

Contents

1	Challenges and Opportunities of the Energy Transition and the Added Value of Energy Systems Integration	1
	<i>Marialaura Di Somma and Giorgio Graditi</i>	
1.1	Energy Transformation Toward Decarbonization and the Added Value of Energy Systems Integration	1
1.2	European Union as the Global Leader in Energy Transition	6
1.3	Pillars for the Transition Toward Integrated Decentralized Energy Systems	11
	List of Abbreviations	13
	References	13
2	Integrated Energy Systems: The Engine for Energy Transition	15
	<i>Marialaura Di Somma and Giorgio Graditi</i>	
2.1	Introduction: the Concept of Integrated Energy System	15
2.2	Key Enablers for Integrated Energy Systems	18
2.2.1	Storage and Conversion Technologies	18
2.2.2	End User Engagement and Empowerment	22
2.2.3	Digitalization Enabler	24
2.2.4	Emergence of an Integrated Energy Market	27
2.3	Integrated Energy Systems at the Local Level	28
2.3.1	Conceptualizing Local Integrated Energy Systems	28
2.3.2	Map of Enabling Technologies	29
2.3.3	Key Stakeholders and Related Benefits from Local Integrated Energy Systems Deployment	31
2.4	Main Barriers for Implementation	33
2.4.1	Techno-economic Barriers	34
2.4.2	Socioeconomic Barriers	35
2.4.3	Policy and Regulatory Barriers	35
2.5	Conclusions	36
	List of Abbreviations	38
	References	38

3	Power Conversion Technologies: The Advent of Power-to-Gas, Power-to-Liquid, and Power-to-Heat	41
	<i>Joshua A. Schaidle, R. Gary Grim, Ling Tao, Mark Ruth, Kevin Harrison, Nancy Dowe, Colin McMillan, Shanti Pless, and Douglas J. Arent</i>	
3.1	Introduction	41
3.1.1	Motivation for Power-to-X	41
3.1.2	Defining Power-to-X Categories	43
3.1.3	Goal of this Chapter	44
3.2	Power-to-X Technologies	44
3.2.1	Power-to-Gas	44
3.2.1.1	Natural Gas Market Demand	45
3.2.1.2	Technology Identification and Overview	46
3.2.1.3	Unique Integration Challenges and Opportunities	47
3.2.2	Power-to-Chemicals-and-Fuels	48
3.2.2.1	Market and Demand	48
3.2.2.2	Technology Identification and Overview	49
3.2.2.3	Unique Integration Challenges and Opportunities	54
3.2.2.4	Implications on Power Generation	54
3.2.3	Power-to-Heat	57
3.2.3.1	Market and Demand	57
3.2.3.2	Technology Identification and Overview	60
3.2.3.3	Unique Integration Challenges and Opportunities	60
3.2.3.4	Implications on Power Generation	62
3.3	Overarching Challenges, Opportunities, and Considerations	62
3.3.1	Feedstock and Energy Sourcing	62
3.3.1.1	Feedstocks (CO ₂ , N ₂ , H ₂ O, and Biomass)	62
3.3.1.2	Operational Flexibility for Grid Integration and Revenue	63
3.3.2	Key Considerations from Life Cycle Analysis and Techno-economic Analysis	64
3.3.2.1	Life Cycle Analysis	64
3.3.2.2	Techno-Economic Analysis	64
3.3.3	Business Model and Business Innovation	65
3.4	Concluding Remarks	66
	Disclaimer	66
	List of Abbreviations	66
	References	67
4	Role of Hydrogen in Low-Carbon Energy Future	71
	<i>Andrea Monforti Ferrario, Viviana Cigolotti, Ana Maria Ruz, Felipe Gallardo, Jose García, and Giulia Monteleone</i>	
4.1	Introduction	71
4.2	Main Drivers for Hydrogen Implementation	72
4.2.1	Increasing Penetration of Stochastic Renewable Energy	73
4.2.2	Opportunity of Hydrogen as a Sector Coupling Enabler	74
4.3	Hydrogen Economy and Policy in Europe and Worldwide	74

4.4	Main Renewable Hydrogen Production, Storage, and Transmission/Distribution Schemes	77
4.4.1	Hydrogen Production Pathways	77
4.4.2	Hydrogen Transmission and Distribution	79
4.4.2.1	Main Hydrogen Storage Technologies	79
4.4.2.2	Methods for Hydrogen Transmission and Distribution	81
4.5	Technological Applications in Integrated Energy Systems and Networks	83
4.5.1	Hydrogen as an Energy Storage System for Flexibility at Different Scales	83
4.5.2	Industrial Use as a Renewable Feedstock in Hard-to-Abate Sectors and for the Production of Derivates	84
4.5.3	Hydrogen Mobility: A Complementary Solution to Battery Electric Vehicles	85
4.5.4	Fuel Cells, Flexible Electrochemical Conversion Systems for High-Efficiency Power, and/or CHP Applications	86
4.6	Conclusions	89
	List of Abbreviations	90
	References	91
5	Review on the Energy Storage Technologies with the Focus on Multi-Energy Systems	105
	<i>Morteza Vahid-Ghavidel, Sara Javadi, Matthew Gough, Mohammad S. Javadi, Sérgio F. Santos, Miadreza Shafie-khah, and João P.S. Catalão</i>	
5.1	Introduction	105
5.2	Energy Storage	106
5.2.1	Main Concept of Energy Storage in the Power System	106
5.2.2	Different Types of Energy Storage Systems	108
5.2.2.1	Electromechanical Energy Storage Systems	110
5.2.2.2	Electromagnetic Energy Storage Systems	111
5.2.2.3	Electrochemical Energy Storage Systems	112
5.2.2.4	Thermal Energy Storage Systems	113
5.2.3	Advantages of Storage in the Energy System	113
5.3	Energy Storage Technology Application in the Multi-Energy Systems	116
5.4	Conclusion	118
	List of Abbreviations	119
	References	119
6	Digitalization and Smart Energy Devices	123
	<i>Maher Chebbo</i>	
6.1	Introduction	123
6.2	Our Vision of the Digital Networks	130
6.3	Enabling State-of-the-Art Digital Technologies	138
6.4	Key Digital Use Cases and Associated Benefits	144

6.5	Integrated Digital Platform Across Stakeholders	149
6.6	Key Digital Recommendations	150
6.7	Conclusion	156
	List of Abbreviations	159
	References	160
	Further Reading	162
7	Smart and Sustainable Mobility Adaptation Toward the Energy Transition	165
	<i>Carla Silva, Catarina Marques, Mariana Raposo, and Angelo Soares</i>	
7.1	Smart and Sustainable Mobility Definitions and Metrics	165
7.1.1	Sustainable Mobility KPI (Key Performance Indicators)	167
7.1.2	KPI of Urban Mobility in Two European Cities	169
7.2	Smart Mobility Applied to Bicycle Sharing in Urban Context and Impacts on Sustainability	175
7.3	Ground-Level Ozone Indicator	178
7.4	Energy Transition	179
7.5	Resilience of the Mobility System	180
7.6	Conclusions	182
	Acknowledgments	182
	List of Abbreviations	183
	References	184
8	Evolution of Electrical Distribution Grids Toward the Smart Grid Concept	187
	<i>Lucía Suárez-Ramón, Pablo Arboleya, José Lorenzo-Álvarez, and José M. Carou-Álvarez</i>	
8.1	Smart Grid Concept	187
8.2	Advanced Metering Infrastructure (AMI) General Description	188
8.3	Communications and Impact on Remote Management	199
8.3.1	PLC PRIME Communication	200
8.3.2	Data Concentrator Unit (DCU) Description	204
8.3.3	Smart Meter Description	205
8.3.4	Future Scenario: Evolution of Communications Toward Hybrid Systems	206
8.4	Central System for Data Reception and Analysis	206
8.4.1	Real-Time Event Management	207
8.4.2	LV Network Monitoring	208
8.4.3	Automatic Diagnostic	208
8.5	DSO Challenge: AMI for LV Network Management	209
8.6	Digital Twin of the LV Network	210
8.7	Evolution of the Functionalities for LV Network Management	212
8.8	Conclusions	213
	List of Abbreviations	213
	References	214

9	Smart Grids for the Efficient Management of Distributed Energy Resources	215
	<i>Roberto Ciavarella, Marialaura Di Somma, Giorgio Graditi, and Maria Valenti</i>	
9.1	Electrical System Toward the Smart Grid Concept	215
9.1.1	Technology Areas of Smart Grids	218
9.1.2	Services and Functionalities of the Smart Grids	219
9.1.2.1	Needs to Integrate New Emerging Technologies	220
9.1.2.2	Improve the Operation of the Network	220
9.1.2.3	New Investment Planning Criteria	220
9.1.2.4	Improve the Functionality of the Market and Services to End Users	220
9.1.2.5	Active Involvement of the End User	221
9.1.2.6	Increased Energy Efficiency and Reduced Environmental Impact	221
9.2	Need of a Multi-Domain Optimization in Smart Grids	221
9.3	Advanced Control Mechanisms for Smart Grid	225
9.3.1	Architecture and Grid Model	225
9.3.2	Congestion Issues in the TSO Domain	226
9.3.3	Congestion Issues in the DSO Domain	228
9.3.4	Frequency Instability in the TSO Domain	230
9.4	Case Studies	231
9.4.1	Case Study 1: Congestion Events at the Transmission Level	231
9.4.2	Case Study 2: Congestion Events at the Distribution Level	232
9.4.3	Case Study 3: Frequency Instability Issues	233
9.5	Conclusions	234
	List of Abbreviations	235
	References	235
10	Nearly Zero-Energy and Positive-Energy Buildings: Status and Trends	239
	<i>Denia Kolokotsa, Gloria Pignatta, and Giulia Ulpiani</i>	
10.1	Introduction	239
10.1.1	Concept of Nearly Zero- and Positive-Energy Buildings	240
10.1.1.1	Definitions, Regulations, and Standards	240
10.1.2	Overview of Design Strategies	242
10.1.2.1	Energy Conservation Strategies	243
10.1.2.2	Energy Generation Strategies	246
10.1.2.3	Smart Readiness	248
10.2	Status and Research Directions on High-Performance Buildings for the Coming Decade	253
10.2.1	Overview of Case Studies and Research Projects	253
10.2.1.1	Challenges, Drivers, and Best Practices	256

10.2.2	Transition from Individual Nearly Zero-Energy Buildings to Positive-Energy Districts (PEDs)	258
10.3	Conclusions	259
	List of Abbreviations	260
	References	261
11	Transition Potential of Local Energy Communities	275
	<i>Gabriele Comodi, Gianluca Spinaci, Marialaura Di Somma, and Giorgio Graditi</i>	
11.1	Introduction	275
11.1.1	“2030 Agenda for Sustainable Development” of United Nations	276
11.1.2	Clean Energy for All European Package: Renewable and Citizen “Energy Communities”	277
11.1.3	Human Capital for Local Energy Communities	278
11.1.4	Local Energy Communities: An Organizational Bottom-Up Model to Empower Final Users	279
11.2	Local Energy Communities Making the Green Deal Going Local	280
11.2.1	Game Changer of the Green Deal	280
11.2.2	Green Deal Going Local	283
11.2.3	Neighborhood Approach and Local Energy Communities in the Green Deal	284
11.3	Local Energy Communities as Integrated Energy Systems at Local Level	285
11.3.1	Local Energy Communities as Promoters for Sector Coupling	285
11.3.2	Optimal Medium-Long-Term Planning for Local Energy Communities	287
11.3.3	Key Technologies in the Context of Local Energy Communities	288
11.3.4	Digitalization to Enable Flexibility and Empower Final Users	296
11.4	Local Energy Communities and Energy Transition: A Vision for the Next Future	298
11.4.1	Some Reflections	299
11.5	Conclusions	300
	List of Abbreviations	301
	References	302
	Index	305