UNIVERSITY OF CAMBRIDGE
Faculty of Economics

Cambridge Working Papers in Economics

Cambridge Working Papers in Economics: 1846

ELECTRIC POWER DISTRIBUTION IN THE WORLD: TODAY AND TOMORROW

Sinan Küfeoğlu

Michael Pollitt

Karim Anaya

16 August 2018

In light of the increasing importance of distributed energy resources (DERs) in the electricity system, there is an ongoing need to understand the current status of electric power distribution across the world. This review paper compiles key information about the distribution systems in 175 countries worldwide. The findings for each country include the number, legal structure and ownership of distribution system operators, the access to electricity they provide, distribution level voltages, electric power frequency and the significance of renewable electricity generation. This study covers 99.4% of the world's population. As of June 2018, there are around 7600 distribution system operators in these 175 countries. After reviewing today's distribution system status, this paper also reviews the various discussions and proposals for tomorrow's electric power distribution. The discussion covers both system operation and market platform roles as well as data management options for DSOs in the near future.

Electric Power Distribution in the World: Today and Tomorrow

EPRG Working Paper 1826

Cambridge Working Paper in Economics 1846

Sinan Küfeoğlu, Michael Pollitt & Karim Anaya

Abstract In light of the increasing importance of distributed energy resources (DERs) in the electricity system, there is an ongoing need to understand the current status of electric power distribution across the world. This review paper compiles key information about the distribution systems in 175 countries worldwide. The findings for each country include the number, legal structure and ownership of distribution system operators, the access to electricity they provide, distribution level voltages, electric power frequency and the significance of renewable electricity generation. This study covers 99.4% of the world's population. As of June 2018, there are around 7600 distribution system operators in these 175 countries. After reviewing today's distribution system status, this paper also reviews the various discussions and proposals for tomorrow's electric power distribution. The discussion covers both system operation and market platform roles as well as data management options for DSOs in the near future.

Keywords distribution system operator; DSO; market platform; transmission system operator; TSO

JEL Classification L94

Contact s.kufeoglu@jbs.cam.ac.uk
Publication August 2018
Financial Support None

Electric Power Distribution in the World: Today and Tomorrow

Sinan Küfeoğlu[1]
Energy Policy Research Group
University of Cambridge

Michael G. Pollitt
Energy Policy Research Group
University of Cambridge

Karim Anaya
Energy Policy Research Group
University of Cambridge

Abstract *In light of the increasing importance of distributed energy resources (DERs) in the electricity system, there is an ongoing need to understand the current status of electric power distribution across the world. This review paper compiles key information about the distribution systems in 175 countries worldwide. The findings for each country include the number, legal structure and ownership of distribution system operators, the access to electricity they provide, distribution level voltages, electric power frequency and the significance of renewable electricity generation. This study covers 99.4% of the world's population. As of June 2018, there are around 7600 distribution system operators in these 175 countries. After reviewing today's distribution system status, we also review the various discussions and proposals for tomorrow's electric power distribution. The discussion covers both system operation and market platform roles as well as data management options for DSOs in the near future.*

Keywords: distribution, system, operator, regulation

1. Introduction

In 2000 the United States (US) National Academy of Engineering chose electrification through vast networks of the electricity grid as the best engineering achievement of the 20th century[2]. It is no surprise that the US Homeland Security defines the energy sector as uniquely critical due to its enabling function across all critical infrastructure sectors (White House, 2013), while Center for the Study of the Presidency & Congress emphasizes the significance of the electric power grid as the most critical of critical infrastructure (Center for the Study of the Presidency & Congress, 2014). In developed countries, we might say that the traditional power systems have served societies well for the last one hundred years. The North American Electricity Reliability Corporation assumes a loss of load expectation to be one day in ten years, which corresponds to an annual average continuity of electricity supply of 99.97% in US (NERC, 2011) and Council of European Energy Regulators report an average of 3 hours of interruption per year which again corresponds to a reliability level of 99.97% in Europe (CEER, 2015a). Electric power systems have been going through a radical transformation due to renewable energy sources, distributed generation, demand-driven planning ambitions, smart grids and smart energy technologies, climate change related pressures and increasing consumer preferences. It is often argued that yesterday's power systems paradigm might not meet the demands

[1] Corresponding author. S. Küfeoğlu. e-mail: s,kufeoglu@jbs.cam.ac.uk. The authors acknowledge the help and contributions of CEER (Council of European Energy Regulators), EURELECTRIC (The Union of the Electricity Industry) and IRENA (International Renewable Energy Agency) in completing this paper. We also acknowledge the help of Ji Tianyao on China.
[2] See http://www.greatachievements.org/Object.File/Master/4/024/Feb22Release.pdf

of the future. Traditional design of the power systems which puts distinct (and varying across countries) boundaries between generation (G), transmission (T), distribution (D) and retail (R) might be regarded as inefficient and incapable of meeting the challenges of the transition to a low carbon electricity system transformation. In the past electricity systems have been built around moving power from large central power plants directly connected to the transmission system to passive loads connected to the distribution system. Increasingly, across the OECD, the system has shifted to a world where most of new generation is connected directly to the distribution system and loads are becoming more active in both importing and exporting power and maintaining power quality. In such a world, distribution systems move from passive networks, often quietly integrated with transmission or retail to being active networks whose role in shaping the system is the subject of increased commercial and regulatory interest.

This review paper compiles some of the significant information about the distribution systems in 175 countries worldwide in order to characterise the current situation of the distribution system as we move to a world where these entities are a focus of interest. The findings for each country include the number, legal structure and ownership of distribution system operators, the access to electricity they provide, distribution level voltages, electric power frequency and the significance of renewable electricity generation. This study covers 99.4% of the world's population. As of June 2018, there are around 7600 distribution system operators in these 175 countries. After reviewing today's distribution system status, this paper also reviews the various discussions and proposals for tomorrow's electric power distribution. This paper also highlights the concept of Distribution System Platforms (DSPs) which are proposed to be a better option in terms of facilitating the shift from passive to active distribution network operation. In addition to active management of two-way power flows, DSPs also provide market mechanisms to trade power products (e.g. reactive power, reserve, frequency support) at a distribution level. The European Commission's directive 2009/72/EC, Article 2(5) defines distribution as (EC, Directive 2009/72):

"distribution means the transport of electricity on high-voltage, medium-voltage and low-voltage distribution systems with a view to its delivery to customers but does not include supply." At the same directive, Article 2(6) defines a Distribution System Operator (DSO) as:

"Distribution System Operator means a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity." This definition remains the same after the 'Winter Energy Package' proposed by the European Commission in December 2016. In line with the European Commission we use the term DSO to cover both network ownership and system operation, as these are currently integrated for almost all (proper) distribution entities in the world (i.e. beyond small network extensions built and owned by third parties to the incumbent DSO in an area).

When we talk about DSOs, we should mention unbundling of distribution from generation, transmission and retailing as well. After the privatization and liberalization waves of 80s that started in Chile and Britain, in many parts of the world vertically integrated undertakings have gone through unbundling. The EC defines a Vertically Integrated Undertaking (VIU) at Directive 2009/72/EC, Article 2(21) as:

‘Vertically integrated undertaking’ in the European Union Internal Electricity Market means an electricity undertaking or a group of electricity undertakings where the same person or the same persons are entitled, directly or indirectly, to exercise control, and where the undertaking or group of undertakings perform at least one of the functions of transmission or distribution, and at least one of the functions of generation or supply of electricity.’

The definition of a VIU is clear and straightforward. However, the definition of an unbundled undertaking is more complex. Unbundling means separation of the distribution from the rest of the VIU. The DSO separation can take various forms. The EC acknowledges four main types of unbundling. These are ownership, legal, functional and accounting unbundling. EC Staff Working Document (EC Evaluation Report, 2016) defines the unbundling rules as:

“- Full ownership unbundling (ownership separation) is where the DSO is a separate company to any interests in generation or supply (not required by the Electricity Directive).

- Legal unbundling is where the DSO is a legally separate entity with its own independent decision making board, but remains within the umbrella of a Vertically-Integrated Undertaking (VIU).

- Functional or management unbundling is where the operational, management and accounting activities of a DSO are separated from other activities in the VIU; and

- Accounting unbundling is where the DSO business unit must keep separate accounts for its activities to prevent cross subsidisation, from the rest of the VIU.”

According to Directive 2009/72/EC, Article 26(4) legal and functional unbundling is binding however it can be exempted for European DSOs with customers less than 100,000. However, in some countries this threshold is lower (50,000 for Austria and Finland, 90,000 for Czech Republic and 1,000 for Slovenia). Moreover, Malta is exempted from EC unbundling rules. Among the Council of European Energy Regulators (CEER) member countries, about 100 DSOs have more than 100,000 customers. We should remind ourselves that as of 2015 only 189 DSOs out of around 2400 were legally unbundled in Europe (CEER, 2015b). Ownership unbundling is a complicated and challenging process. New Zealand is the first country that achieved this in 1998 (Nillesen & Pollitt, 2011). In Europe, only in Netherlands full-ownership unbundling of DSOs is required by law (CEER, 2016).

From the rest of the paper and in line with the European Commission we use the term DSO to cover both network ownership and system operation, as these are currently integrated for almost all (proper) distribution entities in the world (i.e. beyond small network extensions built and owned by third parties to the incumbent DSO in an area).

Section 2 introduces today’s electric power distribution by summarizing the findings of our characterisation of DSOs from 175 countries. Section 3 presents some of the proposals and ideas about the structure of the DSOs in the future. Section 4 includes a brief conclusion and discussion about the paper.

2. Electric Power Distribution of Today

To better present the results of this comprehensive review, we would like to illustrate some of the findings as maps. Figure 1 shows the electric power frequencies used in countries. Figure 2 presents the access to electricity worldwide (World Bank, 2014 and International Energy Agency, 2017). Figure 3 summarizes the renewable electricity generation as a share of the renewable electricity output in the total electricity generation output (EIA, 2015; IRENA, 2015). Figure 4 is about the DSO intensity by simply showing number of connected people served by one DSO in each country (World Bank, 2016). Figure 5 presents the ownership of the DSOs worldwide. In addition to distinguishing public and private ownership, we defined a third classification as mixed ownership. Mixed ownership covers DSOs that have public and private shareholders. Table 1 shows the details of DSO ownership in the US, Australia, Canada, Brazil, India and New Zealand. Finally, Table 2 and Table 3 include all the distribution system information that we gathered for this paper. The DSO structure information per each country is presented with four functions of electricity system, where;

G: Generation

T: Transmission

D: Distribution

R: Retail

The ownership/legal structure of DSOs is a challenging subject on which to make decisive conclusions (e.g. knowing all the shareholders and ultimate parent companies of a given distribution entity is difficult to trace and present, especially when there might be foreign owners). We therefore focus on legal structure of DSOs within the country of interest. Unbundling of the power sector is a grey area for many countries we reviewed. In addition, due to privatization, renationalization, company splits or due to company mergers, the number of DSOs may vary as well[3]. For example, there were 8 DSOs in the Netherlands in 2015, however in 2018, this number is 7. Similarly, number of German DSOs dropped from 884 to 875 in these years.

[3] We welcome contributions from the readers, especially from industry, to update our Tables 2 & 3.

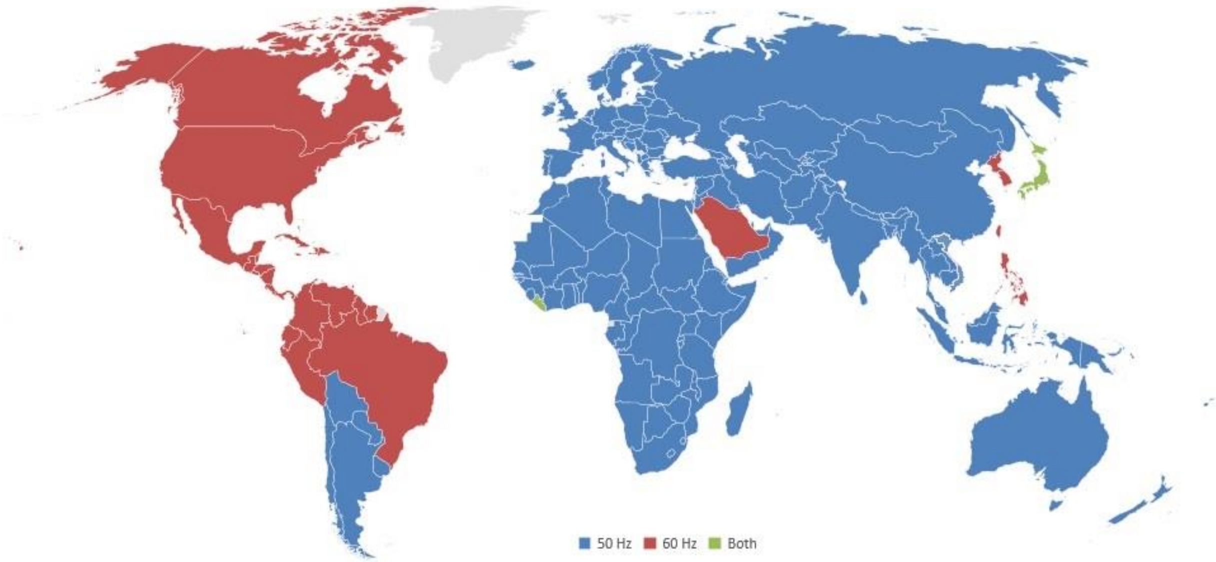

Figure 1. Electric power frequency

50 Hz and 60 Hz are the two AC frequencies used in the world. Africa, Europe, Oceania and majority of Asia use 50 Hz, where North America, Latin America and the majority of South America have 60 Hz power systems. Liberia is on a transition from 60 Hz to 50 Hz. Moreover, Easter Japan runs at 50 Hz whereas western Japan runs at 60 Hz.

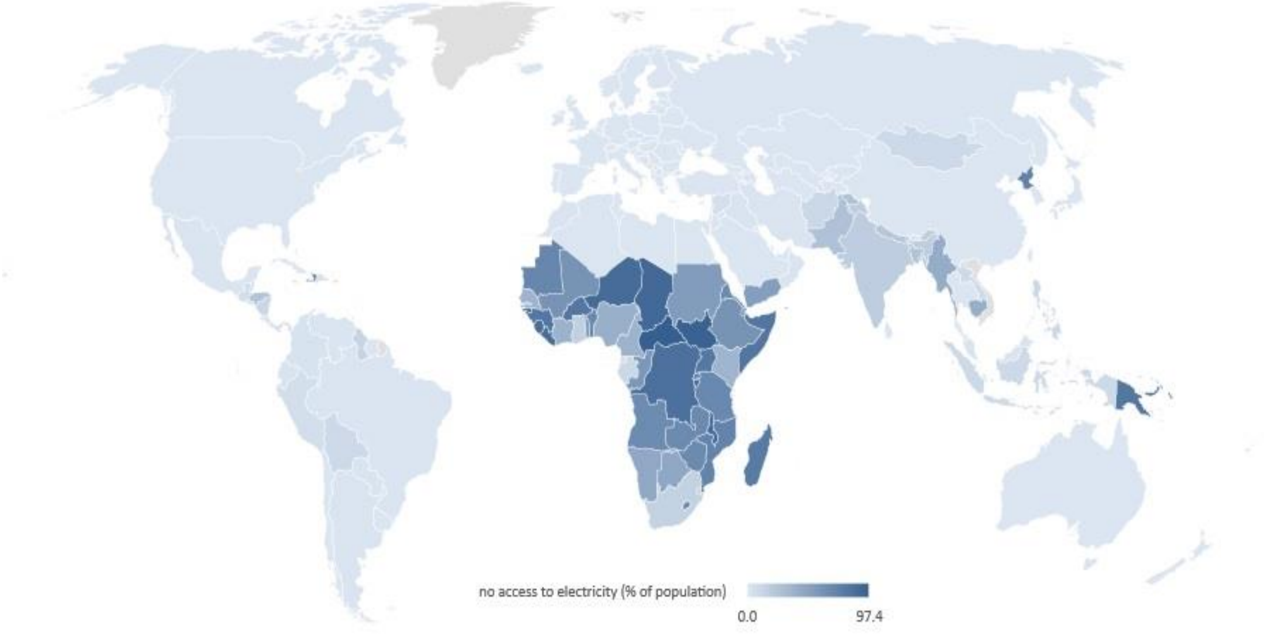

Figure 2. Access to electricity

Access to continuous electric power is a problem in various parts of the world. While developed countries are going through a rapid technological transition by adapting smart grids, around 1.06 billion people lack access to electricity still in 2017 (IEA, 2017; World Bank, 2014). This corresponds to 14.8% of the world's population. The challenge is to succeed in the sustainable energy transition together while urgently extending electricity provision to these large populations.

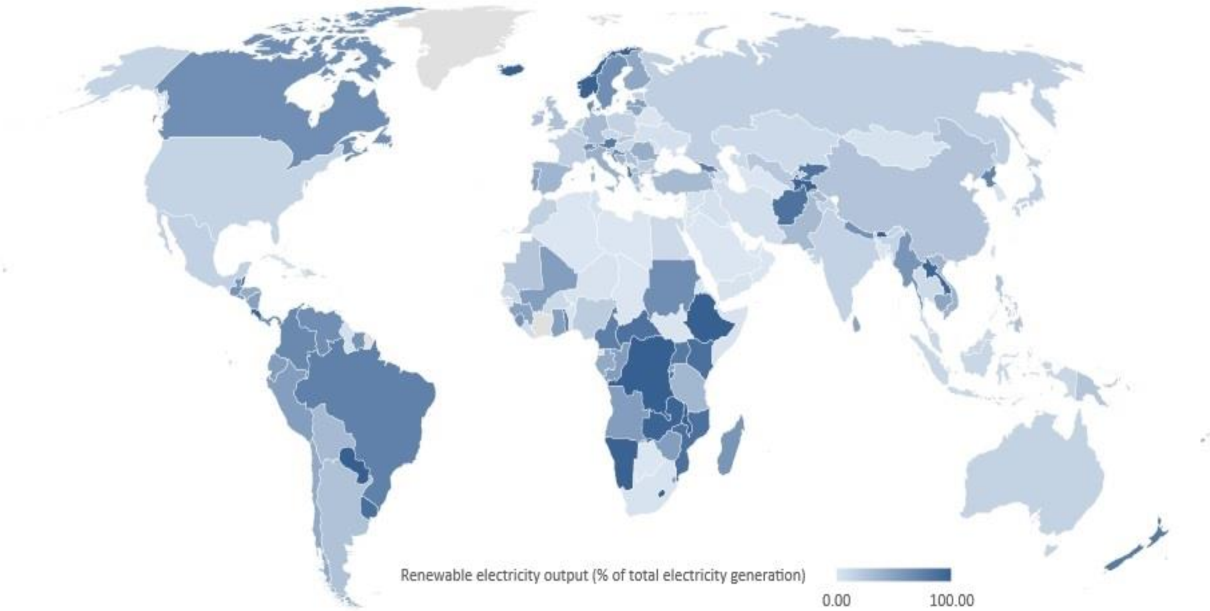

Figure 3. Renewable electricity generation

Renewable electricity generation is on the rise in almost all countries in the world. According to the EIA and IRENA statistics, this output ranges from around 0% (Kuwait, Libya, Saudi Arabia) to 100% (Paraguay, mainly hydropower) in 2015 (EIA, 2015; IRENA, 2015). In 2015, total electricity generation was around 23,254 TWh and the renewable electricity generation was approximately 5,601TWh. The corresponding renewable electricity generation in the world was 24% in the same year.

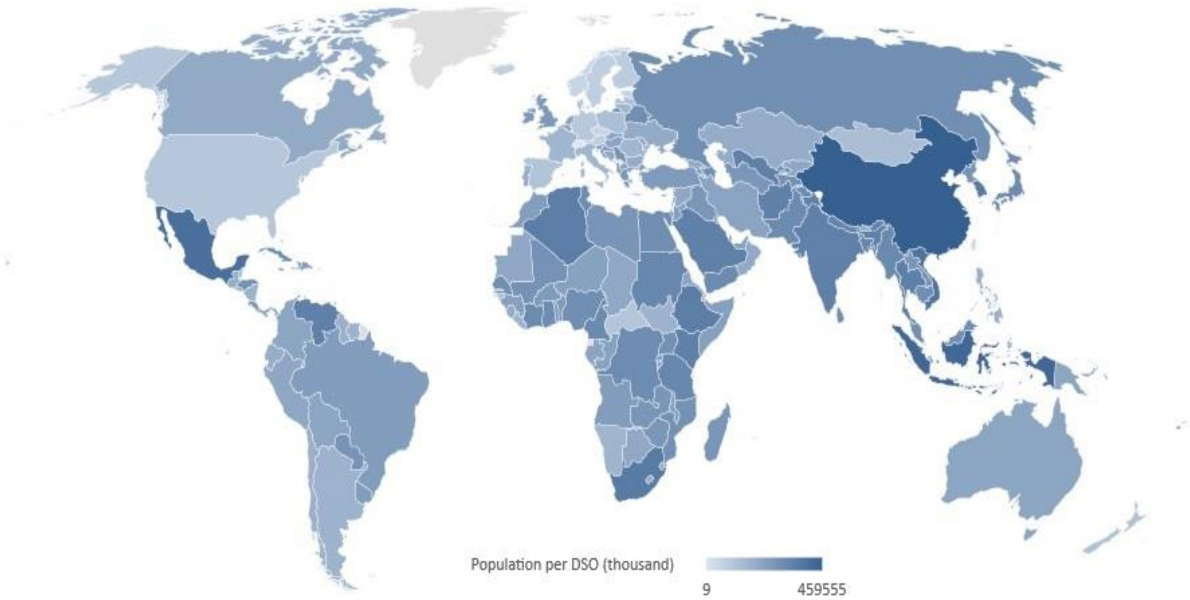

Figure 4. Population per DSO

We prepared Figure 4 to illustrate the average number of people in a country served by one DSO. It is quite notable that there are 900 DSOs in Switzerland serving a total population of 8.3 million, there are only 2 large DSOs (SGCC and CSG) and a relatively small one in China[4], a country with a population of almost 1.4 billion (World Bank, 2016). Arriving at the number of DSOs in a country is challenging as there may be very small network extensions or microgrids not captured by our statistics, but in line with the discussion above a 'proper DSO' is one with area monopoly responsible both the distribution network and its operation and for connecting new customers within its area and physically interconnected with transmission.

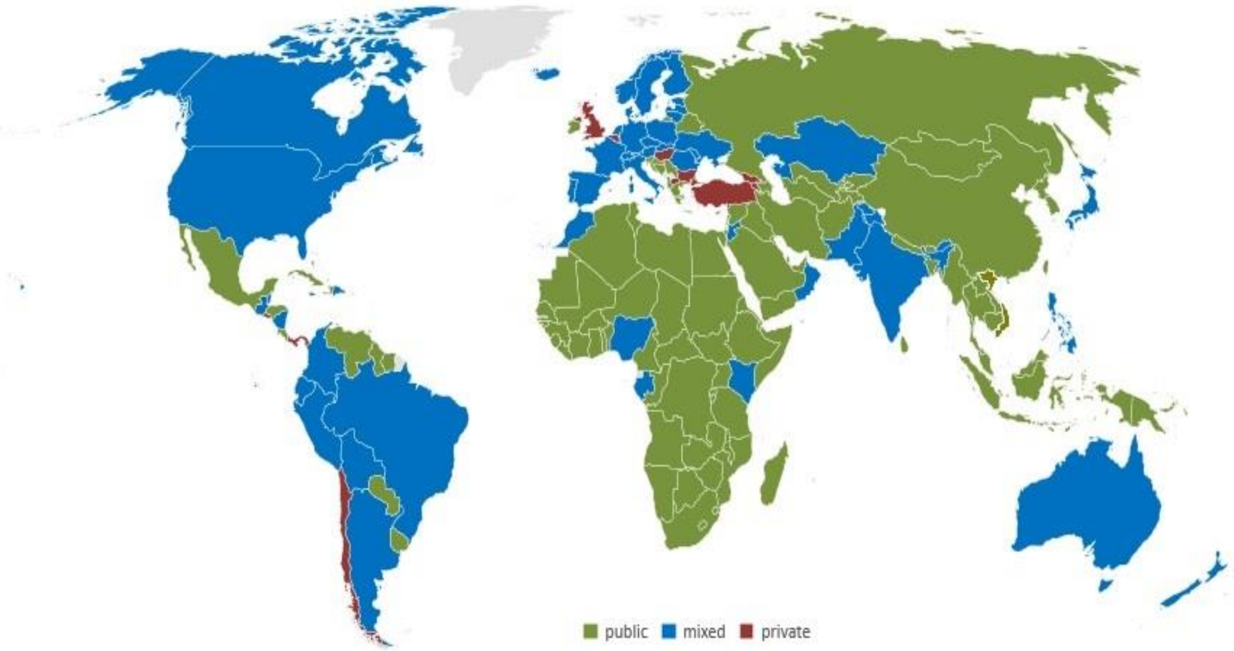

Figure 5. Ownership of the DSOs

Figure 5 is an attempt to summarise DSO ownership. Do private or public DSOs provide higher quality services to customers? Does privatization guarantee lower distribution and energy bills? Is innovation better supported at private DSOs? These matters are still discussed in the electricity community. The answers are out of scope of this paper. However, we see that there are only a few countries in the world that have only fully private DSOs. Mixed ownership means that some DSOs are privately owned and some are publicly owned, or there are both private and public shareholders in the same distribution company. The DSOs with more than 50% ownership by state or other public entities are assumed as publicly owned. Table 1 gives detailed information about 6 countries that have mixed DSO ownership.

[4] We identify the Inner Mongolia Power Company as the small one. The covers a large area of western Inner Mongolia. We believe there may be at least 11 others with exclusive distribution service territories and rights to connect new customers (e.g. in part of the megacity of Shenzhen), but their exact relationship and nature to SGCC and CSG is less clear (indeed at least one previously separate company was recently acquired by SGCC). In China, as in all other countries in this paper, we ignore independent distribution network operators who largely manage customer assets associated within strictly limited areas such as housing estate or a port.

Table 1
Percentage of public ownership
(% number of publicly owned DSOs among all DSOs)

	0-25%	25-50%	50-75%	75-100%
USA[1]				■
Australia			■	
Brazil[2]		■		
Canada[3]				■
India				■
New Zealand[4]			■	

[1] There are Investor owned, cooperative and municipal utilities in the US. Majority of the utilities are small-scaled municipal utilities (about 2000).

[2] As of 2007, about 64% of Brazilian distribution assets were controlled by private sector companies.

[3] There are about 364 smaller utilities across Canada, of which 87% are located in Ontario.

[4] There are 29 trust-owned and non-trust-owned utilities in New Zealand. 18 trust-owned utilities are fully owned by community or consumer trusts. The remaining 11 electricity distribution utilities are non-trust-owned companies. They have various owners, including a mix of community or consumer trusts that own some but not all shares, local authorities, other electricity distribution businesses, private interests, and the public.

Here we should note that in the US, Canada and New Zealand, even though the number of publicly owned DSOs is higher, the number of customers served by these DSOs is much less than those of privately owned ones. Especially in the US and Canada investor owned utilities (or private utilities) are bigger entities serving more customers in aggregate than the municipal or cooperative utilities. In 2016, out of around 138 million electricity customers in US, 90 million of those (65%) were served by the investor owned utilities (EIA, 2017).

Some of the countries we listed in Table 2 with G, T, D, R or with other combinations with at least two functions are specified as "unbundled" countries. However, the definition of unbundling may vary from region to region. A label of legal structure of D only refers to the normal situation in EU countries, where distribution is legally and functionally unbundled from G, T and R. However, a label of D, R implies the distribution activity is in a legal structure which combines D and R. In this study, by unbundling we assume legal and functional unbundling. And we adopt the unbundling rules to be in line with the definition of the EC. Therefore, in an unbundled undertaking the same person or the same persons should not be entitled, directly or indirectly, to exercise control of at least one of the functions of transmission or distribution, and at least one of the functions of generation or supply of electricity. For example, in Egypt the electricity sector is officially unbundled. However, Egyptian Electricity Holding Company owns distribution and transmission and also owns almost 90% of the generation in Egypt. We can say that the unbundling rules are not in line with the definition of the EC. Therefore, we reported the structure of Egyptian power sector as G, T, D, R (vertically integrated) meaning that the same legal body, person or persons directly or indirectly have control over these operations. Another example of confusing legal structure is the power sector in Brazil. Electricity sector in Brazil is legally unbundled. However, in some regions there are companies responsible for generation, transmission and distribution of electricity. The legal structures of small scale municipal and cooperative distribution companies in South and Central America might be different than those of large DSOs (Argentina, Bolivia, Peru for example). Therefore, we did not include these companies into account in Table 2. Moreover, Independent Power Producers (IPPs) exist in many of the G, T, D, R countries. Therefore, G, T, D, R or other combinations of at least two functions such as G, T or G, D do not necessarily mean that all generation is being run by the same entity that has control over the distribution operation.

Table 2
Electric Power Distribution review worldwide

Country	No of DSOs	Legal Structure	Ownership	Access to electricity (%)	Population (thousand)	Population without electricity connection (thousand)	Connected Population per DSO (thousand)
Afghanistan	1	G, T, D, R	public	89.5	34,656.03	3,638.88	31,017.15
Albania	1	D	public	100	2,876.10	0.00	2,876.10
Algeria	4	G, T, D, R	public	100	40,606.05	0.00	10,151.51
Angola	3	G, T, D, R	public	34.7	28,813.46	18,815.19	3,332.76
Argentina	26	D	mixed	99.6	43,847.43	175.39	1,559.72
Armenia	1	T, D	private	100	2,924.82	0.00	2,924.82
Australia	15	D	mixed	100	24,127.16	0.00	1,608.48
Austria	138	D	mixed	100	8,747.36	0.00	63.39
Azerbaijan	1	G, T, D, R	public	100	9,762.27	0.00	9,762.27
Bahamas, The	2	G, T, D, R	mixed	100	391.23	0.00	195.62
Bahrain	1	G, T, D, R	public	100	1,425.17	0.00	1,425.17
Bangladesh	6	G, D	public	75	162,951.56	40,737.89	20,368.95
Barbados	1	G, D, R	private	100	285.00	0.00	285.00
Belarus	1	G, T, D, R	public	100	9,507.12	0.00	9,507.12
Belgium	8	D	private	100	11,348.16	0.00	1,418.52
Belize	1	G, T, D, R	mixed	92.5	366.95	27.52	339.43
Benin	1	G, T, D, R	public	31.9	10,872.30	7,404.04	3,468.26
Bhutan	1	G, T, D, R	public	100	797.76	0.00	797.76
Bolivia	7	T, D	mixed	91.5	10,887.88	925.47	1,660.40
Bosnia & Herzegovina	3	G, T, D, R	public	100	3,516.82	0.00	1,172.27
Botswana	1	G, T, D, R	public	54.8	2,250.26	1,017.12	1,233.14
Brazil	60	G, T, D	mixed	99.6	207,652.86	830.61	3,282.89
Brunei	2	G, T, D, R	public	100	423.20	0.00	211.60
Bulgaria	7	D	private	100	7,127.82	0.00	1,018.26
Burkina Faso	1	G, T, D, R	public	20.3	18,646.43	14,861.20	3,785.23
Burundi	1	G, T, D, R	public	10	10,524.12	9,471.71	1,052.41
Cambodia	1	G, T, D, R	public	59.7	15,762.37	6,352.24	9,410.13
Cameroon	1	G, T, D, R	public	63.3	23,439.19	8,602.18	14,837.01
Canada	34	G, D, R	mixed	100	36,286.43	0.00	1,067.25
Central African Rep.	1	G, T, D, R	public	2.6	4,594.62	4,475.16	119.46
Chad	1	G, T, D, R	public	8.8	14,452.54	13,180.72	1,271.82
Chile	25	D	private	100	17,909.75	0.00	716.39
China (mainland)	3	T, D, R	public	100	1,378,665.00	0.00	689,332.50
China - Macau	1	T, D, R	public	100	612.17	0.00	612.17
China - Hong Kong	2	G, D, R	mixed	100	7,346.70	0.00	3,673.35
Colombia	28	G, T, D, R	mixed	97.8	48,653.42	1,070.38	1,640.79
Comoros	2	G, D	public	71.2	795.60	229.13	283.23
Congo, Dem. Rep.	1	G, T, D, R	public	15.2	78,736.15	66,768.26	11,967.89

Country	No of DSOs	Legal Structure	Ownership	Access to electricity (%)	Population (thousand)	Population without electricity connection (thousand)	Connected Population per DSO (thousand)
Costa Rica	1	G, T, D, R	public	99.2	4,857.27	38.86	4,818.41
Croatia	1	G, T, D, R	public	100	4,170.60	0.00	4,170.60
Cuba	1	G, T, D, R	public	100	11,475.98	0.00	11,475.98
Cyprus	1	G, T, D, R	public	100	1,170.13	0.00	1,170.13
Czech Republic	290	D	mixed	100	10,561.63	0.00	36.42
Denmark	49	D	mixed	100	5,731.12	0.00	116.96
Djibouti	1	G, T, D, R	public	42.3	942.33	543.72	398.61
Dominican Republic	3	G, T, D	mixed	97.1	10,648.79	308.81	3,446.66
Ecuador	11	D	mixed	98.2	16,385.07	294.93	804.51
Egypt	9	G, T, D, R	public	99.9	95,688.68	95.69	10,621.44
El Salvador	8	D	private	96.3	6,344.72	234.75	763.75
Eritrea	1	G, T, D, R	public	32.9	5,152.70	3,457.46	1,695.24
Estonia	37	G, T, D, R	mixed	100	1,316.48	0.00	35.58
Ethiopia	1	G, T, D, R	public	40.4	102,403.20	61,032.31	41,370.89
Fiji	1	G, T, D, R	public	100	898.76	0.00	898.76
Finland	80	D	mixed	100	5,495.10	0.00	68.69
France	148	D	mixed	100	66,896.11	0.00	452.00
Gabon	1	G, T, D, R	mixed	90.1	1,979.79	196.00	1,783.79
Gambia	1	T, D	public	47.5	2,038.50	1,070.21	968.29
Georgia	3	D	private	100	3,719.30	0.00	1,239.77
Germany	875	D	mixed	100	82,667.68	0.00	94.48
Ghana	2	D	public	84.1	28,206.73	4,484.87	11,860.93
Greece	2	G, T, D, R	public	100	10,746.74	0.00	5,373.37
Grenada	1	G, T, D, R	mixed	90.8	107.32	9.87	97.45
Guatemala	19	D	mixed	93.9	16,582.47	1,011.53	819.52
Guinea	1	G, T, D, R	public	19.7	12,395.92	9,953.92	2,442.00
Guinea-Bissau	1	G, T, D, R	public	12.6	1,815.70	1,586.92	228.78
Guyana	1	G, T, D, R	public	86.9	773.30	101.30	672.00
Haiti	1	G, T, D, R	public	32.7	10,847.33	7,300.25	3,547.08
Honduras	1	G, T, D, R	public	76.2	9,112.87	2,168.86	6,944.01
Hungary	6	D, R	private	100	9,817.96	0.00	1,636.33
Iceland	6	D	mixed	100	334.25	0.00	55.71
India	34	G, T, D	mixed	82	1,324,171.35	238,350.84	31,935.90
Indonesia	1	G, D, R	public	91.2	261,115.46	22,978.16	238,137.30
Iran	42	G, T, D, R	public	99.2	80,277.43	642.22	1,896.08
Iraq	7	G, T, D, R	public	98.6	37,202.57	520.84	5,240.25
Ireland	1	D	public	100	4,773.10	0.00	4,773.10
Israel	1	G, T, D, R	public	100	8,547.10	0.00	8,547.10
Italy	135	D	mixed	100	60,600.59	0.00	448.89
Ivory Coast	1	G, T, D, R	public	62.5	23,695.92	8,885.97	14,809.95
Jamaica	1	G, T, D, R	mixed	99.5	2,881.36	14.41	2,866.95

Country	No of DSOs	Legal Structure	Ownership	Access to electricity (%)	Population (thousand)	Population without electricity connection (thousand)	Connected Population per DSO (thousand)
Japan	10	G, T, D, R	mixed	100	126,994.51	0.00	12,699.45
Jordan	3	D	mixed	100	9,455.80	0.00	3,151.93
Kazakhstan	20	D	mixed	100	17,797.03	0.00	889.85
Kenya	1	T, D, R	mixed	64.5	48,461.57	17,203.86	31,257.71
Kiribati	1	G, T, D, R	public	48.1	114.39	59.37	55.02
Kuwait	1	G, T, D, R	public	100	4,052.58	0.00	4,052.58
Kyrgyzstan	4	G, T, D, R	public	99.8	6,082.70	12.17	1,517.63
Laos	1	G, T, D, R	public	91.4	6,758.35	581.22	6,177.13
Latvia	11	D	mixed	100	1,960.42	0.00	178.22
Lebanon	1	G, T, D, R	public	100	6,006.67	0.00	6,006.67
Lesotho	1	G, T, D, R	public	34.4	2,203.82	1,445.71	758.11
Liberia	1	G, T, D, R	public	12.2	4,613.82	4,050.93	562.89
Libya	1	G, T, D, R	public	100	6,293.25	0.00	6,293.25
Lithuania	7	D	mixed	100	2,872.30	0.00	410.33
Luxembourg	6	T, D	mixed	100	582.97	0.00	97.16
Macedonia	1	D	private	100	2,081.21	0.00	2,081.21
Madagascar	1	G, T, D, R	public	22.9	24,894.55	19,193.70	5,700.85
Malawi	1	G, T, D, R	public	11.3	18,091.58	16,047.23	2,044.35
Malaysia	3	G, T, D, R	public	98.6	31,187.26	436.62	10,250.21
Maldives	35	G, D, R	public	100	417.49	0.00	11.93
Mali	1	G, T, D, R	public	40.5	17,994.84	10,706.93	7,287.91
Malta	1	G, T, D, R	mixed	100	436.95	0.00	436.95
Mauritania	1	G, T, D, R	public	31.3	4,301.02	2,954.80	1,346.22
Mauritius	1	G, T, D, R	public	99.9	1,263.47	1.26	1,262.21
Mexico	1	G, T, D, R	public	99.2	127,540.42	1,020.32	126,520.10
Moldova	3	D	mixed	100	3,552.00	0.00	1,184.00
Mongolia	12	D	public	91	3,027.40	272.47	229.58
Morocco	11	T, D	mixed	99	35,276.79	352.77	3,174.91
Mozambique	1	G, T, D, R	public	28.6	28,829.48	20,584.25	8,245.23
Myanmar	2	G, T, D, R	public	58.8	52,885.22	21,788.71	15,548.25
Namibia	3	G, D, R	public	55.9	2,479.71	1,093.55	462.05
Nepal	1	G, T, D, R	public	77.3	28,982.77	6,579.09	22,403.68
Netherlands	7	D	mixed	100	17,018.41	0.00	2,431.20
New Zealand	29	D	mixed	100	4,692.70	0.00	161.82
Nicaragua	10	D	mixed	89	6,149.93	676.49	547.34
Niger	1	G, T, D, R	public	11.2	20,672.99	18,357.62	2,315.37
Nigeria	11	D	mixed	60.6	185,989.64	73,279.92	10,246.34
North Korea	1	G, T, D, R	public	26.9	25,368.62	18,544.46	6,824.16
Norway	146	D	mixed	100	5,232.93	0.00	35.84
Oman	4	D	mixed	99.6	4,424.76	17.70	1,101.77
Pakistan	11	G, D	mixed	73.6	193,203.48	51,005.72	12,927.07

Country	No of DSOs	Legal Structure	Ownership	Access to electricity (%)	Population (thousand)	Population without electricity connection (thousand)	Connected Population per DSO (thousand)
Panama	3	D	private	95.5	4,034.12	181.54	1,284.19
Papua New Guinea	1	G, T, D, R	public	20.3	8,084.99	6,443.74	1,641.25
Paraguay	1	G, T, D, R	public	99.3	6,725.31	47.08	6,678.23
Peru	22	D, R	mixed	95.1	31,773.84	1,556.92	1,373.50
Philippines	140	D	mixed	89.6	103,320.22	10,745.30	661.25
Poland	169	G, D, R	mixed	100	37,948.02	0.00	224.54
Portugal	13	D	mixed	100	10,324.61	0.00	794.20
Qatar	1	G, T, D, R	public	100	2,569.80	0.00	2,569.80
Republic of Congo	1	G, T, D, R	public	43.2	5,125.82	2,911.47	2,214.35
Romania	48	G, D, R	mixed	100	19,705.30	0.00	410.53
Russia	15	G, T, D, R	public	100	144,342.40	0.00	9,622.83
Rwanda	1	G, T, D, R	public	30	11,917.51	8,342.26	3,575.25
Sao Tome & Principe	1	G, T, D, R	public	59.4	199.91	81.16	118.75
Saudi Arabia	1	G, T, D, R	public	100	32,275.69	0.00	32,275.69
Senegal	1	G, T, D, R	public	64	15,411.61	5,548.18	9,863.43
Serbia	1	G, T, D, R	public	100	7,057.41	0.00	7,057.41
Seychelles	1	G, T, D, R	public	99.5	94.68	0.47	94.21
Sierra Leone	1	G, D	public	13.1	7,396.19	6,427.29	968.90
Singapore	1	G, T, D, R	public	100	5,607.28	0.00	5,607.28
Slovakia	3	G, T, D, R	mixed	100	5,428.70	0.00	1,809.57
Slovenia	1	D	public	100	2,064.84	0.00	2,064.84
Somalia	1	G, T, D, R	public	19.1	14,318.00	11,583.26	2,734.74
South Africa	1	G, T, D, R	public	86	55,908.86	7,827.24	48,081.62
South Korea	1	T, D, R	public	100	51,245.71	0.00	51,245.71
South Sudan	1	G, T, D, R	public	4.5	12,230.73	11,680.35	550.38
Spain	340	D	mixed	100	46,443.96	0.00	136.60
Sri Lanka	2	T, D	public	100	21,203.00	0.00	10,601.50
Sudan	1	G, D, R	public	46.2	39,578.83	21,293.41	18,285.42
Suriname	1	G, T, D, R	public	100	558.37	0.00	558.37
Swaziland	1	G, T, D, R	public	84	1,343.10	214.90	1,128.20
Sweden	170	D	mixed	100	9,903.12	0.00	58.25
Switzerland	900	G, D, R	mixed	100	8,372.10	0.00	9.30
Syria	14	G, T, D, R	public	95.7	18,430.45	792.51	1,259.85
Taiwan	1	T, D	public	100	23,557.46	0.00	23,557.46
Tajikistan	1	G, T, D, R	public	100	8,734.95	0.00	8,734.95
Tanzania	1	G, T, D, R	public	32.7	55,572.20	37,400.09	18,172.11
Thailand	2	G, T, D, R	public	100	68,863.51	0.00	34,431.76
Togo	1	G, T, D	public	45.7	7,606.37	4,130.26	3,476.11
Trinidad & Tobago	1	T, D	public	98.6	1,364.96	19.11	1,345.85
Tunisia	1	G, T, D, R	public	100	11,403.25	0.00	11,403.25
Turkey	21	D, R	private	100	79,512.43	0.00	3,786.31

Country	No of DSOs	Legal Structure	Ownership	Access to electricity (%)	Population (thousand)	Population without electricity connection (thousand)	Connected Population per DSO (thousand)
Turkmenistan	1	G, T, D, R	public	100	5,662.54	0.00	5,662.54
Uganda	1	D	public	20.4	41,487.96	33,024.42	8,463.54
Ukraine	44	G, D, R	mixed	100	45,004.64	0.00	1,022.83
United Arab Emirates	4	G, T, D, R	public	100	9,269.61	0.00	2,317.40
United Kingdom, GB	14	D	private	100	64,612.24	0.00	4,615.16
United Kingdom, NI	1	T, D	private	100	1,851.60	0.00	1,851.60
United States	3112	G, D, R	mixed	100	323,127.51	0.00	103.83
Uruguay	1	G, T, D, R	public	99.9	3,444.01	3.44	3,440.57
Uzbekistan	1	G, T, D, R	public	100	31,848.20	0.00	31,848.20
Venezuela	1	G, T, D, R	public	99.5	31,568.18	157.84	31,410.34
Vietnam	1	G, T, D, R	public	98.3	92,701.10	1,575.92	91,125.18
Yemen	1	G, T, D, R	public	48.2	27,584.21	14,288.62	13,295.59
Zambia	1	G, T, D, R	public	33.7	16,591.39	11,000.09	5,591.30
Zimbabwe	1	G, T, D, R	public	33.8	16,150.36	10,691.54	5,458.82

Table 3 is the continuation of the review results. This table also includes the distribution, supply and minimum transmission voltage levels (Pabla, 2005; Khan, 2007; Power Guide, 2009).

Table 3
Electric Power Distribution review worldwide cont.

Country	distribution voltages (kV)	supply voltage (V)	lowest trans. voltage (kV)	highest dist. voltage (kV)	freque ncy (Hz)	Electricity generation (GWh)	Renewable electricity generation (GWh)	Renewable electricity output (% of total electricity output)
Afghanistan	20, 15, 6	380/220	35	20	50	1034	890	86.07
Albania	20, 10, 6	380/220	110	20	50	7135	5866	82.21
Algeria	30, 20, 15, 10, 5.5	380/220	60	30	50	64684	223	0.34
Angola	30	400/230, 380/220	60	30	50	9438	5140	54.46
Argentina	33, 27, 13. 8, 13.2, 6.88	380/ 220	132	33	50	133817	36420	27.22
Armenia	35, 10, 6	380/220	110	35	50	7392	2188	29.60
Australia	33, 22, 11, 19.1, 12.7, 7.2, 6.6, 3.6	440/250, 415/240	66	33	50	239145	34405	14.39
Austria	20, 10, 5	400/230	110	20	50	56940	45553	80.00
Azerbaijan	35, 10	380/220	110	35	50	23300	1813	7.78
Bahamas, The	12.5, 11, 7.2, 2,4	240/120, 208/120, 200/115	33	12.5	60	1807	2	0.10
Bahrain	33, 11, 6.6	415/240, 400/230	66	33	50, 60	26776	10	0.04
Bangladesh	33, 15, 11	400/230	132	33	50	55504	714	1.29

Country	distribution voltages (kV)	supply voltage (V)	lowest trans. voltage (kV)	highest dist. voltage (kV)	frequency (Hz)	Electricity generation (GWh)	Renewable electricity generation (GWh)	Renewable electricity output (% of total electricity output)
Barbados	11	400/230, 230/115, 200/115	24	11	50	915	14	1.53
Belarus	35, 10, 6	400/230, 220/127	110	35	50	32056	326	1.02
Belgium	15, 6	400/230	30	15	50	65713	15612	23.76
Belize	22, 13.2, 11, 6.6	110	34.5	22	60	248	236	95.16
Benin	15, 11, 6.6	380/220	33	15	50	312	8	2.60
Bhutan	33, 11	400/230	66	33	50	7732	7731	99.99
Bolivia	34.5, 12.5	400/230	69	34.5	50	8151	2652	32.54
Bosnia & Herzegovina	35, 20,10, 6.6	380/220	110	35	50	14969	5496	36.72
Botswana	11	400/230	33	11	50	2789	2	0.08
Brazil	138, 69, 34.5, 24, 13.8, 13.2, 11.2, 6.6	440/254, 400/230, 380/220, 220/127	230	138	60	568650	426638	75.03
Brunei	33, 11	415/240	66	33	50	3948	2	0.05
Bulgaria	20, 10, 6	400/230, 380/220	110	20	50	46267	8706	18.82
Burkina Faso	33, 20, 15	400/230	90	33	50	944	93	9.85
Burundi	30, 10	400/230	110	30	50	230	200	86.96
Cambodia	22	380/220	35	22	50	4236	2021	47.71
Cameroon	33, 30, 5.5	380/220	90	33	50	6610	5093	77.05
Canada	34.5, 27.6, 24.94, 20, 14.4, 13.8, 12.47, 8, 7.2, 4.16, 2.4	600/347, 240, 120	44	34.5	60	647045	418679	64.71
Central African Rep.	22, 15	380/220	110	22	50	174	150	86.21
Chad	20	380/220	63	20	50	215	0	0.00
Chile	23, 15, 13.8, 13.2, 12	440, 380/220	66	23	50	72332	32368	44.75
China (mainland)	110, 35, 11, 10, 6	380/220	220	110	50	5581739	1398207	25.05
China - Macau	11, 10, 6	380/220	66	11	50	904	0	0.00
China - Hong Kong	33, 22, 11, 10, 6	380/220	66	33	50	35755	106	0.30
Colombia	13.8, 11.4, 7.2, 6.3, 6.0, 4.16, 2.4	240/120, 208/120	34.5	13.8	60	67256	46649	69.36
Comoros	5.5	380/220	20	5.5	50	54	5	9.26
Congo, Dem. Rep.	30, 20, 15, 6.6	380/220	50	30	50	8852	8837	99.83
Costa Rica	24.9, 14.4, 13.2, 12.47, 7.2, 4.16, 4.16	400/277, 240/120, 208/120	34.5	24.9	60	10725	10623	99.05
Croatia	35, 10, 6.6	380/220	110	35	50	10886	7453	68.46

Country	distribution voltages (kV)	supply voltage (V)	lowest trans. voltage (kV)	highest dist. voltage (kV)	frequency (Hz)	Electricity generation (GWh)	Renewable electricity generation (GWh)	Renewable electricity output (% of total electricity output)
Cuba	34.5, 22, 13.2, 7.2, 6.3, 6.0, 4.16, 2.4	480/277, 400/230, 240/120, 230/115	110	34.5	60	19119	801	4.19
Cyprus	22, 11	400/230	66	22	50	4283	396	9.25
Czech Republic	35, 22, 10, 6, 3	690, 500, 400/230	110	35	50	77830	9454	12.15
Denmark	60, 33, 11, 10	400/230	132	60	50	28393	19713	69.43
Djibouti	20	400/230, 220	63	20	50	405	1	0.12
Dominican Republic	7.2, 4.16	480, 240/120, 220/110, 208, 115	34.5	7.2	60	15644	1906	12.18
Ecuador	13.8, 6.9, 4.16, 2.4	440/220, 220/127, 208/120, 110	24	13.8	60	24973	13513	54.11
Egypt	66, 33, 22, 20, 11, 10, 6.6, 3	380/220	132	66	50	171826	14896	8.67
El Salvador	46, 23, 13.2, 4.16	240/120	115	46	60	5918	3459	58.45
Eritrea	15, 5.5	400/230, 127/220	66	15	50	384	4	1.04
Estonia	35, 6	380/220	110	35	50	9890	1630	16.48
Ethiopia	33, 15	380/220	45	33	50	10341	10337	99.96
Fiji	33, 11	415/240	132	33	50	892	412	46.19
Finland	70, 20, 10, 1	690/400, 400/230	110	70	50	66394	30726	46.28
France	90, 63, 20, 10	400/230	225	90	50	540123	90940	16.84
Gabon	20, 5.5	410/240	90	20	50	2045	921	45.03
Gambia	11	400/230	33	11	50	240	0	0.00
Georgia	35, 10, 6	380/220	110	35	50	10605	8369	78.91
Germany	33, 20, 10, 6	690/400, 400/230	110	33	50	610171	193735	31.75
Ghana	34.5, 11.5, 6.6, 3.3	415/240, 380/220	161	34.5	50	11094	5790	52.19
Greece	22, 20, 15, 6.6	380/220	66	22	50	49272	14646	29.72
Grenada	11, 4.16	400/230	22	11	50	200	1	0.45
Guatemala	34.5, 13.8	240/220	69	34.5	60	10760	6643	61.74
Guinea	11	220	33	11	50	1000	500	50.00
Guinea-Bissau	15	220	33	15	50	34	0	0.00
Guyana	13.8, 11, 4.16	480/240, 240/120	33	13.8	60	1000	44	4.43
Haiti	13.2, 12.47, 7.2, 4.16, 2.4	240/120	23	13.2	60	980	82	8.37
Honduras	13.8, 6.6, 4.16, 2.4	480/277, 240/120,	34.5	13.8	60	8632	3767	43.64

		220/127, 220/110						
Country	**distribution voltages (kV)**	**supply voltage (V)**	**lowest trans. voltage (kV)**	**highest dist. voltage (kV)**	**freque ncy (Hz)**	**Electricity generation (GWh)**	**Renewable electricity generation (GWh)**	**Renewable electricity output (% of total electricity output)**
Hungary	35, 30, 22, 20, 10	380/220	110	35	50	28708	3321	11.57
Iceland	66, 33, 11	400/230	132	66	50	18558	18554	99.98
India	33, 22, 11, 6.6, 3.6	460/230, 440/250, 415/240, 400/230	66	33	50	1294503	195242	15.08
Indonesia	20, 12, 6-7	380/220, 220/127	25	20	50	221306	24797	11.20
Iran	33, 20, 11, 6	400/230, 380/220	63	33	50	264971	14184	5.35
Iraq	33, 11, 6.6, 3.3	400/230	132	33	50	64915	2546	3.92
Ireland	38, 20, 10,	400/230	110	38	50	26638	7923	29.74
Israel	33, 22, 12.6, 6.3	400/230	161	33	50	60445	1214	2.01
Italy	20, 15, 10	400/230	132	20	50	268939	109962	40.89
Ivory Coast	30, 19, 15, 5.5	400/230	90	30	50	8262	1443	17.47
Jamaica	24, 13.8, 12, 11, 3.3, 2.2	415/240, 220/110	69	24	60	3899	422	10.82
Japan	33, 22, 20, 13.8, 11, 6.6, 6, 3.3	440, 400, 220/110, 200/100	66	33	50, 60	976393	169660	17.38
Jordan	33, 20, 11, 6.6, 3.3	415/240, 400/230	132	33	50	17883	183	1.02
Kazakhstan	35, 10, 6	400/230	110	35	50	100557	9358	9.31
Kenya	33, 11, 3.3	415/240	66	33	50	9568	8435	88.16
Kiribati	11, 4	415/240	11	11	50	24	3	11.25
Kuwait	11, 6.6, 3.3	415/240, 400/230	33	11	50	63843	5	0.01
Kyrgyzstan	35, 10, 6	400/230	110	35	50	12803	10989	85.83
Laos	22, 11, 6.6, 3.3	380/220	115	22	50	11460	11060	96.51
Latvia	20, 10, 6	400/230	110	20	50	5349	2757	51.55
Lebanon	33, 20, 15, 11, 6, 5.5	380/220, 190/110	66	33	50	17322	480	2.77
Lesotho	22, 11	380/220	33	22	50	600	600	100.00
Liberia	22, 12.5, 11	400/230/ 120	33	22	50, 60	300	22	7.20
Libya	11, 10, 6	380/220	33	11	50	35450	8	0.02
Lithuania	35, 10, 6	400/230	110	35	50	3603	1733	48.10
Luxembourg	20	400/230	65	20	50	757	493	65.13
Macedonia	35, 20, 10, 6.6, 6	380/220	110	35	50	6073	1986	32.70
Madagascar	35, 30, 20, 15, 5.5, 5	380/220, 220/110	63	35	50	1508	901	59.75
Malawi	33, 11	400/230	66	33	50	2120	2100	99.06
Malaysia	33, 22, 11, 6.6	400/230	132	33	50	141871	14806	10.44

Country	distribution voltages (kV)	supply voltage (V)	lowest trans. voltage (kV)	highest dist. voltage (kV)	frequency (Hz)	Electricity generation (GWh)	Renewable electricity generation (GWh)	Renewable electricity output (% of total electricity output)
Maldives	11, 6	400/230	35	11	50	350	5	1.49
Mali	30	380/220	150	30	50	2175	1175	54.02
Malta	33, 11	400/230	132	33	50	1228	97	7.90
Mauritania	33, 15	380/220	90	33	50	1282	302	23.56
Mauritius	22, 6,6	400/230	66	22	50	2857	680	23.80
Mexico	85, 69, 34.5, 23, 13.8, 13.2, 6.6, 4.16, 2.4	480/277, 240/120, 220/127, 208/120	115	85	60	294818	47095	15.97
Moldova	35, 10, 6	400/230	110	35	50	5742	324	5.64
Mongolia	35, 15, 10, 6	380/220, 220/127	110	35	50	5192	170	3.27
Morocco	22, 20, 6, 5.5	380/220	60	22	50	27967	4392	15.70
Mozambique	33, 11	400/230	66	33	50	19579	17035	87.01
Myanmar	33, 11, 6.6	400/230	66	33	50	15482	9305	60.10
Namibia	33, 22, 19.1, 11	400/230	66	33	50	1519	1487	97.90
Nepal	22, 11	400/230	33	22	50	3493	2232	63.91
Netherlands	50, 25, 23, 20, 12, 10	400/230	110	50	50	104274	15329	14.70
New Zealand	33, 22, 11, 6.6, 3.3	400/230	50	33	50	42912	34689	80.84
Nicaragua	24.9, 13.2, 4.16	120	69	24.9	60	4441	2291	51.59
Niger	33, 20	400/230	132	33	50	499	10	1.98
Nigeria	33, 15, 11, 6.6, 3.3	400/230, 380/220	66	33	50	29830	5664	18.99
North Korea	10, 6, 3.3	380/220, 200/100	66	10	60	13413	9900	73.81
Norway	66, 33, 22, 20, 10, 5	400/230	132	66	50	142381	140240	98.50
Oman	33, 11	240	132	33	50	30793	1	0.00
Pakistan	33, 11, 6.6, 3.3	400/230	66	33	50	104580	34504	32.99
Panama	13.8, 12, 4.16, 2.4	240/120, 220/110	34.5	13.8	60	10024	6668	66.52
Papua New Guinea	22, 11	415/240	33	22	50	3620	860	23.76
Paraguay	23	380/220	66	23	50	55191	55190	100.00
Peru	33, 22.9, 20, 13.2, 7.62, 10	220/110	60	33	60	46646	25206	54.04
Philippines	34.5, 23, 20, 13.8, 13.2, 6.2, 4.8, 4.16, 3.6, 3.3, 2.4	240/120, 220/110	69	34.5	60	78638	20875	26.55
Poland	30, 15, 10, 6.3, 1	400/230	110	30	50	155292	22610	14.56
Portugal	60, 30, 15, 10, 6	400/230	130	60	50	49161	24477	49.79
Qatar	33, 11, 6.6	415/240	66	33	50	39009	206	0.53

Country	distribution voltages (kV)	supply voltage (V)	lowest trans. voltage (kV)	highest dist. voltage (kV)	frequency (Hz)	Electricity generation (GWh)	Renewable electricity generation (GWh)	Renewable electricity output (% of total electricity output)
Republic of Congo	30, 20, 15, 6.6	380/220	70	30	50	1676	916	54.64
Romania	20, 10	400/230	110	20	50	63024	26031	41.30
Russia	110, 35, 20, 10, 6, 3	660/380/ 220/127	220	110	50	1008360	170077	16.87
Rwanda	30, 15, 6.6	380/220	70	30	50	600	341	56.83
Sao Tome & Principe	6	380/220	30	6	50	66	7	10.76
Saudi Arabia	69, 34.5, 33, 13.8, 11, 4.6	415/240, 380/220, 220/127	110	69	60	318036	82	0.03
Senegal	30, 6.6	380/220, 220/127	90	30	50	3673	409	11.14
Serbia	35, 20, 10, 6.6	400/230	110	35	50	35458	10018	28.25
Seychelles	11	400/230	33	11	50	347	9	2.59
Sierra Leone	11	450/250, 400/230	33	11	50	175	110	62.86
Singapore	22, 11, 6.6	400/230	66	22	50	47483	1551	3.27
Slovakia	22, 15, 6, 3	400/230	110	22	50	24848	5901	23.75
Slovenia	35, 20, 10, 6.6, 3.3	400/230	110	35	50	14098	4305	30.54
Somalia	33, 15, 11	440/220, 220/110	45	33	50	345	7	2.06
South Africa	132, 88, 66, 44, 33, 22, 11, 6.6, 3.3	550, 500, 400/230, 380/220	220	132	50	230590	5553	2.41
South Korea	22.9, 13.2, 11, 6.6, 3.3	440, 380/220, 200/100, 110	66	22.9	60	516545	10878	2.11
South Sudan	33, 11	415/240	66	33	50	310	2	0.64
Spain	45, 25, 20, 15, 13.2, 11, 10, 6, 3	380/220, 220/127	66	45	50	264197	95660	36.21
Sri Lanka	11, 3.3	400/230	33	11	50	12711	6327	49.77
Sudan	33, 11, 6.6	415/240	66	33	50	12685	8336	65.71
Suriname	13.8, 12, 6	220/127	33	13.8	60	2190	1342	61.28
Swaziland	11	400/230	66	11	50	431	231	53.60
Sweden	130, 70, 20, 10	400/230	220	130	50	159289	103067	64.70
Switzerland	150, 50, 35, 10	400/230	150	150	50	64070	41922	65.43
Syria	20, 11, 6.6, 6	380/220, 220/115	66	20	50	16829	409	2.43
Taiwan	34.5, 22.8, 22, 11.4, 11, 6.6, 3.3	380/220, 220/110	69	34.5	60	240404	10563	4.39
Tajikistan	110, 35, 10, 6	400/230, 380/220, 220/127	220	110	50	16977	16731	98.55
Tanzania	33, 11	400/230	132	33	50	6025	2129	35.33
Thailand	115, 69, 33, 22, 11, 3.3	380/220	115	115	50	167961	15134	9.01

Country	distribution voltages (kV)	supply voltage (V)	lowest trans. voltage (kV)	highest dist. voltage (kV)	frequency (Hz)	Electricity generation (GWh)	Renewable electricity generation (GWh)	Renewable electricity output (% of total electricity output)
Togo	34.5, 11.5, 6.6	380/220	69	34.5	50	79	60	76.14
Trinidad & Tobago	33, 13.8, 12, 6.6, 4, 2.3	400/230, 230/115, 220/110	66	33	60	9682	4	0.04
Tunisia	30, 22, 15, 10	380/220	90	30	50	18328	558	3.04
Turkey	34.5, 15, 11, 6.3	380/220	66	34.5	50	248863	81911	32.91
Turkmenistan	35, 10, 6	400/230, 380/220, 220/127	110	35	50	21185	3	0.01
Uganda	33, 11	415/240	66	33	50	3235	2615	80.83
Ukraine	35, 10, 6	380/220	69	35	50	152122	7048	4.63
United Arab Emirates	33, 11, 6.6	415/240	132	33	50	119743	316	0.26
United Kingdom, GB[1]	132, 66, 33, 22, 11, 6.6, 3.3	400/230	132	66	50	318,150.38 (UK, total)	87,083.00 (UK, total)	27.37 (UK, total)
United Kingdom, NI	33, 22, 11, 6.6, 3.3	400/230	66	33	50	318,150.38 (UK, total)	87,083.00 (UK, total)	27.37 (UK, total)
United States	34.5, 24, 20.8, 19.9, 14.4, 13.2, 12.47, 12, 11.5, 4.8, 4.16	480/277, 460/265, 240/120, 120/208	69	34.5	60	4088000	562451	13.76
Uruguay	31.5, 15, 6	380/220	150	31.5	50	13564	12086	89.11
Uzbekistan	35, 10, 6	400/230	110	35	50	54423	11700	21.50
Venezuela	34.5, 24, 13.8, 12.47, 8.3, 6.6, 4.8, 4.16, 2.4	480/277, 480/240, 240/120, 208/120	69	34.5	60	114370	74240	64.91
Vietnam	35, 22, 15, 13.2, 10, 6.6, 6, 3	380/220	66	35	50	146902	55742	37.94
Yemen	15, 13.8, 11, 10.5	380/220	33	15	50	5006	101	2.03
Zambia	33, 11	400/230	66	33	50	13285	12905	97.14
Zimbabwe	33, 11	380/220	66	33	50	9384	5069	54.02

[1]In England, 132 kV electricity lines are part of the distribution network.

Table 4 and Table 5 provide 5 countries that have lowest transmission voltages and lowest highest distribution voltages respectively.

Table 4

5 Countries that have lowest transmission network voltages

Country	voltage (kV)
Comoros	20
Grenada	22
Haiti	23
Ecuador	24
Indonesia	25

Table 5

5 Countries that have lowest highest distribution network voltages

Country	Voltage (kV)
Comoros	5.5
Sao Tome & Principe	6
Dominican Republic	7.2
North Korea	10
Barbados	11

Table 6 summarizes the number of countries per different legal structures. Table 7 and Table 8 compile 5-largest DSOs in the world in terms of number of customers served.

Table 6

Summary of the legal structures of countries

legal structure	no. of countries
D	41
T, D	9
T, D, R	4
G, D, R	12
G, T, D, R	97
Other	12

Table 7

Largest 5 publicly owned DSOs in the world

DSO	ownership	number of customers (million)
State Grid Corporation of China	public	447
China Southern Power Grid[1]	public	122
Perusahaan Listrik Negara, Indonesia	public	64.3
Federal Electricity Commission, Mexico	public	34.9
TEPCO[2], Japan	public	29.5

[1]Estimated in ratio to State Grid Corporation of China

[2]State controls equivalent to 50%+ of stock.

Table 8
Largest 5 mixed and private owned DSOs in the world
(Mixed assumed to be more than 10% public and private)

DSO	ownership	number of customers (million)
ENEL, worldwide	mixed	65.5
Enedis, France	mixed	36
Endesa, Spain	private	22
E.ON, Europe	private	17
RWE, Europe	private	16.5

State Grid Corporation of China serves around 1.1 billion people and has about 447 million customers. It is the largest power distribution company in the world. The European DSOs are generally smaller in size. In 2015, around 2370 European DSOs served less than 100,000 customers. Today, in Italy alone, 49 DSOs serve less than 1,000 customers.

3. Electric Power Distribution of Tomorrow

According to a recent extensive DSO survey conducted with 108 executives from 24 countries in Europe, 72% of the respondents think that DSOs will become more service-focused than asset-oriented. For the future role of the DSOs, 89% mention being data hubs to facilitate market access, 82% report actively controlling distributed generation and being responsible for demand response and balancing at the distribution level (Outlook on the European DSO landscape 2020, 2016). Nevertheless, the transition from network-ownership to system operation and hence being service-based companies will not be an easy task. The MIT Utility of the Future report (MIT Energy Initiative, 2016) argued that the degree of complexity is quite high for the distribution networks to decouple network planning from network operation. Therefore, the economies of scope between distribution network ownership and distribution system operation will be higher than for the transmission system. The report suggests three possible future DSO designs;

- Distribution network owner and operator
- Independent distribution system operator and separate network owner
- Closely regulated, vertically integrated utility

Being a distribution network owner and operator or an Independent distribution system operator is discussed in the context of the EU as well. However, we should remember that vertically integrated utilities or VIUs are not allowed in EU since these are against the unbundling rules of EC which are specified in the third energy package in Directive 2009/72. The question here is perhaps why VIUs are considered as an inefficient solution by the EC. The US Federal Energy Regulatory Commission gives the following answer (FERC, 1999, p.35):

"The inherent characteristics of monopolists make it inevitable that they will act in their own self-interest to the detriment of others by refusing transmission and/or providing inferior transmission to competitors in the bulk power markets to favor their own generation, and it is our duty to eradicate unduly discriminatory practices."

Similarly, the EC states that (EC, 2009, L211/56):

"Without effective separation of networks from activities of generation and supply (effective unbundling), there is an inherent risk of discrimination not only in the operation of the network but also in the incentives for vertically integrated undertakings to invest adequately in their networks."

Increasing distributed generation, renewable energy sources, demand response, smart grids and smart technologies require a more active DSO than its traditional passive role. This active management means new capabilities and responsibilities for the DSO. A CEER Report specifies a list of responsibilities of European DSOs and suggests allowable core activities, current prohibited activities and grey areas which are still to be discussed between industry and regulatory bodies (CEER, 2015b). Table 9 summarizes these allowed, prohibited and grey areas for DSOs.

Table 9
Allowed and prohibited activities and grey areas for DSOs

Allowed activities	Prohibited activities	Grey areas
• Planning, developing, operating and maintaining the network • Connecting users to grid • Load shedding • Managing technical data • Managing network losses	• Energy generation • Energy supply	• Managing metering data for small end customers • Monitoring grid and voltage related constraints as more RES connects to the distribution system • Infrastructure for EVs • Ownership/management of meters • Flexibility services – but don't inhibit market for aggregators

Source: CEER (2015b).

As we can see the grey areas raise new areas for discussion about the distribution/retail and distribution/transmission relationships. The relationship between transmission system operators (TSOs) and DSOs will likely to be a hot discussion topic as the distributed generation, demand response and data management concerns increase. TSOs will likely seek to extend their SO function to lower voltages while DSOs will likely seek to provide opportunities for DERs to provide system services traditionally procured by the TSO. In addition to the network operation duties, the DSOs should also become neutral facilitators of open and accessible markets so that they will enable competitive access to markets and the optimal use of both traditional generations and DERs. Hence, in addition to network provision, the main core functions of the future DSOs will likely be providing:

- system operation,
- market platforms,
- data management through data hubs.

3.1. More Active DSOs in System Operation

Creating a fully functional DSO that is capable of core functions and providing a level field for access is not an easy task. In the United Kingdom there are Distribution Network Operators (DNOs). A DNO owns and operates the physical distribution network but does not perform energy balancing role of a typical active DSO. DNOs operate and maintain their networks and invest in their expansion. UKPN is one of the British DNOs which is fully ownership unbundled from G, T and R. On its transition to a full DSO, UKPN is developing the following distribution system operations capabilities (UKPN, 2017, p.37):

Energy flows forecasting (near time, real-time), real-time dispatch of DER, commercial optimisation, TSO coordination, predictive diagnostics, dispatch management visibility, visualisation and simulation, online capacity and queue management, growth forecasting, integrated T&D planning, distributed energy, resource planning and system operability.

However, a full DSO model requires a more expanded role in whole system optimisation, enabling markets for DERs and providing data-hubs for prosumer integration. On the other hand, the Cost of Energy Review (Helm, 2017) suggests the creation of an independent national system operator (NSO) and regional system operators (RSOs) to provide competitive auctions and, at the local level, invite bids for network enhancements, generation and storage, and demand response. Furthermore, the Open Networks Project of the Energy Networks Association defines the roles of National Electricity Transmission System Operator (NETSO) and DSOs and suggests several models for DER services integrated in the whole system (Energy Networks Association, 2017). Among which are:

1. NETSO has an extended role. It leads on procurement and calling up of services from DER.
2. DSO procures flexibility for itself and for the NETSO. It has the central role. To facilitate this the DSO has commercial relationships with the NETSO, DERs, aggregators and suppliers.
3. DSO and NETSO share responsibilities. The DSO manages distribution issues and acts as a commercial aggregator and information provider for the NETSO.

As we can see, how to carry out the four core functions of a DSO is a complicated matter. There are numerous proposals on how to achieve a fully functional DSO which actively interacts with DERs. Therefore, we can say that the transition from DNOs to DSOs will likely take some time in UK.

The TSO-DSO coordination and the allocation of activities and responsibilities are among the top priorities of the electricity industry and its associated research community. Kristov et al. (2016) and Gerard et al. (2017) present some in-depth analysis about various TSO-DSO relationship scenarios. These scenarios include a similar discussion with the Energy Networks Association. Both raise the question of what is the relative position of the DSO and the TSO in future system operation?

3.2 DSOs as Market Platforms

In New York State, US the Distribution System Platform (DSP) will be the next step in evolving more active distribution systems that will also provide a market platform in addition to the system operation duties. The DSP is defined as "an intelligent network platform that will provide safe, reliable and efficient electric services by integrating diverse resources to meet customers' and society's evolving needs. The DSP fosters broad market activity that monetizes system and social values, by enabling active customer and third-party engagement that is aligned with the wholesale market and bulk power system", (NYDPS, 2014 p. 31). DSP is the central component of the New York Energy Reform (Reforming the Energy Vision – REV) launched in 2014 by the New York Department of Public Service Commission (NYDPS, 2014) which sets the basis for the transition to a modern electric utility. REV constitutes a pioneering initiative that helps to build a cleaner, resilient and affordable energy system, stimulating new investments, innovation and improving customer choices. Among the main drivers behind REV were the high cost of traditional solutions for delivering electricity (in contrast with the cost reduction of alternative solutions), change in customer preferences (own generation and self-consumption), and not enough progress on emission reductions. REV mandates the New York's six largest investor-owned utilities[5] to evolve into a DSP.

Hawaii is another US state that will adopt the Distribution System Platform Provider (DSPP) concept. The state is aiming to increase its Renewable Portfolio Standard (RPS) to 100% by the year 2045 (Warwick et al., 2016). Therefore, the Hawaiian utilities' traditional role might not answer the challenges that will arise with the increasing distributed generation. Nonetheless, the concern about New York and Hawaii DSPPs is that the incumbent utilities might not be sufficiently impartial or creative in their new roles (Warwick et al., 2016). DSOs as system operators in coordination with the Regional Transmission Operators (RTOs) might be alternatives to the DSPP concepts. The utility owned DSPP may provide a precursor to a genuine separation of system operation and network ownership at the distribution level which we have increasingly seen at the transmission level (Chawla and Pollitt, 2013).

3.3 DSOs as Data-Hubs

According to the EU 2020 goals, the smart meter rollout should reach 80% by the year 2020. Data management will be a more prominent issue as the smart metering adoption approaches 100% among end-users. Smart metering and data management will enable frameworks for facilitating network planning, peak shaving and peak shifting, demand response and active prosumer participation. In addition, billing, designing more efficient and fairer tariffs and switching among suppliers will be easier after smart metering adoption. Retail Data Hubs are considered for providing secure and equal access to data and increasing efficient communication among network operators, suppliers and prosumers. There are a few Retail Data Hub trials in Europe. In Belgium, there is Central Market System (CMS) operated by ATRIAS (ATRIAS, 2018). The system is run by the DSOs and the main focus is the data access and data exchange among DSOs, retailers, TSO and other related parties. In Norway, ElHub is designed to enable efficient use of smart metering through more efficient communication and data management and it is operated by the Norwegian TSO Statnett (NVE, 2017). The data will be collected from DSOs and retailers and then it will be shared to increase competition and innovation in the retail market. In Germany, however, the approach is different from the Belgian and Norwegian cases. Instead of creating a Retail Hub, the priority is given to develop a GridHub for a better and more efficient network operation (Consentec, 2016). The GridHub will work as a data hub, which collects all data from smart meters, generators and from the network infrastructure. The platform will then share these data with the network operators for system operation. This hub will be

[5] Consolidated Edison, National Grid, Central Hudson Gas&Electric, New York State Electric&Gas (NYSEG), Orange and Rockland Utilities, Rochester Gas&Electric. The six electric utilities together refer to the Joint Utilities which represents activities or proposals the six utilities undertake as a collective, single group.

run and operated by the TSOs. In Great Britain, smart meters are owned and operated by retail companies (not DSOs) and the data is held by a Data Communications Company called Smart DCC. This is owned by an outsourcing company, Capita plc. As we can see from these examples, access to data and data management may be a potential function of future DSOs but the reality is that alternative ways of handling data exist which remove much of this function from DSOs.

4. Conclusions and Discussion

This review paper compiles electric power system distribution information from 175 countries, which corresponds to 99.4% of the world's population. There are about 7600 DSOs in the world, among which more than half are in the United States (around 3100) and in Europe (around 2500). As we can see from Table 2 and Table 3, there are significant differences among DSOs. These include; size of the distribution system, distribution voltage level, voltage level of connecting to the transmission system, amount of renewable energy generation and hence distributed generation, number of customers served, ownership, operational structure and so on. In addition to the physical and functional characteristics, there are other emerging issues such as smart metering adoptions and data management responsibilities. We should also highlight the geographical differences as well. The data management, new business models and unbundling discussions are primarily dominant in European and North American DSOs. However, in Africa and some other parts of the world, access to the electricity is still a serious problem. There are about 1.1 billion people in the world without a continuous access to electric power. Publicly owned Vertically Integrated Undertakings are widely seen in these regions and one might argue that there is still time for these places to start discussing privatization and deregulation. Therefore, proposing one single DSO model might not fit for the interest of all countries in the world. Instead, various solutions might be proposed for various regions by paying attention to the local conditions. Therefore, digital innovation is a must in achieving the vast energy transformation. Natural monopolies (and the conservative corporate culture that can often accompany them) might be considered to hinder innovation in electric power distribution. An incumbent vertical market power, where the incumbent leverages its regulated status to increase market power in a downstream competitive market is still effective especially in the retail sector (Kiesling, 2014). Deregulation has been completed in some parts of the world; it is still going in some other parts. Achieving full ownership unbundling will be one of the most challenging tasks for the regulators and for the utilities. A Competitive joint venture (CJV) is proposed for replacing the natural monopoly regulation of the distribution network (Boffa & Kiesling, 2006). Access to wires is a key issue in network planning and operation and CJV proposes ownership and wires access charge determination rules, with wires use and control rights determined by the utility's market share in the retail market.

Bundling the electric power distribution and retail with other services such as gas, telecommunications and water is another disputed idea among the electric power industry. There are strict regulations about vertical unbundling in Europe; however, bundling with other businesses and services is allowed. 45% of the distribution operators surveyed in the Outlook on the European DSO landscape 2020 also manage other networks as well. Data management and new business models for the energy sector are other popular discussion topics. The pace of smart metering roll-out is increasing and various retail data-hubs are introduced in Belgium and Norway and a more comprehensive grid-hub is being discussed in Germany. British Office of Gas and Electricity Markets (Ofgem) is running a call for innovative ideas for new business models (Ofgem, 2017).

There is a view that in the future the majority of the transmission lines and a significant portion of the distribution lines might disappear due to DERs (MIT Energy Initiative, 2016). However, the Integrated Grid report by the Electric Power Research Institute points out that in the United States, providing distributed energy to a customer connected to the grid is about $51/month, whilst for residential PV systems, providing the same service without the power grid connection would be four to eight times more expensive (EPRI, 2014). Therefore, we might conclude that the necessity for a robust and resilient power grid will likely to persist in the future as well.

References

ATRIAS, 2018. Round Table for the Energy Market of Tomorrow, Online available at: http://www.atrias.be/UK/Pages/About.aspx

Boffa, F. and Kiesling, L., 2006. Network regulation through ownership structure: An application to the electric power industry. August, 14, pp.21-24.

CEER, 2015a. Benchmarking Report 5.2 on the Continuity of Electricity Supply Data update Ref: C14-EQS-62-03 12 February, Brussels, Belgium.

CEER, 2015b. The Future Role of DSOs a CEER Conclusions Paper, 13 July 2015, Brussels, Belgium.

CEER, 2016. Status Review, Status Review on the Implementation of Distribution System Operators' Unbundling Provisions of the 3rd Energy Package, Ref: C15-LTF-43-03, 1 April 2016, Brussels, Belgium.

Center for the Study of the Presidency & Congress, 2014. "Securing the U.S. Electrical Grid, Understanding the threats to the most critical of critical infrastructure, while securing a changing grid."

Consentec GmbH, 2016. Necessary data and information needs to ensure a secure network and System management in the transmission network, Online available at: https://www.netztransparenz.de/portals/1/Content/Ver%C3%B6ffentlichungen/Gutachten%20zum%20Energieinformationsnetz/Consentec-FGH_4UeNB_Datenbedarf-EIN_GA_komplett.pdf

EC, Directive 2009/72. European Commission, Concerning Common Rules for the Internal Market in Electricity and Repealing Directive 2003/54/EC. Brussels, Belgium: European Commission. July 2009, Online available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0072&from=EN

EC, European Commission Evaluation Report, 2016, Online available at: http://eur-lex.europa.eu/legal-content/EL/TXT/?uri=CELEX%3A52016SC0412

EIA, 2015. US Energy Information Agency, International Energy Statistics, Online available at: https://www.eia.gov/beta/international/data

EIA, 2017. US Energy Information Agency, Electric power sales, revenue, and energy efficiency Form EIA-861 detailed data files, Online available at: https://www.eia.gov/electricity/data/eia861

Energy networks association, 2017. Open Networks Project, Commercial Principles for Contracted Flexibility: Promoting Access to Markets for Distributed Energy Resources. London, UK.

EPRI, 2014. Electric Power Research Institute, the Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources., Palo Alto, California, USA.

Eurostat, 2018. Electricity prices components for household consumers, Online available at: https://data.europa.eu

FERC, 1999. Order No. 2000, Final Rule. Regulation Transmission Organizations (Docket No. RM99-20-000). Washington DC: US Federal Energy Regulatory Commission. December 20, 1999.

Gerard, H., Puente, E. I. R. and Six, D., 2017. Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework. Utilities Policy, 50, 40-48.

Helm, D., 2017. Cost of energy review. Department for Business, Energy & Industrial Strategy, London, UK.

International Energy Agency, 2017. IEA, access to electricity, Online available at: https://www.iea.org/energyaccess/database/

IRENA, 2015. International Renewable Energy Agency, renewable electricity generation, Online available at: http://resourceirena.irena.org/gateway/dashboard/?q=renewable%20electricity&topic=4&subTopic=54

Khan, S., 2007. Industrial Power Systems, CRC Press, Florida, US, pp. 18-19.

Kiesling, L., 2014. Incumbent Vertical Market Power, Experimentation, and Institutional Design in the Deregulating Electricity Industry. The Independent Review, vol. 19, no. 2, pp. 239–264.

Kristov, L., Martini P. D. and Taft J. D., 2016. A Tale of Two Visions: Designing a Decentralized Transactive Electric System. IEEE Power and Energy Magazine, 14(3), 63-69.

NERC, 2012. North American Electricity Reliability Corporation. Planning Resource Adequacy Analysis, Assessment and Documentation, pp. 1–8.

Nillesen, P.H. and Pollitt, M.G., 2011. Ownership unbundling in electricity distribution: empirical evidence from New Zealand. Review of Industrial Organization, 38(1), pp.61-93.

NVE, 2017. The Norwegian Water Resources and Energy Directorate, Online available at: https://www.nve.no/energy-market-and-regulation/retail-market/elhub/

NY DPS, 2014. Reforming the Energy Vision. Staff Report and Proposal. CASE 14-M-0101 - Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision.

Office of the Press Secretary, 2013. "Presidential Policy Directive/Ppd-21, Critical Infrastructure Security and Resilience," The White House, Washington D.C..

Ofgem, 2017. Office of Gas and Electricity Markets, Update on regulatory sandbox, Online available at: https://www.ofgem.gov.uk/publications-and-updates/update-regulatory-sandbox

Tackx, K. and Meeus, L., 2016, Outlook on the European DSO landscape 2020, Vlerick Business School.

Pabla, A.S., 2005. Electric Power Distribution, McGraw-Hill, New York, US, pp. 836-840.

Power Guide, 2009. Electrical Energy Supply, Book 3, Legrand, Limoges Cedex, France, pp. 20-23.

State of New York, 2015. State of New York Public Service Commission Case 14-M-0101, Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision.

UKPN, 2017, Consultation Report, Future Smart A smart grid for all: Our transition to Distribution System Operator, London, UK.

MIT Energy Initiative, 2016. Utility of the Future: An MIT Energy Initiative Response to an Industry in Transition. MIT Energy Initiative.

Warwick, W.M., Hardy, T.D., Hoffman, M.G. and Homer, J.S., 2016, Electricity Distribution System Baseline Report, July, Pacific Northwest National Laboratory, Richland, Washington, US.

World Bank, 2014, access to power, Online available at: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS

World Bank, 2016, world population, Online available at: https://data.worldbank.org/indicator/SP.POP.TOTL

World Energy Council, 2016, Average electricity consumption per electrified household, Online available at: https://wec-indicators.enerdata.net/household-electricity-use.html