

TABLE OF CONTENTS

Executive summary	13
1. Global overview	17
Highlights.....	17
Recent deployment trends.....	18
Recent policy trends.....	20
Global outlook.....	23
Renewable heat	25
Renewable electricity.....	26
Renewable energy in transport.....	28
References.....	32
2. Renewable electricity.....	35
Highlights.....	35
Recent deployment trends.....	36
Main case technology forecast summary	37
Main case regional forecast summary	40
Accelerated case technology and regional summaries.....	41
China.....	44
Asia-Pacific	51
North America	62
Europe	72
Latin America	83
Sub-Saharan Africa (SSA).....	88
The Middle East and North Africa (MENA)	95
References.....	100
3. Transport biofuels.....	105
Highlights.....	105
Conventional biofuel markets.....	106
Advanced biofuel markets	115
Focus on aviation biofuels.....	123
Air quality implications of transport biofuel consumption.....	128
References.....	133
4. Renewable heat.....	135
Highlights.....	135
Global overview and outlook	136
Recent policy developments	138

Industry and agriculture	139
Focus on bioenergy in industry	142
Increasing bioenergy use in the cement industry.....	152
Buildings.....	153
References.....	160
5. Renewable energy trends to watch	163
Key questions	163
1. Are auctions the primary policy mechanism driving utility-scale renewable electricity capacity expansion over the forecast period?	164
2. Have the prices from competitive auctions become the “new normal” prices for renewables?	165
3. Will renewables be cost-competitive with new coal and gas plants by 2023?.....	167
4. Will distributed generation dominate solar PV growth over 2018-23, and will utilities lose a lot of revenue?	169
5. Why is solar PV capacity growing more quickly than any other renewable electricity technology?.....	172
6. Will system integration of renewables be a major challenge by 2023?	174
7. Can trade barriers hamper the growth of renewable energy technologies?	177
8. Will pumped storage hydropower capacity expand more quickly than stationary battery storage over 2018-23?	178
9. Will concentrating solar power (CSP) contribute to global energy storage growth over the forecast period?	181
10. Is there scope for renewable heat technology costs to fall as they have for solar PV and wind?.....	182
11. Is there a future for co-firing biomass in the electricity sector?.....	183
12. Will energy from waste become the key from of bioenergy in Asia?.....	186
13. How competitive is biofuel production in Brazil and the United States?	189
14. Does household use of solid biomass-based heating affect air quality?	192
References.....	194
6. Data tables.....	197
Glossary.....	206
Regional and country groupings	206
List of acronyms, abbreviations and units of measure	207

LIST OF FIGURES

Figure 1.1	Energy production and consumption flow chart.....	18
Figure 1.2	Modern renewable energy consumption: Annual growth, 2017 (left), and total consumption, 2017 (right).....	19
Figure 1.3	Renewable energy policies by sector and region, 2010 and 2017.....	21
Figure 1.4	Renewable energy consumption by technology, 2017-23.....	23
Figure 1.5	Share of modern renewable energy by end-use (left) and in total final energy consumption by end-use, 2017-23 (right).....	24
Figure 1.6	Renewable energy consumption in major markets, 2017 and 2023	25
Figure 1.7	Renewable heat consumption by technology (left) and shares in major countries/regions (right)	26
Figure 1.8	Electricity generation growth by fuel, 2006-23.....	27
Figure 1.9	Global renewable electricity generation by technology (left) and shares in selected markets (right).....	28
Figure 1.10	Renewable energy in transport by fuel (left) and renewable consumption by transport mode in 2023 (right).....	28
Figure 1.11	Renewable energy in transport and share of total transport demand in selected countries and regions.....	30
Figure 2.1	Annual net electricity capacity additions by source, 2001-17	36
Figure 2.2	Historical and main case net renewable capacity additions by technology, 2006-23	38
Figure 2.3	Renewable capacity growth by country/region, 2000-23.....	40
Figure 2.4	Main and accelerated case forecasts of annual capacity additions by technology, 2017-23.....	42
Figure 2.5	China: Total renewable capacity (left) and generation (right), 2009-23.....	44
Figure 2.6	China: Electricity generation and consumption, and renewable energy curtailment by region, 2017.....	45
Figure 2.7	China: Renewable energy consumption by province in 2017 and quotas for 2020	47
Figure 2.8	China: Solar PV capacity additions, 2014-23 (left), and recent Top Runner auction winning bids (right).....	48
Figure 2.9	China: Onshore wind capacity additions by region (left) and hydropower, bioenergy and CSP capacity additions, 2014-23	49
Figure 2.10	Asia-Pacific: Renewable electricity capacity growth, 2012-23 (left), and generation by source, 2017-23 (right).....	52
Figure 2.11	India: Capacity additions, 2014-23 (left), and solar PV capacity needed to reach 2022 targets vs financial health of utilities per state as of July 2018 (right).....	52
Figure 2.12	India: Average PV winning bids, 2009-20 (left), and domestic cell manufacturing vs demand, 2014-2017 (right)	54
Figure 2.13	India: Average solar PV levelised cost of energy vs. commercial prices (left) and residential retail prices (right)	55
Figure 2.14	Japan: Annual net renewable capacity additions, 2016-23 (left), and estimated solar PV project cancellations and installations (right).....	57
Figure 2.15	ASEAN cumulative renewable capacity, 2017 and 2023.....	60
Figure 2.16	North America: Renewable electricity capacity growth, 2012-23 (left), and generation by source, 2017-23 (right).....	63

Figure 2.17	United States: PV module import shipments by country in 2017 (left) and PV capacity available to US market after PV import tariff, end of 2017 (right)	64
Figure 2.18	United States: RPS demand by state, 2017 and 2023 (left), and announced corporate PPAs, 2010-17 (right).....	66
Figure 2.19	United States: estimated PV investment costs with import tariff (left) and PV net capacity additions, 2011-23 (right).....	67
Figure 2.20	United States: Net wind capacity additions, 2015-23 (left), and five-year forecast for other renewables (right).....	68
Figure 2.21	Canada: Provincial wind auction results (left) and net renewable capacity additions, 2016-23 (right).....	69
Figure 2.22	Mexico: CEL and energy auction results for wind and solar PV (left) and net renewable capacity additions, 2016-23 (right).....	70
Figure 2.23	Europe: Renewable electricity capacity growth, 2012-23 (left), and generation by source, 2017 and 2023 (right)	72
Figure 2.24	Germany: Annual net renewable capacity additions, 2016-23 (left), and average winning bids from onshore wind auctions (right)	74
Figure 2.25	Germany: Annual net solar PV capacity additions by segment (left) and winning bids from solar PV auctions (right).....	75
Figure 2.26	France: Annual net renewable capacity additions, 2016-23 (left), and solar PV auction schedule vs. forecast (right)	76
Figure 2.27	United Kingdom: Annual net renewable capacity additions, 2016-23	78
Figure 2.28	Net renewable capacity growth in selected countries in Europe, 2018-23	81
Figure 2.29	Latin America: Renewable electricity capacity growth, 2012-23 (left), and generation by source, 2017 and 2023 (right).....	83
Figure 2.30	Brazil: Macroeconomic indicators, 2015-18 (left), and net annual renewable capacity additions, 2016-23 (right).....	84
Figure 2.31	Argentina: Renewable energy auction results (left) and net renewable capacity additions, 2016-23 (right).....	86
Figure 2.32	SSA: Renewable electricity capacity growth, 2012-23 (left), and renewable generation by source, 2017 and 2023 (right).....	88
Figure 2.33	South Africa: Annual net renewable capacity additions, 2017-23 (left), and solar PV capacity shares by segment (right).....	89
Figure 2.34	Kenya: Total renewable capacity (left) and generation, 2017 and 2023 (right)	91
Figure 2.35	SSA: Renewable electricity policies (left) and solar PV forecast for selected countries by auction stage (right)	94
Figure 2.36	MENA: Renewable electricity capacity growth, 2012-23 (left), and generation by source, 2017 and 2023 (right)	96
Figure 2.37	MENA: Renewable capacity growth for selected countries, 2011-23.....	97
Figure 3.1	Global conventional biofuel production (left) and indexed road transport fuel demand in selected countries, 2011-23 (right)	106
Figure 3.2	Forecast change in ethanol production between 2017 and 2023 (left) and share of global ethanol output by country (right)	109
Figure 3.3	Forecast change in biodiesel and HVO production between 2017 and 2023 (left) and share of global biodiesel and HVO output by country (right)	113
Figure 3.4	Main and accelerated case overview (left) and additional production breakdown by country (right).....	114

Figure 3.5	Novel advanced biofuel production (left) and annual capacity additions (right)	117
Figure 3.6	Global novel advanced biofuel project development by country (left) and cellulosic ethanol and biomethane consumption in the United States' RFS2 (right)	119
Figure 3.7	Global novel advanced biofuel plants by fuel type (left) and biomethane market development in the European Union (right)	122
Figure 3.8	Break-even crude oil prices for different aviation biofuel production pathways	125
Figure 3.9	Additional cost per passenger for a one-way flight from London to selected destinations with 15% HEFA blends	126
Figure 4.1	Fuel shares in global heat consumption, 2017	136
Figure 4.2	Renewable heat consumption by country/region (left) and by source (right)	137
Figure 4.3	Industry renewable heat consumption by country/region (left) and growth in consumption by technology (right)	140
Figure 4.4	Geothermal consumption growth, 2011-23 (left), and geothermal use in agriculture by country, 2016 (right)	141
Figure 4.5	Share of bioenergy in energy demand by industry subsector, 2016	143
Figure 4.6	Bioenergy and waste use in selected industries in 2017 and 2023	143
Figure 4.7	Pulp (left) and black liquor production (right), 2016	144
Figure 4.8	Production of sugar cane (left) and bagasse (right) in selected countries, 2016	146
Figure 4.9	Bagasse-fuelled electricity capacity, 2005-17	147
Figure 4.10	Global electricity production potential in the sugar and ethanol industry	148
Figure 4.11	Bioenergy and waste consumption in the cement sector and associated benefits	149
Figure 4.12	Global cement production, 2017 (left), and bioenergy consumption (right)	150
Figure 4.13	Estimated costs of coal, waste and biomass fuels used in clinker production	151
Figure 4.14	Buildings renewable heat consumption by country/region (left) and growth in final consumption by technology (right)	154
Figure 4.15	Illustrative daily profile of space cooling load and solar PV output	155
Figure 4.16	Residential bioenergy consumption by country, 2016 (left), and pellet appliance sales in selected countries (right)	156
Figure 4.17	Solar thermal gross capacity additions (left) and consumption growth in buildings (right)	157
Figure 4.18	Global heat pump sales by technology, 2012-17 (left) and regional shares in 2017 (right)	159
Figure 4.19	European heat pump sales, 2012-17 (left), and shares of households with heat pumps (right)	159
Figure 5.1	Utility-scale renewable capacity growth by remuneration type, 2018-23	164
Figure 5.2	Awarded utility-scale, competitively remunerated renewable capacity (left) and average auction price by project commissioning date (right)	165
Figure 5.3	Average auction prices for solar PV and wind, by region and commissioning date	166
Figure 5.4	Global average LCOEs and auction results for utility-scale solar PV by commissioning date (left) and FITs versus auction prices for selected countries, 2017 (right)	167
Figure 5.5	LCOE ranges for new utility-scale onshore wind, solar PV and coal and gas plants by commissioning date, 2011-23	168
Figure 5.6	Solar PV capacity growth and total generation, 2006-23	169
Figure 5.7	Residential electricity prices compared with average residential LCOE, 2017	170

Figure 5.8	Policies for remuneration of all or excess generation from distributed PV generation capacity, 2018-23	171
Figure 5.9	Retail value of self-consumption by residential and commercial PV applications.....	172
Figure 5.10	Global average LCOEs for renewable technologies, 2017.....	172
Figure 5.11	System integration phases, transition challenges and flexibility measures.....	175
Figure 5.12	Selected countries by integration phase and share of VRE, 2017.....	176
Figure 5.13	Share of variable renewables in global electricity mix.....	176
Figure 5.14	PV cell manufacturing capacity, demand and import dependency	177
Figure 5.15	Cumulative installed storage capacity (left) and annual additions, 2018-23 (right)...	179
Figure 5.16	Annual PSH capacity additions by region (left) and range in capacity factors over 2000-16 (right).....	180
Figure 5.17	CSP capacity by technology (left) and CSP thermal storage volume (right).....	181
Figure 5.18	Co-fired generation in selected countries, 2017-23 (left), and wood pellet imports in Japan and Korea, 2015-17 (right)	183
Figure 5.19	Urban population shares, 2006-16 (left), and MSW production (right)	186
Figure 5.20	EfW capacity growth, 2010-16 (left), and bioenergy additions in China, 2013-17 (right)	187
Figure 5.21	Biofuel and fossil-based transport fuel production cost comparison, 2017	191

LIST OF TABLES

Table 1.1	Recent developments in renewables policies and markets included in the forecast.....	22
Table 1.2	Estimated renewable electricity consumption in road and rail transport	29
Table 2.1	Top five countries for renewable capacity additions by technology, 2017	37
Table 2.2	Top five countries for renewable capacity growth by technology, 2018-23	38
Table 2.3	Policy and market development assumptions in the accelerated case forecast for selected countries/regions	43
Table 2.4	China: Conditions of accelerated case forecast and cumulative capacity by 2023	51
Table 2.5	Asia-Pacific: Main drivers and challenges of renewable electricity deployment.....	60
Table 2.6	Asia-Pacific: Main and accelerated case forecast summary, 2017 and 2023	62
Table 2.7	North America: Main drivers and challenges of renewable electricity deployment	71
Table 2.8	North America: Main and accelerated case forecast summary, 2017 and 2023	72
Table 2.9	Europe: Main drivers and challenges of renewable electricity deployment	79
Table 2.10	Europe: Main and accelerated case forecast summary, 2017 and 2023	82
Table 2.11	Latin America: Main drivers and challenges of renewable electricity deployment.....	87
Table 2.12	Latin America: Main and accelerated case forecast summary, 2017 and 2023.....	88
Table 2.13	SSA: Main drivers and challenges of renewable electricity deployment	93
Table 2.14	SSA: Main and accelerated case forecast summary, 2017 and 2023.....	95
Table 2.15	MENA: Main drivers and challenges of renewable electricity deployment.....	98
Table 2.16	MENA: Main and accelerated case forecast summary, 2017 and 2023.....	100
Table 3.1	Global conventional biofuel production	107
Table 3.2	Mandates, targets and carbon intensity policies for biofuels in selected countries	108
Table 3.3	Annual ethanol production: Accelerated case (billion L)	115
Table 3.4	Annual biodiesel and HVO production: Accelerated case (billion L).....	115
Table 3.5	Classification of certain advanced biofuels	116

Table 3.6	Alternative conditions for HEFA fuels to be competitive with fossil jet kerosene.....	125
Table 3.7	Biofuel volumes and investment to meet 2% of international aviation fuel demand	127
Table 3.8	Air pollutant emissions by fuel from modern and older cars.....	130
Table 3.9	Air pollutant emissions by fuel from modern and older heavy-duty vehicles	131
Table 3.10	Estimated average scrappage age of passenger and heavy-duty vehicles (years)	132
Table 3.11	Euro emissions standards for NOx and mass of particles (g/km) for passenger cars	132
Table 4.1	Global trends and outlook for renewable heat, 2010-23.....	137
Table 5.1.	Solar heat and natural gas heating costs in selected countries	183
Table 5.2.	Ethanol and biodiesel production costs and break-even oil price 2017	190
Table 5.3.	Typical emissions factors for various biomass heating devices	193

LIST OF BOXES

Box 1.1	Quantifying renewable energy consumption.....	18
Box 1.2	What is the traditional use of biomass?.....	19
Box 1.3	Sustainability is critically important for bioenergy deployment	31
Box 2.1	System integration challenges in China	45
Box 2.2	System integration of renewables in India.....	53
Box 3.1	Could car conversion kits boost ethanol consumption in France?	111
Box 3.2	Advanced biofuel definitions.....	116
Box 4.1	Renewables and cooling.....	154