

The New World of Utilities

Vincent Petit

The New World of Utilities

A Historical Transition Towards a New
Energy System

 Springer

Vincent Petit
Schneider Electric
Hong Kong

ISBN 978-3-030-00186-5 ISBN 978-3-030-00187-2 (eBook)
<https://doi.org/10.1007/978-3-030-00187-2>

Library of Congress Control Number: 2018956562

© Springer Nature Switzerland AG 2019

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

List of Countries

Asia (Non-OECD)

Samoa, Bangladesh, Brunei Darussalam, Bhutan, Channel Islands, Fiji, Guam, Micronesia, Fed. Sts., Indonesia, Cambodia, Kiribati, Korea, Rep., Lao PDR, Sri Lanka, Maldives, Marshall Islands, Myanmar, Mongolia, Northern Mariana Islands, Malaysia, Nepal, Pakistan, the Philippines, Palau, Papua New Guinea, Singapore, Solomon Islands, Suriname, Timor-Leste, Thailand, Tuvalu, Taiwan, China, Vietnam, Vanuatu

Africa

Aruba, Angola, Burundi, Benin, Burkina Faso, Botswana, Central African Republic, Cote d'Ivoire, Cameroon, Congo, Rep., Comoros, Cabo Verde, Djibouti, Algeria, Egypt, Arab Rep., Eritrea, Ethiopia, Gabon, Ghana, Guinea, Gambia, Guinea-Bissau, Equatorial Guinea, Kenya, Liberia, Libya, Lesotho, Morocco, Madagascar, Mali, Mozambique, Mauritania, Mauritius, Malawi, Namibia, Niger, Nigeria, Rwanda, São Tomé and Príncipe, Sudan, Senegal, Sierra Leone, Somalia, South Sudan, Swaziland, Chad, Togo, Tonga, Tunisia, Tanzania, Uganda, South Africa, Congo, Dem. Rep., Zambia, Zimbabwe

Eurasia

Afghanistan, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyz Republic, Russian Federation, Tajikistan, Turkmenistan, Uzbekistan

Europe

Andorra, Albania, Austria, Belgium, Bulgaria, Bosnia and Herzegovina, Central Europe and the Baltics, Switzerland, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, Faeroe Islands, United Kingdom, Greece, Grenada, Greenland, Croatia, Hungary, Isle of Man, Ireland, Iceland, Italy, Kosovo, Liechtenstein, Lithuania, Luxembourg, Latvia, Monaco, Moldova, Macedonia, FYR, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Sweden, Ukraine

Middle East

United Arab Emirates, Bahrain, Iran, Islamic Rep., Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Turkey, West Bank and Gaza, Yemen Rep.

North America

Canada, Mexico, United States

OECD Asia

Australia, Japan, New Caledonia, New Zealand, Korea, Dem. Rep., Pacific island small states, French Polynesia

South America

Argentina, Antigua and Barbuda, Bahamas, The, Belize, Bermuda, Bolivia, Brazil, Barbados, Chile, Colombia, Costa Rica, Caribbean small states, Cuba, Curacao, Cayman Islands, Dominica, Dominican Republic, Ecuador, Guatemala, Guyana, Honduras, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Martin (French part), Nicaragua, Panama, Peru, Puerto Rico, Paraguay, El Salvador, Sint Maarten (Dutch part), Seychelles, Turks and Caicos Islands, Trinidad and Tobago, Uruguay, St. Vincent and the Grenadines, Venezuela, Virgin Islands (U.S.)

Contents

1	Introduction	1
	References	4
2	The Transition to a New Electric World	5
2.1	Spectacular Growth of Electricity Consumption	5
2.1.1	All Forecasts Confirm Trend Towards a Significant Increase	5
2.1.2	Increased Usage in All Sectors, but Dynamics Vary	8
2.2	A Model to Understand the Electricity Consumption Evolution	11
2.2.1	Four Factors that Impact Overall Electricity Consumption Forecast	11
2.2.2	Population Growth	12
2.2.3	Energy Efficiency	14
2.2.4	Fuel Switching Strategies	18
2.2.5	Living Standards	24
2.3	Summary: The Transition to a New Electric World	27
	References	31
3	The Transition to a New Power Mix	33
3.1	New Competition Landscape for Electricity Generation	33
3.1.1	Competitiveness of Power Generation Sources	34
3.1.2	The Upcoming Evolution of the New Power Generation Competitive Landscape	52
3.1.3	The Transition Leads to a Pressure on Prices	58
3.2	Massive Investments in Power Generation	62
3.2.1	Various Scenarios of Power Generation Investments by Source	62
3.2.2	Regional Perspectives on Power Generation Investments	68
3.3	High Penetration of Renewable Electricity	71
3.3.1	The Renewable Electricity Mix	71
3.3.2	The Dawn of Distributed Generation	75

3.4	Summary: Cost of Transiting to a New Power Mix	82
	References	87
4	The Transition to a New Grid	91
4.1	A Model for Understanding Grid Challenges: The “Duck” Curve . . .	91
4.1.1	Main Issues Associated with High Share of Variable Renewable Energies	91
4.1.2	The “Duck” Curve	93
4.1.3	A Model to Enable Quantitative Analysis	95
4.2	New Grid Challenges	99
4.2.1	Structural Evolution of Conventional Generation	99
4.2.2	The Problem of the “Peak”	103
4.2.3	Facing Increased Uncertainty: Balancing Services	109
4.2.4	Real-Time Frequency Control Issues: Ancillary Services . . .	112
4.2.5	Additional Grid Costs	114
4.2.6	A Regional Perspective	118
4.3	How New Grid Challenges Disrupt the Traditional Economic Model	130
4.4	Main Regulation Challenges	135
4.5	Summary	138
	References	141
5	Solutions for a Sustainable Transition	145
5.1	Digitizing the Distribution System	147
5.2	Optimizing Revenues for Renewable Operators	154
5.3	Reaching New Levels of Flexibility with Active Energy Management	158
5.3.1	Digitizing the Demand Side	159
5.3.2	The Fantastic Potential of Energy Storage	163
5.3.3	Electric Vehicles	173
5.3.4	Telecom and Utility Infrastructures: A Possible Convergence?	177
5.3.5	Summary	179
5.4	Different Pathways to a Successful Transition	180
	References	185
6	Facilitating the Transition Through Digital Technologies	189

List of Figures

Fig. 2.1	Electricity final consumption (© OECD/IEA, WEO 2012)	6
Fig. 2.2	Electricity final consumption to 2035 (Greenpeace 2015; © OECD/IEA, WEO 2014)	6
Fig. 2.3	Electricity final consumption per capita (© OECD/IEA, WEO 2012; Our World in Data 2016)	8
Fig. 2.4	Electricity final consumption in buildings (© OECD/IEA, WEO 2012, 2014)	9
Fig. 2.5	Electricity final consumption in industry (© OECD/IEA, WEO 2012, 2014)	9
Fig. 2.6	Electricity final consumption in transport (© OECD/IEA, WEO 2012, 2014)	10
Fig. 2.7	A model for electricity consumption forecasting	11
Fig. 2.8	(a) World population (Planetoscope 2016; Geohive 2016). (b) World population (Our World in Data 2016; Planetoscope 2016)	12
Fig. 2.9	Impact of population growth on electricity consumption (© OECD/IEA, WEO 2012, 2014; Our World in Data 2016; Planetoscope 2016)	13
Fig. 2.10	Electricity savings in buildings (ADEME/Energy Efficiency 2013; © OECD/IEA, WEO 2012, 2014)	16
Fig. 2.11	Electricity savings in industry (© OECD/IEA, Technology industry 2009; © OECD/IEA, WEO 2012, 2014)	17
Fig. 2.12	Electricity savings from energy efficiency (ADEME/Energy Efficiency 2013; © OECD/IEA, Technology Industry 2009; © OECD/IEA, WEO 2012, 2014)	18
Fig. 2.13	Evolution of energy consumption mix in sectors (© OECD/IEA, WEO 2012)	19
Fig. 2.14	Evolution of the mix of usages in the residential segment (© OECD/IEA, Buildings 2013)	19
Fig. 2.15	Fuel switching to electricity in buildings (© OECD/IEA, Buildings 2013; © OECD/IEA, WEO 2012, 2014)	21

Fig. 2.16	Industry mix by region (© OECD/IEA, Sankey 2014)	22
Fig. 2.17	Electrification potential in industry (© OECD/IEA, Sankey 2014; ETC 2017)	22
Fig. 2.18	Fuel switching to electric in industry (© OECD/IEA, WEO 2012, 2014)	23
Fig. 2.19	Fuel switching to electricity in transport (Greenpeace 2015; © OECD/IEA, WEO 2012, 2014)	24
Fig. 2.20	Fuel switching to electricity (Greenpeace 2015; © OECD/IEA, Buildings 2013; © OECD/IEA, WEO 2012, 2014)	24
Fig. 2.21	Living standards' impact on electricity consumption (Author's own calculation based on data from International Energy Agency)	25
Fig. 2.22	Evolution of world population urbanization (UN 2014)	25
Fig. 2.23	Evolution of Gross Domestic Product (EIA/GDP 2014)	26
Fig. 2.24	Electricity consumption evolution by 2035 (© OECD/IEA, WEO 2012, 2014)	27
Fig. 2.25	Electricity consumption evolution by 2035—CPS scenario (Source: author's own calculation based on data from IEA)	29
Fig. 2.26	Share of each element in the electricity consumption evolution (Source: author's own calculation based on data from IEA)	29
Fig. 2.27	Electricity consumption evolution by 2035—concurrent scenario (Source: author's own calculation)	30
Fig. 2.28	Electricity consumption evolution by 2035 (Source: author's own calculation)	30
Fig. 2.29	Electricity final consumption per year (Greenpeace 2015; © OECD/IEA, WEO 2012, 2014)	31
Fig. 3.1	Worldwide power generation capacity (Greenpeace 2015)	34
Fig. 3.2	Overnight costs for power generation (Business Insights 2010; EIA/Power Generation 2015; Fraunhofer 2013; © OECD/IEA, Costs 2015; ILAR 2012; NREL 2010)	35
Fig. 3.3	Photovoltaic solar costs evolution (© OECD/IEA, Solar 2014; Irena/Solar 2012)	36
Fig. 3.4	Variation of overnight costs by country (© OECD/IEA, Costs 2015)	37
Fig. 3.5	Overnight costs for power generation—global average (© OECD/IEA, Costs 2015)	38
Fig. 3.6	Ratio of fixed vs. variable operation and maintenance costs (EIA/Power Generation 2015; Kalam et al. 2009)	39
Fig. 3.7	Operation and maintenance costs for power generation—global average (© OECD/IEA, Costs 2015)	39
Fig. 3.8	Variation of operation and maintenance costs by country (© OECD/IEA, Costs 2015)	40
Fig. 3.9	Fuel costs for power generation—global average (© OECD/IEA, Costs 2015)	40
Fig. 3.10	Variation of fuel costs by country (© OECD/IEA, Costs 2015) . . .	41

Fig. 3.11	Overall operation, maintenance and fuel costs—global average (© OECD/IEA, Costs 2015)	41
Fig. 3.12	Variation of operation, maintenance and fuel costs by country/region (© OECD/IEA, Costs 2015)	42
Fig. 3.13	Theoretical capacity factors (IPCC 2011; NREL 2010)	42
Fig. 3.14	Theoretical vs. measured capacity factors (Greenpeace 2015; IPCC 2011; NREL 2010)	43
Fig. 3.15	Capacity factors evolution by region (Greenpeace 2015)	43
Fig. 3.16	Cost of capital by power technology (© OECD/IEA, Costs 2015)	45
Fig. 3.17	Ratio of financing by power technology (© OECD/IEA, Costs 2015)	46
Fig. 3.18	Cost of capital by country (© OECD/IEA, Costs 2015)	46
Fig. 3.19	Average levelized cost of capital (© OECD/IEA, Costs 2015) ...	47
Fig. 3.20	Average levelized cost of capital by region (© OECD/IEA, Costs 2015)	47
Fig. 3.21	Sensitivity of the LCOE by technology (© OECD/IEA, Costs 2015)	49
Fig. 3.22	Carbon pricing (World Bank/Carbon pricing 2015)	50
Fig. 3.23	LCOE by technology (Source: author's own calculation based on data from IEA)	52
Fig. 3.24	Variations of LCOE by technology (Source: author's own calculation based on data from IEA)	53
Fig. 3.25	Evolution of LCOE in the United States (EIA/Power Generation 2015)	54
Fig. 3.26	Evolution of LCOE in Germany (Fraunhofer 2013)	55
Fig. 3.27	Evolution of LCOE (EIA/Power Generation 2015; Fraunhofer 2013; Greenpeace 2015; NREL/Projections 2015; PSI 2014) ...	56
Fig. 3.28	New simulated LCOE (Source: author's own calculation)	56
Fig. 3.29	A model for the local power market competitiveness	57
Fig. 3.30	North America LCOE (EIA/Wholesale 2016; © OECD/IEA, Costs 2015)	58
Fig. 3.31	Europe LCOE (EIA/Wholesale 2016; © OECD/IEA, Costs 2015)	59
Fig. 3.32	China LCOE (EIA/Wholesale 2016; © OECD/IEA, Costs 2015)	59
Fig. 3.33	OECD Asia LCOE (EIA/Wholesale 2016; © OECD/IEA, Costs 2015)	59
Fig. 3.34	Evolution of existing generation LCOE over the years (Institute for Energy Research 2015)	61
Fig. 3.35	Global evolution of LCOE and wholesale prices (Source: author's own calculation based on data from IEA and Greenpeace)	61
Fig. 3.36	Evolution of power generation capacity (Greenpeace 2015; © OECD/IEA, WEO 2014)	65

Fig. 3.37	Evolution of power generation capacity—current policy scenario (Greenpeace 2015)	65
Fig. 3.38	Evolution of power generation capacity—450 scenario (© OECD/IEA, WEO 2014)	66
Fig. 3.39	Power generation investments by source (Greenpeace 2015; © OECD/IEA, WEIO 2014)	67
Fig. 3.40	Evolution of power generation capacity by region/country (Greenpeace 2015; © OECD/IEA, WEO 2014)	68
Fig. 3.41	Evolution of power generation capacity—current policy scenario (Greenpeace 2015)	69
Fig. 3.42	Evolution of power generation capacity—450 scenario (© OECD/IEA, WEO 2014)	69
Fig. 3.43	Power generation investments by region/country (Greenpeace 2015; © OECD/IEA, WEIO 2014)	70
Fig. 3.44	Rate of penetration of renewable energies (Greenpeace 2015) ...	71
Fig. 3.45	Electricity generation mix in 2030–450 scenario (© OECD/IEA, WEO 2014)	72
Fig. 3.46	Electricity generation mix in 2030—Energy [R]evolution scenario (Greenpeace 2015)	72
Fig. 3.47	Rate of penetration of renewable vs. investments (Greenpeace 2015; © OECD/IEA, WEIO 2014; © OECD/IEA, WEO 2014)	73
Fig. 3.48	Maximum possible rate of penetration of intermittent renewable (Greenpeace 2015; © OECD/IEA, WEO 2014)	74
Fig. 3.49	Renewable penetration in the grid	77
Fig. 3.50	Retail electricity prices compared to rooftop solar LCOE (AER 2016; ANEEL 2016; BOI 2016; Brazil Business 2016; Business Tech 2016; DEWA 2016; EIA Price 2016; European Commission/Wholesale 2016; EWB 2016; Global Climate Scope 2016; Hong Kong Electric 2016; JPEX 2016; © OECD/IEA, Costs 2015; Kepco 2016; Lumo Energy 2016; Manitoba Hydro 2016; MB 2016; Ovo Energy 2016; PLN 2016; Saudi Electric 2016; Shenzhen 2016; Singapore Power 2016; Storm Report 2016; Sudan Tribune 2016; Times of Israel 2016; TNB 2016; TurkStat 2016; Vietnam News 2016)	77
Fig. 3.51	Distributed rooftop solar systems power generation (California Photon 2010; PVEducation 2016)	79
Fig. 3.52	Rooftop solar systems' capacity vs. demand (California Photon 2010; PVEducation 2016; Greenpeace 2015)	80
Fig. 3.53	Forecasted share of electricity consumption directly supplied by rooftop solar systems (Greenpeace 2015; Roland Berger 2015) . . .	80
Fig. 3.54	The cost of transition to renewable (Source: author's own calculation based on data from IEA and Greenpeace)	84

Fig. 4.1 The new grid challenges 94

Fig. 4.2 Net load curve (duck curve) evolution (California ISO 2016) 94

Fig. 4.3 Average contribution of solar and wind power to total capacity (Source: Author’s basic model used in reference) 96

Fig. 4.4 Forecasts for wind renewable in 2030 (ADEME 2016; ERCOT/ Forecast 2016; Irena 2014; McKinsey/Forecast 2016; NSW government 2015; pv magazine 2015a, b; STORE project 2016; Wind Power Monthly 2015; WWF 2014) 97

Fig. 4.5 Forecasts for solar renewable in 2030 (ADEME 2016; ERCOT/ Forecast 2016; Irena 2014; McKinsey/Forecast 2016; NSW government 2015; pv magazine 2015a, b; STORE project 2016; Wind Power Monthly 2015; WWF 2014) 97

Fig. 4.6 Evolution of minimum load balancing (W: winter; S: summer) (Source: Author’s own calculation) 100

Fig. 4.7 Evolution of maximum load balancing (Source: Author’s own calculation) 101

Fig. 4.8 Delta between maximum and minimum load balancing (Source: Author’s own calculation) 102

Fig. 4.9 Daily load profile for various segments (Jardini et al. 2000) 104

Fig. 4.10 Residential segment power consumption usages (Energy Research and Social Science 2014; Intertek 2012; RTE/Usages 2014) 104

Fig. 4.11 Daily load profiles for the residential segment in the UK—no electric heating (Intertek 2012) 105

Fig. 4.12 Daily load profiles for the residential segment in the UK—electric heating (Intertek 2012) 105

Fig. 4.13 Daily load profiles for the residential segment in New South Wales—winter (Energymag 2016) 106

Fig. 4.14 Daily load profiles for the residential segment in New South Wales—summer (Energymag 2016) 106

Fig. 4.15 Different load profiles (Amprion 2016; California ISO 2016; ERCOT 2016; InterRAO 2009; PLN 2006; Red Electrica 2016; RTE 2016; Statnett 2016; TEIAS 2008; Tennet 2016; Tepco 2001; Transgrid 2014; Transnet BW 2016; 50 Hertz 2016) 107

Fig. 4.16 Load curve vs. net load curve—Germany (Amprion 2016; Tennet 2016; Transnet BW 2016; 50 Hertz 2016) 108

Fig. 4.17 Maximum ramp up (Source: Author’s own calculation) 109

Fig. 4.18 Load curve vs. net load curve in Germany with +/- 10% evolution on renewable output (Source: Author’s own calculation) 110

Fig. 4.19 Impact of renewable penetration on balancing services (Source: Author’s own calculation) 111

Fig. 4.20 Impact of renewable penetration on ancillary services (Source: Author’s own calculation) 113

Fig. 4.21 T&D asset utilization (Source: Author’s own calculation) 115

Fig. 4.22	T&D asset utilization—percentage of time below a certain load (Source: Author’s own calculation)	116
Fig. 4.23	Split of investments in the grid (© OECD/IEA, WEIO 2014)	117
Fig. 4.24	Evolution of grid investments’ costs (© OECD/IEA, WEIO 2014)	117
Fig. 4.25	Load curve 2016—France (RTE 2016)	118
Fig. 4.26	Net load curve 2016—France (Source: Author’s own calculation)	119
Fig. 4.27	Net load curve 2030—France (Source: Author’s own calculation)	120
Fig. 4.28	Load curve 2016—Germany (Amprion 2016; Tennet 2016; Transnet BW 2016; 50 Hertz 2016)	121
Fig. 4.29	Net load curve 2016—Germany (Source: Author’s own calculation)	121
Fig. 4.30	Net load curve 2030—Germany (Source: Author’s own calculation)	122
Fig. 4.31	Load curve 2016—Spain (Red Electrica 2016)	123
Fig. 4.32	Net load curve 2016—Spain (Source: Author’s own calculation)	123
Fig. 4.33	Net load curve 2030—Spain (Source: Author’s own calculation)	124
Fig. 4.34	Load curve 2016—California (California ISO 2016)	125
Fig. 4.35	Net load curve 2016—California (Source: Author’s own calculation)	125
Fig. 4.36	Net load curve 2030—California (Source: Author’s own calculation)	126
Fig. 4.37	Load curve 2016—Texas (ERCOT 2016)	127
Fig. 4.38	Net load curve 2016—Texas (Source: Author’s own calculation)	127
Fig. 4.39	Net load curve 2030—Texas (Source: Author’s own calculation)	128
Fig. 4.40	Load curve 2016—New South Wales (Transgrid 2014)	129
Fig. 4.41	Net load curve 2016—New South Wales (Source: Author’s own calculation)	129
Fig. 4.42	Net load curve 2030—New South Wales (Source: Author’s own calculation)	130
Fig. 4.43	Diversity of power markets (© OECD/IEA, Markets 2016)	135
Fig. 5.1	The utility digital landscape	153
Fig. 5.2	Example of demand management—Spain, summer (Source: Author’s own calculation)	160
Fig. 5.3	Example of demand management—Spain, summer (with renewable) (Source: Author’s own calculation)	161
Fig. 5.4	Storage applications (Elsevier 2012; © OECD/IEA, Storage 2014)	164

Fig. 5.5	Storage technologies (Elsevier 2012; © OECD/IEA, Storage 2014)	167
Fig. 5.6	Storage costs variation (© OECD/IEA, Costs 2015; © OECD/IEA, Storage 2014; Lazard/Storage 2015)	169
Fig. 5.7	Storage costs variation for various applications (Lazard/Storage 2015)	170
Fig. 5.8	Storage costs variation for various applications (Lazard/Storage 2015)	171
Fig. 5.9	Share of light vehicle transportation (© OECD/IEA, WEO 2012)	174
Fig. 5.10	Share of small distance travels (© OECD/IEA, WEO 2012)	175
Fig. 5.11	Projection of number of cars worldwide (WHO 2016)	175
Fig. 5.12	Additional electricity consumption potential from electric cars (Source: Author's own calculation)	176
Fig. 5.13	Different pathways for the transition (NREL/Power Future 2015)	181
Fig. 5.14	Mapping of countries according to speed and extent of change (Source: Author's own evaluation)	183
Fig. 5.15	Different pathways for the transition to new energy landscape (Source: Author's own evaluation)	183

List of Tables

Table 3.1 Rate of penetration of renewables 76

Table 5.1 Country evaluation against transition scenarios 182