms should be designed to foster effective system operations.

- New groups of agents have entered the markets in the downstream part of the power sector's value chain seizing new business opportunities. New suppliers got access to retail and wholesale markets to stimulate competition, which poses challenges to incumbent utilities. Moreover, there are more and more aggregators active in the market, which bundle small generating capacities as well as flexible loads. They do not only offer energy in the wholesale market but also ancillary services to system operators. Similar to local utilities offering flexible supply from CHP facilities, flexibility is also offered by aggregators of small-scale CHP plants as well as storage on a local level. Aggregators moreover utilise ICT infrastructure to bundle small producers and flexible consumers into VPPs and provide flexibility to the DSO.

- In addition, communities of consumers and self-generators form micro- and mini-grids, i.e. small local networks based on third-party DG or mutual exchange of energy. Within interconnected systems, these mini-grids are attached permanently to the distribution grid for some services. Because they are connected to the larger grid but can function as isolated grids, micro-grids are put in place around critical infrastructure such as hospitals, schools, police stations, and shelters. If the greater grid experiences an outage caused e.g. by a natural disaster, the micro-grid can be restored first, providing people with critical power before restoring power within the greater grid.

3.2.3 Challenges Associated with Digitalisation

The application of ICT in the electricity sector – known for instance as 'smart energy' or 'smart grids' – should be distinguished from the above-mentioned trends and challenges. Digitalisation is often not only premise, but also facilitator for these changes. That is even more so the case since digitalisation forms an integral part of the responses to the discussed challenges. The ICT industry is strongly involved in two major processes of change, namely (i) the introduction of smart grids and (ii) the establishment of smart end user appliances – both of which are further elaborated on in the following.

There is a strong movement to apply ICT in the electricity sector, independent of RE and DER. Resulting smart grids allow for more rapid and efficient operations on all levels. These changes would strengthen the role of a central actor of a proprietary system (TSO, DSO or other). Advanced tools, e.g. for trading, can also enhance the interaction between stakeholders on all levels, including consumers or prosumers.

ICT additionally allows consumers to automate processes and use remote control applications and will be used broadly. The terms 'smart home', 'smart services' and 'Industry 4.0' pertain to digital solutions that affect electricity services and consumption. These developments are subject to regulation outside the power sector. However, utilities are increasingly participating in the discussion on adequate regulatory frameworks because the mentioned developments may heavily impact their operations.

A key ICT innovation encompasses the communication of electricity consumption and supply, the so-called smart meter. This is in fact much more than just a device for billing. It enables the collection and transmission of data, better supervision of consumption (and thus identification of technical and non-technical losses), the provision of price and other scarcity signals, or even the remote control (by the supplier, aggregator, or DSO) of consumer appliances. The latter may be heating and cooling equipment, an EV or a household's solar modules. This technology could catalyse the whole energy system and optimise it, including the operation of grids and offering of ancillary services. Smart meters can enable the widespread use of DG with numerous prosumers acting as consumers, producers, and stabilisers at the same time. To do so, however, smart regulation and (market-based) incentive schemes will be required.

3.2.4 Challenges to Prevailing Business Models

The profound changes in the power sector challenge the incumbent businesses and force them to reinvent their business models. As a matter of fact, the described innovations are opening up a multitude of business models apart from those of traditional asset-based utilities. The range of services usually increases with the market size.

- Service-based business models are introduced by companies offering not only standard energy power products, but rather associated services.
- ICT companies create new business models and act as 'service utilities' competing with the customary ones.
- Distribution grid operators offer platforms for local/regional markets and the management of DERs.

- Aggregators of DER offer products and services on previously mentioned platforms.
- Utilities offer a range of non-traditional energy-related services, e.g. as community plant operators or operators of consumer site plants.
- Virtual utilities aggregate the generation from various distributed systems and act as the intermediary between DERs and energy markets.
- Product innovators promote new applications and respective business models, such as EV charging, the provision of prosumer-site infrastructure, the management of rooftop solar installations, and the like.
- Renewable energy IPPs, but even fossil-based IPPs, are equipped with more flexible PPAs.
- New business models emerge around mini-grids. That applies to the grid operators themselves, but also to independent small power producers.
- Non-profit utilities provide specific services for small-sized standard applications, such as mobile phone charging, which are billed via phone.

3.2.5 Challenges in Deficient Electricity Supply Situations

For countries where electricity access is still far from universal, innovation and cost reductions for vRE and storage multiply the options for faster electrification. Mini-grids, SHS as well as PAYGO and other basic supply systems will be available at lower cost, even with storage. Although these innovations improve the options for electrification, making use of them requires suitable institutional arrangements and possibly some adjustments thereof.

Achieving universal energy access until 2030, as set forth in Sustainable Development Goal (SDG) number 7 of the UN-Agenda 2030,[24] is a major challenge. However, the innovations and cost reductions mentioned can help to meet this challenge (see also Section 5.4).

The currently deficient technical state of interconnected grids in a number of emerging and DCs, however, may result in an aggravation of the discussed challenges. Systems suffering from frequent power losses, load shedding, and thus low power quality as well as poor system reliability, will need to address deficiencies in the institutional set-up while technical parameters continue to evolve in parallel. In a number of countries, individuals and companies will (quickly) apply some of the innovations discussed and defect from the grid in order to assure reliable power supply. Solar PV in combination with storage are likely to become a welcomed alternative for consumers that operate diesel plants for emergency back-up, or have a generator permanently embedded into the system. These responses by electricity consumers, however, require a revision of the national regulatory framework in order to optimise joint operations of suppliers and prosumers.

[24] See UN (2018a).

3.3 Longer Term Results of Change

The on-going profound changes will lead to a complete transformation, whose contours are still in the process of emerging. Details are obviously uncertain, and the time line and shape of the transformation will differ between countries.

3.3.1 Elements of Future Power Systems

Many observers agree that in the long-run power sectors will undergo a profound metamorphosis[25] and consequently emerge as something very different from what they used to be only recently. Presumably, the future system will consist of more components as well as more actors, and further will be characterised by greater complexity.

We outline some of the elements of future power systems here, beginning at the consumer level and moving up to higher voltage levels of the grid:

Consumer level: prosumers, internet-of-things appliances, control of electrical and thermal systems, intelligent homes, intelligent commerce and services, EVs with charging, energy storage, rooftop PV, peer-to-peer trading, connection and exchange with local or distribution grid, SHS with small storage in stand-alone systems, PAYGO;

Local networks: mini-grids in stand-alone mode possibly including exchange (feeding into, drawing from) with secondary distribution grid, interchange of energy and services, platform (e.g. blockchain) and local grid independent or operated by a third party;

Secondary distribution level (low to medium voltage): connected to local grids or individual consumers/prosumers (residential, commerce and services, small industry customers) that are also self-generators (prosumers), exchanging power and supplying services, supplying EV charging stations, operating or connecting to energy storage, thermal (heating, cooling) supply coupled to power (power-to-heat), flexible switchgear to allow upward flow;

Primary distribution level (medium to high voltage): connecting transmission to secondary (local) distribution or industrial customers, receiving feed-in from utility-scale generation from RE and other generation types (including CHP) including exchange with industrial consumers that may also be self-generators, flexible switchgear in transformer stations, large to intermediate storage (hydro, chemical), possibly power-to-heat, power-to-gas;

National transmission level (high voltage): interconnecting central generation, including large hydro with storage capacities, long-distance direct current transmission lines, interconnecting island grids, interconnection to neighbouring grids (border coupling), international (regional) transmission cooperation, feeding into primary distribution (and thereby even receiving upward flow);

Cross-border transmission: International cooperation and controls of flows.

The components are supposed to be connected by overall information and communication systems to assure interoperability and enhance flexibility.[26] This aspect is closely associated with the challenges and opportunities arising from the process of digitalisation in the energy sector as outlined in Section 3.2.3.

As seen in Section 3.1, many elements of such future power systems are already emerging. In some countries, a version or variation of this new system may exist as soon as 2030, in others the discussed alternations will not manifest before 2040 or 2050.

[25] See e.g. the results of a Delphi study in BDEW et al. (2016).
[26] Such as organic growth approaches; the cellular system proposed in Siemens (2016) is a concrete example.

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However, there are still uncertainties about which elements of the current system will prevail and which role the latter will play in the new system, in particular regarding current technological innovations: what kind of storage will be applied and where? Will plug-in EVs become the principle individual transport technology, or rather hydrogen-based fuel cells, or others? Moreover, will power-to-gas be the main enabler of increased flexibility and sector coupling, or rather power-to-heat? The uncertainty regarding these questions is even bigger considering the fact that we probably do not know all the technology options that will become available and relevant in the long run. Nonetheless, the shape of the system will also depend on the underlying policy framework.

The speed of change, however, will vary also depending on the policies of the respective country, namely whether a country is proactive, neutral, or defensive. The system configuration of an existing and already developed system might prove somewhat persistent and there could remain strong resistance in many places by significant stakeholders that are in danger of losing out in the transformation process.

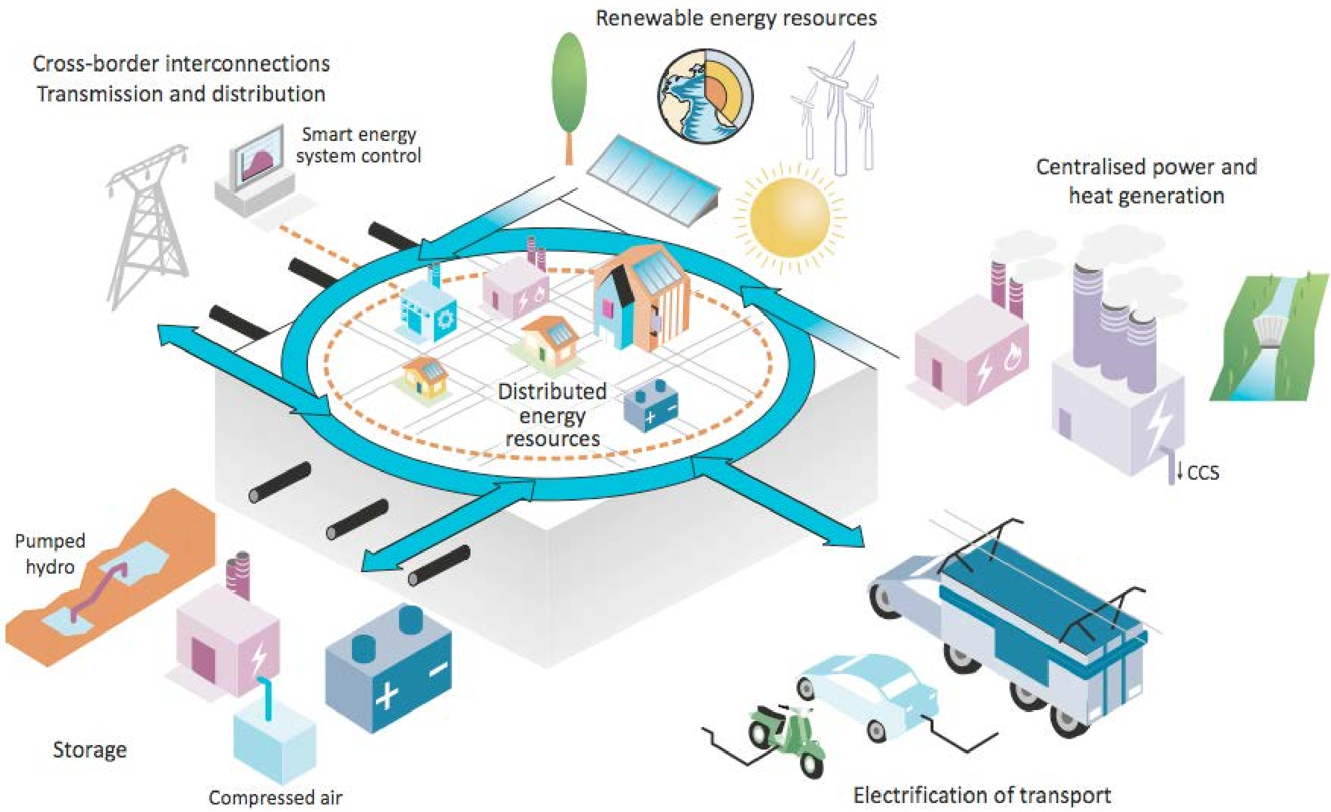

Figure 6: Smart distribution grids at the heart of a future power system (source: IEA (2016a))

3.3.2 Long-Term Institutional Development

The principle future options for power systems are related to the degree and shape of decentralisation. They are primarily characterised by a shift away from customary centralised systems with utility-sized plants on an intermediate (medium voltage) level. Most certainly, as well as regardless of the various pressures different trends exert on the system, some mixed central and decentralised form will remain. Even where most of the power transactions will happen on the local level, the regional as well as central level grids and central generation will continue to exist. They will support in meeting the need for energy, reliability, and capacity.

In view of the altered structure of the power system, its power-flows and respective functions, a number of new regulatory issues emerge:

- The customary vertical separation according to the functions generation, transmission, and distribution does no longer seem fitting. The classical separation, definition, and function of transmission and distribution systems do not accommodate the growing importance of distribution by off-taking generation from utility-sized plants. Following the modified function in the system, the operation of primary distribution grids might have to be separated, redefined, or even combined with transmission system operation and submitted to a corresponding regulation. The new role of smart distribution systems as a core element of the future power system is depicted in Figure 6.

- The relationship of the (secondary) distribution grid and prosumers is another area that will have to be re-regulated. In case local mini-grids prevail, a whole range of new regulatory challenges will have to be resolved – in particular regarding system reliability, e.g. balancing and alike.

- Issues with respect to long-term supply security combined with low-carbon objectives will need to be addressed in the new setting, such as capacity markets or mechanisms and competitive procurement of supply.

- The choice between zonal versus nodal pricing will become virulent, just as retail pricing in general, with time-of-use pricing is becoming more appropriate for load management.

In the next section, we will look at how ICs – where significant changes are already in place or under way – respond to impacts on the power market design and regulatory developments.

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4 Responses and Institutional Modifications in Industrialised Countries

Even though the global trends and innovations, which drive the power sector change are active worldwide, their impact and relevance differ in time, order, and pace from country to country. ICs like Germany or the UK, other EU countries, some US States or Australia are the first ones to confront implications. DCs will follow, although not necessarily on the same development paths as the frontrunners – some may also lead in some aspects of the transformation. Before discussing the DCs in Chapters 5 and 6, we want to show that the observed responses in ICs are determined by the mature state of sector development and the predominant market type of arrangement and, thus, of limited applicability in DCs.

The overall objective of institutional modifications is to ensure an effective and efficient power supply and management of the grid. Supply has to be secure, reliable, and sustainable. In order to meet these goals in times of profound change, it is necessary to adjust the organisational and institutional framework by changing existing rules and regulations and/or establishing new ones.

4.1 Responses in Countries with Competitive Power Markets – Focus on Germany

Several ICs and other jurisdictions, such as federal states, are on the way to consider and impose institutional changes. Except for some regions in North America, almost all OECD countries have introduced competitive power markets nationwide, not only on the wholesale but also on the retail level (see Chapter 2). Generally, it can be observed that ICs tend to expand the competitive power market beyond the delivery of energy by including capacity and ancillary services. Furthermore, these countries are struggling to reconcile mechanisms for the promotion of RE and their effects on the overall constitution of the power market. Some illustrative examples are elaborated on in the following.

4.1.1 Adjustments in the Bulk Power Area

In Germany, power system flexibility has become one of the main issues[27] as vRE sources have already attained a relatively high share in power capacity and generation and are set to grow even further (see Figure 7) based on increasing cost competitiveness and on-going political support. Mobilising and utilising flexibility options however require suitable mechanisms. An efficient allocation of available flexibility options, such as load management, storage, and new power applications like e-mobility, make it necessary to readdress rules and regulation so as to remove obstacles and disincentives, and possibly introduce incentives and new submarkets for ancillary services. These responses signify further functional unbundling and a deepening of the competitive market design.

Germany recently opted against a capacity market mechanism,[28] existing in other EU countries. In view of significant overcapacities in generation and continuously growing RE-capacity, the regulator has been entrusted with the task of providing for sufficient capacity for the years to come. The regulator is entitled to disallow the closure of fossil power plants even though the operating company would like to decommission them. In addition,

[27] The Green Paper of the Federal Ministry of Economic Affairs and Energy (BMWi), see BMWi (2014), exposes the challenge for the German power system that is integrating high shares of vRE, much of which is fed-in on the low-voltage level. BMWi has proposed to create and exploit multiple flexibility options as a solution.

[28] See White Paper by the Federal Ministry of Economic Affairs and Energy (BMWi), in BMWi (2015), which followed the aforementioned Green Paper.

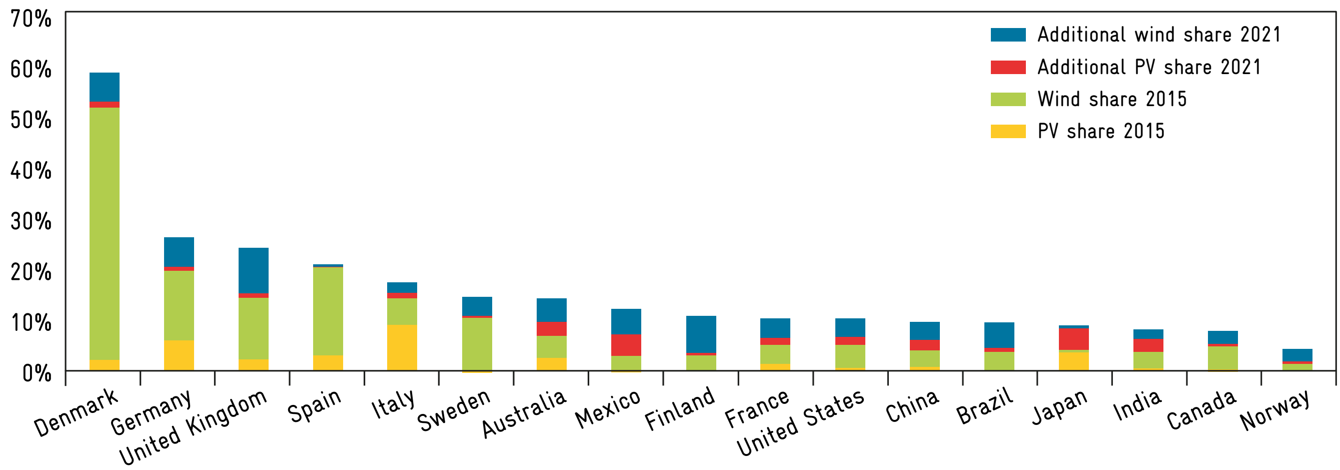

Figure 7: Countries with high share of vRE in power generation; missing Ireland had a wind share of 17.7%; 2015 (source: IEA, 2016a)

for regional and employment policy reasons, some plants remain in cold reserve. As a result, a costly reserve system is established. Nevertheless, the issue of capacity sufficiency will come up again when a coal power exit plan is prepared in view of the last nuclear power stations to be closed in 2022

Up to now, the transmission system has shown great resilience in absorbing ever higher vRE output and the TSOs managed to keep the system reliable. Transmission companies are regulated but are also market participants in the ancillary service markets. A regional reorientation of power generation is ongoing, with high wind power capacities in the north and solar power in the south of Germany. Large nuclear and coal power plants are planned to phase out. Consequently, new high-voltage transmission lines have been planned by the government and the regulator. This is also due to the political will that is favouring a unified price for electricity in the whole country. Generation price and transmission fee differences between northern and southern Germany are met with opposition and nodal pricing is discussed only in academic circles. On the contrary, regulated distribution fee varies strongly.

The changes on the bulk power level endanger the business model of the incumbent German power companies. Already struggling for survival, they are trying to adapt by going through profound corporate restructurings as has been done by E.ON and RWE. However, their losses occur in the generation and marketing of energy since decreased wholesale market prices now only cover the variable cost of power plant operations but not the total cost of most conventional power plants.

4.1.2 Adjustments in the Distribution and Retail Area

Due to a mandatory unbundling, the distribution system operation is organised as a separate regulated business in Germany. Even on the distribution level, profit margins have dropped. Due to existing feed-in rules the distribution companies – mostly local municipal utilities, the so-called 'Stadtwerke' – have to absorb increasing quantities of DG, which are remunerated by a fee. Thus, up to now, only little revenue losses have occurred for distribution services that are remunerated by a distribution charge per kWh drawn from the grid. Herein, a strong difference to the case under net billing rules is found, since the quantities delivered by the prosumer to the grid under FiTs are not offset from the kWh drawn.

Only recently new solar PV and other DG cost have fallen below grid parity in Germany. This was due to high

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taxes and fees, particularly the fees needed to recover the FiT payments for RE. Therefore, the proprietary use of self-generated power became competitive to feed-in conditions and prosumers renounce FiT and start to use the power they produce reducing their billed consumption. Consequently, distributors as well as retailers may face on-going losses in revenue and market share.

Nonetheless, retail pricing regulations are discussed also in Germany. One issue is the lacking connection between retail and wholesale market prices and the absence of incentives to react to changing wholesale market prices. This aspect could be addressed through the introduction of smart meters and smart home appliances that would allow for alternating consumption patterns based on price signals.

However, besides the issue of standardisation, which is beyond the scope of the paper at hand, the introduction of smart meters has raised questions about the use of data i.e. data access through third parties and therewith associated privacy issues.

In the U.S., namely California as well as some north-western[29] and north-eastern states, particularly New York,[30] are at the forefront of discussing and piloting reforms to manage DERs. They involve multiple and fast response options from smart homes, DG, and energy storage. Additionally, national organisations have developed generic concepts, such as the so-called transactive energy concept.[31]

In several U.S. States net metering for prosumers has accelerated the disruption of utilities' business models and therefore challenged the effective operation of the system. Together with other factors, the reduction of quantities of kWh accounted for in the net-metered electricity bills has substantially eroded the distribution turnover of utilities, whilst operational cost stagnated or rose. Consequently, regulators have modified the net metering rules and limited the credits for surplus fed-in back to the grid. However, it has become obvious that the challenges are complex and thus a fundamental institutional change is required beyond a mere tariff tweaking.

Other places of regulatory modifications include the UK and Australia. In the UK, the distribution function was modified, and a performance-based regulation replaced the cost-of-service-based regulation.[32]

[29] In response to the challenge of managing the growing multiple and fast response options from smart homes, distributed generation, and energy storage, the concept of aggregating response was implemented in a pilot project in Pacific North-West. The Bonneville Power Administration (BPA), a regional north-western federal power marketing agency and balancing authority, has solicited for aggregated DR resources as a pilot project. The proposal of Energy Northwest, a public power joint operating agency, was adopted and has started to operate in early 2015. It involves demand reduction by distributers, fast industry demand reduction and an electricity storage facility. It is governed by a so-called Demand Response Aggregated Control System (DRACS). DRACS is hosted at the Pacific Northwest National Lab (PNNL), one of the key technical advisors in the new grid operation systems. See Energy Northwest (2015).

[30] For more information see PSC (2017).

[31] The transactive energy concept was developed by an Expert Group convened by the U.S. governmental agency DoE. The key idea was to put an energy carrier's value to the system at the forefront in all energy and ancillary services transactions. The concept is presented in detail in Gridwise (2015). For a critical analysis of its applicability see CPUC (2014). The Electric Power Research Institute (EPRI), the research organisation of the U.S. utilities, has expressed support for the underlying conceptual idea in 2018.

[32] The Office of Gas and Electricity Markets (OFGEM) developed RIIO (Revenue = Incentives + Innovation + Outputs), a performance-based model for setting the network companies' price controls. For more details see OFGEM (2018).

4.2 Lessons for Market Design and Regulatory Modifications

Industrialised countries most concerned with and responding to the profound changes are characterised by a highly liberalised legal framework. The solutions discussed in this regard are either (i) diversifying the unbundled systems through the creation of specific markets (e.g. for ancillary services), (ii) facilitating market access and competition, or (iii) through revising existing regulation.

This means, that the current system is not abandoned but rather maintained as a basis for further adjustments. These adjustments pertain to further separation between different partial/local markets as well as differentiation of markets for energy and ancillary service products (such as dynamic prices, reactive power, different reserve services).

One principal idea for a reform in the mentioned countries is that new types of transactions, such as transactions of energy and ancillary services, should be rated by the value or contribution of the service (to the system) instead of its cost. Thus, in addition a value-based pricing is envisaged to replace the traditional cost-based optimisation and regulation, and instead of a performance-based regulation. This implies much more price-differentiation for consumption and feed-in back to the grid, corresponding to the market situation at hand. In addition, prosumers need to be included in the provision of ancillary services and system flexibility.

Alternative proposals also include modifications of the present energy markets, in particular the spot market. A notable approach is the creation of new regional market places for energy and ancillary services where distribution companies may act as buyers of services from prosumers and others, such as flexible consumers and storage operators.[33] All this can be enabled by innovative ICT applications (smart metering, intelligent grids) for which adequate standards, rules and regulation are still required.

Revising the underlying market paradigm is hardly considered, although the fragmentation into many markets for service products may make it even more difficult to coordinate scarcity signals that originate from generation and transmission and consequently turn them into price signals to end-users or even to individual devices.[34] There is a risk that the underlying market system gets overburdened and ineffective due to a rising complexity, and the system might become unstable. This could happen when (too) many actors immediately react to price signals, inverting the scarcity situation in certain parts of the system, which would then trigger the opposite reaction and send out opposite signals. From an ICT point of view, however, the complexity seems manageable.

The challenges and complexities discussed in combination with the changing energy flow and operation mode on the distribution level led some experts to suggest a re-integration of the distribution and transmission operations.[35]

The capacity issue discussed at the beginning of this chapter shows that, besides intensification and multiplication of markets, regulation continues to play a strong role and is not limited to the regulation of transmission and distribution grids. Observers speak of hybrid institutional elements, which can also be found in some power markets of OECD countries[36] (see also 2.4.2). Suggestions made proposing an evolution of the power market design in the EU e.g. could look as follows: the government/regulatory authority plays the role of the meta-coordinator that adapts and prepares its market-based coordination modules to a hybrid future where DERs coexist with centralised generation, while decentralised market participants trade with each other as well as with market incumbents.[37]

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[33] The German association of new market innovators (Bundesverband Neuer Energieanbieter, BNE) proposes regional flexibility markets, see BNE (2015). Similarly, but restricted to ancillary services: VDE ETG (2014).

[34] A disagreeing comment from an IEA working group on smart grids is notified: the working group doubts whether systems with increasing number of participants are appropriate for managing smart grids, see IEA (2011).

[35] See e.g. O'Malley (2015).

[36] See e.g. IEA RETD TCP (2016).

[37] See OIES (2017).

5 Intensity of Power Sector Transformation Challenges in Developing Countries

DCs face many of the same dramatic changes in power sector evolution as do ICs, sooner or later reflecting strong impacts from drivers and enabling policies, markets and innovations.

Following the organisation of prior chapters, in treating the DCs we will first touch upon the institutional status of the power sectors in DCs and the intensity and imminence of challenges from profound innovation changes, before discussing institutional responses or provisions. The present chapter classifies countries by their institutional status and by the urgency to deal with them in different areas of the power sector i.e. i) bulk power, ii) on-grid retail, and iii) off-grid electrification. The criteria for the classification of challenge intensity are presented in the Sections 5.2 to 5.4.[28] In Table 2 to Table 4 we match the current and emerging power sectors' institutional frameworks in EEs and DCs, according to categories adopted in Chapter 2, with intensities of change in the three areas or subsystems of the power sector i) bulk power, ii) on-grid retail, and iii) off-grid electrification.

5.1 Overview of Institutional Arrangements and Challenge Intensity

This graphical juxtaposition in Table 2 to Table 4 allows some general observations:

- All DCs face significant challenges dealing with the currently on-going changes in bulk power area, retail electricity area, or electrification area. Many countries face issues in all three areas.
- Countries with competitive power markets, or countries close to implementing competitive markets, tend to face challenges in all three areas, and face intense challenges from change in the bulk power area.
- Many countries that have unbundled generation from grid services while not liberalising wholesale or retail power prices, and vertically integrated systems that allow IPP-access, are also facing changes in the bulk power area, triggered by renewable energy-related policies and economic opportunities.
- Most countries facing challenges related to off-grid areas are smaller and low-income economies, but even some EEs are still struggling with this challenge.
- Many of these smaller countries stick with vertically integrated electric power systems without IPPs confront electrification challenges. To date, these countries show little change to their overall power institutions other than rural electrification.

In many African countries, particularly those with internal conflicts, power sectors show little or no evolution of wholesale or retail power markets and face severe technical and market deficiencies that deter policy and technology innovation.

[38] In this classification attempt numerous sources were used including: Bloomberg NEF Climatescope (2017), Energypedia Countries Portal, IBRD/WB & IEA GTF (2017), IEA (2016a), IEA (2017a), IEA (2017b), REN21 (2017), World Bank Rise (2017) Some further countries may have started to respond to the challenge more recently, which is not yet considered in this classification.

Power sector institutional arrangements and intensity of challenges

Table 2: Africa (selection)

Country	B	R	E	Framework
Algeria				I.b
Angola				I.b
Benin				I.a
Botswana				I.a
Burkina Faso				I.a
Burundi				I.a
Cameroon				I.b
Cape Verde				I.b
Central Afr. Republic				I.a
Chad				I.a
Congo				I.a
Congo (D.R.)				I.a
Cote d'Ivoire				I.b
Egypt				I.b
Eritrea				I.a
Ethiopia*				I.a
Ghana*				I.b
Guinea				I.a
Guinea-Bissau				I.a
Kenya*				I.b/II
Liberia				I.a
Madagascar				I.b
Malawi				I.a
Mali				I.a
Mauretania				I.a
Morocco				I.b
Mozambique				I.a
Namibia				I.a
Niger				I.a
Nigeria*				I.b/II
Rwanda*				I.b
Senegal				I.b
Sierra Leone				I.b

Country	B	R	E	Framework
Somalia				I.a
South Africa				I.b
South Sudan				I.a
Sudan				I.a
Tanzania				I.b
Togo				I.a
Tunisia				I.b
Uganda*				I.b
Zambia				I.b
Zimbabwe				I.b

Table 3: Americas (selection)

Country	B	R	E	Framework
Argentina*				III.a
Bolivia				I.b
Brazil*				III.a
Chile*				III.a
Colombia*				III.b
Costa Rica*				I.b
Cuba				I.b
Dominican R.				I.b
Ecuador*				I.b
Guatemala				I.b
Haiti				I.a
Honduras*				I.b
Jamaica				I.b
Mexico*				III.a
Nicaragua				I.b
Panama*				I.b
Paraguay*				I.a
Peru*				III.a
Uruguay				I.b

Table 4: Asia (selection)

Country	B	R	E	Framework
Afghanistan				II
Bangladesh				II
Cambodia				I.b
China P.R.				II/III.a
India				II/III.a
Indonesia*				II
Jordan				I.b
Lao D.R.*				I.b
Malaysia				II
Mongolia				I.a
Myanmar				I.b
Nepal*				I.b
Pakistan				II
Philippines*				III.a/III.b
Sri Lanka				I.b
Thailand				I.a/I.b
Vietnam				II
Yemen				I.b

Source: In this classification attempt numerous sources were used including: Bloomberg NEF Climatescope (2017), Energypedia Countries Portal, IBRD/WB & IEA GTF (2017), IEA (2016a), IEA (2017a), IEA (2017b), REN21 (2017), WBG Rise (2017), WBG (2018)

Legend

B	Bulk power area
R	On-grid retail and distribution area
E	Off-grid electrification
*	Hydropower and geothermal generation options

Challenge Intensity

	High
	Intermediate
	Noteworthy
	Marginal

Current Institutional Framework

I.a	Fully vertically integrated monopoly
I.b	Vertically integrated monopoly with procurement from IPPs
II	Unbundled & IPPs; competition limited to long-term contract procurement
III.a	Competitive wholesale market
III.b	Competitive wholesale and retail markets

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5.2 Countries Challenged by Transformation in the Bulk Power Area

We classify institutional challenges from change and transformation in the bulk power – meaning central generation, transmission, and wholesale markets – as high (red), intermediate (orange), or low (green). High and intermediate countries are those that:

- have a significant or noticeable (around 5% or more) share – and rapid growth – of vRE, either overall or in a regional part of the power system;
- have ambitious policy targets (20% or more) for variable renewable energy in the medium term;
- have adopted effective policy support policies (FiT, renewable portfolio standard, net metering, or fiscal support) for vRE sources;
- have the technical capacity to apply innovations, i.e. a sufficiently skilled and trained staff within a currently well operating system;
- are either able to afford the relatively high upfront investment of vRE themselves or offer good investment conditions and reasonable risks for external investors in these technologies.

Further to the lists of countries in above Tables 2 to 4, Figure 8 shows the intensity of power system challenges and urgency to modify power sector institutional frameworks:

- Countries with the highest intensity of power system challenges have implemented wholesale market competition. These countries are reform-oriented in both institutional and technological aspects of power sector evolution.
- Some countries rated as facing high intensity of challenges have undergone unbundling of generation and transmission and have IPPs, while others have monopolistic, vertically-integrated systems with IPP participation.
- Many, mainly Asian, countries with partly unbundled sectors and IPPs are categorised as facing either high or intermediate intensity of challenges. Many African or Central-American countries are still rated as integrated but allowing IPP also face high or intermediate challenges.
- Only a few countries with full vertical integration and no IPPs face high intensity of challenges, but many nonetheless are considering or preparing access for IPPs in some form.
- Note: Countries facing institutional challenges which have significant hydropower and geothermal capacity (or potential) - marked by an asterisk in the tables - are much better equipped to balance high shares of vRE.

Further observations regarding individual countries:

- Mexico, China, Brazil and India, the large EEs are among the countries facing the most intense challenges. These countries are expected to reach approximately a 10%-share or more in power generation from wind and solar power by 2020.
- Other countries with 2020 targets of over 10%-share in generation from solar and wind power include Egypt, Ethiopia, Jordan, and Morocco. Uruguay, Cape Verde, and other island states attain much higher shares.
- Some subnational territories within interconnected systems in DCs are reaching very high shares of variable renewable energy. Examples include Xinjiang and Inner Mongolia in China, Tamil Nadu in India, Northern Chile, and Negros in the Philippines.
- South Africa is an example where IPPs are designed specifically for RE development, thereby modifying the institutional arrangement, since IPPs did not exist before.
- In some countries, including Costa Rica, IPPs are limited specifically to RE generation.

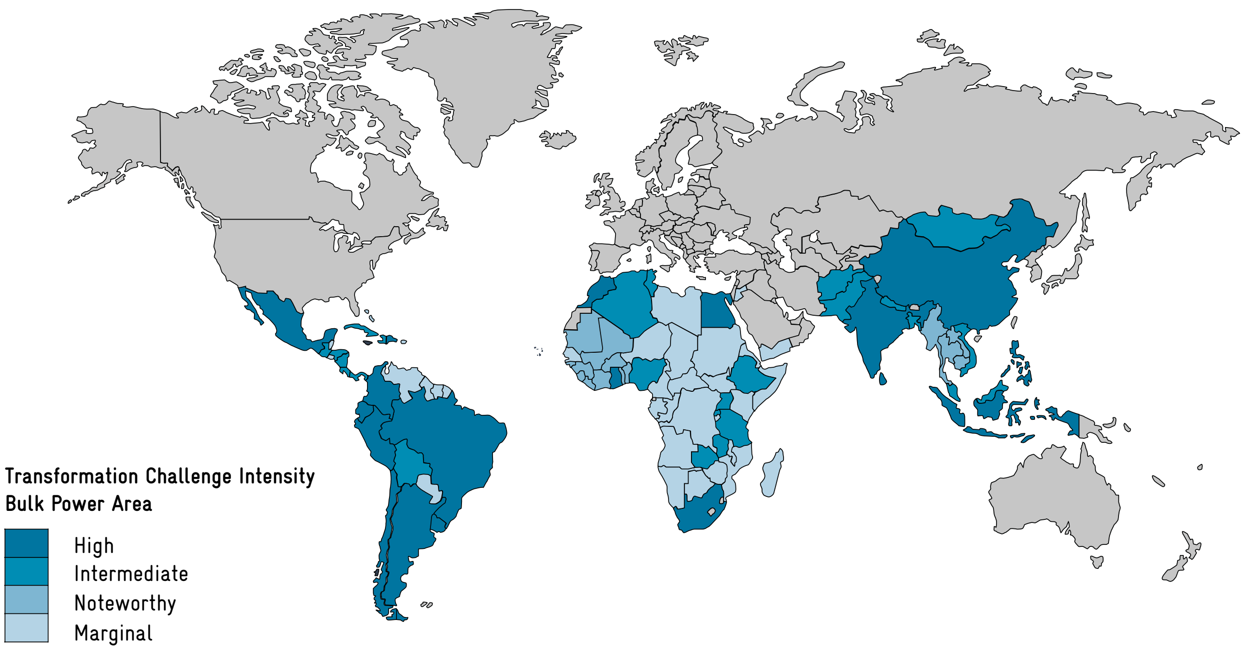

Figure 8: EEs and DCs most concerned by transformation challenges in the bulk power area (source: illustration of Tables 2 to 4 by authors)

5.3 Countries Facing Challenges in the Distribution and Retail Area

The intensity of the challenge faced by countries in their retail and distribution area depends on the presence and intensity of the following factors:

- Presence of national or subnational policies that promote DG, including net metering, DG-specific feed-in-tariffs, digitalisation of metering & grid, or embedded mini-grids;
- High retail electricity prices;
- Poor power supply quality;
- Frequency of residential and commercial consumers with back-up power generators;
- Few obstacles to self-generation by consumers;
- Availability of DG equipment in local markets;
- Presence of viable business models for equipment suppliers and services.

According to this analysis (visualised in tables 2 to 4 and in Figure 9), EEs with advanced regulatory frameworks face the highest intensity of change in power sector retail and distribution. Two factors drive this conclusion: policies promoting DG and accelerated introduction of intelligent grids.

Countries with little or no power sector competition are often categorised as facing intermediate level of challenge – driven by relatively high consumer electricity prices in many countries in Africa, the Caribbean, Central-America, and Asia. Given unreliable supply, many wealthier residential consumers and businesses in many lower-income countries invest in self-generation. Third-party investors are frequently engaged in such countries, either operating small generators at or near a client's property, or by also supplying both electricity and heat.

The combination of high consumer prices, unreliable power supply, and decreasing cost of solar PV and storage together are pushing an increasing number of residential and commercial consumers to generate their own power. Many do so without coordinating with or even informing their respective distribution companies. It is inherently difficult to quantify informal and unregistered DG or assess trends in its deployment. Where distribution companies do not have a good information and control system in place, DG can disrupt local grids and potentially further strain the reliability and stability of power supplies.

Some countries in all continents – including Chile, Brazil, Guatemala, Dominican Republic, Tunisia, Ghana, Kenya, Jordan, Sri Lanka, Pakistan, South Africa, and the Philippines – have launched net metering and net billing schemes geared toward tapping the potential for DG. Still more countries have adopted DG-specific FiTs, typically limited them to small or medium-sized installations. However, nowhere in the developing world distributed vRE reached the level of Germany (which promoted distributed energy via a FiT) or California (which primarily relied on net metering). Recently, China is using a DG-specific FiT and subsidy to promote rooftop solar PV in addition to larger, ground-mounted distributed solar plants.

In some EEs, mostly in Asia, utilities are introducing smart metering systems in order to save cost and speed-up communication in metering and billing. In other countries, such as in Barbados, utilities have introduced a somewhat wider scope of smart grids that allow monitoring and eventually controlling the DG.

China is experimenting with smart grids in cooperation with grid operators and IT companies. They aim to explore standards and institutional implications, partly in order to compete in the future global market for smart appliances and meters.

Intelligent grids are also looked at in so-called 'smart cities' schemes, mostly in Asia where the affinity to ICT and the IoT is high.

Finally, some EEs are experimenting with local networks, mini-grids, and VPPs both, in rural but also urban environments.

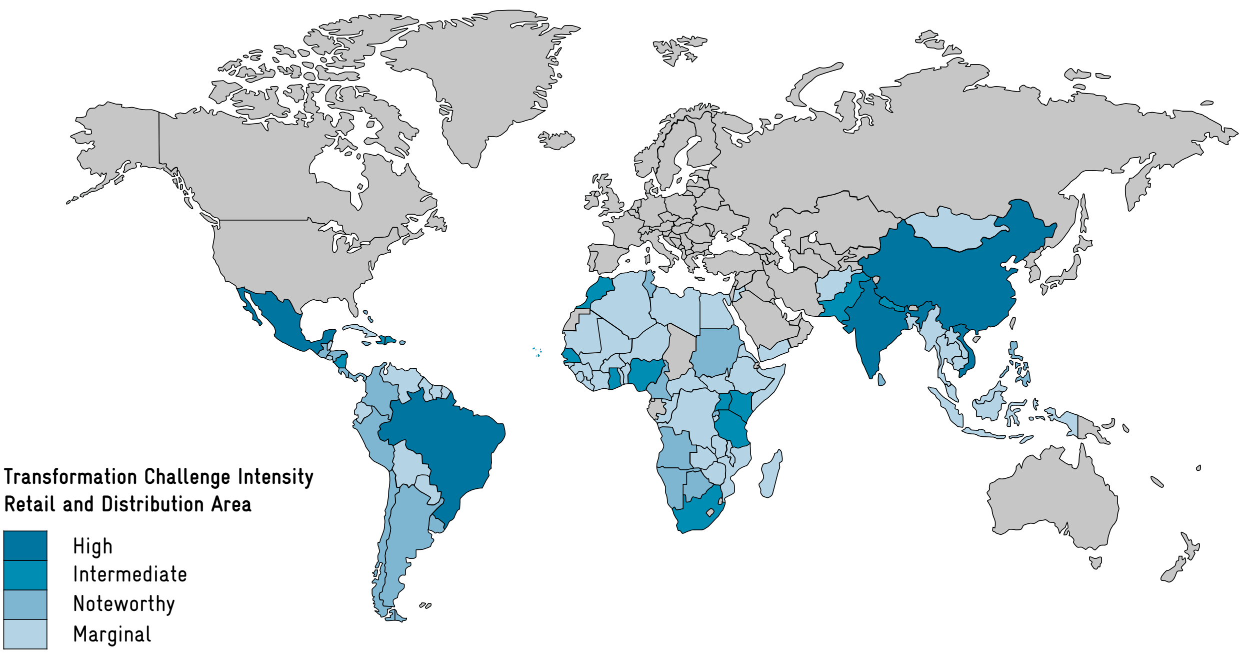

Figure 9: EEs and DCs most concerned by transformation challenges in the retail and distribution area (source: illustration of Tables 2 to 4 by authors)

5.4 Countries Most Concerned with Electrification

Figure 10 shows an illustration of countries with challenges to provide access to electricity, classified according to the number of people without access (see also Figure 4).[39] High intensity signifies 50 million and more; Intermediate signifies more than 10 and less than 50 million; Noteworthy means more than 1 and less than 10 million people.[40]

There is a concentration of high numbers of people without access to power in South Asia. Some South-East Asian countries also still face this problem, yet, to a lesser extent. Electrification is close to be completed in Latin America. Only very few LAC countries appear with more than one million people without access to electricity in this list. Similarly, North African countries do not face major electrification issues.

In contrast, almost all sub-Saharan countries appear in this list except for South Africa, Gabon, and Cape Verde. Very small countries like the Gambia or Djibouti have fewer than 1 million people, but have large shares of people without access to electricity.

In most countries facing challenges around access the power sector is still fully integrated (many countries in Africa plus Yemen) or somewhat unbundled and admitting IPPs in the interconnected system. However, India, Pakistan, and Nigeria as well as Bangladesh and Indonesia have advanced IPP participation with SBs.

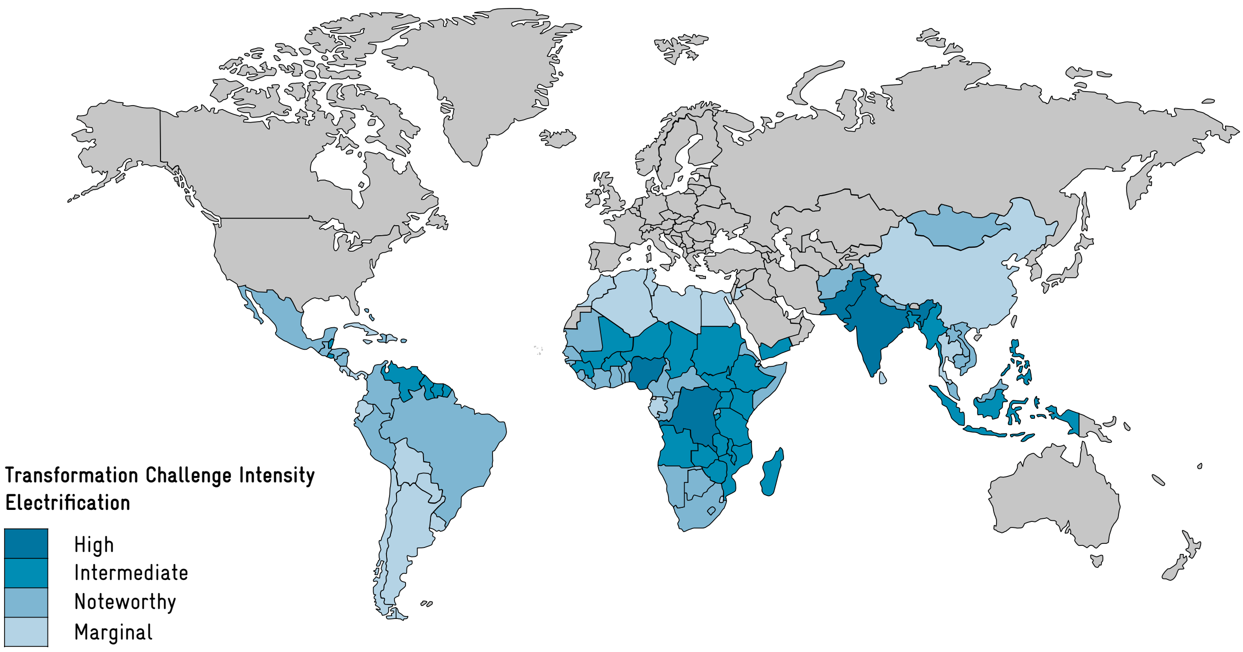

Figure 10: EEs and DCs most concerned by transformation challenges with electrification (source: illustration of Tables 2 to 4 by authors)

[39] Source for the number of people is IEA (2017b).

[40] The downside of this classification: large countries appear with important challenges even when share of population non-supplied is small; very small countries are probably listed as having a low challenge intensity, even when the share of inhabitants without electricity access is significant. See also the presentation according to share in figure 4, chapter 2.

The challenges are not new. Indeed, they originated well before the profound changes began to transform power sectors, but now that PV is becoming more affordable these challenges have become more immediate.

Electricity access has improved during the last decade, particularly in Asia. This improvement has brought the overall number of people lacking access down to 1.1 billion in 2016 from 2.3 billion in 2000.

The IEA distinguishes three categories of grid access: central grid-access, mini-grids, and off-grid, meaning individual systems including solar home or smaller task specific devices, like lanterns. The IEA is confident that universal access can be largely completed in Asia by 2030, leaving approximately 0.6 billion unconnected, mostly in sub-Sahara Africa. According to the IEA's projection, of those gaining access through 2030, just fewer than 200 million will be connected to the central grid, just fewer than 300 million will be connected to mini-grids, and approximately 200 million will use individual supply (home systems or smaller devices).[41]

Unfortunately, the projected number of people gaining energy access by 2030 would not be sufficient to attain the respective objective of the Sustainable Energy for All (SEforAll) initiative, to 'ensure universal access to modern energy services', adopted also in the UN Sustainable Development Goal 7.[42] SEforAll is stepping up its efforts pointing to intensified policies to accelerate achieving the goals.[43]

According to forecasts, the majority of those newly acquiring access will rely on decentralised renewable energy. SEforAll therefore emphasises the need for policies to use these technologies with highly beneficial development benefits.[44]

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[41] See IEA (2017c).
[42] See UN (2018a).
[43] See various policy briefs in UN (2018b).
[44] This emphasis is particularly outlined in Policy Brief #24, see BMZ et al. (2018).

6 Reform – Challenges and Options

Given the transformative changes on-going and expected also in DCs, it is important to consider policy options and recommendations, prominently for institutional issues and challenges. These include suggestions for the regulatory framework of generation and transmission (i.e. bulk power), framework for power distribution and retail, and also for expanding access to electricity.

6.1 Pathways of Reform – Adaptive Realignment or Evolutionary Transformation but Little Revolutionary Change

In this section we present options and suggestions for realigning institutional frameworks without changing the basic setup of the power sector institutions. Such shifts may or may not lead to an evolutionary transformation of the institution. Adaptive realignment and evolutionary transformation are often difficult to distinguish until after the process has been completed: What starts as a mere adaptation might set-off an evolution.[45]

The introduction and contracting of IPPs through a competitive bidding process in an initially fully integrated system without IPPs, for instance, represents a transformational move from a type I.a framework to type I.b. Furthermore, an unbundling of the initially integrated system with IPPs, eventually separating the TSO from the SB, we classify as a shift from type I.b to type II. This may include reconsidering where transmission and distribution functions should be separated, in order to better coordinate vRE offtake in primary distribution grids. A further unbundling of the system to create a wholesale platform represents a move from type II to type III.a.

More drastic institutional change – that is revolutionary and rapid change in power sector institutions to a competitive market framework – would imply a sudden change, as exemplified by the institutional changes in many ICs in the 1990s and 2000s. These drastic institutional reforms of the power sector are fairly uncommon, particularly in the recent two decades.

The power sector has instead seen evolutionary processes leading in new directions. This includes hybrid designs of competitive power markets, with competitive bidding for long-term PPAs. Such hybrid reforms were unforeseen by power reform textbook authors.

6.2 General Suggestions

Some countries face major challenges in all segments of the power sector, while others face strong challenges in only a few segments. Most of the institutional options to deal with these challenges are specific to the subsystems and to the initial market and institutional framework in each country. In this chapter, we therefore describe policy options for the three areas of the power system distinguished in chapter 5. In addition, some general suggestions apply across subsectors.[46]

In general, there must be political will, manifesting in high-level and broad support from government leaders and policymakers, to shape the power sector according to the development objectives in the face of the inevitable change. Energy policy executives and regulators need to be strengthened for the upcoming change, since they play a decisive role in guiding the transformation. Policy and regulation must act independently and not be influenced by strong companies.

It is essential that legislation provides an appropriate framework for changes in the power sector. Legal

[45] This terminology for pathways (adaptive realignment, evolutionary transformation, reconstruction or revolution) is taken from NREL (2015).

[46] Described policy options are a result of research, discussions within GIZ sector project 'Technology Cooperation in the Energy Sector' and consultants, and comments from expatriate experts; recently revised, taking into account IEA (2017a), IEA (2016a), IEA (2016b), IEA RETD TCP (2016), IRENA (2017).

frameworks set the stage for regulators and other authorities to respond appropriately to market changes. Legal frameworks include tools like codes for technical and operational requirements – namely, grid codes, licenses, standards for respective products and services, custom and tax laws. Legal frameworks also establish requirements for setting tariff levels and systems for grid and other charges, such as charges for ancillary services. To improve economic efficiency and create incentives for a more dynamic and sustainable power system, regulators are recommended to adopt performance and incentive regulation principles for grid operators.

Additional suggestions include:

- Adopt mechanisms to ensure adequate investment in generation and grids in view of growing demand, ensuring resource adequacy and reliability.
- Support low-carbon technologies and renewable energy, using mechanisms that are compatible with the existing power sector framework.
- Design appropriate, long-term support mechanisms for low-carbon technology. Support mechanisms should be compatible with wholesale power markets and minimise distortions – for example, by being designed as complementary to an eventual carbon tax or carbon emissions trading system.
- Adopt pricing of negative externalities, including meaningful prices for carbon and other air pollution emissions as well as for water consumption and pollution. Such pricing mechanisms can reduce the cost of support schemes for low-carbon technologies and gradually reduce the need for explicit RE promotion schemes.
- To the extent possible, undertake overall power sector planning activities – including in competitive markets such as those with competitive bidding. Coherent energy and especially power system planning may include harmonising additions of central and DG with transmission and distribution grid planning, applying integrated resource planning, and working to resolve the spatial and temporal distribution of generation assets and grid investments.[47]
- Establish or enhance an independent power sector regulatory framework, whether for competitive market frameworks or vertically integrated systems. Strengthen the regulator and enforce regulatory rules, to ensure fairness and to counterbalance distortions that may arise from political intervention by the largest and most powerful players in the electricity sector.
- Consider performance regulation of grid companies: shift towards a service-based approach and include performance criteria instead of mainly cost criteria.
- Prepare the frameworks for the incorporation of new emerging technologies (e.g. storage technologies, CSP, hydrogen, sector coupling).
- Build understanding of importance and capacities of institutional regulatory development, based on international, in particular from DCs' experiences.

[47] Discussed in EUEI PDF, GIZ (2018) and GIZ (2018).

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6.3 Challenges and Options in the Bulk Power Area

The general recommendations highlighted above are relevant for the bulk power subsector. In this section we add or specify options for this subsector by type of the challenge.

6.3.1 Adequate and Clean Power

Challenge: Ensure sufficient and clean power in view of a growing demand on the one hand and the need to prepare for a profound transition of the power sector on the other. Newly added generation resources must not only meet immediate needs, but reflect future needs for clean and reliable power in the context of power sector transformation. In other words, the challenge is to avoid stranded investments in both generation and transmission.

i) Regional interconnection and cross border exchange

All frameworks can benefit from enhancing their potential to exchange electricity over larger geographical areas, including both facilitation of cross-border trading as well as investment in new interconnections. This involves implementing regulation and legal frameworks allowing bilateral cooperation within countries, and a regional coordination agency with a mandate to optimise system operation on a regional basis.

vRE development tends to concentrate in geographical 'hot spots' with good wind and solar resources. For utility-scale vRE, these 'hot spots' are typically located in remote areas far from major cities or prior transmission corridors, leading to difficulty enabling energy to reach consumption centres. In some cases, this reduces investment in otherwise valuable renewable energy, and in others it leads to transmission congestion and renewable curtailment. This situation can be seen in China, India, South Africa, Chile, and Germany – in other words in a variety of economic, institutional, and geographical contexts. Resolving this challenge requires not only investment in new transmission, but also better coordination between constituencies within and between countries. For example, to address the issue of renewable integration India has set up the 'Green Energy Corridors' program.[48]

ii) Expanding clean generation in countries or regions without competitive wholesale power markets

We suggest various regulatory reforms to accommodate clean energy and distributed energy in countries and regions without competitive wholesale markets. These recommendations apply to those countries open for IPPs (type I.b), considering allowing IPPs (type I.a), as well as vertically separated systems with SBs and IPPs (type II).

Incumbent generation operators, whether generation departments of integrated utilities or unbundled entities, tend to be conservative in terms of generation investments. In addition, incumbent generators tend to create obstacles for third-party investors in low-carbon generation – particularly if incumbents face falling revenues and risks of asset stranding. In such settings, incumbent generators often face risks that affect their entire value chain, heightening opposition to reform. Often incumbent generators can mobilise support from local government authorities, especially when vRE generation or its upstream manufacturing centres are concentrated in other jurisdictions or regions – or even in other countries. Central governments and local economic actors need to find a constructive solution that is satisfactory for all.

Some generic regulatory options in this situation include:

- Introduce low-carbon or renewable portfolio obligations for incumbent generators, perhaps connected to performance-based regulation.
- Reduce the market influence of incumbent generators, such as by unbundling generation from transmission, possibly creating a SB.

[48] See Power Grid Corp. of India (2012) and KfW (2016). The program is supported by German technical and financial development cooperation with funding from Federal Ministry for Economic Cooperation and Development (BMZ).

- Strengthen regulators, including through augmenting legal frameworks, adding resources, and introducing requirements for market and planning transparency.

The expansion of low-emission generation in DCs where IPPs are active and PPAs are used faces various obstacles: contractual, financial, legal, or regulatory. These obstacles can only be removed by policy and regulation.

Contractual obstacles: Incumbent IPPs and their long-term PPAs for fossil energy or hydropower often constitute contractual obstacles to expanding vRE. Such contracts typically include take-or-pay clauses. Since payments of the off-taker (e.g. a single-buyer) cannot be reduced, even if cost (and greenhouse gas emissions) of the overall system could be reduced, by decreasing the operation of the IPPs' conventional plants, this directly reduces the revenue available for newly added vRE. Therefore, where possible, existing contracts should be revised and renegotiated to introduce higher flexibility according to vRE volumes. This can include compensation for a loss of incumbent generator profit margins or a capacity payment. If done well, such compromises can be cost-efficient and reduce emissions. It is urgent for regulators to change the framework of new IPP contracts and reduce existing inflexible take-or-pay clauses.

Financial obstacles: Developers and investors in low-carbon generation face high risk and need some degree of revenue certainty. Increasingly, PPAs have become the solution of choice. PPAs are popular in vertically integrated systems and can be contracted with the integrated utility, as well as in unbundled systems with a dedicated SB. PPAs can also be undertaken by a system operator, such as the transmission company, although even many utility-scale wind and solar plants are connected at distribution-level voltages. As seen above, it is important to structure general PPAs appropriately for the future system in terms of delivery, and avoid take-or-pay clauses and other contractual inflexibility. A way to balance risk and profitability is competitive procurement, such as auctions. South Africa demonstrates how this can be done even in vertically integrated systems. To make PPA contracts more attractive for RE, the value of capacity and ancillary services can be included.

Legal obstacles: Large self-generators in DCs often face legal obstacles concerning grid access, especially in cases with a monopoly grid operator. Obstacles are particularly severe if the self-generation is located distant from consumption and involves the use of the existing grid, possibly based on a bilateral supply contract with a dedicated RE-IPP plant. Therefore, it is strongly recommended to apply transparent and non-discriminatory rules for third-party access. The regulator should also assure that the grid-connected self-generator receives non-discriminatory ancillary services such as peak load, reserve, frequency, and voltage control.

Regulatory obstacles: At the bulk power or wholesale power market level, it is important for the regulator to enable aggregated DG to contribute to overall supply, where existing in wholesale markets. In the future, as DG volumes rise, there will be regions where DG exceeds local consumption, requiring off-take via transmission grids and in wholesale markets.

iii) Expanding generation in set-ups with wholesale competition

ICs have examples that can provide solutions for issues around the expansion of generation in unbundled systems, with competition at least on wholesale level (type III). Since future demand differs considerably from today's levels, EEs show a tendency to deviate from the patterns of ICs. Instead of fully unbundled and liberalised power sectors, many EEs have adopted hybrid systems.[49] Examples include Chile and Brazil, as well as Mexico and the Philippines. These countries have addressed needs for new capacity and/or future energy supply by conducting government-supervised auctions for long-term power procurement contracts similar to PPAs. This type of auction mechanism includes a significant degree of centralisation of market design – layered on top of decentralised wholesale market price signals. This approach also allows the government to define eligible technologies to shift towards

[49] The capacity markets approach used in the United Kingdom and France is equally considered to make the system hybrid but is apparently not regarded as being attractive in developing countries. Similarly, the German approach of the regulator ensuring capacity by prohibiting plant decommissioning may not find imitators among the countries without market competition.

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a low-carbon system. It even allows regulators to determine generation zones as a function of resources availability, and thereby plan corresponding grid investments.

Countries with more competitive power markets have also studied this hybrid design. However, it is important to carefully design the interface between centralised and decentralised processes. The hybrid approach requires careful planning in terms of capacity and energy needs as well as analysis of trading volumes and load profiles. It also requires regulators model future resource areas, grid capacity, as well as ancillary services. Furthermore, the competitive procurement process requires significant process transparency, which not all institutional frameworks are prepared to provide. To ensure adequate generation resources, guarantee mechanisms and mandatory risk hedging contracts should also be awarded through transparent auctions.[50]

In competitive markets, regulators should ensure that the revenues of low-carbon-generators also dependably reflect not only energy payments and eventual payments for co-benefits such as carbon reduction, but also their contribution to system security and other services. Barriers for the ancillary market participation for new technologies need to be eliminated.

6.3.2 Expanding and Restructuring of Transmission

Challenge: Ensure that the transmission system including the substations and dispatch is physically able to work efficiently and reliably, even in the face of increased vRE and DG. Meeting this challenge requires targeted investment, aiming at sufficient transmission capacity at any time. Adequate transmission capacity will be required to connect central generation, large vRE plants located in solar or wind resource zones, large storage plants, and border coupling stations on higher-voltage levels of the system. Furthermore, sufficient transmission is needed to connect new types of users, such as power-to-X, and substations with specific demand profiles, for instance large industry or consumption centres.

To meet this objective, the existing transmission system has to be reinforced and expanded, based on new principles, anticipating future vRE. In most DCs this will coincide with rising electricity demand and increased regional integration through additional interconnections. Therefore, close cooperation is required between regulator and governments and their planning on the one side, and the grid operators, owners, and investors on the other.

All countries face challenges restructuring the grid planning process in light of these new conditions. This requires advanced planning tools for generation, transmission, and distribution. Planners will often find that optimising costs and benefits involves emphasising sites with lower yield of RE generation, closer to consumption, and near under-utilised transmission capacity, eventually using nodal pricing

To assure national policies and priorities are enforced and upheld, as much as possible grid planning should be performed independently from the incumbent grid operators and closely supervised by regulators. In countries with public service utilities, such as those inspired by the design of the French system, a regulator with strong planning capacity must be involved.

6.3.3 Flexibility and Use of Excess Power

Challenge: Increased flexibility is an imperative for a changing power system with increasing shares of vRE. In most markets, vRE generation is dispatched first in the merit order and makes residual load even more variable. This requires dispatchable resources, supported by other measures on the demand side, to become more flexible. For regions with very high proportions of vRE, supply flexibility plus new uses of electricity are expected to be the principle means of resolving grid integration issues. This raises a host of issues for market design and regulation.

Integrated utilities or system operators have a number of options to increase flexibility: power system management, demand-side management (DSM), increased supply flex-

[50] GIZ (2015), Eberhard et al. (2016).

ibility, network flexibility, and storage.[51] In moments of very high generation from renewable sources, power can be exported or used for new applications, such as electric mobility or power-to-X.

Considerable amounts of flexibility can be accessed by low-cost changes. Investment is needed for storage, EV and power-to-X. For some, including storage and power-to-X, substantial research and development investment is still needed. Other measures require a change in system operations, such as DSM and power system management.[52] In any case, flexibility measures involve some kind of regulatory attention.

While investment in enhancing system flexibility may be viewed as an unwelcome cost, system inflexibility imposes hidden costs on society. Reducing excess generation of RE by curtailment represents an opportunity cost, which is borne by both investors in renewable energy and related infrastructure, as well as by society as a whole in the form of negative externalities from unnecessary consumption of fossil fuels. When renewable energy is not curtailed, but rather sold at a zero or negative price due to lack of system flexibility, this may represent a loss of economic value for the generation sector as a whole.

In principle, power imports and exports can be an efficient flexibility measure because they potentially expand the balancing area of generation beyond borders. This has value particularly if the demand load profiles differ significantly across geographical areas, or when one side has a high potential for low-carbon power generation, such as in hydropower. As mentioned before, this situation requires regulatory and legal frameworks for bilateral cooperation – potentially including a regional coordination agency responsible for planning or system optimisation. Several such agencies and cooperation agreements exist, but few have broad mandates covering all such functions.

Some recommended measures to increase flexibility are regulatory, such as grid codes. Precise forecasting of RE generation and demand also allow for higher flexibility; as do ancillary service markets that offer payment for flexibility options. Experts also recommend measures to shorten time intervals in scheduling and dispatch to better reflect variation in renewable energy production profiles. Other regulatory measures involve the expansion of the boundaries of balancing areas.

Demand response (DR) has proven a cost-effective flexibility measure in many markets – including in many power regulatory frameworks, and thus is recommended by most experts as a measure for enhancing system flexibility. DR may be associated with other flexibility mechanisms, such as energy storage. DR, energy storage, and vRE may be aggregated to create VPPs, in systems where the respective aggregators are active. Distribution companies may become the platform operator for such transactions, as discussed in greater detail below.

One of the most cost-effective options for flexible supply is hydropower. Apart from the rapid response time (fast ramping) of hydropower, insertion of hydro storage also offers the possibility of daily or longer-term flexibility. Availability generally fluctuates though throughout the year, allowing for more or less flexibility in different seasons. Furthermore, climate change can impact the future availability, making it a less reliable resource.

Gas turbines are fairly cost-effective ramping tools when not only used for ramping but also for peaking and capacity provision and appropriately remunerated in electricity and system service markets. In some cases, regulators may allow capacity payments to ensure sufficient revenue for peaking plants that would otherwise be economically uncompetitive in wholesale markets – a topic requiring careful consideration to avoid market discrimination in favour of incumbent resources or entities.

Coal-fired steam turbines in contrast are expensive and need refurbishment for higher flexibility. The approval of such refurbishment is also a contentious regulatory, including air quality standards, and political issue – which creates further path dependencies.

[51] See also NREL (2014).

[52] IEA offers a scale of priorities and order of importance, that can serve as a guide to countries at the beginning of their RE expansion; see IEA (2017d).

Flexible network management and smart substations are another low-cost measure for enhancing system flexibility. Dynamic line rating can be an alternative to new transmission investment. These measures typically involve changes in regulation, even more so when applied to cooperating transmission and distribution companies. Expanding and reinforcing the transmission system seems costly when considering flexibility on its own, but the cost of such upgrades may seem more justified when taking into account longer-term needs to reconfigure the transmission system for changing generation types and locations as well as distributed energy. Recent cases show that system operators are starting to embrace new and innovative approaches for flexibility.[53]

Improving the short-term flexibility of CHP stations is another cost-efficient option. Flexibility can be increased by expanding and reducing the power or heat production, using the inertia of heat energy in district heating pipes (and dedicated thermal storage) for maintaining supply in the heating system. Such changes may not even require altering power sector regulations, but rather in updating standards of heat supply.

Energy storage is another option for flexibility in power systems and is presently considered expensive in all but a few markets with advanced designs and high penetration of renewables. Several electrochemical storage technologies have reached the commercial stage at scale, recently in South Australia, while other appealing storage technologies remain in the development stage. In Australia and Europe, residential and commercial energy storage systems have been commercialised and are available at rapidly falling cost. It remains unclear, due to a lack of knowledge base and experience, whether electrochemical storage will work better at the end-user level, with or without EV-batteries, or within the primary (medium voltage), secondary (low voltage) distribution levels, or within the transmission system. The permission for grid companies to operate storage is a regulatory issue in competitive systems where unbundling determines the separation of distribution service, generation, and trading.

A number of countries and regions are shifting towards electro-mobility, including for passenger cars and freight trucks. However, in countries that already have large numbers of public EV charging stations, these charging stations currently do not enhance power system flexibility, and only a few utilities have experimented with EV charging DR programs such as interruptible charging, timed charging, or dedicated EV charging rates with time-of-use pricing. In most jurisdictions, implementing EV charging as a DR measure – whether modulating charging times, or vehicle-to-grid services that inject power into the grid from EV batteries – would likely require regulatory reforms. In the long run, controlled EV charging as well as power-to-heat, power-to-gas, or other variable demand 'sinks' will help to absorb surplus generation in the power sector, particularly in regions with a very high share of wind and solar. This however would require the development of a spatially inclusive and comprehensive charging infrastructure.

6.3.4 Efficient Operation of Bulk Power Area

Challenge: Prepare the transmission system and wholesale market for growing shares of vRE, injected at multiple points, and for multidirectional flow, including upwards from distribution.

This challenge requires the operator – integrated or not, SB or TSO – to adjust the transmission system, in particular dispatch, and enable it to become more flexible in response to a changing mix of generation and DR resources. Dispatch practices have to be improved by refining short-term forecasting of generation and demand and taking faster operational decisions.

Policymakers and regulators must accompany this process by keeping the dispatch and transmission independent and free from discrimination. To do so, it is necessary for regulators to closely monitor dispatch and also give

[53] See NREL (2014), p. 11.

priority to dispatch of low-carbon-energy in cases where it would otherwise face distortionary obstacles, such as curtailment due to take-or-pay PPA contracts, and make sure that the benefits of low-carbon are included in the price signals. To enable a rapid transition to low-carbon energy sources and prevent investments in potentially stranded fossil generation, regulators must also push the system operators to adapt rapidly to new circumstances. Adaptation goes hand in hand with investment planning and approval processes. Where possible and the respective wholesale market signals exist, least-cost dispatch can be combined with high value criteria (depending on scarcity). Regulators may introduce standards relating to the performance of the TSOs and SBs and, if applicable, market operators.

To improve the efficiency of wholesale power markets, pricing can reflect temporal scarcity situations in both the grid capacity and generation. Such measures could be introduced for the entire grid or only for parts of it. In order to reflect grid capacity shortages, zonal or nodal pricing can be employed to better reflect availability of variable resources.

Finally, operational efficiency can be enhanced by reforming or introducing mechanisms for the procurement of system services, creating or adapting payment. It is important that also demand and RE are admitted to participate in balancing markets. Recommendations focus on adjusting balancing markets, in particular by enlarging dispatch or balancing areas, or shifting to shorter dispatch intervals.

6.4 Challenges and Options in the Distribution and Retail Area

Many of the same recommendations that apply overall or to bulk power area also apply to the retail subsector.[54] Since so far only few countries have unbundled distribution from retail and other functions, and thereby introduced retail competition (type III.b), we disregard that market design here. We focus on all other categories where the distributor is not only operator but also supplier in a territorial monopoly. And we disregard whether the distributor is part of an integrated utility or a separate entity.

Distribution companies in many DCs are in a weak position, economically and technically. This is due to price levels set too low to recover costs, unpaid services (that is, so-called non-technical losses), also technical losses, as well as high debt levels, including supplier credits from generators or SBs.

Even in the face of all these challenges, stretched distribution companies will nevertheless also have to cope with potentially transformational changes in the power sector, and they will be on the front lines on issues of integrating distributed solar and storage. Policymakers and regulators will have to pay close attention to enhance the ability of distribution companies to serve customers and maintain reliability in this rapidly changing context – and this includes maintaining revenue sufficient to perform this service.

6.4.1 Smart Metering

Challenge: Smart metering – meaning meters with digital and advanced communication technology for metering, respective software for smart meter control, and incentive – has developed independently from vRE and distributed energy innovations. Smart metering can potentially serve as an enabling application for distributed energy and DR for balancing vRE. At the same time, smart metering opens a new world of data that itself is a valuable resource. Smart meters introduce entirely new challenges, from fraud protection to privacy issues.

[54] In addition to above cited IEA and IRENA sources, see also ECDSO-E (2017)

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Standardising and supervising energy meters have always been key matters for regulation in order to ensure accuracy and security, and smart meters have only brought these issues to the forefront. Smart metering has also boosted the economic significance of metering, as more industries are now interested in metering systems. Therefore, policymakers in legislation and executive administration, as well as regulators have to get involved,[55] but smart metering also needs independent expertise on questions of standardisation, competition, information handling, customer communication, and privacy protection.

With digitalisation progressing on the consumer side (smart homes, IoT) or prosumer side (control of self-generation and self-use, small-scale storage, EV charging) regulatory complexity is increasing exponentially.

6.4.2 Integrating Distributed Generation and Intelligent Grid Technology

Challenge: Higher rates of vRE growth, combined with the relative speed of wind and solar additions compared to traditionally slow grid reinforcement and operational changes.

To cope with rising wind and solar capacity in widely dispersed regions, regulators and grid companies have to think ahead and ensure upgrades including both technical control and operation solutions. Securing rights-of-way for new grid additions, speeding grid operational reforms, and coordination with generators all require action of the regulator.

The overall challenge is one of two-speed growth: i) Utility-scale wind and solar resources, most of which connect to the medium-voltage distribution grid, are often added within a year or two, and grid companies may have limited data or visibility on where such additions are taking place, whereas grid investments and upgrades may take place on longer cycles; ii) Distributed solar and energy storage resources often connect at low voltages and these can be added at an even shorter time-frame than utility-scale wind and solar.

Technical difficulties arise when the total capacity of generation within a distribution grid exceeds the capacity of the transformer station where the power feed is received.

The simplest solution would be to reinforce the distribution grid. But that is a costly solution, which the regulator might accept after full consideration of other possibilities:

- If curtailment is projected to happen rarely, such as a few hours per year, curtailing some plants would reduce the need for and the cost of grid reinforcement substantially, considering the cost for ICT equipment for communication and control as well as the compensation cost for the generation outage.
- Other technical measures, including reactive power management and load management, could substantially reduce the cost of distribution reinforcement in many cases.[56]

Looking specifically at distributed vRE in the low-voltage distribution grid, mainly from rooftop solar PV, the solutions are somewhat different. At this level, the issues result from the different time profile of demand and generation. A study for GIZ India,[57] based on modelling of operating concrete grids, recommends the following successive steps: automatic voltage control at transformer stations, wide area control, and active power controllability of utility-scale plants as well as for rooftop PV. If these are not feasible, the production from small PV units should either be capped, or they should be equipped with a peak-shaving storage.

Such measures would need to be accepted and possibly incentivised by the grid regulator, which determines grid charges, basing the remuneration of distribution companies on their active grid management instead of their cost is way to cope with these challenges. This means DSOs should be compensated for performance with a focus on smart grid investment.

[55] In Germany the regulation for energy grids and telecommunication is united in one regulatory agency, the 'Bundesnetzagentur'.
[56] See E-Bridge et al. (2014).
[57] See GIZ (2017).

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Regulators should insist to begin building a database of distributed projects and their characteristics. This information will be essential once a significant share of DG exists and will be very hard to construct later on.

Practically all of the described measures involve ICT, and need to be addressed by the regulation of technical standards and telecommunication, information transparency as well as privacy protection.

Distribution-level micro-grids have been piloted in the U.S., Germany, and China, as well as in other industrial and EEs.[58] These local networks are connected to the distributor only for the temporary exchange of power and ancillary services. They connect a number of prosumers who are mutually exchanging power, sometimes also thermal energy, on the basis of a clearing platform. In the future, this may be implemented by blockchain technology. Blockchain is a potential solution, also for elimination of market intermediaries and thus, asymmetrical information access.

While the power systems may become technically and organisationally further disaggregated, the informational connections become more complex. For overall system optimisation and for higher security and resilience, an interconnected communication system would be ideal, even in systems undergoing disaggregation. In such a system all levels, such as local cells, secondary and primary distribution level with substantial DG, national transmission level with central generation as well as the international interconnections, could communicate via a network.[59] Some EEs may choose this option – but it requires substantial regulatory backing.

6.4.3 Economic Viability of Distributors

Challenge: Self-generation reduces the quantity of energy supplied to the consumer. In tariff systems where the grid charge is billed principally for the energy quantity, self-generation reduces the revenue of the distributor, without a corresponding reduction in grid cost. The issue gets even more difficult in net metering and net billing schemes, when the prosumer can receive credit in one period for excess generation in a prior period, further stressing the relationship between revenues and costs. (In general, feed-in-tariff schemes avoid this problem, because distributed energy is metered separately and compensated from other funds.)

The issue of distribution revenue and distributed energy is a hot topic in many regions, such as in many U.S. states, as well as countries with substantial small-scale distributed solar. Policymakers, regulators, and clean energy proponents are seeking solutions that keep incentives for solar (and distributed storage, in some cases) without imposing a large burden on other customer classes. For those who have already invested in distributed energy, maintaining incentives is especially contentious, since their investment decisions and financing are both likely based on expectations of stable incentive policy. However, reforms need to maintain the economic viability of distribution companies not least because they continue to provide generation backup and ancillary services. The details of metering, billing for energy capacity or connection and for crediting are modified in many countries, at least for new net metering arrangements. Potential modifications include a limitation of individual or aggregated installed capacity of net metered generation, a reduced period of time over which energy injections can be offset with energy withdrawals, and/or a changed structure of retail tariffs and compensation rules.

[58] The smart grid development in China and its regulatory framing is supported by the Sino-German Technical Cooperation. See Brunekreeft, et al. (2015).
[59] Siemens is bringing such idea involving satellite communication into discussion, see Siemens (2016).

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A further penetration of small, DG challenges the traditional supply business of distributors.[60] However, new business opportunities arise, including distribution level storage, or EV charging stations. Also, distributors may invest in and operate utility-scale plants themselves, such as RE or municipal waste plants and other CHP plants supplying also district heating or cooling.[61] Moreover, DG can also become an opportunity for the distributors. They may even strike agreements with consumers on the installation and/or operation of plants on their sites. Activities of this sort have to do – among others – with market access and possible misuse of market power. Those have to be addressed by policymakers and regulators. Policymakers should establish a framework that is open for innovations and new solutions rather than restrictions.[62]

6.4.4 Securing Market Access for Self-Generation

Challenge: The distribution company, in particular when it is linked to the incumbent generator or when it fears loss of revenues, might be reluctant to connect and serve the prospective prosumer or require excessive fees or tariffs to do so.

Regulators and policymakers generally seek to avoid abuse of monopoly power in such situations. Many distributed energy policies include safeguards for prosumers, such as clauses for connection or fixed dispatch of the power generated. Policymakers may also set the conditions for aggregation of consumers (mini-grids, community solar, also ESCOs) and their relation to the distributor in a monopoly area.

In any case, policymakers have to consider how to balance rights and obligations between distributors and future prosumers, leaving room for new arrangements. Regulators for their part have to ensure fair implementation and enforcement.

6.4.5 Avoiding Informal Self-Generation and Grid Defection

Challenge: Defection from the grid, in particular informal grid defection, is becoming an issue in many DCs.

When consumers install self-generation without coordinating or informing system operators, it can create planning, safety, and reliability issues for the distribution entity. Informal additions of self-generation often occur in countries with weak regulatory frameworks and enforcement, with self-generation (PV, diesel genset) equipment supply, where end-user electricity prices are relatively high, and where supply security and quality are low.

When such informal self-generators continue to obtain services from the grid but pay only for parts of them, they are free riders at the expense of others. In this case at the expense of all other consumers that normally carry the cost of distribution jointly - or at the expense of the taxpayer. Prosumers often have the highest ability to pay. Informal self-generation increases social imbalances and should therefore be avoided.

Establishing full autonomy from the grid – including storage, controls, smart homes energy management – is less harmful to the distribution company, although grid defection also means a former distribution customer will no longer pay for public infrastructure that has already been installed.

For these reasons, self-generators should be regulated by an official process, and penalised for installing or operating self-generation unless certain conditions have been met. Distributors should have a complete picture of DG in their service areas and share this information with the authorities and the regulator.

[60] This causes further squeeze especially in systems where retail competition is implemented and competitors are active in retail trade, such as aggregators of DSM and others.
[61] Many distributors are municipal energy utilities supplying electricity, heat and gas.
[62] Where retail competition is implemented the distributor and basic supplier faces competition in functions other than the distribution service, but may also compete with the new suppliers in these functions.

6.4.6 End-User Pricing for Efficiency and Low-Carbon Self-Generation

Challenge: End-user pricing in DCs has to balance affordability with the need to both, cover costs and provide adequate market signals for energy saving, especially at times of scarce energy resources. vRE changes the supply-demand pattern and daily wholesale power prices reflect this in many areas.[63] Yet in most markets, even large consumers have no direct exposure to wholesale price signals, and hence demand will not respond.

With time-of-use (TOU) and dynamic retail pricing, some customers – such as large industrial and commercial customers – can adjust their consumption to reduce demand at peaking times and shift demand to lower price periods, with corresponding improvements in system efficiency and operational cost. For balancing renewable energy, time-of-use prices are inadequate since they are not synchronised flexibly with moving peaks and off-peaks. Real-time dynamic price signals can do this and are more suitable. Digitalisation enables such dynamic pricing. Well-functioning wholesale markets are a precondition.

In the same vein, grid usage tariffs can be adapted to strengthen incentives for efficient self-generation as well as DSM. While fixed or capacity-based elements ensure the revenue basis for the DSO, these should be based and metered not only from the capacity demand of the user but also reflecting the situation in the grid. Using idle grid capacity should not be impeded by high a capacity demand charge.

Where wholesale spot markets and ancillary services markets exist, regulators should allow DERs to be aggregated and bid into these markets. Price differentiation could be implemented based on the specification of ancillary services, such as capacity and reserve provision. Ad-hoc regulatory mechanisms, such as non-firm connection agreements, could be allowed.

In principle, spatial differences in value could also be determined and communicated to investors within distribution systems. That would require zonal or even nodal aspects be reflected in pricing at least for larger self-generators on primary distribution level. To do so, however, bilateral agreements or local markets may be necessary, as is done on bulk power level.

Charges and taxes for consumption of power are also important for pricing, whether they are drawn from the grid or self-produced. Regulators should examine if the two customer classes should be charged differently or not. It appears counterproductive to impose taxes or fees on self-consumed low-carbon electricity by prosumers who do not profit from financial support schemes.

[63] Increasing vRE does not necessarily mean that price peaks are more pronounced. Where the vRE generation time profile concurs with the load time profile, price peaks in wholesale markets are lower and move to other times of day.

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6.5 Challenges and Options in Electrification

Countries with low rates of electricity access in view of their power sector institutional arrangement face special challenges, as this section highlights.

6.5.1 Planning, Coordination of Grid Expansion, and Densification

Challenge: Need for an overall plan that includes different electrification approaches and actors.

The textbook approach for electrification is based on the existing infrastructure, interconnected as well as island mini-grids, and the principle lines of medium- and long-term grid extension. To reach grid densification, regional (urban and rural) development plans should be established. They should be based on a comparison of grid expansion cost vs. the cost of mini-grids. Availability of local energy resources is another criterion. Planning should rely on a modelling to explore policy scenarios and implications. Apart from the integrated utility and/or eventual distribution companies other actors should participate in the exercise – a specialised national authority, the regulator, local governments, and stakeholders.

In practice, electrification is often planned and prepared by local distribution entities or local dependencies of the integrated utilities together with local authorities. These electrification plans have to be coordinated with transmission planning and approved by government authorities as well as the regulator. Investment plans and significant expansion projects need approval by the government. Policymakers, the regulator, and the utility should try to maintain a unified electricity tariff for customers within the connected grid, with pricing differentiated only by customer classes.

This utility-driven approach tends to ignore non-utility infrastructure, especially the option of connecting mini-grids to the grid. Maintaining mini-grids while connecting has several advantages, especially lower cost, since generators in the mini-grid would continue to provide services in case of a blackout in the interconnected system.[64] This issue deserves more attention from regulators and national electrification actors.

6.5.2 Mini-Grid Business Models and Regulation

Challenges: Mini-grids have been around for decades, first for small hydro, then diesel generators. More recently, micro-grids have emerged based on vRE, as well as biomass and other local resources. Sometimes these renewable sources are still deployed in hybrid with diesel, and increasingly with storage. With falling equipment cost the vRE combined with storage has the potential to become the option of choice in many markets. Energy and IT innovation will continue to improve the market potential of mini-grids, provided that governments create the appropriate regulatory framework.[65]

In addition, new business models involving the private sector and small power producers for mini-grids are coming into play.[66] New business models are appearing around commercial providers (contractors) that offer full-service to large individual users like industries, hospitals, or hotels. These business models replace or partly substitute diesel plants with solar PV and thus help reducing load shedding, backup cost, and emissions.

The regulators need to accept this third-party activity within the established regulatory framework, whether regulated monopoly or partly unbundled IPP-SB-frameworks. In the case of renewable energy technology, such systems typically benefit from government support like investment tax credits, such as in India for example.[67] Such decentralised renewable back-up power schemes

[64] For examples see Vivid Economics (2015).
[65] For an overview of policies and business frameworks for mini-grid roll out, see EUEI PDF (2014).
[66] See Tenenbaum et al. (2014).
[67] Unpublished paper and discussion output with Dr. Langniss - Energie & Analyse, in November 2015.

may also be run by non-profit actors and benefit from grants from international cooperation and non-governmental organisations, as in the case of Nepal.[68]

Mini-grids intersect with many regulatory matters, including licenses, tariffs, and grid connection. Though every project is special to some extent, in the future many of these regulations could be unified to simplify the process of establishing mini-grids, as many jurisdictions have previously done to enable distributed energy.

6.5.3 Individual Home Systems

Challenge: Owners of small residential PV or storage systems have little technical knowledge and must rely on the market to provide quality products and information.

The falling cost of solar PV and storage has made them an attractive option for rural residents who otherwise lack access to electricity. Since they are operated by individuals, not connected to the grid, the installations do not face any codes or coordination, and there are few regulatory requirements.

One important issue is product and service quality. Quality certification that meets international standards is needed. Supervision of imported energy product at customs is one potential solution. Domestic production, at least domestic assembly and trade are recommended, in particular when information on such products is costly. Several suppliers for quality products should exist to ensure competition.

6.5.4 Basic Service Options – PAYGO

Challenge: In recent years, new business models have emerged for power supply with even smaller appliances in remote regions, including for internet and mobile phone charging. These systems pose little threat to the incumbent utilities. However, policymakers and regulators could make utilities support this type of low-level electrification because of their potential for mass appeal.[69]

Availability of communication by wireless telephone network allows inexpensive remote control and monitoring of small, distributed units. The PAYGO model on the basis of user codes transmitted through mobile phones (in particular SMS) has opened up new opportunities to transfer even small amounts of money economically. As a result, companies have multiplied to offer this service, not all reliable. The fairness and transparency of PAYGO business practices deserves additional attention from anti-trust and fraud-prevention regulators in many countries.

[68] See IEA-PVPS (2014).
[69] Find examples in IEA-PVPS (2014).

7 Conclusions – Relevance for International Cooperation

The power sector is poised to undergo profound changes over the coming decades, challenging utilities, and regulators around the world. How DCs approach and manage this challenge will shape their energy future across multiple dimensions including climate, electricity access, innovation, and competitiveness. The stakes are enormous.

As we have shown in our analysis of the intensity of change and challenges, many countries are already affected in some or all aspects of the power sector, including bulk power, retail markets, transmission and distribution, distributed energy, and decentralised off-grid electrification. Each of these poses numerous challenges for institutional response, involving market structure, market design, and regulation. Some challenges are similar to those faced by ICs; others are unique to DCs. Because of the huge differences between the developing and the industrialised world, we present recommendations specifically geared towards EEs and DCs as to how they can approach power system transformation.

Each individual country also differs in the extent of need and demand for international cooperation on the topic of power sector transformation. It is quite clear that energy transition is a matter of when not if. Policymakers and regulators will play a large role in how smoothly and how quickly this transformation takes place, but change is inevitable. In our view, it is better to anticipate and shape the transformation based on best practices and sharing of insights across borders – the alternative is to rely on prior assumptions and the recommendations of domestic stakeholders that may have an interest in blocking needed reforms. The goals of this process are improved power systems in terms of efficiency, stability, affordability, environmental safeguards, as well as low-carbon emissions and climate change resilience and – last but not least – energy access for all.

Private consulting companies are actively providing power sector policy and utility advisory services, which is not in itself a negative development. However, to guard against empowering large, incumbent companies at the expense of smaller players or individuals, DCs need independent analysis and expert convening. International cooperation can support this process.

German international cooperation concerning the power sector has concentrated on the promotion of renewable energy and efficiency, both through development assistance as well as in international environmental and climate cooperation. In recent years, technical cooperation has more and more addressed the integration of vRE in the power sector. In the future, German international cooperation on these topics should be paired with greater attention to advice on power systems development that plays a critical role in enabling sustainable energy transitions.[70] German cooperation has doubtlessly already contributed to shaping the power sector framework DCs, in some cases without doing so consciously. As this paper shows, these issues need more detailed attention, especially since German official development assistance in the energy sector has grown substantially and the implications for the operations in the power sector can no longer be ignored. Similarly, international climate finance that is focussing on low carbon power sector, is well advised to consider the institutional side in addition to appropriate planning policy. This would make the investment more efficient and effective.

vRE integration into the power sector has become an inevitable part of energy cooperation in several programs.[71] GIZ is perceived as an honest broker on these topics, and its experiences are respected worldwide. In the future, policy advisory and capacity building for institutional responses should be considered, even if not explicitly mentioned in the project mandate.

[70] GIZ has outlined the respective guidance in a position paper, see GIZ (2017).

A general mandate for German international cooperation to address these questions can be inferred from the Federal Ministry for Economic Cooperation and Development's (BMZ) policies, in particular focusing on decentralized renewable energy for universal energy access, as well as the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety's (BMU) programs. Also, the bilateral energy partnership programs financed by the German Ministry for Economic Affairs and Energy (BMWi) providing support for exchange on energy policy takes up institutional issues and solutions. However, this German engagement should be even more pronounced and substantial in favour of RE integration in power sectors in DCs and the respective institutional and regulatory matters.

The next steps in the discussion should deal with the scope of dealing with institutional issues in future German development and climate cooperation. Worthy of discussion is the degree and depth of the involvement in market design and regulation in the power sector, professional capacity development of the development partners, as well as the required resources and particular capacity development of expert staff.

[71] Apart from the cited case of China, cooperation with Chile, South Africa, Morocco, Ghana, India, Vietnam - to name a few cases – has already touched upon regulatory issues of the power sector.

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