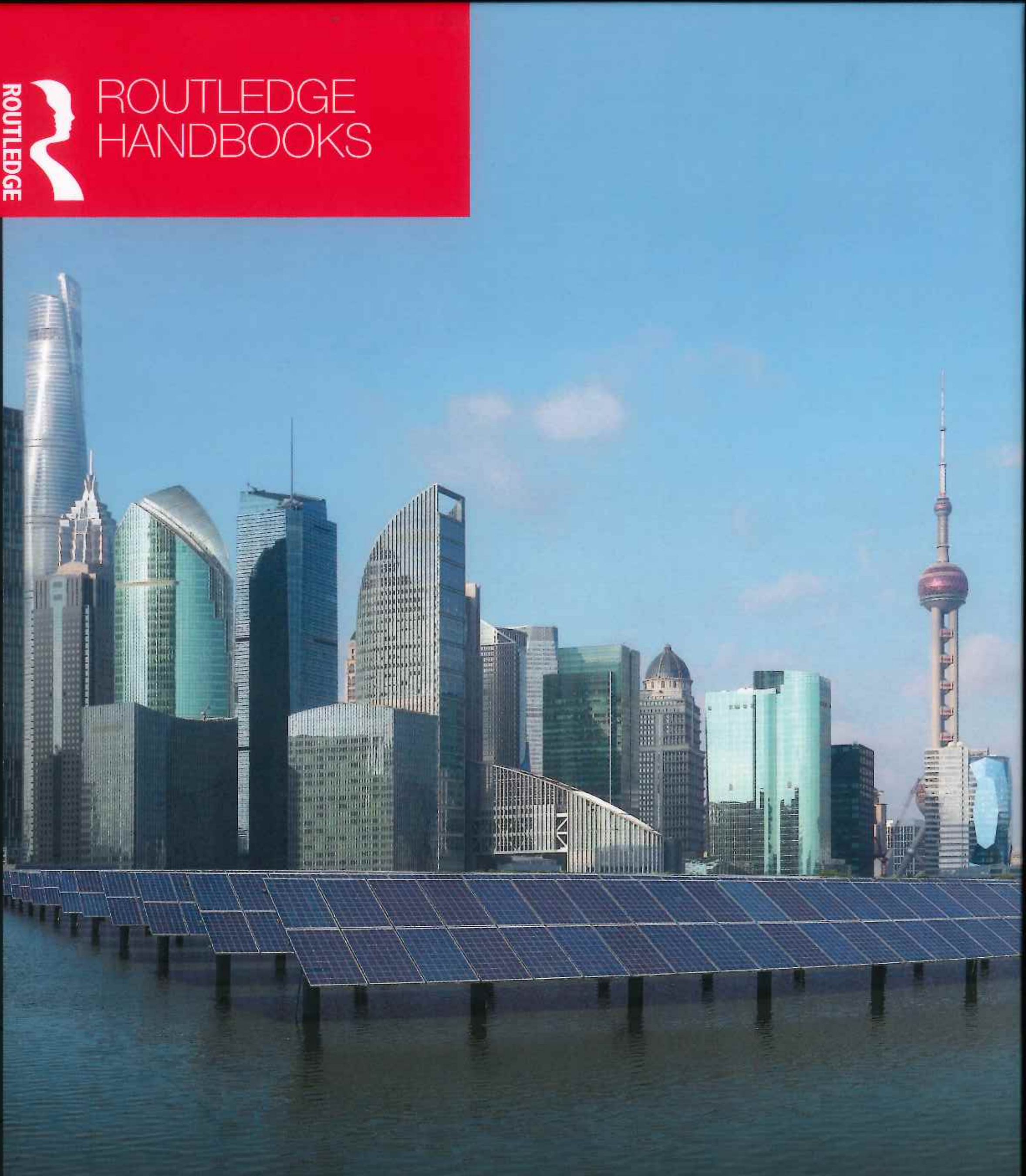
ROUTLEDGE HANDBOOKS



Routledge Handbook of Energy in Asia

Edited by Subhes C. Bhattacharyya

ROUTLEDGE HANDBOOK OF ENERGY IN ASIA

The Routledge Handbook of Energy in Asia presents a comprehensive review of the unprecedented growth of Asian energy over the past quarter of a century. It provides insightful analysis into variation across the continent, whilst highlighting areas of cross-learning and regional cooperation between the developed and developing countries of Asia. Prepared by a team of leading international experts, this book not only captures East Asian domination, particularly that of China, but also highlights the growing influence of South Asia and the ASEAN.

Organised into four parts, the sections include:

- the demand for energy in the region and its main drivers at the sector level;
- developments in energy supply, including fossil fuels and renewable energy sources;
- energy policies and issues such as sector reform and climate change;
- the transition to a low carbon pathway.

This handbook offers a complete picture of Asian energy, covering supply and demand, as well as contemporary challenges in the sector. As such, it is a valuable resource for students and scholars of energy policy, Environmental Studies, and Asian Studies.

Subhes C. Bhattacharyya is Professor of Energy Economics and Policy in the School of Engineering and Sustainable Development at De Montfort University, UK.

ROUTLEDGE HANDBOOK OF ENERGY IN ASIA

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CONTENTS

FIGURES

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PREFACE

The story of Asia's economic development over the past three decades or so is a fascinating one. The steady economic growth, led by China since the 1990s and India since the new millennium, has transformed the region pulling millions of people out of poverty. The export-led economic growth model has spread from the newly industrialised countries to a wider range of countries and the region as a whole benefited from the relocation of industrial activities from the developed world. But the vast internal market of the region and the growing affluence of the population have also ensured that the economy of the region is resilient to withstand economic shocks. The region is thus shifting from the factory of the world to a major consumer market that the world cannot ignore.

Reliable and affordable supply of energy has underpinned the economic performance and the growing demand for energy in the region has resulted in a greater influence on the global energy market over the past two decades. The region boasts of unprecedented developments in this sector that the world cannot ignore. The exceptional expansion of the coal industry to feed the electric power generation, the rapid growth in electric power generation capacity over the past two decades, and the phenomenal developments in renewable energy industries such as solar and wind power have transformed the region into the world leader in these areas. The aggressive participation of the region's National Oil Companies in foreign oil and gas exploration as well as in the acquisition of assets from around the world did not go unnoticed either. As the petroleum market dynamics have changed in the past few years with the Shale Explosion, producers and exporters started to look eastwards for rescue and the region has provided the necessary support.

Yet, there are still areas for further development. The region still has a large number of people without access to electricity or clean cooking energy. Despite improvements in recent times, millions of people lack access to electricity and billions still rely on solid fuels including traditional energies for cooking. The lack of access to energy hinders economic development and affects the poor disproportionately. Similarly, high reliance on fossil fuels to support economic development has caused severe environmental damage, particularly in urban areas, that imposes significant economic and social costs. The region has to grow economically to eradicate poverty and to ensure better living conditions for its growing population. But the region cannot continue with its legacy energy system in view of environmental and climate change concerns. The system has to change to a smart, low carbon path, which in turn requires careful governance and investment in infrastructure development.

Collectively, the region has vast experience of transforming economies and improving conditions. Countries of the region will aspire to move to the next level of economic development by becoming high income economies. The developed countries of the region provide living examples of such transformation. On that journey, the countries will face changing economic structures as well as social and demographic changes. This will have a tremendous impact on the energy needs of the economies and the region will have to manage the process effectively to emerge victorious. Learning from one another through cooperation and better regional integration of markets and infrastructure will be essential in this new phase of development, which will certainly become another fascinating story for the future.

This handbook offers reviews and reflections by academic leaders in Asian energy from all over the world covering a range of issues and developments. It recounts the progress made so far and explores the way forward, particularly the path towards a low carbon energy future. This book highlights the tremendous growth and improvement over the past two to three decades and provides insightful analysis of the drivers, contexts and issues. The book captures the collective wisdom of these experts in their respective areas and I hope it will serves as a valuable reference for anyone interested in Asian energy studies.

Clearly, it was a tremendous challenge to put together such a collection of works authored by these extremely busy contributors. The process of commissioning external reviewers and completing the internal and external review was also time-consuming. I am extremely grateful to all the contributors for their generous voluntary time contribution and support for this book project. I know they all had to reorganise their schedules to make room for this work and respond to my requests for information, clarification and details at short notice. Without their continued support despite their busy schedules this work could not have been completed.

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ABBREVIATIONS

AEC	ASEAN Economic Community
AEPC	Alternative Energy Promotion Centre
AIIB	Asian Infrastructure Investment Bank
AJEEP	ASEAN-Japan Energy Efficiency Partnership
APAECASEAN	Plan of Action for Energy Cooperation
APG	ASEAN Power Grid
ASEAN	Association of South East Asian Nations
BEE	Bureau of Energy Efficiency
BOM	Build-Own-Maintain
BOOM	Build-Own-Operate-Maintain
BOOT	Build-Own-Operate-Transfer
BP	British Petroleum
BPDB	Bangladesh Power Development Board
BRT	Bus Rapid Transit
CCS	Carbon Capture and Storage
CFSP	Cambodian Fuelwood Saving Project
CIF	Climate Investment Funds
CIL	Coal Indian Limited
CLP	China Light and Power
CMA	Central Mining Administrations
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
CREDA	Chhattisgarh Renewable Energy Development Agency
CREP	Community Rural Electrification Programme
CRIB	Climate Relevant Innovation-system Builders
CSP	Concentrated Solar Power
CSPO	Certified Sustainable Palm Oil
CSR	Corporate Social Responsibility
DBT	Direct Benefit Transfer
DDG	Decentralized Distributed Generation
DISCOMs	Distribution Companies

DME	Dubai Mercantile Exchange
DNA	Designated National Authority
ECA	Energy Conservation Act
EEO	Energy Efficiency Obligation
ERIA	Economic Research Institute for ASEAN and East Asia
EROI	Energy Return on Investment
ESCO	Energy Service Companies
ESPO	East Siberia – Pacific Ocean
ESSPA	Energy Supply Security Planning for ASEAN
FiT	Feed-in-tariff
FLNG	Floating LNG
FYP	Five Year Plan
GBEP	Global Bioenergy Partnership
GCF	Green Climate Fund
GEF	Global Environmental Facility
GOI	Government of India
GSCI	Goldman Sachs Commodity Index
GWEC	Global Wind Energy Council
HELE	High Efficiency Low Emission
HPS	Husk Power Systems
IBF	Input-Based Franchises
ICE	Inter Continental Exchange
IDA	International Development Association
IDCOL	Infrastructure Development Company Limited
IGCC	Integrated Gasification Combined Cycle
IHA	International Hydropower Association
INDC	Intended Nationally Determined Contributions
INE	Shanghai International Energy Exchange
IRENA	International Renewable Energy Agency
ITMO	Internationally Transferred Mitigation Outcomes
JBIC	Japan Bank for International Cooperation
JCC	Japanese Customs Cleared (Japan Crude Cocktail)
JNOC	Japanese National Oil Company
KDB	Korea Development Bank
KEPCO	Korea Electric Power Corporation
KfW	Kreditanstalt für Wiederaufbau
KNOC	Korea National Oil Corporation
MHP	Micro Hydro Power
MLP	Multi-Level Perspective
MNRE	Ministry of New and Renewable Energy
MOEF	Ministry of Environment and Forestry, India
MOEJ	Ministry of the Environment, Japan
MOF	Ministry of Finance
MoP	Ministry of Power, India
NAMA	Nationally Appropriate Mitigation Actions
NAPCC	National Action Plan of Climate Change
NBCI	National Biomass Cookstoves Initiative

NDRC	National Development and Reform Commission
NEA	Nepal Electricity Authority
NEA	National Energy Administration
NEC	National Energy Commission
NOC	National Oil Company
NORAD	Norwegian Agency for Development Cooperation
NPBD	National Program of Biogas Development
NPC	National People's Congress
NPIC	National Program on Improved Cookstoves
NSI	National Systems of Innovation
OECF	Overseas Economic Cooperation Fund
ONGC	Oil and Natural Gas Corporation
PALECO	Palawan Electric Cooperative
PAYG	Pay-As-You-Go
PCC	Political Consultative Conference
Petronas	Petroliam Nasional Berhad
PLN	Perusahaan Listrik Negara
PO	Partner Organisations
PRA	Price Reporting Agencies
PSF	Private Sector Facility
PTA	Power Trade Agreement
PTC	Power Trading Corporation
QTP	Qualified Third Party
REA	Renewable Energy Act
REC	Rural Electrification Corporation, India
REDD	Reduced Emissions from Deforestation and Forest Degradation
REEE	Renewable Energy and Energy Efficiency
REEEP	Renewable Energy and Energy Efficiency Partnership
REP	Rural Electricity Policy
REST	Rural Electricity Supply Technology
RISE	Readiness for Investment in Sustainable Energy
RPS	Renewable Portfolio Standard
SARI	South Asia Regional Energy Initiative
SCGC	South China Grid Corporation
SDG	Sustainable Development Goals
SE4ALL	Sustainable Energy for All
SEB	State Electricity Board
SEC	Singapore Environment Council
SERC	State Electricity Regulatory Commission
SGC	State Grid Corporation
SHFE	Shanghai Futures Exchange
SHS	Solar Home Systems
SOE	State Owned Enterprises
SPC	State Power Corporation
SREP	Scaling up Renewable Energy Programme
SRI	Socially Responsible Investment
TAGP	Trans-ASEAN Gas Pipeline

TIS	Technological Innovation System
TPES	Total Primary Energy Supply
TVE	Town and Village Enterprises
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations International Development Organisation
USD	United States Dollar
VGF	Viability Gap Funding
WBREDA	West Bengal Renewable Energy Development Agency
WTI	West Texas Intermediate
WTO	World Trade Organisation

12

ON-GRID SOLAR ENERGY IN ASIA

Status, policies, and future prospects

Tania Urmee and S. Kumar

Introduction

The developing countries in Asia are currently poised for rapid economic growth and industrialisation. The energy demand of these countries has increased significantly in the past few decades, and is projected to almost double by 2030 (ADB, 2016). Most of the Asian countries have targeted at least 80% electrification access by 2030, and renewable energy sources and technologies are expected to play an important role in meeting this target, notably through solar, wind, biomass and micro hydro using grid, mini-grids and individual solar home systems (ADB, 2015). Large parts of Asia are endowed with high solar insolation levels, and because of this the electricity generation potential for both large-scale grid and off-grid applications are very high. With solar technology solutions diversifying rapidly in terms of application, efficiency and cost, solar energy could play a crucial role in the energy mix in the medium to long term.

Solar energy can refer to any phenomenon that traces its origin to energy from the sun and can be harnessed as useable energy, directly or indirectly. The sun is an average star of radius 0.7 million km and has a mass of about 2×10^{30} kg. It radiates energy from an effective surface temperature of about 5760 K. From the fusion furnace of the sun, energy is transmitted radially, (i.e. outward) as electromagnetic radiation called 'solar energy'. The quantity of energy radiated by the sun can be estimated from knowledge of the sun's radius and its surface temperature (assuming it to be black body), which amounts to about 3.8×10^{23} kW (Duffie and Beckman, 2013).

Harnessing the sun's energy on the surface of the earth includes a diverse set of technologies that range from simple sun drying of crops to direct generation of electricity using photovoltaic (PV) cells. Solar energy technologies can be divided into two broad categories based on their intended use/applications: solar thermal applications that convert solar radiation to thermal energy, which can then be directly used for heating or cooling (e.g. solar hot water systems, solar drying systems or solar absorption cooling) or conversion of thermal energy further into electricity (e.g. concentrating solar power (CSP)); and solar electricity applications using the photovoltaic effect that directly generates electricity from sunlight. Solar energy technologies have the advantages of being a renewable resource, local availability, the technologies can be modular and no or little impact to climate change, among others. Thus, solar technologies used for the generation of electricity ranges from W (Watt) to MW (Mega Watt) ranges, i.e. from street lights to off-grid and on-grid systems. The focus of this chapter is on-grid solar technologies that convert solar energy to electricity, and accordingly, this chapter presents an overview of the solar energy powered electricity generation in Asia and discusses its status, policies and market potential. This is discussed in detail country-wise to show the status of on-grid solar applications.

Resource potential and technological options

Before the application of any solar technology, the solar resource potential needs to be assessed. This resource potential depends largely on the level of solar irradiation, the estimated land area suitable for solar technology installation and the efficiency of the solar energy systems. The solar energy potential can be assessed in terms of theoretical, technical and economic terms. The theoretical potential is based on land area available and current scientific knowledge, and considers only the geographic and climatic factors, while technical potential also takes into account the conversion technologies and its efficiency of conversion. The economic potential considers the cost of the competitive technologies. The solar radiation on a horizontal surface is composed of direct and diffuse components, and is usually available as monthly average values of hourly and/or daily radiation. In most of Asia, the average solar radiation is promising, as can be observed from the monthly average daily total solar insolation and yearly average for selected countries presented in Table 12.1. The average land use factor for a centralised PV system in South Asia is 1.92, East Asia is 2.14 and South East Asia is 0.51, and technical losses in conversion process are considered as 10% (ECOFYS, 2008).

Solar energy technologies can be categorised as: (1) passive and active; (2) thermal and photovoltaic; and (3) concentrating and non-concentrating. A number of text books discuss in detail the various solar energy technologies (Duffie and Beckman, 2013; Goswami et al., 2000; Kalogirou, 2009). Figure 12.1 shows one classification route of solar energy technologies.

The active solar energy technologies harness the energy from the sun that is either stored or converted to another application, which could be classified as photovoltaic or solar thermal. On the other hand, in passive form, energy collected from the sun is not converted or used in another form. It is essentially an approach to building design and features. Passive use of solar energy has been practiced for thousands of years and includes such considerations as site selection, placement of windows, dark walls and so forth, to maximise the collection of heat and light (Bradford, 2006; Chiras, 2002). Most of the solar energy for on-grid application is in active form, and is based on solar PVs or solar thermal-based electricity technologies.

Solar PV

Though many technologies are currently under development, almost 85–90% of PV modules of the global annual market are made from wafer-based crystalline silicon (c-Si). The process of manufacturing c-Si modules involves growing ingots of silicon, slicing the ingots into wafers to make the solar cells, electrically interconnecting the cells and encapsulating the strings of cells to form a module. Modules currently use silicon in one of two main forms: single crystalline silicon (sc-Si) or multi crystalline silicon (mc-Si). Conversion efficiency of current commercial sc-Si modules is about 14–20% and is expected to increase to 23% by 2020 and to 25% in the longer term (IEA, 2014). Crystalline silicon PV modules are expected to remain a dominant PV technology until at least 2020, with a forecasted market share of about 50% by that time (IEA, 2008) due to their proven and reliable technology, and long lifetime.

Table 12.1 Average solar insolation for selected Asian cities and countries

Country	*City*	*Latitude*	*Longitude*	*Average insolation (10-year average) (kWh/m²)*												
				Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Yearly average*
Bangladesh	Dhaka	23′42″N	90′22″E	4.44	5.08	5.87	6.06	5.5	4.41	4.09	4.37	4.17	4.5	4.37	4.13	4.75
Cambodia	Phnom Penh	11′33″N	104′51″E	5.27	5.78	6.02	5.76	5.09	4.3	4.55	4.07	4.34	4.41	4.88	5.03	4.85
China	Beijing	39′55″N	116′25″E	2.37	2.92	3.58	5.61	4.83	5.68	5.42	4.49	4.25	3.2	2.66	2.04	3.92
	Nanjing	32′03″N	118′53″E	2.04	2.22	2.65	4.5	3.84	4.47	4.93	4.5	3.67	3.02	2.88	2.09	3.40
	Shanghai	31′10″N	121′28″E	2.29	2.63	3.07	4.54	4.38	4.59	5.52	5.23	4.03	3.39	2.97	2.38	4.01
	Hongkong	22′18″N	114′10″E	2.59	2.56	3.06	3.93	4.13	4.74	5.81	4.95	7.68	4.05	3.56	2.93	4.18
India	New Delhi	28′N	77′E	3.68	4.47	5.5	6.6	7.08	6.55	5.01	4.62	5.11	4.99	4.15	3.42	5.10
	Bombay	18′33″N	18′33″E	5.22	6.03	6.66	7.05	6.77	4.59	3.54	3.4	4.72	5.39	5.15	4.8	5.28
	Bangalore	12′57″N	77′37″E	5	5.9	6.44	6.42	6.13	4.76	4.48	4.59	4.98	4.68	4.34	4.4	5.18
Indonesia	Jakarta	6′11″N	106′50″E	4.15	5.49	5	4.94	4.88	4.71	5.09	5.46	5.66	5.36	4.76	4.47	5.03
Japan	Tokyo	35′45″N	139′38″E	2.31	2.99	3.7	4.9	5.07	4.47	4.88	5.42	3.82	2.98	2.5	2.23	4.00
Korea	Seoul	37′31″N	127′E	2.62	3.4	4.29	5.24	5.83	5.15	4.26	4.55	3.99	3.64	2.6	2.24	4.16
Laos	Vientiane	18′07″N	102′35″E	4.3	4.94	5.52	5.74	5.11	4.24	5.22	4.19	4.61	4.26	4.21	4.24	4.63
Malaysia	Kuala Lumpur	3′07″N	101′42″E	4.54	5.27	5.14	5.05	4.8	4.98	4.91	4.78	4.54	4.51	4.23	7.07	4.70
Mongolia	Ullanbaatar	47′55″N	106′54″E	1.79	2.77	4.24	5.53	6.26	6.15	5.55	4.88	4.17	3	1.82	1.14	4.30
Myanmar	Yangon	16′47″N	96′09″E	5.4	6.06	6.65	6.69	5.14	3.24	3.3	2.99	4.12	4.51	4.82	5.05	4.65
Philippines	Manila	14′37″N	120′58″E	4.82	5.82	6.42	6.75	6.19	4.96	4.94	4.41	4.86	4.63	4.59	4.5	5.07
Singapore	Singapore City	1′N	103′E	4.43	5.52	5.05	5.05	4.62	4.66	4.51	4.61	4.49	4.5	3.98	3.93	4.61
Thailand	Bangkok	13′47″N	100′30″E	4.42	4.65	4.84	5.03	4.75	3.77	4.22	3.46	3.63	3.89	4.16	4.4	4.27
	Chiang Mai	18′N	99′E	4.79	5.51	6.11	6.29	5.53	4.44	4.16	4.18	4.5	4.34	4.28	4.48	4.88
Vietnam	Hanoi	18′N	105′54″E	2.52	2.94	3.81	4.34	4.66	4.51	4.62	4.62	4.57	3.64	3.29	3.17	3.89

Data source: NASA (2016).

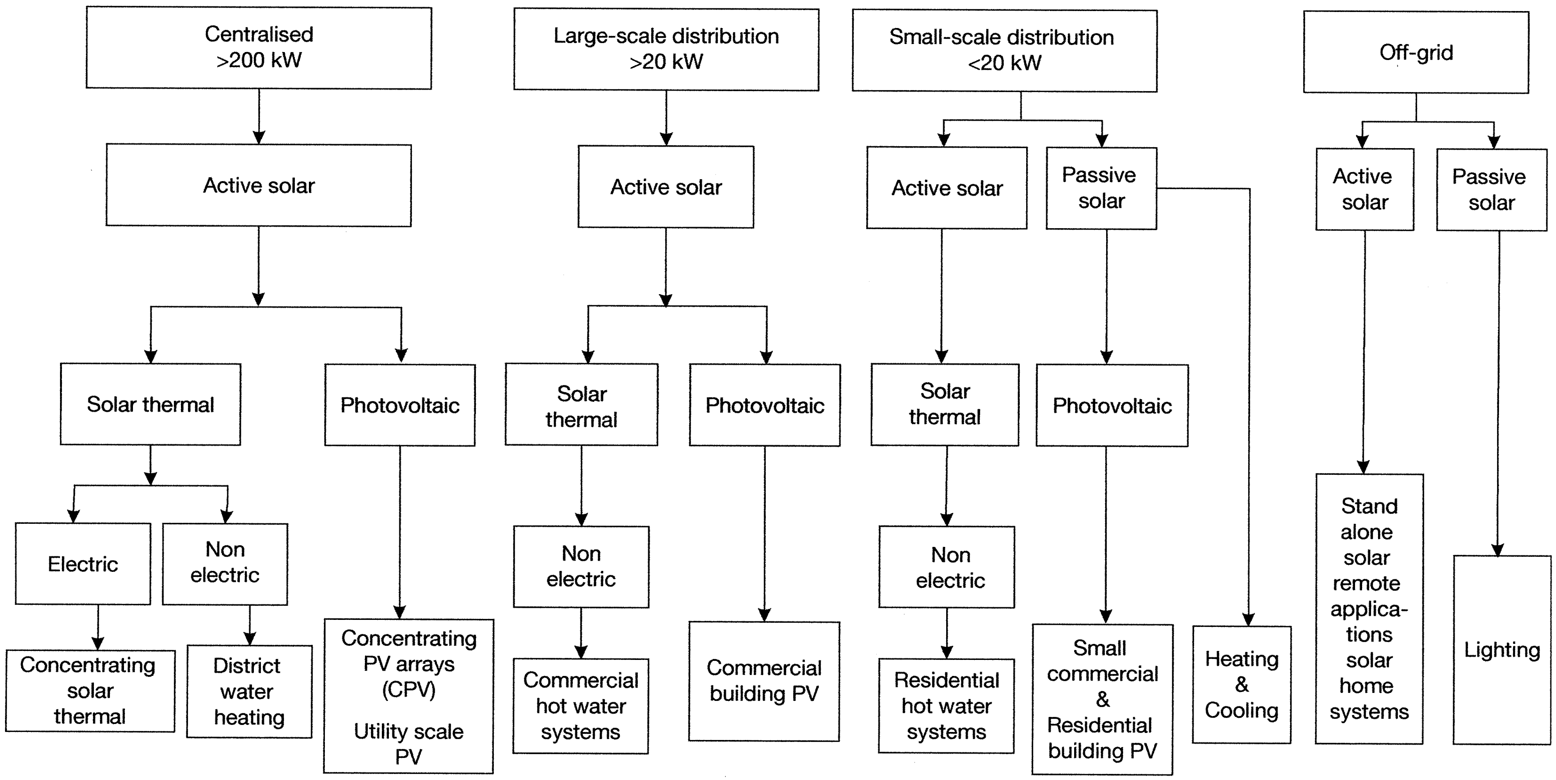

Figure 12.1 Classifications of solar technologies

Data source: Adapted from Bradford (2006).

Thin-film technology is based on semiconductors that are extensively and cost-effectively applied to substrates such as glass, metal or plastic films. Thin films have relatively low consumption of raw materials and their production efficiency is higher. Their flexibility of integrating into building, good performance at high ambient temperature and reduced sensitivity to overheating makes them more attractive (Shukla and Khare, 2014). The major drawbacks are its lower efficiency and the industry's limited experience with lifetime performances. As this requires more area than crystalline silicon technologies in order to reach the same capacity, it faces challenges for large-scale generation. In recent years, thin-film production units have increased from pilot scale to 50 MW lines, with some manufacturing units in the gigawatt (GW) range. As a result, thin films technologies are expected to increase their market share significantly by 2020 (IEA, 2014).

Solar thermal/concentrated solar power

The flat plate collector is the most common solar thermal technology, but it is only suitable for applications requiring temperatures of the order of up to about 80–85°C. When higher delivery temperatures are required (e.g. typically for electricity generation or for industrial process heat), as the input radiation cannot be increased, the reduction of heat losses could be possible by reducing the surface area of the absorber. In order to do that, an optical device is placed between the radiant source and the absorbing surface. Solar concentrators can be classified into three types: (1) planar and non-concentrating type; (2) line-focusing type that produces a high density of radiation on a line at the focus; (3) and point-focusing type that produces higher density of radiation in the vicinity of a point. Concentrating collectors need to follow the path of the sun during the day and according to the seasons continuously to focus the solar radiation on to the absorber. Likewise, trackers are used to follow the path of the sun in order to maximise the solar radiation incident on the photovoltaic surface. In the one-axis tracking, the array tracks the sun east to west, and so is used mostly with PV systems and with concentrator systems. On the other hand, in the two-axis tracking system, the panel or the concentrator points at the sun at all times.

The four types of CSP technologies are parabolic trough, Fresnel reflector, solar tower (heliostat) and solar dish. The first two systems are called line-focusing systems, while the latter are point-focusing systems. Currently, parabolic troughs are the most mature. They use synthetic oil, steam or molten salt to transfer the solar heat to a steam generator, and molten salt for thermal storage. Typical capacities of parabolic plants are in the range of 14–80 MWe, with efficiencies of the order of about 14–16%. The capacity factor depends on the location and is about 25–30%.

Though solar concentrators for electricity generation had been initiated in the 1980s with parabolic concentrators, a significant growth is observed only after 2008 (from less than 0.5 GW in 2008 to about 5.8 GW in 2015), and both parabolic and tower based technologies are used (REN21, 2016).

Online solar PV market and current status in Asia

In recent years, renewable energy technologies have increased their contributions to the Asian energy supply portfolio. This contribution is expected to increase in the coming years and decades, due to the increasing number of countries that are creating favourable conditions for renewable energy applications by setting renewable energy targets, and the supporting policies being put in place to meet those targets. The specific details with regard to solar energy for a number of Asian countries are given in Box 12.1, which clearly indicates this favourable trend.

Among the active solar energy technologies, the first solar PV applications were initiated since the late 1950s when they were used on space satellites to generate electricity. Following the

Box 12.1 Country-wise statistics of solar PV and CSP in Asia

Bangladesh *has more than 3 million solar home systems (SHS) operating at the end of 2014. The average size of the system is around 50–60 W for lighting, TV connections and mobile phone charging. Infrastructure Development Company Ltd. (IDCOL) has targeted 10,000 irrigation PV pumps (80 MW). The government started to introduce more PV power by setting a Solar Energy Program and is planning to introduce 500 MW of solar energy by 2017 (340 MW for commercial and 160 MW for grid connection). Bangladesh Power Development Board (BPDB) under the Ministry of Power, Energy and Mineral Resources signed a Power Purchasing Agreement (PPA) for a 60 MW PV power plant in July 2014 (BPDB, 2014).*

China *is expected to install approximately 19.5 GW in 2016 (Alex Nussbaum, 2015), a rise of 14.7% over 2015 and is expected to reach the target from 100 GW to 150 GW, which will bring about 21 GW of annual installation between 2016 through 2020 (Movellan, 2016). The target for the total installed solar PV capacity in 2050 is 1000 GW (Wang Sicheng, 2015). By 2018, a large number of concentrated solar power plants will be in place, and the 13th Five Year Electric Development Plan indicates that Concentrate Solar Power installation target is 5 GW.*

India's *PV market is driven by a mix of national targets and support schemes at various legislative levels. The Jawaharlal Nehru National Solar Mission aims to install 20 GW of grid-connected PV system by 2022 and an additional 2 GW of off-grid systems, including 20 million solar lights. Some states have announced policies targeting large shares of solar photovoltaic installations over the coming years; 2 GW of off-grid PV systems will be installed by 2017. However, in 2014 a new target of 10–60 GW of centralised PV and 40 GW of rooftop PV was announced (ADB, 2015). Total grid-connected solar power capacity in India is 8 GW at the end of the July 2016 (Mahapatra, 2016). The concentrated solar power installed by 2015 was 225 MW (REN21, 2016).*

Japan *had a total annual installed PV capacity of 9.7 GW (DC) in 2014, a 40% increase compared to 2013. The total cumulative installed capacity of PV systems in Japan reached 23.4 GW in 2014. About 60 GW of solar capacity has been approved but not been installed (ADB, 2015). The Japanese Ministry of Economy, Trade and Industry is discussing a revision of the current feed-in tariff (FiT) policy and the introduction of an auction process to promote lower cost operation (Movellan, 2016).*

Korea *enjoyed a record-breaking year in 2008 that saw 276 MW of PV installations. The PV market remained stagnant in the country during the following three years, mainly due to the limited FiT scheme. However, 230 MW in 2012, 530 MW in 2013 and finally 909 MW in 2014 were installed, reaching the highest level of installations so far. Thanks mainly to the newly introduced RPS scheme, at the end of 2014, the total installed capacity was about 2.4 GW, wherein the grid-connected centralised system accounted for around 87% of the total cumulative installed power. Korea installed 1 GW in 2015 (IEA PVPS, 2016b). The grid-connected distributed system amounted to around 13% of the total cumulative installed PV power. The share of off-grid non-domestic and domestic systems has continued to decrease and represents less than 1% of the total cumulative installed PV power.*

Malaysia *now has a total installed capacity of 168 MW. For the third year of its FiT system, the country installed 26.83 MW in 2015 (IEA PVPS, 2016b). The 2014 grid-connected distributed installations represented 86.7 MW compared to 48.2 MW in 2013. The residential segment remained stable in 2014 while the commercial segment doubled compared to 2013.*

Myanmar *plans to install a 220 MW* solar *PV plant, which is expected to be built in the Magway region.*

Nepal's *Electricity Agency planned to develop PV power plants totalling 325 MW by 2017.*

The Philippines *have installed 30 MW solar PV systems in 2014. The government approved 1.2 GW of utility-scale PV projects in 2014, and as in many countries, the tender was oversubscribed. Philippines PV market reached 110 MW in 2015 (IEA PVPS, 2016b).*

***Singapore** had a total PV installed capacity of 30 MW at the end of 2014. 15 MW of PV on rooftops have been installed in 2014, mostly in the commercial and industrial segments. The country has targeted 350 MW by 2020.*

***Taiwan** installed about 227 MW, mostly as grid-connected roof top installations (IEA PVPS, 2016b). The total installed capacity at the end of 2015 is estimated at around 615 MW.*

***Thailand's** cumulative grid-connected PV power reached to 1.3 GW at the end of 2014, with around 30 MW of off-grid applications. Thailand installed 121 MW in 2015 (IEA PVPS, 2016b). The concentrated solar power (CSP) installed by 2015 was 5 MW (REN21, 2016).*

***Uzbekistan** has the intention to install 2 GW of PV plants and two utility-scale plants are being developed (100 MW and 130 MW).*

***Vietnam's** solar PV capacity was approximately 4.5 MWp at the end of 2014, used typically for self-consumption purposes. However, its potential is estimated to be about 2–5 GW (residential and commercial rooftops), and 20 GW for ground-mounted PV power plants.*

oil-shocks in 1970s, applications of PV technology expanded. For almost fifteen years, from 1983 to 1999, the PV industry maintained an upward, but not spectacular, growth trend of about 15% per year in the shipments of photovoltaics (Turkenburg, 2000). The grid-connected PV capacity dominated the market, by sustained dramatic growth rates in the early 2000s, and by 2008 this market sustained dramatic increases in cumulative installed capacity, growing from about 5.1 GW in 2006 to 7.8 GW in 2007, crossing 13 GW by the end of 2008 and reaching 123.2 GW at the end of 2013 (REN21, 2008, 2009, 2013; WSSD, 2002; IEA PVPS, 2014). As of 2015, the global installed capacity of solar photovoltaics reached 227 GW, an increase of about 25% (50 GW) from 2014 (REN21, 2016).

Figure 12.2 shows the total installed solar PV in Asia, which amounts to 83,860 MW (IRENA, 2016a).

Solar PV is by far the most popular solar technology for online grid-connected systems, through solar farms and roof top systems, and concentrated solar power systems are slowly making strong inroads. The trend is significant in South, East and South Asia. In Asia, a total of 87.75 GW PV systems, mainly grid-connected systems, have been installed by the end of 2015 (ADB, 2015, 2016; Alex Nussbaum, 2015; IEA PVPS, 2016a, 2016b; Mahapatra, 2016; REN21, 2016; IRENA, 2016b).

Policies promoting solar electricity technologies in Asia

The price of solar PV modules has declined significantly over the past years (Figure 12.3), with a sharp drop from over US$3.25/Wp in 2006 to an average of US$0.72/Wp in 2014 – a drop of about 78%.[1] This was mainly driven by the oversupply in China, coupled with the declining demand in Europe, mainly in Germany. The shortage of polysilicon, which makes up a very significant part of the total module cost, increased the price to about US$400/kg. This led the producers of polysilicon to add additional capacity that dragged the price down to US$25/kg in 2010 (http://solarcellcentral.com/cost_page.html) and subsequently a drop in the cell and module price. This is expected to continue over the next few years until the excess supply of polysilicon is used up. The drop in cell and module price has also resulted in the decrease of installed cost of PV systems. For example, in the US, the cost of residential PV system has dropped from US$7.06/DC watt in 2009 to US$2.93/DC watt in 2016; the cost of commercial-scale PV dropped by about 60% between 2009 and 2016; and the cost of utility-scale PV (fixed tilt)

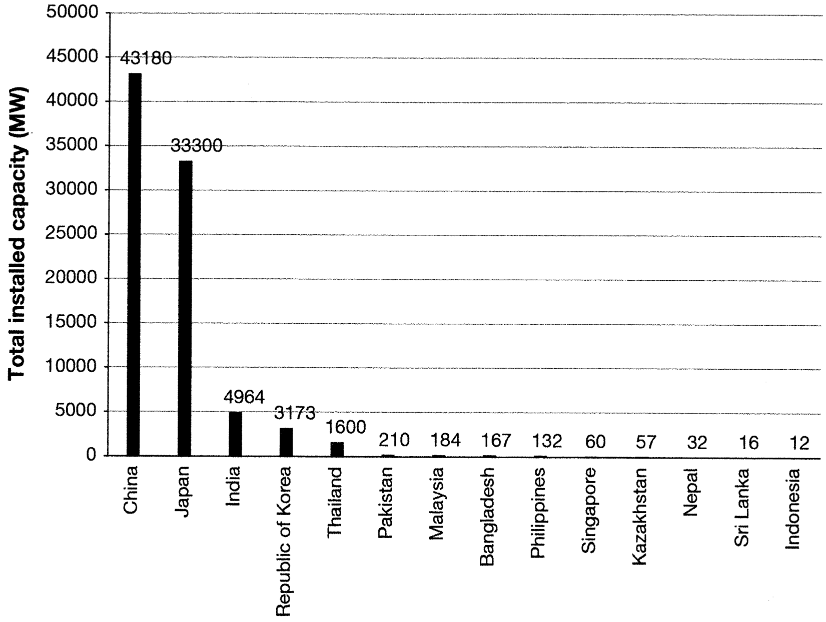

Figure 12.2 Total installed solar PV capacity at the end of 2014

Data source: Adapted from IRENA (2016b).

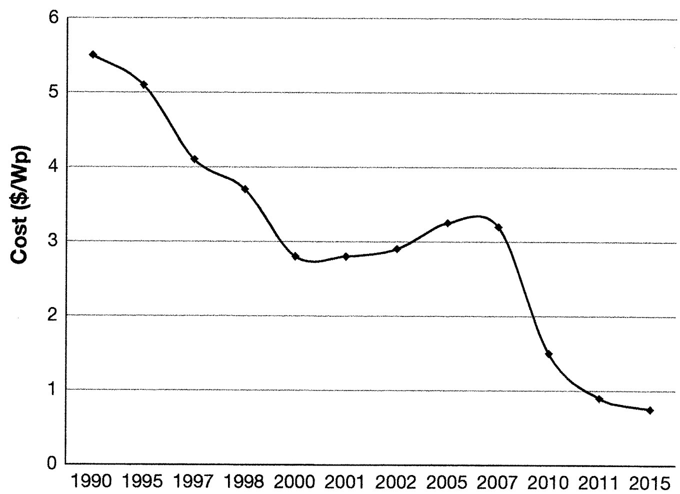

Figure 12.3 Solar PV cost trend

Data source: Solar Cell Central (2015).

dropped by about 70% during the same period (Solar Cell Central, 2016). Along with the cost reduction and technology development of solar PV technologies, policies have also contributed to the increase in the installation of solar PV installations in Asia. A summary of country-wise status of policies promoting solar PV are given in Box 12.2.

Box 12.2 Country-wise policy features for promoting solar PV

Bangladesh *is making a progress on grid-connected solar PV systems, mainly utility-scale, which has started to take-off recently. When the 200 MW grid-connected PV project is completed in 2018, the total grid-connected system would be about 300 MW (BPDB, 2014; Kenning, 2017; Photon.info, 2014). The government is attracting private sector investment through long-term power purchase agreement and aims to establish a FiT for the grid-connected system in the near future. The promotion of solar home systems in Bangladesh has been a great success with over 4.1 million SHS installed in the country (IDCOL, 2016). Through the Bangladesh Climate Change Strategy and Action Plan 2009 and with support from the World Bank and other donors, the government provides incentives schemes to encourage entrepreneurs who wish to start PV-based applications.*

Brunei *is considering a FiT policy.*

China *is using several schemes to incentivise the development of PV. They aim at developing utility-scale PV through rooftop PV in city areas and micro-grids and off-grid applications in un-electrified areas of the country. By 2014, China had a stable FiT scheme, which was financed by the surcharge paid by electricity consumers for utility-scale PV and rooftop PV. In that year, the National Energy Agency pushed for PV development on roofs, including PV power applications for large-scale industrial development districts and commercial enterprises with large roofs, high electrical load and high retail electricity prices, and for poverty reduction in Hebei, Shanxi, Anhui, Gansu, Qinghai and Ningxia provinces targeting 1.5 GW of installations.*

India's *solar energy projects, at the end 2016, had an aggregate capacity of over 8727.62 MW. The Ministry of New and Renewable Energy has initiated policy measures for achieving the target of renewable energy capacity to 175 GW by the year 2022, which includes: enforcement of Renewable Purchase Obligation and for providing Renewable Generation Obligation; setting up of exclusive solar parks; development of power transmission network through Green Energy Corridor project; identification of large government complexes/buildings for rooftop projects; provision of roof top solar and 10% renewable energy as mandatory under Mission Statement and Guidelines for development of smart cities; providing long tenor loans; and making roof top solar as a part of housing loan and others (MNRE, 2016).*

Indonesia *introduced a solar policy in 2014 which supports the purchase of solar photovoltaic power on the capacity quota offered through online public auction by the Directorate General of New Renewable Energy and Energy Conservation (MEMRI, 2014). The plant that wins the auction will sign a power purchase agreement with the National Electric Company at the price determined by the regulation. The maximum purchase price is 0.25 US$/kWh, which is increased to 0.30 US$/kWh in case of a local content requirement of 40%, and about 20 MW was installed in 2014 (MEMRI, 2014).*

Japan *established the FiT programme for solar PV in July 2012 – this has fostered the rapid growth of public, industrial application and utility-scale PV systems (IEA PVPS, 2016b). The breakdown of PV systems installed in 2014 is 1.4 MW for off-grid domestic application, and 9.7 GW for grid-connected distributed application. While the PV market in Japan developed in the traditional rooftop market which at the end of 2014 represented almost 5 GW of the cumulative capacity, 2013 and 2014 have seen the development of large-scale centralised PV systems, especially in 2014 with 3 GW up from 1.7 GW of centralised plants installed in 2013 (Hahn, 2014), and the market was balanced between residential (< 10 kW), commercial, industrial and large-scale centralised plants in 2014 (ADB, 2016).*

Kazakhstan *aims at installing 700 MW and has established a FiT programme in 2014.*

Korea *has developed various incentives to support PV development. In 2014, the "Fourth Basic Plan for the Promotion of Technological Development, Use, and Diffusion of New and Renewable Energy" based on the "Second National Energy Basic Plan" was issued. This plan includes many new subsidy measures including the development of "Eco-friendly Energy Towns," "Energy-independent Islands," and "PV Rental*

Programs." The Renewable Portfolio Scheme launched in 2012 will be active until 2024 and is expected to be the major driving force for PV installations in Korea, with improved details such as boosting the small-scale installations (less than 100 kW size) by adjusting the Renewable Energy Certificate and multipliers, and unifying the PV and non-PV markets (IEA PVPS, 2016a, b).

***Malaysia's** long-term goals and commitment to renewable energy is explicated in The National Renewable Energy Policy and Action Plan. The Sustainable Energy Development Authority has the responsibility to implement and administer the FiT mechanism, which is financed by a Renewable Energy Fund. Building Integrated Photovoltaic installations were an additional premium on top of the FiT. The two main policy references were the Third Outline Perspective Plan and the Eighth Malaysia Plan (2001–2005) (Umar et al., 2014). Within the plan period, the Fifth-Fuel Diversification Policy 2001 has been established and the Small Renewable Energy Programme has been created (Ahmad et al., 2011). The Fifth-Fuel Diversification Policy 2001, is a major policy instrument that aims to increase the share of renewable energy in the power supply, that also includes solar among other six renewable energy resources (ADB, 2015).*

***Myanmar** has seven line Ministries responsible for energy sector matters. The Ministry of Energy is a focal point for overall energy policy and planning coordination with the concerned Ministries; however, its major focus has been on planning and policies in the oil and gas sectors. National Energy Management Corporation published the National Energy Policy in 2014 where some key objectives were to develop energy resources that are accessible, while considering environmental and social impact, institute laws, rules and regulations to promote private sector participation, and implement sustainable energy development programmes that scale up use of renewable resources (MEMR, 2012; Suryadi, 2014; IEA, 2015). The National Electrification Plan started in June 2014 has a goal to electrify the whole country by 2030–2031 (World Bank, 2014).*

***Pakistan** has approved 793 MW of solar plants to be commissioned in 2015. A FiT has been introduced for utility-scale PV in 2014. The initiatives aimed to boost the solar market include net metering programme and the introduction of a funding scheme allowing homeowners to borrow against their mortgage for solar installations (IFC, 2016; Government of Pakistan, 2006):*

*In **Taiwan**, the market is supported by a FiT scheme guaranteed for 20 years. This scheme is part of the Renewable Energy Development Act passed in 2009. The initial FiT was combined with capital subsidy. It has later been reduced and now applies with different tariffs to rooftops and ground-mounted systems. Larger systems and ground based systems have to be approved in a competitive bidding process based on the lowest FiT offered. Property owners can receive an additional capital subsidy. It is intended to favour small-scale rooftops at the expense of larger systems, in particular ground based installations. So far, agricultural facilities and commercial rooftops have led the market. The country targeted 842 MW of PV installations in 2015, 2.1 GW in 2020 and 6.2 GW in 2030 (3 GW on rooftops, 3.2 GW for utility-scale PV). In 2012, Taiwan launched the "Million Roof Solar Project" aiming at developing the PV market in the country, with the support of municipalities.*

***Thailand** had introduced the feed-in premium or "adder" in 2007 aimed at promoting the development of grid-connected solar energy. This "adder" came in addition to the regular tariff of electricity, around 3 THB/kWh. It was phased out at the end of 2013 and has been replaced by a 25-year FiT scheme. In 2013, the solar power generation target was increased to 3 GW (and increased to 3.8 GW in 2015) together with the reopening of the solar PV rooftop Very Small Power Producer scheme with a new FiT. 1 GW has been granted for utility-scale ground-mounted PV systems. In addition, the Thai government also approved a generation scheme of 800 MW for agricultural cooperatives. With these schemes, Thailand aims at continuing the deployment of grid-connected PV in the rooftop segments, after a rapid start in the utility-scale segment (IEA PVPS, 2016a, b).*

Table 12.2 Feed-in tariff in different countries in Asia

Country	*FiT rates (US$/kWh)*	*Comments*
China	0.14–0.16	Different FiT for solar PV projects in different parts of China
India	0.15	The Indian government has set up power purchase tariffs for solar photovoltaic and solar thermal systems. The preferential tariffs are reviewed annually by the Central Electricity Regulatory Commission
Indonesia	0.145–0.25	Initiated in 2015, the tariff depends on project location. Java has been allocated the highest capacity of 150 MW but the lowest tariff, with individual project sizes capped at 20 MW
Japan	0.369–0.371 (2013) 0.338–0.390 (2014)	Starting from 1 April 2014 to 31 March 2015, the FiT rates for solar energy have been slightly revised downwards (excluding tax)
Korea	0.70	The government set an upper limit of support for 20 MW for solar
Malaysia	0.16–0.34	The FiT is capped at a generation capacity of 30 MW
Mongolia	0.15–0.18	
Philippines	0.22	Government has guidelines for the Selection Process of Renewable Energy Projects under the Feed-in Tariff System and the Award of Certificate for Feed-in Tariff Eligibility. Projects are selected on the basis of this guideline
Thailand	0.20	It is called the "adder" scheme since the tariff is added to the base electricity price

Sources: Pocci (2014), PVTech (2016), IEA (2014) and Mekhilef et al. (2014).

Table 12.2 summarises the FiT rates and related details in the selected Asian countries. Based on the observations on the promotion of solar-based electricity generation in Asia, it is clear that FiT has been the main instrument in Asia to have successfully increased the implementation of solar electricity generation technologies.

This has been contributed also by the falling costs of PV modules. The cost has seen a downward trend due to fall in polysilicon prices, technological innovations, scaling up and other factors, and have fallen by more than 80% since 2008 contributing to a reduction in the total system costs. In actual terms, the lowest tariff from a solar plant in Rajasthan (India) is lower than that of thermal (coal) power plants. These indicate the most favourable situations for the solar electricity growth in Asia in the coming decades.

A number of policies and measures have been employed by the countries (e.g. China, India, Japan, and Thailand) who have installed more than 1 GW installed capacity of online grid systems, for example: FiTs; competitive bidding; promotion of installation of solar PV in roof tops of various building types; and promotion of green cities and municipalities. Other countries with lower installed capacity (Malaysia, Singapore, Vietnam) as well as emerging economies (Bangladesh, Cambodia, Myanmar, etc.) are also introducing similar policies for solar PV promotion.

As of 2015, globally feed-in policies were the most widely adopted form of renewable power policy support. The market conditions in the country, type of technology (mature or less mature), and scale of implementation have contributed to the rates and the modalities of these policies. Moreover, market conditions are changing due to technological innovation, increasing deployment of renewable energy technologies, falling prices and shifting public opinion.

For example, with regard to mature technologies, countries have considered competitive bidding to support larger-scale projects (e.g. solar PV). The constant and continuing review and revision of the feed-in rate has occurred in China, Japan, the Philippines and Thailand, while new rates have been introduced in Malaysia and Pakistan.

The countries that adopted the global climate deal in Paris in December 2015 have identified renewable energy technologies deployment as the preferred option to reduce emissions. Of the 162 Intended Nationally Determined Contributions (INDCs) submitted, 106 countries have noted their intention to increase renewable energy, and 26 have set specific targets for electricity and other energy sources. Thus, some countries are using the INDC process to introduce more ambitious targets and strategies.

Roof tops are becoming increasingly attractive locations for placing solar PV systems/plants, especially in urban concentration countries (e.g. Singapore) or otherwise (e.g. China, India, Thailand). Different types of roofs are being considered for installation – from industry to government to private. This also resonates well with the "green cities, green town" initiatives of local and federal governments. In the recent auction of rooftop solar power projects in Rajasthan (India), the solar tariffs in 2016 reduced to Rs3 per unit, that is lower than that of thermal (coal) power plants. The rooftop projects will be installed on non-governmental organisation buildings, educational institutes, hospitals, trusts and not-for-profit companies. This trend, if found to be successful, is likely to find applicability in the other growing economies as well.

Future potential for solar electricity technology promotion

The prospects for the deployment of solar energy-based electricity generation systems could be gauged considering the need for electricity in the region (given by the need to increase the energy access in terms of quantity and quality), availability of resources for the generation of electricity, technologies available and transfer of technologies, energy demand, country policies, costs of the technologies and financing models, greenhouse gas mitigation considerations, among others.

Energy access and provision of modern energy services, such as those provided by electricity, gasoline and liquefied petroleum gas is important for a country's economic development, as it can help provide lighting, communication, clean water and sanitation. However, at present, around 455 million people lack access to electricity in the Asia Pacific region, while in absolute terms, India, Bangladesh, Pakistan, Indonesia and Myanmar have the largest electricity access deficit (G20, 2016). Asia, in general, is well endowed with solar radiation availability, and access to data on the quantity of radiation for designing systems is also readily available. In the ASEAN region, for example, the solar radiation averages over 1500–2000 kWh per square meter annually, which allows for capacity factors of 20% and above.

The future electricity demand would be in rural and in peri-urban Asia that would require electricity generation and supply in various levels. Solar technologies, especially PV, has seen an important decreasing trend in cost in recent years, which along with the country-specific financial models through Energy Service Companies and Public Private Partnerships and government incentives (as indicated by the FiT presented in Table 12.2), is expected to contribute to the growth of the market for solar-based electricity systems at all levels.

It is thus clear that Asia is poised for an energy transition towards improving energy access and modern energy services. At the same time, INDCs have been submitted by the countries to reduce greenhouse gas emissions in 2015. The commitments made by Asian countries on their intended reductions of emissions is given in Table 12.3, and these emission mitigations would be mainly through the promotion of renewable energy and energy efficiency Moreover, Goal 7 of

Table 12.3 A summary of the INDC targets (emission reduction) of selected Asian countries

Country	*INDC targets*
Cambodia	Reduction of 3100 $GgCO_2eq$ (27%) in the year 2030 compared to the baseline of 2010
China	To lower CO_2 emissions per GDP by 60–65% from 2005 by 2030
India	To reduce emissions intensity of GDP by 30–35% from 2005 levels in 2030
Indonesia	Reduction of GHG emissions by 29% from the projected BAU level in 2030
Malaysia	Reduce GHG emissions intensity of GDP by 35% (additional 10% with international aid) by 2030 from 2005
Philippines	Reduction of GHG emissions by 70% by 2030 relative to its BAU scenario of 2000
Singapore	Reduce its emission intensity by 36% in 2030 from the 2005 baseline
Thailand	Reduce GHG emissions by 20% (111 $MtCO_2eq.$) from the projected BAU level by 2030
Vietnam	Reduce 8% (up to 25% with international aid) GHG emissions by 2030 from 2010 levels

Data source: INDC Submissions to UNFCCC by the countries, compiled by the authors.

Note: BAU, business as usual; GDP, gross domestic product; GHG, greenhouse gases.

the 2030 Agenda for Sustainable Development aims to provide universal access to affordable, reliable, sustainable and modern energy services. For electricity, this would be through the measures of grid, off-grid and on-grid supply. Currently, solar energy-based electricity generation is observed in all these categories of measures.

According to ACE and IRENA (2016), "renewables are increasingly the least-cost option for electricity production, a trend that will accelerate over the coming decade". Comparing the levelised cost of electricity, it is estimated that by 2025 renewable power technologies (specifically, solar PV and wind) would have the fastest deployment in capacity growth, as for example, the levelised cost of electricity in 2025 could be US$40 per MWh for solar PV compared to about US$60 per MWh for coal.

The primary energy supply in the Asia is expected to increase to 8794 million tons of oil equivalent (Mtoe) in 2040 compared to 2012, while the demand for electricity is expected to almost double. Renewable energy consumption in Asia will also increase from 759 Mtoe in 2012 to 1174 Mtoe in 2040. The PV installed capacity could increase to about 17 TWh in 2040 (IEEJ, 2014).

Therefore, the Paris Agreement, and the implementation of the 2030 Agenda, along with the availability of solar radiation widely and the easy availability of PV panels, and cost factor is expected to further help deploy solar-based electricity generation in the region.

Conclusions

The world now adds more renewable power capacity compared to all fossil fuels combined, and this amounted to about 60% in 2015. This significant growth of renewable energy technologies in the power sector is primarily due to cost competitiveness of solar technologies, favourable policies and attractive financing options, and concerns about greenhouse gas emissions. According to REN21 (2016), solar photovoltaics and concentrated solar power installations at the end of 2015 totalled 227 GW and 4.8 GW, respectively. In Asia, China, India and Japan together have installed more than 83 GW of PV, while India and Thailand have installed about 0.23 GW of concentrated solar power. The investment in solar energy technologies reached more than US$161 billion in 2015, compared to about US$286 billion for the entire renewable energy sector. The renewable energy sector's employment in 2015 was about 8.1 million jobs worldwide. The regional shifts in deployment to Asia resulted in this continent's share to the global employment to be about 60%, and, of this, more than 2.7 million were in the PV sector, an increase of 11% from the previous year (IRENA, 2016a).

Looking at the future, China is planning to install about 100 GW by 2020, while India plans to install a similar target by 2022 (60 GW of land mounted grid-connected solar power and 40 GW of rooftop grid interactive solar power). Japan and Thailand plan to install about 65.7 GW and 3 GW, respectively, by 2021 (ADB, 2012; Allendorf and Allendorf, 2013; Aung, 2014; Bodenbender et al., 2012; Cook, 2013; Fullbrook, 2013; Greacen, 2014; Greve, 1999; Kyaw et al., 2009; Martinot and Reiche, 2000; Practical Action, 2010, 2012, 2013a, 2013b). A major development in the industry has been the falling costs of PV modules due to fall in polysilicon prices, technological innovations, scaling up and other factors, and this has fallen by more than 80% since 2008 contributing to a reduction in the total system costs. In India's recent auction of rooftop solar power projects, the solar tariffs in 2016 reduced to Rs3 per unit, that is lower than that of thermal (coal) power plants.

During the last few years, advances in technology, reduction in costs, impetus from climate change, novel financing models and market transformations have contributed to the significant developments in the promotion of the solar and renewable energy-based electric power sector worldwide, and particularly in Asia. This is indicated by the fact that solar PV is cost competitive compared to fossil fuel-based electricity generation, and is dominated by large-scale generation, including the private sector. The government policies are also conducive and many countries have renewable energy targets. These factors, combined with the Sustainable Development Goal commitments and the Paris COP 21 agreements, indicate the significant role for solar and other renewable energy resource technologies in the coming decades.

Note

1 http://solarcellcentral.com/cost_page.html

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The Routledge Handbook of Energy in Asia presents a comprehensive review of the unprecedented growth of Asian energy over the past quarter of a century. It provides insightful analysis into variation across the continent, whilst highlighting areas of cross-learning and regional cooperation between the developed and developing countries of Asia. Prepared by a team of leading international experts, this book not only captures the East Asian domination, particularly that of China, but also highlights the growing influence of South Asia and the ASEAN.

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