ENERGY TECHNOLOGY INNOVATION IN SOUTH ASIA

IMPLICATIONS FOR GENDER EQUALITY AND SOCIAL INCLUSION

Reihana Mohideen

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Energy Technology Innovation in South Asia
Implications for Gender Equality and Social Inclusion

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ABBREVIATIONS

ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
ASEAN	Association of Southeast Asian Nations
BPL	below poverty line
CEB	Ceylon Electricity Board
GESI	gender equality and social inclusion
GIS	geographic information system
HLT	high-level technology
ICS	improved cookstoves
ICT	information and communication technology
IDCOL	Infrastructure Development Company Limited
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LCOE	levelized cost of electricity
MMR	maternal mortality ratio
MNRE	Ministry of New and Renewable Energy
MSMEs	micro, small, and medium-sized enterprises
NBMMP	National Biogas and Manure Management Programme
NRREP	National Rural and Renewable Energy Programme
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
PRC	People's Republic of China
PUCSL	Public Utilities Commission of Sri Lanka
R&D	research and development
RTS	rooftop solar
SARD	South Asia Department
SHP	small hydropower
SHS	solar home system
SLSEA	Sri Lanka Sustainable Energy Authority
SREDA	Sustainable and Renewable Energy Development Authority
STS	science and technology studies
TFC	total final consumption
UNDP	United Nations Development Programme

WEIGHTS AND MEASURES

EJ	exajoule
GJ	gigajoule
GW	gigawatt
GWh	gigawatt-hour
kgoe	kilogram of oil equivalent
km	kilometer
kWh	kilowatt-hour
kWp	kilowatt-peak
m^3	cubic meter
MW	megawatt
MWh	megawatt-hour

GLOSSARY

Agile energy system	–	an energy system that is flexible in its production capabilities and physical location, such as solar and wind power generators, and can incorporate some modern technical functionalities such as communication and remote control abilities, power factor correction, harmonic analysis and correction, phase correction, and general voltage stability functions for integration into the traditional grid or a mini-grid
Biodiesel	–	a diesel equivalent, processed fuel made from the transesterification (a chemical process of removing glycerin from oil) of both vegetable oils and animal fats
Bioenergy	–	a material that is directly or indirectly produced by photosynthesis and used as feedstock in the manufacture of fuels and substitutes for petrochemical and other energy-intensive products
Biofuel	–	a fuel derived from biomass or waste feedstocks, includes ethanol and biodiesel, and can be classified as conventional or advanced biofuel according to the technologies used to produce it and its respective maturity
Biogas	–	a mixture of methane and carbon dioxide (CO_2) produced by bacterial degradation of organic matter and used as a fuel
Biomass	–	a biological material that can be used as fuel or for industrial production; includes solid biomass such as wood, plant and animal products, gases and liquids derived from biomass, industrial waste, and municipal waste
Capacity (electricity)	–	the amount of power produced, transmitted, distributed, or used at a given moment (measured in megawatts)
Coal	–	includes both primary coal (including hard coal and brown coal) and derived fuels (including patent fuel, brown-coal briquettes, coke-oven coke, gas coke, gas-works gas, coke-oven gas, blast furnace gas, oxygen steel furnace gas, and peat)
Co-generation	–	refers to the combined production of heat and power
Demand response	–	a mechanism by which electricity demand is shifted over given time periods in response to price changes or other incentives, but does not necessarily reduce overall electrical energy consumption; can be used to reduce peak demand and provide electricity system flexibility
Demand management (or demand side management)	–	the process of managing the consumption of energy, generally to optimize available and planned generation resources.*** Actions that form part of this management include moderation of customer's power supply, activation or deactivation of distributed resources (solar panels, battery storage, etc.), and activation or deactivation of smart appliances or products.
Direct current	–	a type of electricity transmission and distribution by which electricity flows in one direction through the conductor; usually relatively low voltage and high current; typically abbreviated as DC
Distributed generation	–	a term used by the power industry to describe localized or on-site power generation

Distribution	–	electricity distribution systems transporting electricity from the transmission system to end users
Electrical energy	–	indicates the net amount of electricity generated, transmitted, distributed, or used over a given period; measured in megawatt-hours or kilowatt-hours
Electricity generation	–	the total amount of electricity generated by power only or co-generation (combined heat and power) plants including generation required for own use; also referred to as gross generation
Energy intensity	–	a measure where energy is divided by a physical or economic denominator, e.g., energy use per unit of gross domestic product or energy use per ton of cement
Energy storage	–	the process of storing or converting energy from one form to another for later use; storage devices and systems include batteries, conventional and pumped storage hydroelectric, flywheels, compressed gas, and thermal mass
Energy systems approach	–	a holistic way of addressing complex issues surrounding innovation potential at the interface of science, environment, technology, and society with respect to energy generation and use
Energy transition	–	the transition from traditional thermal energy generation to a sustainable energy generation and management system that is low in carbon emissions and uses renewable energy resources and the management of these resources so that production and use is as clean as possible
Fuel cell	–	a device that can be used to convert hydrogen or natural gas into electricity. Various types exist that can be operated at temperatures ranging from 80°C to 1,000°C. Their efficiency ranges from 40% to 60%. For the time being, their application is limited to niche markets and demonstration projects due to their high cost and the immature status of the technology, but their use is growing fast.
Gas	–	includes natural gas, both associated and nonassociated with petroleum deposits, but excludes natural gas liquids
Gender-friendly technology	–	women's access to technologies as well as the processes by which technology is designed, developed, and used and how women especially are drawn into these processes
Hybrid system	–	a renewable energy system that includes two different types of technologies that produce the same type of energy, e.g., a wind turbine and a solar photovoltaic array combined to meet a power demand
Hydropower	–	refers to the energy content of the electricity produced in hydro plants, assuming 100% efficiency; excludes output from pumped storage and marine (tide and wave) plants*
Independent power producer	–	a business, institution, or individual that is not directly regulated as a power provider; these entities produce power for their own use and/or sell it to regulated power providers
Losses (Energy)	–	a general term applied to the energy that is converted to a form that cannot be effectively used (lost) during the operation of an energy producing, conducting, or consuming system

Low-carbon energy technologies	–	energy technologies that emit less CO_2 (in comparison with conventional sources) from all sectors (buildings, industry, power, and transport) that are being pursued in an effort to mitigate climate change
Maternal mortality ratio	–	the annual number of female deaths per 100,000 live births from any cause related to or aggravated by pregnancy or its management (excluding accidental or incidental causes)
Net metering	–	the practice of using a single meter to measure consumption and generation of electricity by a small generation facility (such as a house with a wind or solar photovoltaic system). The net energy produced or consumed is purchased from or sold to the power provider, respectively.
Non-energy use	–	fuels used for chemical feedstocks and non-energy products; examples of non-energy products include lubricants, paraffin waxes, coal tars and oils as timber preservatives
Power generation	–	fuel use in electricity plants, heat plants, and co-generation plants; both main activity producer plants and so-called autoproducer plants that produce electricity or heat for their own use are included
Power grid	–	a system of synchronized power providers and consumers connected by transmission and distribution lines and operated by one or more control centers
Reference energy system	–	a network representation of all of the technical activities required to supply various forms of energy to end use activities. Analytical techniques are described to examine all operations involving specific fuels including their extraction, refinement, conversion, transport, distribution, and utilization. Each of these activities is represented by a link in the network for which efficiency, environmental impact, and cost coefficients may be specified. The network is quantified for a given year with the level of energy demands and the energy flows through the supply activities that are required to serve those demands.
Renewables	–	Renewable energy sources (renewables) include biomass and waste, geothermal, hydro, solar photovoltaic, concentrating solar power, wind, and marine (tide and wave) energy for electricity and heat generation
Smart grid	–	an electrical grid which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficient resources. It is also an adaptive system, embodied by the classical electrical grid but with a variety of modern concepts and technological resources appended, including but not limited to smart meters, smart appliances, renewable energy resources, and energy efficient resources
Social inclusion	–	the process of improving the terms of participation in society, particularly for people who are disadvantaged, through enhancing opportunities, access to resources, voice, and respect for rights
Technology audit	–	an evaluation of the technical capacity, procedures, needs, history, and development of a particular entity, usually an organization or country; a characterization of the strengths and weaknesses of the particular entity, contextually, with respect to existing standards

Technology innovation	–	a new product and/or process or a significant improvement in a product and/or process, usually the result of research and development, with better than average commercialization or adoption potential
Total final consumption (TFC)	–	is the sum of consumption by the different end use sectors, excluding conversion losses from the transformation sector (power plants, oil refineries, etc.), energy industry own energy use, and other losses. TFC is broken down into energy demand in the following sectors: industry (including manufacturing and mining), transport, buildings (including residential and services), and others (including agriculture and non-energy use). In the Energy Technology Perspectives (ETP) scenarios, the final consumption of the transport sector on a regional or national level includes international marine and aviation bunkers, but not pipeline transport, which is included under energy-industry own energy use. Energy use from blast furnaces and coke ovens is included in the final consumption of the industry sector.
Total primary energy supply	–	is equivalent to total primary energy demand. It represents inland demand only and, except for world energy demand, excludes international marine and aviation bunkers. Deviating from this International Energy Agency (IEA) definition, ETP results at regional or national level also include primary energy use for international aviation and shipping
Traditional use of biomass	–	the use of fuel wood, charcoal, animal dung, and agricultural residues for cooking and heating in the residential sector; tends to have very low conversion efficiency (10% to 20%) and often unsustainable biomass supply
Transmission	–	Electricity transmission systems transfer electricity from generation (from all types, such as variable and large-scale centralized generation, and large-scale hydro with storage) to distribution systems (including small and large consumers) or to other electricity systems

EXECUTIVE SUMMARY

Asia's energy transition is being driven by rising energy demand and the commitment to reduce carbon dioxide (CO_2) and greenhouse gas emissions. Electricity generation is at the center of this transition from which developing Asia has much to gain. Climate change is a threat to the whole planet, but developing Asia has some of the most dramatic and damaging early manifestations of climate change. The transition will also mitigate other problems such as air pollution and traffic congestion, and benefit the preservation of natural assets, agricultural production, and food security. This transition has important implications for gender equality and social inclusion (GESI).

The traditional electricity grid is an astonishing engineering achievement, but there are emerging problems with it, such as the following:

- It is not well suited to integrate renewable energy sources and distributed generation.
- It is becoming too big to manage manually.
- With increasing penetration of renewables, it is becoming more unreliable and much harder to control, requiring significant investment in measurement technology and faster actuators.
- With expanding renewable energy assets, it will become more expensive to maintain.
- It is increasingly experiencing peak-to-average power load problems (as transmission assets have to be provided for the peak).
- In its classical energy sources configuration, it is a major contributor to global warming.
- It is not well suited to incorporate distributed energy from a technical management point of view as well as from a safety point of view.
- It is experiencing more difficult contingency restoration problems, more so as renewable generation increases.
- It is not well suited to serve constant power loads.
- By its centralized nature, it is socially inequitable and not available to everyone as minimum demand and energy thresholds have to be met to make an economically viable case to connect distant demand.

Access to electricity is a factor in rising life expectancy, particularly female life expectancy, and falling maternal and infant mortality. There is a correlation between maternal mortality ratios and per capita energy consumption, and variation in maternal mortality ratios reflects inequality in access to energy.

Access to electricity, and energy in general, and its use is valuable not in itself, but for what it enables women and men "to do or achieve" (Moss and McGann 2011). The history of energy transitions highlights the importance of end use—consumers and demand—and indicates that technology and the social settings coevolve, depending on each other (Grubler 2012).

Renewable energy technologies as "disruptive technologies" can transform how energy is produced, distributed, and consumed. Distributed systems such as mini-grids can provide solutions for inclusive energy access.

The study addresses how energy systems and services can improve women's economic empowerment and save women's time spent on domestic chores. We live in a technological culture. Integrating gender equity considerations into technology design and drawing women into this process is not only an equal employment opportunity issue, but is also crucially about how the world we live in is shaped, and for whom (Wajcman 2010). This is the focus of this study.

The study is aimed at a cross-disciplinary community of researchers and practitioners—specifically engineers (with a focus on energy and power systems) and social specialists (with a focus on GESI)—working in the energy and power sector primarily in developing countries in Asia.

The study includes a renewable energy technology audit that was conducted to

(i) identify the technology types and systems being deployed,
(ii) understand the type of information being collected, and
(iii) inform GESI integrated system design.

The technology audit was limited to Bangladesh, Nepal, and Sri Lanka based on government data. The results of the technology audit are collated in an appendix. The data collected can be clustered under the following main categories:

(i) technology and system types;
(ii) installed capacity (targets, achievements, and cumulative capacity over the period of the program or scheme);
(iii) off-grid systems (numbers of units installed); and
(iv) financial assistance for each technology type.

These categories form a template for the collection of technology and systems data. Information on target beneficiaries of financial assistance is sometimes included, but is not consistently reflected. There is little or no household data.

The water–energy nexus has emerged as a critical issue. Design of energy projects and power systems needs to consider an integrated approach in relation to powering water systems for agriculture and household consumption.

Technology innovation is enabled by the policy and regulatory environment. This includes financial assistance and tariff incentives, as demonstrated by the net metering measures and Net Plus program in Sri Lanka and the targeted subsidy policies in Nepal. In both cases, household consumers and low-income and below poverty line (BPL) consumers were targeted beneficiaries. The Nepal case demonstrates that social criteria, including GESI criteria, can be effectively integrated to promote technology uptake for rural electrification solutions. The findings in the Nepal case show a correlation between targeted financial assistance and technology uptake in BPL and marginalized communities.

The collection of technology data needs to reflect the energy transition from the old grid to the new one. It needs to have a greater focus on information relevant to distributed generation, in both on-grid and off-grid systems. This requires accurate information at the level of households and small power producers. This transition is starting to be reflected in the technology data collected by energy agencies, which now includes some household data. The Alternative Energy Promotion Centre (AEPC) in Nepal is a good practice case study of GESI mainstreaming in energy programs and the collection of GESI data to monitor implementation.

The study proposes to use Nerini's five pillars for rural electrification pathways: technology (T), cost (C), environmental (E), social (S), and institutional (I). According to Nerini, the criteria may have weighted subcriteria to form a single macrocriterion—T, C, E, S, or I. The macrocriteria in turn may be weighted to reach a final composite index. The weights are chosen pursuing a participatory approach, and to reflect a "unit-less" approach to enable some comparison of otherwise incompatible units (e.g., how to compare social with institutional outcomes). The present study integrates GESI considerations into Nerini's composite index at the sub-criterion level to reflect the GESI issues broadly. GESI considerations could potentially play a role in all of the criteria T, C, E, S, and I.

The World Bank Global Tracking Framework's five-tier model for transitioning toward advanced energy access is used as a guide. The study concludes that electricity access at tier 3 or tier 4 is necessary to achieve meaningful GESI outcomes linked to reducing women's labor time on household chores, and to enable women's economic empowerment. Tier 3 is the minimum required to provide pumped water services, access medium and high-power appliances, and have electricity for at least 50% of normal working hours. Tier 4 is required to cover "most of working hours" (International Energy Agency (IEA) and World Bank 2015). As the World Bank model does not reflect reliability and resilience, or scalability, some care has to be taken to interpret the results.

GESI can and should be integrated into energy service modeling. Phase 2 of this study will involve a pilot project with GESI mainstreaming in a community energy system, to be monitored over 3–5 years to assess results properly. Participatory consultation is important.

The study notes that direct current (DC) powered mini-grids (with appropriate appliances) are emerging as a potential option, especially for rural electrification of remote and island communities, where scale may be of less importance in the medium to long term. However, this option has not been included in the scope of the present study in relation to the technology audit or the modeling of energy systems. It has been identified as an area for further study under phase 2 of the research.

The process and structure of the study is illustrated in Figure 1. Stage 1 sets the framework and approaches for the study, drawing from literature review and learnings of lateral learning programs on the topic of inclusive energy solutions in South Asia (Sections 2–3). Stage 2 is a renewable energy technology audit of Bangladesh, Nepal, and Sri Lanka (Sections 4–6). From Stages 1 and 2 the GESI criteria were identified and a technology template integrating GESI considerations was designed (Appendix, Figure A2). These informed Stage 3 of the research, which created a modified reference energy system integrating GESI criteria (Section 7).

This study is the beginning of an ongoing research project. The next phase of the research is to pilot the GESI-integrated reference energy system in the field (Section 8).

RECOMMENDATIONS

A. Main Recommendations

1. Pilot a smart reference energy system modified to integrate GESI criteria. The key elements for the design are

    (i) renewable energy-based system;

    (ii) mini-grid structure, allowing for scale through a (future) grid interconnection;

    (iii) size for household consumption of at least tier 3 or higher (keeping the options open to scale, either by mini-grid expansion or grid interconnection, or both);

    (iv) reduction of time dedicated to household chores to enable the economic empowerment of the local community;

    (v) GESI-inclusive participatory and educationally responsible processes; and

    (vi) integration with local infrastructure to support maternal health, water, and sanitation services.

2. This system should be piloted in an urban or rural setting with weak or nonexistent grid connection, where the quality of supply and electricity consumption capacity need to be improved to support local economic development.

3. The system should be "smart" to simultaneously leapfrog the access and technology divide resulting from poverty, remoteness, and social marginalization. The design must be adaptable to technological evolution for at least 2 decades.

4. The pilot should be monitored for at least 2 years (preferably 3–5 years) to further refine the GESI mainstreamed model and to demonstrate overall success of its design.

B. Other Recommendations

5. Develop a social pillar as an essential component of energy system design and integrate GESI considerations into this social pillar.

6. Prioritize reducing women's time spent on household chores and supporting women's economic empowerment. The criteria may be quantified.

7. Develop a framework for prioritizing women's time and economic empowerment criteria. In particular, consider links between energy and water, low-carbon transport and communication, as well as the role of "smart communities" in education and development.

8. Develop policy with associated strategies to allow women and marginalized groups to participate in new energy industries (such as the photovoltaic sector) from their inception by taking advantage of the small power producers in these industries.

9. Consider social inclusion criteria in the policy and regulatory environment, including financial assistance and tariff incentives, to promote technology uptake.

10. Ensure that the collection of (technology) data is embedded, so that accurate information at the household and community levels is gathered. Enable data exchange so that small power producers can better service their communities in both on-grid and off-grid systems.

11. Conduct further studies in the following areas:

    (i) a framework for smart grid models, considering the Institute of Electrical and Electronics Engineers smart grid framework, that integrates GESI considerations to inform policy and planning;
    (ii) GESI trends in employment in renewable energy industries in Asia;
    (iii) expansion of the GESI reference energy system to include DC mini-grid options; and
    (iv) technology audits that include DC mini-grids and DC appliances.

1. INTRODUCTION AND SCOPE

1.1 Introduction

1. The research study examines aspects of energy transition to an environmentally sustainable low-carbon future in developing Asia—specifically Bangladesh, Nepal, and Sri Lanka—and assesses potential implications of the energy transition for gender equality and social inclusion (GESI). The study identifies various features of the energy transition based on technologies and systems deployed by the government agencies, assesses opportunities for integrating GESI considerations, and proposes methodologies for doing so.

2. The key features of this energy transition depend on the extent of use of new technologies for energy generation and consumption, such as smart grids, new energy storage, and new technologies for energy efficiency. At the center of these transformations is electricity generation.[1] And significant investments in research and development will be needed to adapt these technologies to different country contexts.

3. The study commenced with a literature review of energy studies, technology, society theories, and gender and development frameworks and approaches. The research also drew heavily from the lateral learning programs organized in Australia and India by the Asian Development Bank (ADB) and the University of Melbourne, School of Engineering, where various aspects and stages of the research were presented. The methodology evolved during the course of the study to also include energy systems modeling.

4. While the scope of the study is GESI, the primary focus of the research is gender equity and women's welfare and empowerment. Social inclusion issues related to remoteness, caste, and ethnicity are identified primarily in the context of the government programs in Nepal, focusing on access to technology.

1.2 Rationale

5. Why did technologies take the form they did? What assumptions were made by engineers, politicians, and businesspeople about the role that people or machines might play in the brave new worlds they sought after? How can we find multidisciplinary ways of looking at social and technical relations evenhandedly? While the study does not attempt to tackle all these questions, several aspects of the research impinge on these questions. Specifically, the study examines aspects of the energy transition to an environmentally sustainable low-carbon future in Asia and assesses that the energy transition potentially provides important opportunities for transforming gender relations.

6. Asia's energy transition is being driven by energy demand and the commitment by developing Asia's economies to reduce emissions to reduce the average rise in global mean surface temperature. A substantial global effort is required to meet the 2°C warming limit under the Paris Agreement, in which Asia has a critical role to play. Asia has been the largest energy-producing region in the world since 2011, but ranked second in 2014 behind the Organisation for Economic Co-operation and Development

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[1] ADB. 2016. Sub-regional Conference: Going Beyond the Meter: Inclusive Energy Solutions in South Asia. Jaipur, India. 11–12 April. https://www.adb.org/news/events/inclusive-energy-solutions-south-asia; ADB. 2016. Deep Dive Lateral Learning Program on Inclusive Energy Solutions. University of Melbourne, Australia. 29 August–2 September. http://conference.eng.unimelb.edu.au/inclusive-energy/; ADB. 2017. Smart Grid Technologies and Implications for Inclusive Development. Madhya Pradesh, India. 19–20 April. https://www.adb.org/sites/default/files/related/68466/workshop-booklet-inclusive-energy-workshop.pdf

(OECD). Asia accounted for almost 30% of global production in 2014. Total final consumption (TFC) in Asia has increased five times over 4 decades. Over a period of 43 years, from 1971 to 2014, there was a seven-fold increase in energy consumption by the industrial sector, which is by far the biggest energy consuming sector in Asia, representing 42% of the region's TFC in 2014. Coal remains the main fuel consumed in industries (55% in 2014), and is now followed by electricity (27%). The residential sector, as now the second consumer behind the industrial sector, increased consumption by 120% between 1971 and 2014. While main fuel consumed by the residential sector is still traditional biomass, the use of electricity and natural gas has significantly increased. The transport sector has multiplied its energy consumption by 12 times , but relies mainly on oil. Given Asia's continued dependency on fossil fuels for energy consumption, the region's low-carbon transition must start with the energy sector, which has substantial potential to reduce emissions (IEA 2016a).

7. The imperatives of inclusive development have also driven the need to integrate social considerations such as social equity, participatory planning processes, and the integration of qualitative methodologies into energy sector development, ranging from assessing the sustainability of technologies and systems modeling to planning. An emerging trend in energy studies reasons that an additional pillar based on social considerations needs to be included to that of economic and environmental considerations (Nerini et al. 2014, 2016a, 2016b). Energy specialists are also attempting to develop social indicators to assess the sustainability of energy technologies. Gender and development studies and practitioners are making an important contribution to energy studies research in this space (Section 2).

8. Developing Asia has much to gain from this energy transition. Climate change poses substantial risks to regional economies. Action on climate change can bring substantial co-benefits across several dimensions, such as reduced air pollution and traffic congestion. A healthier environment will contribute to reducing mortality and morbidity from air pollution, improving the preservation of natural assets, and potentially increasing agricultural production and food security. These benefits have potentially significant implications for reducing women's vulnerability.

9. The energy transition implies that the way we produce and consume energy has to change. While the conventional power grid is undoubtedly an astonishing scientific and engineering achievement, transforming living standards in the last century—female and male life expectancy, maternal mortality, education—it now has to change. The world's conventional power grids are old, unreliable, harder to control, expensive to maintain, experiencing peak-to-average problems, not well suited to market restructure, increasingly contributing to global warming, not suited to incorporation of distributed energy, experiencing contingency restoration problems, increasing the use of constant power loads and inverters, unable to scale, and socially inequitable. They are not available to everyone and have been unable to solve the challenges of energy access in Asia and the Pacific. This can be the result of insufficient power capacity or the issue of scalability, which makes the conventional power grid unsuitable in rural areas with low population density. The energy transition is a response to this and is already underway. Driven by technology innovation, the energy transition is a transformation from the old grid to a new "smarter" grid, albeit its features have not been as yet clearly defined or understood.

10. The transformation that's taking place has important implications for GESI. The system of energy production and distribution that has existed for over a century was also gender-biased. It was (and still is, to a large extent) an industry designed and dominated by men due to persistent gender inequality in secondary and higher education, especially in science, engineering, and mathematics, as well as gender stereotypes in the labor market and gender discrimination in hiring practices, severely restricting women's access to technical training and participation in the energy sector (ADB 2012). Therefore, the transformation of the energy sector in Asia should be of tremendous interest to gender and development advocates and practitioners, as it has potentially important implications for gender equity and women's empowerment. It is in the context of these changes in the energy sector that the study is situated.

11. A diverse technology workforce will produce different (and by many metrics, better) technologies. If women and other marginalized groups are not involved in the early development of technology, they will, to a greater or lesser extent, remain outsiders for the life of that technology, which may be decades.

1.3 Methodology

12. The literature review is built on the materials and theoretical analysis of a doctor of philosophy research study conducted by the author in 2013–2015 on the gender implications of renewable energy development in rural communities in South Asia. The lateral learning programs were based on (i) the ADB South Asia Department (SARD) energy portfolio and the lessons learned from mainstreaming GESI in SARD energy projects; and (ii) international research in energy technology and power systems design in relation to cost-effectiveness, environmental sustainability, and social and gender criteria and implications.

13. The next stage of the methodology is a "technology audit"—a desk study that included the collection of data on renewable energy technologies and systems deployed in South Asia. The objective of the audit was to identify technology types and systems being deployed and the scope and type of information collected by energy agencies in the subregion to assess emerging trends in technology innovation that would provide entry points for integrating GESI considerations. The audit was conducted for Bangladesh, Nepal, and Sri Lanka, where a level of consistent baseline data was available based on the statistics compiled by the government agencies with the primary responsibility for renewable energy programs in the respective countries (Figure 1). National government agencies were the main data source as their scope is to collect data on a national scale. They are also ADB's main partners in the energy sector.

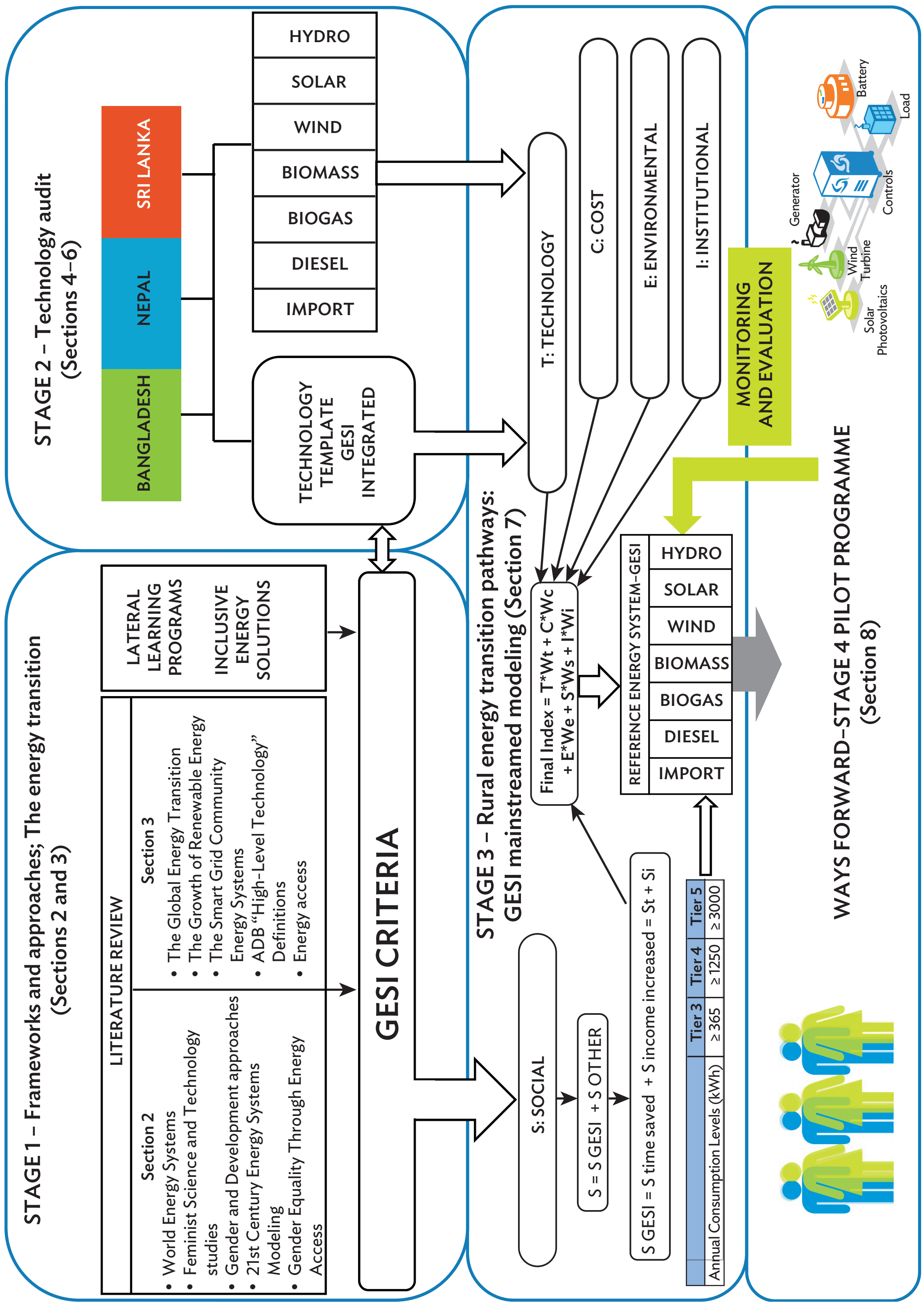
14. While the technology audit did identify some entry points to integrate GESI in new technology trends such as rooftop solar (RTS) photovoltaic (PV) in Sri Lanka, catalyzing an industry of small independent power producers, an assessment was made that it would also be useful to identify pathways to mainstream GESI in energy systems design and modeling related to specific technology types, linked to simultaneously solving the problems related to energy access, specifically electrification, and access to the technological advancements driving the energy transition in Asia. This was partly because of the type of information collected by energy agencies and reflected discussions during the lateral learning program of the need to identify mid- to long-term pathways, mindful of the evolution of the system, before locking into a specific technology type.

15. The technology pathways were determined by GESI pathways to enable (i) reduction of women's labor time on household chores, and (ii) economic empowerment related to increased income. This also required adapting the information collected in compiling technology data by including GESI disaggregated social data, as well as the information collected in compiling GESI data by including a gender division of labor analysis in technology types and vice versa. To address the energy access challenge, the research draws on the World Bank Global Tracking Framework of multi-tiers of energy access and modifies this framework in the process.

1.4 Areas for Further Study

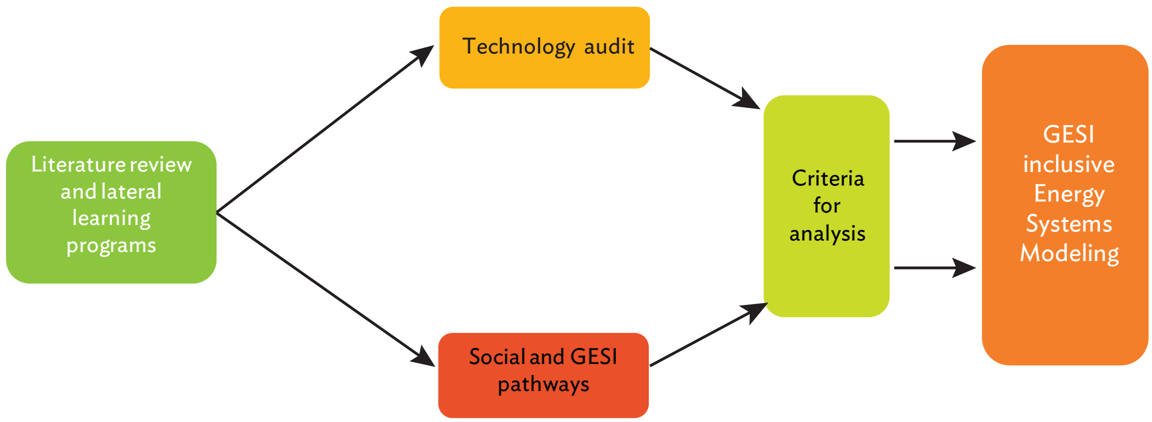
16. Areas for future study are proposed. Ways forward are also suggested: piloting a GESI mainstreamed smart community energy system, based on the modified GESI integrated reference energy system that is linked to a project in the ADB SARD portfolio. The key elements of such a system are the following: (i) renewable energy-based mini-grids, (ii) design for household consumption of at least tier 3 levels of

Figure 1: Study Process and Structure



GESI = gender equality and social inclusion.
Source: Author.

Figure 2: Study Methodology



GESI = gender and social inclusion.
Source: Author.

access, (iii) system design with GESI criteria of reducing women's time burden and enabling women's economic empowerment, (iv) GESI-inclusive participatory processes, and (v) integrated systems with an emphasis on the water–energy nexus. The community energy system should be piloted in a remote community, where household electrification and quality of supply need to be improved to support local economic development. The system should be smart, i.e., simultaneously leapfrog the access and technology divide resulting from poverty, remoteness, and social marginalization (smart systems, in this sense, include smart grids described in Section 3). The system needs to be adaptable to the evolution of the socio-technical system for 2 decades. The pilot project is to be monitored and evaluated for 2–3 years to further refine the GESI mainstreamed model. Figure 2 describes the study methodology.

2. FRAMEWORKS AND APPROACHES

2.1 Introduction

17. The study is based on an interdisciplinary framework. Tools and multiple approaches from engineering, feminist science and technology studies (STS), development theory, and ADB's approaches for identifying entry points for GESI mainstreaming to subsectors in their energy portfolio are used to analyze data on energy generation and transition and GESI indicators.

2.2 Energy Studies

18. A basic engineering approach is to find an optimal solution in the face of the overall problem's complexity, i.e., finding an approximation of the reality, or the optimality, to pose the problem neatly and then solve it. Social systems and societal impacts, however, are complex and nonlinear. The prediction of developments in the underlying technology, for example, is not as much the problem as its unintended societal consequences; in this case, people are a key factor. The job of engineers is to constantly interact with and negotiate this linear and nonlinear divide. It is through such an interaction that real-life engineering problems are, albeit sometimes approximately, solved.

19. Engineering studies on energy expose a serious lack of social analysis and little or no analysis of gender equality impacts (whether positive or negative). The socioeconomic focus is almost overwhelmingly on cost analysis and market viability. One of the few attempts to analyze women's welfare in energy studies was done by Vaclav Smil (2003). Smil looked at the relationship between energy consumption and quality of life based on an interdisciplinary research. Smil (2003) argued that "All of the commonly used measures of energy use—be it conversion efficiencies, energy costs, per capita utilization levels, growth rates, consumption elasticities, or output rations—are just helpful indicators of the performance and the dynamics of processes whose aim should not be merely to secure basic existential needs or to satisfy assorted consumerist urges but also to enrich intellectual lives and to make us more successful as a social and caring species." Smil acknowledged the difficulties in gender-related energy studies as household energy use data are rare and unreliable.[2]

20. Smil identified infant mortality and life expectancy as two of the most important indicators of the "physical" quality of life and, using United Nations Development Programme (UNDP) 2001 data, correlated these indicators with average per capita energy consumption in the world's 57 most populous countries. Smil found that "female life expectancies above 70 years are seen in countries consuming no more than 45–50 [gigajoules] GJ of energy per capita, the seventy-five-year threshold is surpassed at about 60 GJ, but the averages above 80 years are not found in any country consuming less than about 110 GJ/capita."

21. Based on Smil's methodology, Mohideen (2013) found a strong negative correlation between energy consumption and maternal mortality ratio (MMR) for 18 Asian countries for which the latest United Nations data was available. For low levels of MMR (below 40–50 maternal deaths for every 100,000 births), at least 2,000kilograms of oil equivalent (kgoe)/capita or approximately 84 gigajoules (GJ)/capita of energy consumption is necessary. Saturation levels are reached at approximately 2,500–3,000kgoe/capita or approximately 105–126GJ/capita, as in the case of industrialized countries with MMR levels of 10 and below, such as Australia and Japan.

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[2] Vaclav Smil, e-mail message to author, December 2012.

22. Mohideen (2013) also assessed that in the context of rural South Asia, where renewable energy technology is emerging as an essential infrastructure to improve modern energy access of poor communities, a unique opportunity is provided to configure a "social product" that can contribute to improving GESI and even reconfigure gender relations.

23. Energy studies, which look at historical trends in technology innovation, have provided useful insights on linkages with societal impacts and transformation, as well as issues related to causality. Grubler (2012), in his case study of energy technology innovation from a historical as well as futures scenario perspective, argued that in terms of causality, technology and institutional and social settings "*co-evolve*, mutually depending on, mutually cross-enhancing each other" (p. 1673). He outlined four "grand" patterns that characterize technological change and their corresponding energy transitions: "*First*, no individual technology, as important as it may be, is able to transform whole energy systems that are large and complex. . . . *Second*, any new technology introduced is initially crude, imperfect, and very expensive. . . . *Third*, the history of past energy transitions highlights the critical importance of *end use* (i.e., consumers, energy demand). . . . *Fourth*, the process of technological change (from innovation to widespread diffusion) takes considerable time, as a rule many decades, and rates of change become slower the larger the energy system (components) affected" (p. 1673). These grand patterns provide useful insights to the "co-evolution" of technological change and social and gender transformation.

24. Moss and McGann (2011) applied the capability approach to energy use. "While there is a clear connection between energy availability and wellbeing, it is important to understand that access to an affordable and reliable supply of energy is an indirect (or extrinsic) good rather than something that is valued in its own right. Energy use is valuable not in itself, but for what it enables us *to do* or *achieve"* (p. 11). Drawing from Nussbaum's (2000) list of interdependent "central human capabilities," they assessed that energy use is important if people are to enjoy the central capabilities of life, bodily health, bodily integrity, and control over one's environment. Medical and health services, tap water, refrigeration, heating, cooling—all key to life and bodily health—depend on energy services. Information technology and mass media are linked to the capability to exercise effective "control over one's environment" in the 21st century. Street lighting can improve physical safety, promoting the capability of "bodily integrity." They also identify some gender equality linkages of energy access: the use of biomass fuels for cooking and its negative impact on women's health; pumped water reducing women's time spent on household chores; radio and TV access to information and knowledge, including public health programs and campaigns.

25. Energy systems models are important methods used to generate a range of insight and analysis on the supply and demand of energy. Developed over the second half of the 20th century, energy systems models are now seeing increased relevance in the face of stringent climate policy, energy security, and economic development concerns, as well as increased challenges due to the changing nature of the 21st-century energy system (Pfenninger, Hawkes, and Keirstead 2014). Nerini et al. (2014) developed a multicriteria analysis—techno-economic, environmental, social, and institutional criteria—to explore the options and pathways for rural electrification. They weighed these criteria through participatory consultation with key stakeholders. This present study draws from and builds on Nerini's multicriteria analysis by integrating GESI criteria into Nerini's model (see Section 7 for details).

26. Can technologies disrupt the status quo and transform the way people live and work, think and behave? An area of study, which assesses the potentials of certain technologies and their development, has emerged to provide the answer. These technologies are described as "disruptive technologies" (Mohideen 2015).

2.3 Feminist Science and Technology Studies

27. A shared theoretical position in STS is that technology is not only technological, but is also shaped by, and embedded in, the social circumstances within which it takes place; and therefore, is a socio-technical product, and not simply a product of rational technical imperatives (Bijker and Law 1992).

28. Feminist studies within the field of STS has theorized over the last 2 decades the relationship between gender and technology as one of mutual shaping. According to Wajcman (2010), the distinguishing insight of feminist STS (or what she also described as “technofeminism”) is the embeddedness of socio-technical process in the gender culture. This means that gender power relation influences the materiality of technology, and vice-versa. Wajcman further argued that bringing more women into the design—the configuration of artifacts—is not only an issue of equal employment opportunity, but also a matter of for whom the world is shaped. Living in a technological culture implies that the politics of technology is integral to the renegotiation of gender power relations (Wajcman 2010).

29. Hence, as Wajcman posited, feminist theories in the 1980s shifted the discourse from asking how women can be equitably treated within and by science to asking how science can be transformed to empower women, given the historical evolution of science as a distinctly and predominantly masculine. Feminist analyses of technology also shifted from examining women’s access to technology to looking at how the very processes by which technology is developed and used have shaped and exacerbated traditional gender power relations. These studies provided a compelling critique of technological determinism, arguing that technology is not an autonomous force, but is crucially affected by the social relations of production.

30. Since the 1990s, feminist approaches have also been influenced by the dawn of the digital age with the development of information and communication technology (ICT). These approaches acknowledge the possibilities of ICT to empower women and transform gender relations. To sum up this optimism, Donna Haraway (1985, 1997) coined the cyborg metaphor, which conveys the idea that technology is an aspect of our identity and fully part of all of us. She explained that conceiving ourselves as ‘cyborgs’ provides a tool for challenging traditional notions of gender identity and transforming the gender relations of techno-science and the relationship between women and technology.

31. Wajcman, however, while acknowledging that developments in digital technology calls for some radical rethinking of the gender and technology relationship, warned against what she perceived as being an overly optimistic view. The possibility and the fluidity of gender discourse in the virtual world, she argued, is constrained by the gender relations actually experienced in the material world (Wajcman 2010).

32. Lerman, Oldenziel, and Mohun (2003) theorized that technology must be considered in an anthropological and historical way, and that its study involves not only material things but also people. Technology shapes gender and gender shapes technology at every level. Some technologies can be read as codes for gender, such as ovens and cookstoves, for example. But this then begs the question: Are cookstoves feminine technologies? This is especially relevant to energy studies, where improved smoke-free cookstoves are in many instances considered to be “gender-friendly” or feminine technologies.

33. McGaw (1996) brought an archaeological perspective to the discussion and described feminine technology as those associated with women by virtue of their biology. Therefore, kitchen utensils, bras, and intrauterine devices are all feminine technologies. McGaw theorized that subjecting contemporary artifacts to the same scrutiny that archaeologists reserve for the study of prehistoric and precapitalist objects could shed light on our understanding of technologies of contemporary and earlier times. Studying feminine technologies in this way is necessary, she argued, to illuminate and expose contemporary society’s relationship to technology.

34. Does the description of certain types of contemporary artifacts, such as improved cookstoves (ICS), as feminine or gender-friendly technology reinforce traditional sex roles and gender stereotypes? Yes and no, it seems. Gender and technology are historically contingent and context driven, situated in time and place, argued Lerman, Oldenziel, and Mohun (2003), pointing to the electric self-starting ignition, which was initially marketed "for the wife" in the United States (US). Technologies have no power of their own. Human beings made these technologies and human beings choose to use them, often based on their desire for, or resistance to, change (Lerman, Oldenziel, and Mohun 2003).

2.4 Development Approaches

35. Much of the analysis on the role of women in energy development and the gender linkages and impacts of energy access is to be found in gender and development studies and literature. A particular focus is on women's reproductive labor in the home, such as cooking, household water collection, and household management, as well as household production activities such as food production and processing for market consumption, and their related energy needs and uses.

36. Much of the methodologies used are those prevalent in development studies, which include gender analysis with an emphasis on ethnographic or qualitative research for the collection of sex-disaggregated and gender data, gender toolkits and checklists, and case studies to assess gender benefits and results. While there is some analysis of technologies in relation to end use household appliances, such as clean ICS for reducing indoor air pollution, the use of different energy systems and electricity supply technologies and their consequences for gender equality benefits and impacts have not been analyzed adequately to date. This research builds on the work done in gender studies, focusing on renewable energy systems and technologies and their probable gender linkages and impacts to address this gap.

37. The role of women in energy development is a recent area of study that began in the 1980s, with pioneering works by those such as Cecelski (1984). A substantial body of literature has been built up since then, albeit heavily influenced by development theories and practice. The World Bank-sponsored energy, poverty, and gender studies (1999–2001) analyzed the linkages between energy poverty and gender. Massé (2003) studied the gender impacts of rural electrification in Sri Lanka, which reduced the time spent by poor women on household chores and increased their leisure (and quality) time spent with their families at night. Massé's study also reported that given the increase in available working hours, women's home-based livelihood activities increased markedly in comparison with unelectrified areas. However, due to gender inequalities in access to productive assets such as land and natural resources, as well as labor-saving technology and affordable credit, women's ability to tap into these opportunities is limited.

38. Drawing on the existing body of literature on the subject, this study summarizes the gender issues in energy production and distribution in South Asia as follows:

(a) **Women's health and security**. An important characteristic of the energy mix of South Asian countries is their heavy dependence on traditional use of fuels (wood, agricultural residues, and animal dung) in meeting total energy consumption. The International Energy Agency (IEA) (2016a) estimated the percentage of the global population dependent on the traditional use of biomass for cooking to have increased and the deteriorating situation to be primarily due to population growth outpacing the provision of clean cooking facilities. Additionally, new research found that there are 3.6 million premature deaths each year, higher than previous estimates, as a result of household air pollution from using solid fuels (Lim et al. 2012). Although there is an increasing understanding among governments and energy sector agencies in South Asia on the importance of prioritizing investments in the provision of clean and safe cooking energy, much more needs to be done. Similarly, while street lighting can improve women's safety and mobility, these services too are often not prioritized for investment (ADB 2012).

(b) **Affordability**. Where modern energy services are available, however, lack of affordability prevents access to these services by the poor. Tariff levels, for example, generally don't take into account women's lower incomes, thus limiting women's access to energy services. Public consultation processes, including assessing communities' willingness to pay, are not always gender or socially inclusive. Various policy instruments exist—such as affordable tariffs, subsidies, and schemes, as well as revolving funds providing cheap credit to connect—that need to be utilized and adapted to target the poor, women, and disadvantaged consumers in the lower consumption band (Clancy et al. 2011)

(c) **Livelihood opportunities and employment**. Lack of electricity, including poor and unreliable quality of supply resulting in prolonged outages or shortages, also makes it difficult for poor households, including women, to maximize potential opportunities such as the functioning of women's small and microenterprises (Massé 2003).While the energy sector can provide employment opportunities for women and men, persistent gender inequalities in secondary and higher education, as well as gender stereotypes in the labor market, restrict women's participation in the sector. Women's access to opportunities for technical and skills training are also limited. Case studies demonstrate positive and significant results when special measures are taken to provide poor women with the opportunities to access technical training.[3]

(d) **Awareness-raising and user education**. Household energy efficiency is of special relevance to women. However, user education programs in the safe and efficient use of electricity in the household, which should complement energy efficiency projects, are overlooked or not effectively targeted at women household consumers (ADB 2012).

(e) **Gender roles in decision-making**. The types of fuels used, the amount of energy purchased, the devices and technology chosen, as well as domestic infrastructure related to ventilation, lighting priorities, and energy-based equipment purchased, are usually made by the male head of the household, but affect women's daily lives in very immediate and practical ways (Masud, Sharan, and Lohani 2007). Women and men's perception of the benefits of modern energy can be different. Women would place a greater emphasis on benefits related to improving health care and children's education, reducing expenditure, reducing their workload, and improving household safety. The provision of electricity and diesel for tractors to look after draft animals, for instance, can reduce men's manual labor, while it can have little or no impact on women's daily chores.

(f) **Access to information**. Where radios and television sets are purchased for leisure and entertainment, both women and men have identified the access to information and entertainment as a benefit (UNDP 2004). This can also have unexpected results on the self-esteem and empowerment of isolated and confined women, particularly as they become aware of modern labor-saving alternatives and lifestyles that they may otherwise be ignorant about (Mohideen 2013).

[3] For case studies, see Barefoot College. Solar Solutions. https://www.barefootcollege.org/solution/solar/.

2.5 Multiple Pathways

39. Multiple pathways to address gender equality through energy have been identified.

a. Electricity and Network Technologies

40. Jacobsen (2011) assessed four network technologies—water, electricity, internet, and mobile phones—in the framework of multiple pathways to change gender equity through technology. She concluded that electricity provision is "more promising" as it substitutes for physical labor and complements a wide range of productive activities. Internet services, while minimally utilized by women in low-income countries, significantly reduce transaction costs on information flows. Mobile phones reduce the physical labor of travel (to access information, for example), reduce the costs of money transfers, and increase the ability of women entrepreneurs to coordinate their family work and working lives. Given their relatively low cost and multiple uses, they are widely used in many poor rural communities in Asia. Jacobsen concluded that "changes in gender equity can be credited to any one, or any set, of technologies may be ultimately unanswerable given the holistic nature of transformation" (p. 31).

b. Beyond Traditional Roles and toward Women's Empowerment

41. Skutsch (1998) contended that access to energy services is primarily a welfare function as they don't challenge systemic gender inequality: "A welfare approach aims to lighten women's daily problems, but not structurally to change their roles" (p. 948). The goal of women's empowerment, however, presupposes a transformation in gender roles and relations to enable women "to break through tradition if they wish to, and to take on new roles and challenges" (p. 40). This may not always be a realistic goal in energy as "gender equality and empowerment are rarely the real, steering objectives or outcomes" of energy projects (p. 39).

42. Skutsch (2005) identified another reason, i.e., project efficiency, in addition to welfare, income, and empowerment. While the aim here is not gender equality, failure by project management to recognize that men and women have different needs and different access to resources means that projects can easily miss their target of benefiting consumers by addressing their needs. She suggested that the process by which the energy service is planned, implemented, and maintained, if done in a gender-sensitive manner, maybe more empowering than the energy technology itself.

43. Clancy et al. (2011) concurred with Skutsch and examined the evidence supporting whether there are changes in gender relations and found that the evidence is mixed. While in Sri Lanka men were found to share household work such as ironing after household electrification, in Bangladesh no changes in the gender division of labor were found. Therefore, the "access to modern energy appears to enable women to fulfill their traditional roles (to their satisfaction and wellbeing) rather than bringing significant transformation in gender roles" (p. 21). Clancy et al. (2011) concluded that "energy access alone is not sufficient, and other contextual factors such as legal and policy frameworks are needed to support such a change (p. 21)."

c. Increasing the "Economic Worth" of Women's Labor

44. While these multiple pathways or gender goals are interdependent and overlap, it is worth asking if some pathways are more conducive to enabling the transformation of gender relations. Kelkar and Nathan (2005) proposed that a key factor to promote the rural fuel transition in Asia from unhealthy fuel wood (and related traditional biomass) to electricity and improved biomass technology "is to increase the productivity of women's income-earning labor in order to bring about an economic worth in the

use of women's labor and thus induce a change in the household energy use system" (p. 25). They used research conducted in the People's Republic of China (PRC) and other parts of rural Asia, which found that when there were opportunities for women to significantly participate in income-earning activities, there was a strong incentive to economize on women's unpaid labor time in fuel collection and other household tasks.

45. In the PRC, the improved stoves program has been most successful in villages, where women have significantly participated in income-earning activities in industry and commercial production of livestock and vegetables, and where the drive to economize on women's labor in fuel collection and housework resulted in a high adoption rate of improved stoves. Similarly, studies on microcredit in Bangladesh have found that women, with increases in their economic activity and income, are more likely to assert their role in household decision-making. This proposition could be extended to suggest that women's economic empowerment related to energy access is thus a more conducive pathway to enable the transformation of gender relations (Kelkar and Nathan 2005).

46. However, the causality can also work both ways. In social contexts where women have a higher economic and social status, they can and, in many instances, do exert greater influence on public policy and expenditure, including access to energy services and their use. For example, Kelkar and Nathan's case study of the Luoshui village in Yunnan, PRC included reference to the historical background of the area when "people began to seize political power" and the "gendered division of labor tended to be equal" (p. 29). Kelkar and Nathan pointed out, "It is not energy itself that has certain inevitable consequences, but the economic and social situation in which technologies are introduced and the balance of forces at any time" (p. 17).

2.6 Entry Points and Subsector Analysis

47. ADB has developed approaches for identifying entry points for GESI mainstreaming in relation to subsectors in the ADB energy portfolio. The key entry points broadly cover increasing access and affordability, providing employment opportunities, developing local economies and improving community livelihoods based on the productive use of energy, and opening up capacity building and training opportunities for women.

48. **Increasing accessibility to clean and renewable energy for poor communities through household electrification.** Special targets can be set for the electrification of poor households headed by women and socially disadvantaged groups. Access to energy, however, includes a broad scope of services. Energy efficiency, for example, which is an important focus of the ADB energy portfolio, also results in improved services. This is not only in relation to supply-side technical losses and cost-effectiveness, but also in relation to the demand for improved quality of supply by end users. Improved quality of supply, resulting in increased hours of electricity in a day and reduction in outages, is an improved service with potentially direct benefits for women.

49. **Improving affordability.** This can be addressed through targeted subsidies and the design of appropriate financial instruments, such as establishing revolving funds to provide grant-financed connections or cheap credit for household connections (pole to house and residential wiring).

50. **Increasing employment opportunities.** Projects that open up opportunities to employ women in the industry can make an important contribution to supporting women's economic empowerment. Employment opportunities, however, can vary considerably depending on the energy system and the technology used. There is more scope for employment opportunities in some large-scale hydropower (hereinafter hydro) generation and transmission projects during construction. There are greater ongoing employment opportunities in distribution system projects such as rural electrification. In large-

scale renewable energy systems, such as solar parks, some ongoing employment is being generated. Furthermore, the quality of jobs created (and not only the number of jobs) needs to be taken into account, especially in an industry which has benefited from rapid technological developments, providing opportunities for women to pioneer or break into emerging technology industries.

51. **Capacity building and training.** Women's participation in the energy sector cannot be enabled without adequate capacity building and training conducted at all levels of entry into the industry. Therefore, it is essential that every possible opportunity be utilized to introduce capacity building and training programs and activities in energy projects. This ranges from end users to meter readers and other service providers, from basic technical training for routine operation and maintenance (O&M) to upgrading the skills of women engineers and professional female technical staff and gender training for energy agencies.

52. Where the trend is the introduction of smart systems and technologies, capacity building takes on an added importance and is invariably included as a standard output in energy projects today. Therefore, capacity building has emerged as a cross-cutting activity across various systems, from generation and transmission to distribution, energy efficiency, and small renewable energy systems. Innovative approaches are needed to identify and incorporate gender elements based on the specific requirements of the project, such as the technologies and systems being introduced, as well as the institutional culture of the energy utilities.

53. **End user education or awareness-raising in demand-side management.** Raising consumer awareness about the safe and efficient use of energy is an important aspect of electrification and energy access. Anecdotes abound among energy utility staff about electricity-related accidents affecting newly electrified consumers. Several energy utilities in the region conduct campaigns to raise user awareness on energy efficiency. A study on the public campaigns conducted by energy utilities in Bangladesh concluded that, in order to be more effective, the campaigns need to be better targeted at different groups of consumers (Islam). It also pointed to the need for user education campaigns targeted at housewives as residential consumers, distinct from those targeted at farmers, industry, and the public sector.

54. **Productive energy use.** The economic development of the electrified communities is important as an aim in itself, linked to the poverty reduction objectives and targets of governments in the region. Additionally, it is important for the cost-effectiveness of energy systems, especially in the case of grid expansion in remote areas, where economies of scale in energy consumption are necessary to justify system costs and therefore the system's long-term economic viability and sustainability. Support for the development of more productive and new local industries and enterprises, based on modern energy services and applications, presents opportunities for the economic empowerment of poor women and men.

55. **Risk mitigation.** This is a key concern, especially in relation to large energy projects that can result in resettlement of local communities in project-affected areas and potentially have negative environmental impacts. Some energy utilities undertake community development programs to mitigate risks associated with large-scale energy projects, such as resettlement and environmental impacts, as part of their corporate social responsibility activities. However, resettlement and environment impact assessments are due diligence requirements, which is not the case with gender equity impacts. Risk mitigation in large-scale power generation projects, even when addressing the specific vulnerabilities of poor women, is essentially a risk management activity. Risk management only deals with gender equity impacts in a broad sense, and often tangentially, e.g., in terms of reputation risk. Therefore, these areas are demarcated as such and dealt with separately along with the associated requirements. A detailed study of gender issues in risk assessment and mitigation is beyond the scope of this research.

56. The entry points can be adapted to different types of energy systems, which in ADB projects are broadly classified under power generation, transmission and distribution, rural electrification, renewable energy, and energy efficiency. These classifications are also described as energy subsectors. ADB has established a framework to assess opportunities for directly addressing poverty and GESI considerations, which are incorporated into project outputs and activities and other aspects of the project design and implementation, but in different classifications or subsectors. It broadly describes these subsectors as "hard" or "soft" in relation to the potential for addressing GESI issues. The "soft" subsectors are those where several of the entry points can come into play, while the "hard" subsectors are those where none of the entry points come into play. For example, the strongest opportunities are presented in distribution systems, where there is end user interface. This can be through on-grid conventional electrification or off-grid, distributed, decentralized renewable energy systems. Distribution projects, such as rural household electrification, enable several of the entry points to come into play, thus presenting very strong opportunities for GESI considerations to be directly integrated into project design and implementation. Table 1 is an attempt to broadly categorize the hard and soft subsectors.

57. ADB categorizes projects as (i) *gender equity as a theme*, when the project's main objective is to address gender equity issues; (ii) *effective gender mainstreaming,* when gender equity is addressed as one of the project outcomes or objectives, and is incorporated in the majority of project outputs; (iii) *some gender elements*, when an effort is made to acknowledge gender equity issues during project preparation and design, and if the project is expected to indirectly result in some benefits for women and contribute toward gender equity; and(iv) *no gender elements*, when the project does not include any gender design features. These categories inform the potential for GESI integration in the hard and soft subsectors. However, many of the project design features of energy subsectors overlap. The Bangladesh Power System Efficiency Improvement Project had renewable energy power generation and mini-grids (ADB, 2011b). The Madhya Pradesh Energy Efficiency Improvement Investment Program contributed to rural electrification of villages (ADB, 2011c). The Gujarat Solar Power Transmission Project in India is a 500-megawatts (MW) solar power generation project (ADB, 2011a). The Tanahu Hydropower Project in Nepal, although a generation project, achieved an effective gender mainstreaming category due to innovative community development programs (ADB, 2013). The Bhutan Rural Renewable Energy Development Project was designed to electrify remote rural communities (ADB, 2010).

Table 1: Gender Equality and Social Inclusion Analysis: "Hard" and "Soft" Energy Systems

Energy Subsectors	Potential
(a) Power Generation and Transmission	
Gender-mainstreamed resettlement plans and risk mitigation activities in project-affected communities Improved quality of power supply Gender-sensitive capacity building of energy utilities Unskilled employment for women in civil works and electromechanical works Investment in street lighting and household compact fluorescent lamp programs **ADB project in category: Tanahu Hydropower Project (Nepal) [Project 43281-013]**[a]	Little or no end user interface, no distribution systems for household electrification **Soft: poor potential**
(b) Rural Electrification	
Increase in number of electrified below poverty line households, including all households headed by poor women Institutional electrification for schools and hospitals, including street lighting Strengthening of women's participation and leadership in community-managed decentralized distribution systems Maximizing of opportunities for energy-based women's entrepreneurship and related skills training Maximizing of women's skilled and semi-skilled employment opportunities in the energy sector with technical training Gender-sensitive user education programs Capacity building for local women's organizations Gender-sensitivity training of stakeholders for gender action plan implementation **ADB project in category: Madhya Pradesh Energy Efficiency Improvement Investment Program (Facility Concept)(India) [Project 43467-014]**[b]	End user interface, with distribution systems for household electrification **Soft: Good to very good potential**
(c) Renewable Energy	
As in (b) Women's employment in developing a skilled national or local labor force for renewable energy development Promotion of women as service providers in renewable energy systems and technologies Promotion of targeted investments in renewable energy technologies to maximize impacts on gender equality and women's empowerment Promotion of gender issues in climate mitigation financing schemes **ADB project in category (on-grid, utility scale): Gujarat Solar Power Transmission Project (India) [Project 44431-013]** **ADB project in category (off-grid, distributed): Rural Renewable Energy Development Project (Bhutan) [Project 42252-022]**[c]	Off-grid, distributed, decentralized generation systems **Soft: Very good potential** Utility scale power generation: **Fair to good potential**

continued on next page

Table 1 *continued*

(d) Energy Efficiency	
Improved quality of supply to benefit local economies and the livelihoods of women and men in poor communities Energy conservation targeted at women household consumers, micro and small entrepreneurs, farmers Introduction of new transmission and loss reduction systems generating employment opportunities for young women and men in poor communities **ADB project in category: Power System Efficiency Improvement Project (Bangladesh) [Project 37113-013]**[d]	**Fair to good potential** if coupled with distribution

[a] ADB. 2013. *Report and Recommendation of the President to the Board of Directors: Proposed Loans and Administration of Technical Assistance Grants to Nepal for the Tanahu Hydropower Project*. Manila.
[b] ADB. 2011. *Report and Recommendation of the President to the Board of Directors: Proposed Multitranche Financing Facility and Technical Assistance Grant to India for the Madhya Pradesh Energy Efficiency Improvement Investment Program*. Manila.
[c] ADB. 2011. *Report and Recommendation of the President to the Board of Directors: Proposed Loan to India for the Gujarat Solar Power Transmission Project*. Manila.
[d] ADB. 2010. *Report and Recommendation of the President to the Board of Directors: Proposed Grant to the Kingdom of Bhutan for the Rural Renewable Energy Development Project*. Manila.
[e] ADB. 2011. *Report and Recommendation of the President to the Board of Directors: Proposed Loan to the People's Republic of Bangladesh for the Power System Efficiency Improvement Project*. Manila.

Source: R. Mohideen and F. Tornieri

58. **Power generation and transmission systems.** With no scope for distribution of household electrification, i.e., limited end user interface, opportunities for directly addressing GESI issues incorporated into project outputs and activities are limited. However, some opportunities do exist. If increased generation capacity and transmission efficiency leads to improved quality of supply in already grid-connected households, for example, opportunities are presented to carry out longer-term social or community development activities in project areas. These include livelihood improvement through productive energy use and the development of local economies based on increased hours of supply and improved productivity of labor. Most energy utilities are also prepared to consider activities that complement power generation and transmission projects, such as introducing or upgrading street lighting, which can be expected to improve community safety with potential benefits for women. If there are any capacity development or training activities associated with big generation and transmission projects, these can provide some opportunities to include gender-related activities. Therefore, power generation and transmission systems have been categorized as hard systems, i.e., with limited or poor potential to directly incorporate and address GESI considerations.

59. **Rural household electrification.** Both on-grid and off-grid systems are soft systems with potentially very good opportunities to directly address and contribute to GESI benefits. All the entry points can come into play: (i) energy access of poor communities and marginalized groups, including poor households headed by women; (ii) addressing affordability issues through subsidies to connect to the grid, including internal household wiring; (iii) employment opportunities for women, such as meter reading, bill collection, routine maintenance, and provision of other one-stop shop services; (iv) improving women and men's livelihoods through productive energy use and the development of local economies; (v) improving local infrastructure through the provision of pumped water and electrification of schools, health centers, and other essential services; and (vi) training and capacity building for end users and energy utilities.

60. **Renewable energy.** If renewable energy is used as a source in large-scale power generation, such as in solar or wind parks, then the opportunities are limited to directly incorporate GESI considerations into the project. However, in many instances in South Asia where solar or wind parks are being constructed, these are newly emerging technologies and systems requiring the creation of a newly skilled local labor

force trained in O&M. This can provide opportunities for women to enter a newly emerging labor market based on renewable energy development. This is somewhat of a contrast to conventional power generation systems where, invariably, a local pool of skilled labor already exists, albeit requiring some retraining if energy efficiency technologies are introduced. Therefore, newly emerging renewable energy systems in South Asia are assessed as being somewhat softer than conventional power generation systems in providing opportunities to directly address and incorporate GESI considerations.

61. Small-scale, distributed renewable energy systems, such as small hydro and mini-grids for rural electrification, have been assessed as providing greater opportunities than conventional, grid-connected household electrification. The decentralized management of smaller, distributed systems do provide opportunities for targeted promotion or piloting of women's participation in all levels of the system operation, maintenance, and management. It also opens up avenues for the development of local economies based on productive energy use and women's participation in related socioeconomic and livelihood activities.

62. **Energy efficiency.** Energy efficiency can be achieved in many ways, such as residential energy conservation, energy audits, manufacture and use of energy efficient equipment, reduction of systems losses, proper energy planning and management, efficient transport planning, use of alternative and renewable fuels, energy pricing and tax policy, and cogeneration. Given the high percentage of system losses in all countries in South Asia—technical losses in old systems and commercial losses due to electricity pilfering being some of the most common reasons—many of the ADB energy efficiency projects have focused on transmission and distribution system loss reduction. Distribution system loss reduction has included installing meters in households, thus generating employment in local communities. This has provided opportunities to train and employ local women and unemployed youth as meter readers. Distribution system loss reduction projects also pave the way to address household energy conservation. A common approach has been to design and implement household user education programs, targeted at women and housewives as household consumers, who have subsequently been trained as community motivators in household energy conservation. At the energy utilities, the establishment of energy auditing systems to locate losses and the use of new technologies for loss reduction have opened up training opportunities for women and men engineers to upgrade their professional skills. Targets have been set for the participation of women engineers in these training programs. Improving system losses contributes to improved quality of supply, which then provides opportunities for strengthening local economies and improving the livelihoods of poor communities and poor women. Energy efficiency projects have, therefore, been assessed as having fair to good potential for incorporating GESI considerations.

63. While there is demonstrable evidence that energy services improve women's welfare, the question remains about whether they transform gender roles or lead to women's empowerment. Energy access itself is not necessarily sufficient and other contextual factors, such as policy and legal frameworks, are needed to support women's empowerment.

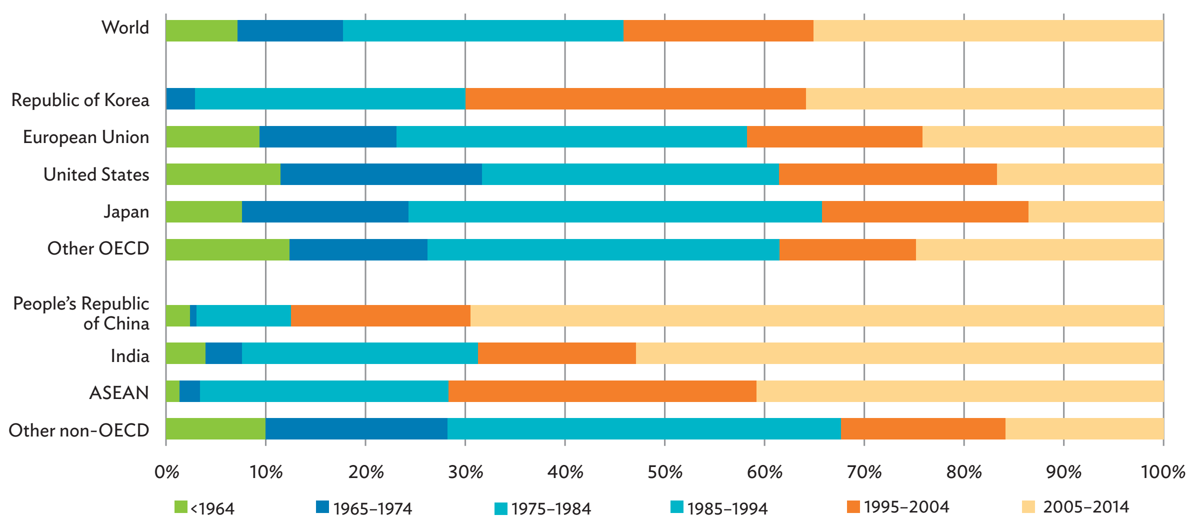
64. ADB's approach of applying gender analysis to energy subsectors indicates that rural electrification programs and renewable energy sourced distributed systems have greater potential to integrate and therefore address GESI considerations.

3. THE ENERGY TRANSITION: CLEAN ENERGY TECHNOLOGY PROGRESS AND FOSTERING INNOVATION

3.1 Introduction

65. The energy transition is well under way in Asia. In the PRC and India, more than 50% of power generation capacity was built in 10 years (2005–2014); in the Association of Southeast Asian Nations (ASEAN) countries, more than 40% (Figure 3). Rapid urbanization and economic growth also create the opportunity to use newer, more sustainable technologies from the outset. Some of the increase in energy use, however, can be attributed to increased inefficiencies brought about by rapid urbanization, e.g., in the transport sector.

Figure 3: Age Structure of Existing Power Capacity by Region, 2014
(%)



ASEAN = Association of Southeast Asian Nations, OECD = Organisation for Economic Co-operation and Development.
Source: International Energy Agency (IEA). 2016. *Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems.* Paris: OECD / IEA.

66. This section examines the increasing role of renewables in power generation globally and particularly in the non-OECD countries, and its relationship to various drivers of increasing demand for energy. It describes disruptive technologies, such as smart grid systems for electricity distribution, and looks at how renewables and technological innovation relate to concepts such as "community energy" to suggest how new energy capacity creation can impact GESI outcomes.

3.2 Increasing Energy Demand and Generation Capacity

67. Rapid economic growth and the need for more electricity have also led to massive capacity additions in countries in over the last 10 years—India doubled its installed capacity, as mentioned, and the PRC accounted for more than 40% of global new capacity additions. Since 2012, the PRC has the largest installed power capacity, which has increased by 14% since 2012 to reach 1,245 gigawatts (GW) in 2014, or 21% of global capacity, slightly ahead of the US (IEA 2016b).

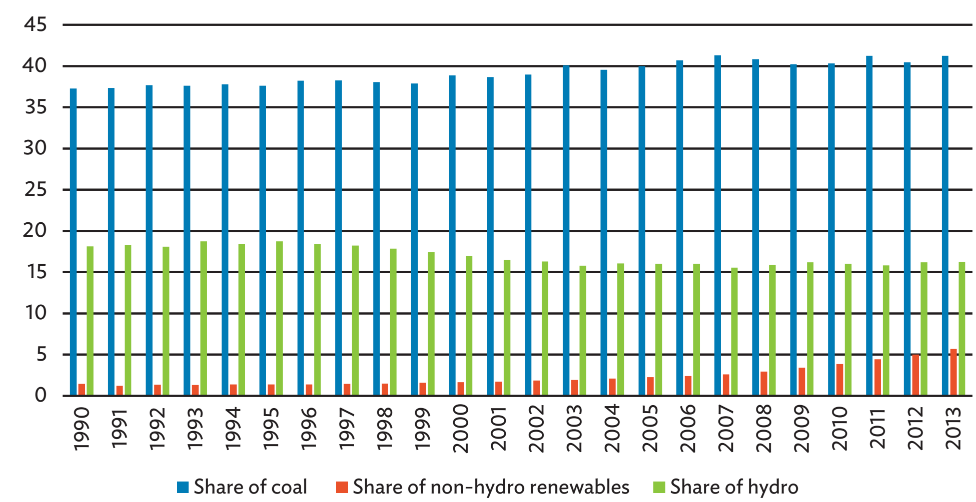
68. The differences in the age structure of power plants illustrate the different challenges countries face in decarbonizing the power sector. Where demand growth is limited and the generation capacity is aging, such as in the US or the European Union (EU), the main challenge is gradually replacing existing plants with variable renewables. Growing economies in Asia must meet a growing demand for electricity. Such deployment creates the opportunity to deploy low-carbon technologies from the outset, providing a unique opportunity for technology innovation. This poses additional challenges, requiring financing and trained personnel.

69. While coal remains the dominant fuel for electricity generation, followed by hydro, renewable sources are steadily increasing, approximately 3.5 times what it was in 2000 (Figure 4).

70. The decarbonization of the energy sector has resulted in the uptake and growth of clean energy technologies. The importance of technology innovation for decarbonization was reflected in the 21st Conference of the Parties Paris Agreement, which acknowledges that accelerating and enabling technology innovation is critical for an effective global response to climate change.

71. Renewable power capacity was at a record high with over 150 GW installed in 2015. Energy efficiency improvements continue along with successes in energy storage solutions (a result of long-term technical innovation). "The threshold of one million electric cars was crossed in 2015, with an overall annual sales growth rate of 70%" (IEA 2016a).

Figure 4: Electricity Generation from Fossil and Nonfossil Fuels
(%)

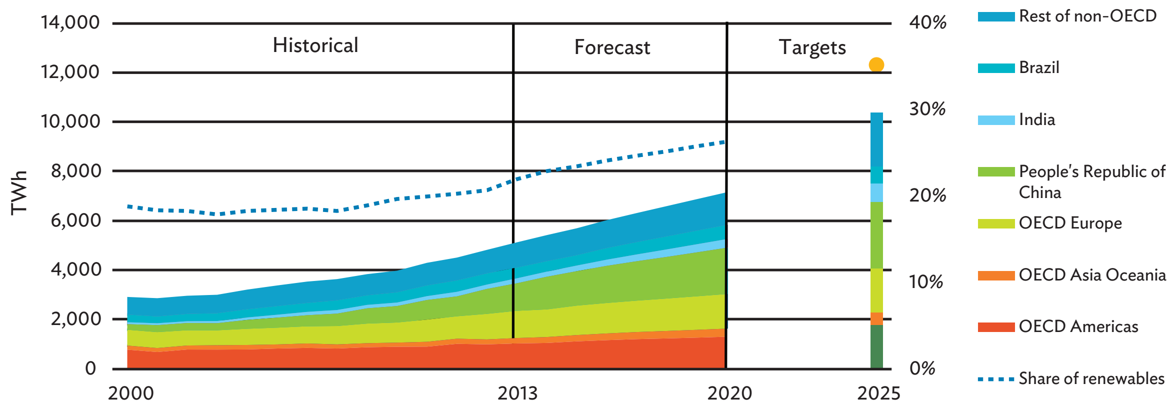


Source: International Energy Agency (IEA). 2016. *Tracking Clean Energy Progress 2016*. Paris: Organisation for Economic Co-operation and Development / IEA.

3.3 Renewable Energy

72. According to the IEA (2016a), renewable power generation grew by an estimated 5% and accounted for around 23% of overall generation in 2015. The PRC accounted for an estimated 23% of global renewable electricity generation, followed by the EU (17%), and the US (11%) (Figure 5).

Figure 5: Renewable Energy Power Generation by Region

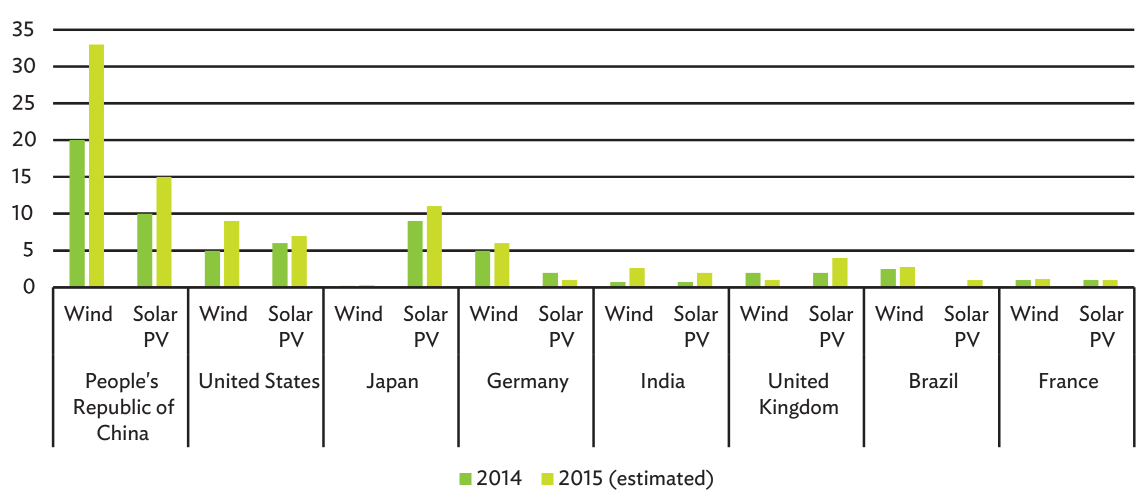


OECD = Organisation for Economic Co-operation and Development, TWh = terawatt-hour.
Source: International Energy Agency (IEA). 2016. *Tracking Clean Energy Progress 2016*. Paris: OECD / IEA.

73. In 2015, around 40% of new renewable additions came from onshore wind, with the commissioning of an estimated 60 GW of new grid-integrated capacity. The PRC installed more than half of global onshore wind additions at 33 GW. The EU added around 10 GW, which was slightly lower than 2014 additions. The US added close to 8.5 GW, followed by Brazil (2.7 GW) and India (2.3 GW) (Figure 6).

74. Solar photovoltaic (PV) capacity grew by 45–50 GW in 2015. The PRC (15 GW) and Japan (11 GW) together represented more than half of this growth. New additions in the US were 15% higher than the previous year, with around 7.3 GW installed. In the EU, where annual solar PV installations increased by around 10% to 7.5 GW, new capacity was led by the United Kingdom (3.6 GW), Germany (1.3 GW), and France (1 GW). The expansion of solar PV in India picked up and reached 2 GW last year (Figure 6).

Figure 6: Wind and Solar Photovoltaic Additions
(gigawatt)



GW = gigawatt, PV = photovoltaic.
Source: International Energy Agency (IEA). 2016. *Tracking Clean Energy Progress 2016*. Paris: Organisation for Economic Co-operation and Development / IEA.

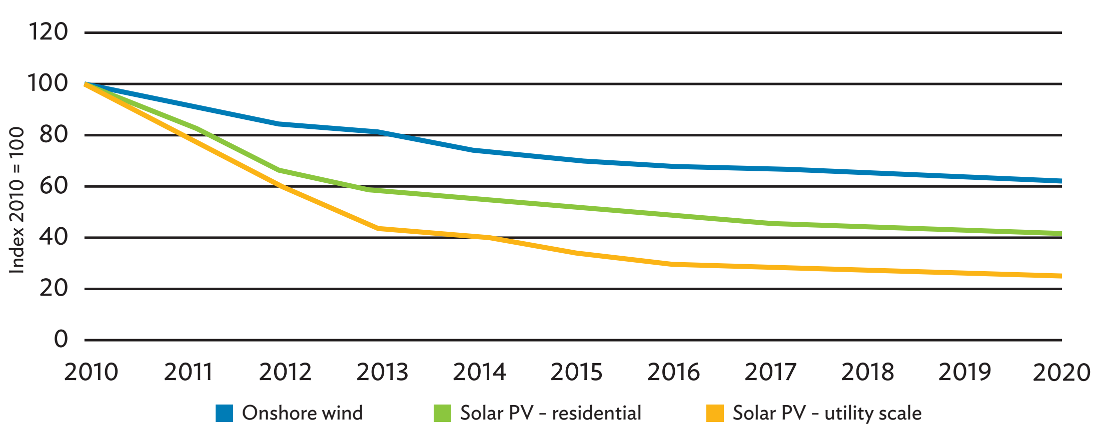
75. Renewable costs, especially solar PV and onshore wind, have fallen dramatically in recent years. From 2010 to 2015, indicative global average onshore wind generation costs for new plants fell by an estimated 30% on average, while costs for new utility-scale solar PV declined by two-thirds. Over 2015–2020, new onshore wind costs are expected to decline by a further 12%, while new utility-scale solar PV will decline by an additional quarter (Figure 7). Sustained technology progress has been an important factor in the cost-effectiveness of some renewable options. According to IEA (2016a), new onshore wind can be contracted in some countries at $60–$80/megawatt-hour (MWh), with the best cases closer to $50/MWh (e.g., Brazil, Peru, Egypt, and some US states). Meanwhile, new utility-scale solar PV projects can be contracted at $80–$100/MWh (e.g., France, Germany, and Uruguay), with the best cases at around $60/MWh (e.g., Chile, Peru, United Arab Emirates, Jordan, South Africa, and some US states).

76. As renewable energy becomes a key contributor to the energy mix, their integration to power grid poses significant technical challenges. Owing to the inherent variability, integration of such generation into the grid is a challenge to short-term system operation and long-term grid planning. Compared with traditional thermal power plants, renewable power output has random and fluctuant characteristics. Additionally, the existing power grids would have insufficient capacity to transfer those additional renewable energies, which increases the risk of the transmission line overload (Wu et al. 2017). Power quality is an important aspect of renewable energy integration. The major power quality concerns are the following:

(i) **Voltage and frequency fluctuations, which are caused by noncontrollable variability of renewable energy resources.** The intermittent nature of renewable energy resources due to ever-changing weather conditions leads to voltage and frequency fluctuations at the interconnected power grid.

(ii) **Harmonics, which are introduced by power electronic devices utilized in renewable energy generation.** When penetration level of renewable energy is high, the influence of harmonics could be significant (Liang 2017).In the Australian case, a study conducted by the Melbourne Energy Institute, University of Melbourne found that "while there are significant challenges in operating a low inertia power system, the analyses performed demonstrate that there is significant potential to use operational measures and electricity market designs to ensure frequency response adequacy in [variable renewable electricity] VRE-rich power systems" (Mancarella et al. 2017).

Figure 7: Indexed Levelized Cost of Electricity



PV = photovoltaic.

Source: International Energy Agency (IEA). 2016. *Tracking Clean Energy Progress 2016.* Paris: Organisation for Economic Co-operation and Development / IEA.

3.4 Employment

77. The International Renewable Energy Agency (IRENA) (2016) estimated that global renewable energy employment increased by 5% in 2015 to 8.1 million. An additional 1.3 million people are employed in large hydro. While the growth in jobs slowed down compared with previous years, the total number of jobs in renewables continued to rise worldwide, in stark contrast with depressed labor markets in the broader energy sector. Countries with the highest number of renewable energy jobs were the PRC, Brazil, the US, India, Japan, and Germany. Jobs continued to shift toward Asia and the share of the continent in global employment increased to 60%.

78. Solar PV was the largest renewable energy employer with 2.8 million jobs worldwide in 2016, an 11% increase from 2014. Bioenergy is a key employer, with liquid biofuels accounting for 1.7 million, biomass 822,000, and biogas 382,000 jobs. Biofuel employment declined by 6% due to mechanization in some countries and low biofuel production in others. Jobs in solar water heating and cooling declined to 940,000, as markets in the PRC, Brazil, and the EU contracted. Direct jobs in large hydro fell to 1.3 million due to a drop in new installations. Most of the jobs lost were in O&M, and the PRC, Brazil, and India were key employers.

79. The PRC led employment with 3.5 million jobs, a minor reduction of 2%. Gains in solar PV and wind were offset by losses in the solar heating and cooling and small hydro sectors. The slow growth can be attributed to (i) automation in the solar PV manufacturing sector; (ii) use of leftover stocks of solar PV panels from 2014; and (iii) consolidation of market shares in favor of large suppliers/manufacturers, resulting in economies of scale.

80. In India, the solar and wind markets have seen substantial activity, as the ambitious renewable energy targets are translated into concrete policy frameworks. Solar PV employs an estimated 103,000 people in grid-connected (31,000 jobs) and off-grid applications (72,000 jobs). Reaching the government's goal of 100-GW PV by 2022 could generate 1.1 million jobs in construction, project commissioning and design, business development, and O&M. However, given that 30% of these jobs would be highly skilled requires stepping up training and educational initiatives. The Indian wind energy industry employment has remained steady at 48,000 jobs (IRENA, 2016).

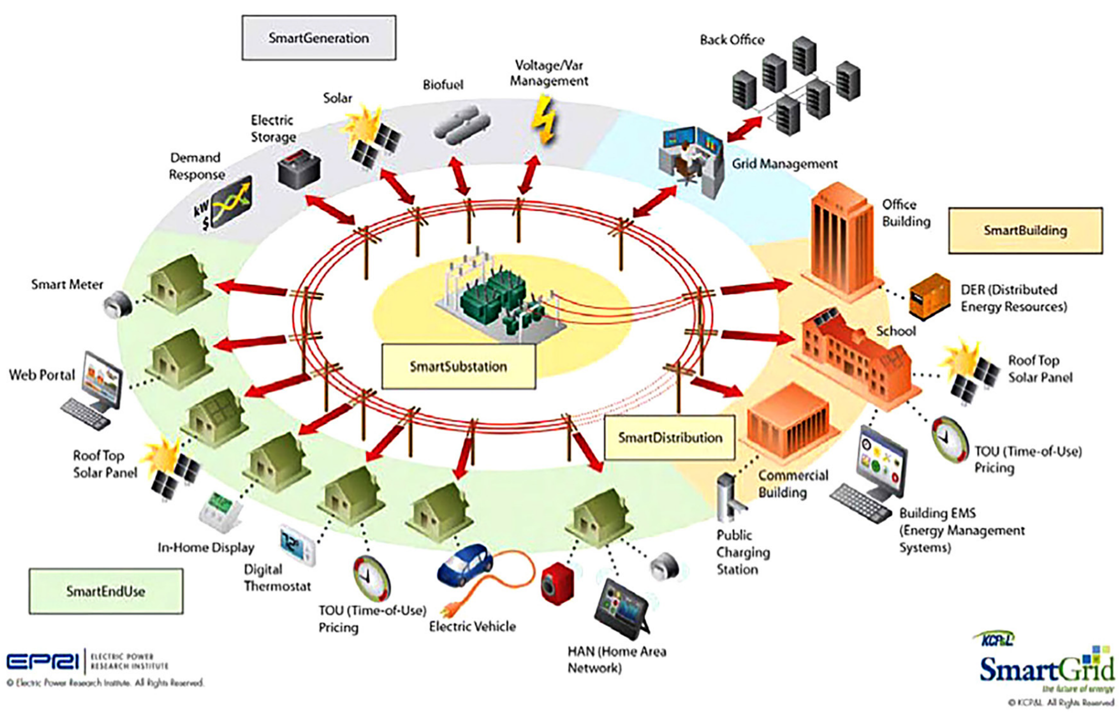
81. Japan experienced impressive gains in solar PV in recent years, resulting in a 28% increase in employment in 2014. Several other Asian countries are also showing signs of progress in solar PV. Malaysia was home to 19,000 direct solar PV jobs in 2015. Given the limited number of domestic installations, around 60% of these jobs are in solar PV manufacturing plants that have been set up to cater to foreign markets. The Republic of Korea supports more than 8,200 jobs in solar PV manufacturing and distribution. Pakistan created jobs primarily through small-scale installations in residential and commercial sectors. The solar industry in the country imported and installed an estimated 800 MW of PV modules in 2015, creating jobs for around 20,000 people.

82. Gender disaggregated employment data in the renewable energy sector is scarce. IRENA's preliminary research based on an online survey of 90 private sector companies from 40 countries indicated that the renewable energy features more gender parity than the broader energy sector. The companies represented the entire value chain of the renewable energy sector, including manufacturing, O&M, and policy making. Women represented 35% of the workforce, compared with 20%–25% of the workforce in the overall energy sector. More research, including country-specific research, is needed to assess women's employment trends in this sector.

3.5 Smart Grid

83. A smart electrical grid or a smart grid refers to new energy technology measures, such as smart meters, smart appliances, renewable energy resources, and energy efficient resources. Its purpose is, among others, to control the production and distribution of electricity. Figure 8 is a good introductory visualization of a smart grid setup.

Figure 8: Smart Grid Community



Source: Electric Power Research Institute. 2010. *Kansas City Power and Light Smart Grid Demonstration Project*. https://www.smartgrid.gov/files/Kansas_City_Power_Light_Smart_Grid_Demonstration_Project_201006.pdf

84. A smart meter is something that is often heard when discussing smart grids. A smart meter is a device that enables two-way data transfer between the customer and the distributor; data examples are electricity consumption, electricity production, tariff options (time of use), and grid health.

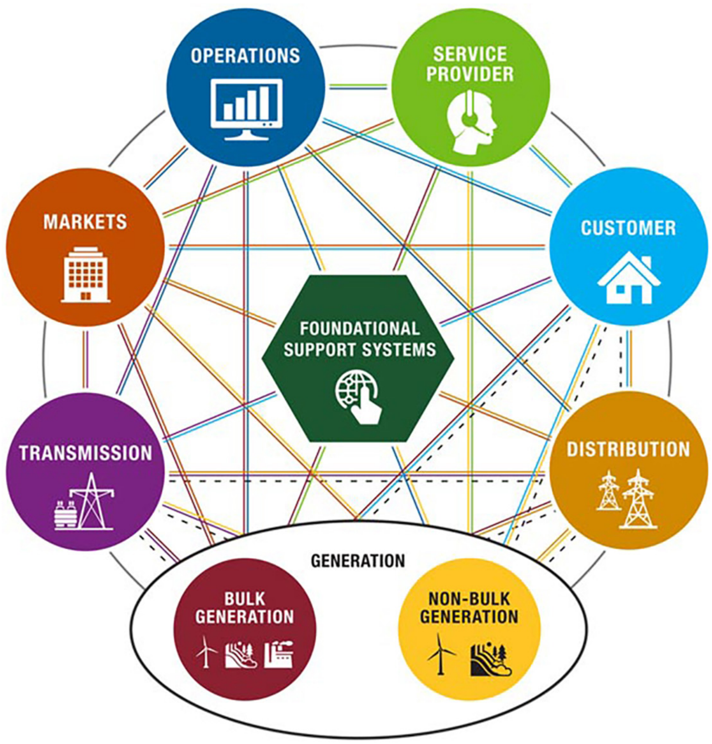
85. Grid integration of renewables and fault tolerance are integral to the smart grid operation. Ideally, a grid could be powered entirely with renewable sources and battery storage, or, as we might expect, could work with base loads as load followers or as a base load with load followers (or some other combination). Fault tolerance involves fault detection and self-healing; this can mean that if a fault is detected, the fault area can be isolated from the grid and operation can continue.

86. All of these ideas contribute to the definition of the smart grid; however, this definition is ever changing and so we need to maintain flexibility in our future visions. Essentially what we are looking at is power production and distribution in a modern world where innovations in communications, controls,

measurement, sensors, automotive, renewable energy, and many other areas, technical or not, will govern its structure and operation.

87. The Institute of Electrical and Electronics Engineers has designed a domain-based approach to the smart grid (Figure 9). This domain-based approach gives us a working platform on which we may be able to build ideas and work on the smart grid design while retaining flexibility in including future innovations.

Figure 9: Smart Grid Domains



Source: Institute of Electrical and Electronics Engineers (IEEE). IEEE Smart Grid Domains and Sub-domains. http://smartgrid.ieee.org/domains.

88. Generation forms the foundation of the domain structure. Power production from both renewable and nonrenewable sources need to be grid integrated effectively. Any of these plants could operate as a base load, load follower, or peak demand plant depending on the arrangement. Distributed power sources are an essential feature of the smart grid. The variable nature of renewables means that planning their role as sources in grid has been challenging. However, with the advent of cheaper and more reliable power storage solutions (Tesla Powerwall, redox flow battery), renewables may also be incorporated into the smart grid as more stable power sources.

89. Transmission systems are key to delivering power from larger scale generation sources. The quality of power that these systems deliver is of the utmost importance, and a smart grid incorporates modern technology to monitor and improve the state of transmission. One key piece of technology in the future grid is the incorporation of phasor measurement unit to measure syncrophasors. Measurement of these syncrophasors at critical substations allows operators to monitor the stability of the grid and properly

synchronize power from multiple generation sources, which may be inherently different in nature, and hence maximize power flow.

90. The medium between transmission technology and home users is the distribution network, where there is substantial room for growth using modern technology. Substation automation will greatly improve the quality of power, as well as interact directly with consumers to manage supply. Automatic volt-ampere reactive regulation systems can improve the power factor of substations. Smart metering from end users allows substations to use advanced demand response systems. Demand response in this sense means that the substation may request systems that do not really need to be active at a certain time to switch off and commence operation at a later time instead. This means that peak power management is no longer a matter of turning on expensive high emission plants, and is rather about managing the end users' actual power needs, which saves both the consumer and distributor money. Also, the demand response is adaptable to distributed systems, as the communication allows the substation to monitor the trends and output from sources, such as solar panels or small wind. A final and very important part of the smart grid distribution technology is fault detection, isolation, and restoration. This technology will allow the detection of faults from feeders and transformers, and advanced algorithms even allow predicted faults to be isolated in advance. In addition, instead of a technician needing to physically visit the fault site to restore service, the fault isolation mechanisms will return to normal state automatically.

91. Customer interaction is one of the keys to effective distribution management. The hub of consumer interaction is the smart meter, which allows communication directly with service providers and indirectly with the substations. These sorts of interactions are often labeled "customer enablement." Presently, there are a few tariff options available for consumers. Time of use tariffs are one of the most well-known concepts of the smart grid. These flexible tariffs allow consumers to set nonessential machines and devices to operate at times when the price of electricity is lower or to even check the going rate and choose whether to operate certain appliances or not—e.g., setting the washing machine or dishwasher to run late at night, and turning on the air conditioner at a right time. Perhaps one of the most advanced areas of tariff management relates to plug-in vehicles. Vehicle-to-grid is a system whereby a plugged-in electric vehicle may interact with the grid and electricity market to buy electricity to charge (slowly or throttled depending on price) or even sell back to the grid from its batteries if the price is high.

92. Mini-grids are a form of consumer interaction. Power producers and consumers in a neighborhood can sell and purchase power from their own interconnected distributed resources, their mini-grid. Even more useful is the fact that if other parts of the grid are damaged, or if there is a potential fault detected, or if there is severe weather, these mini-grids may disengage from the grid and operate in isolation.

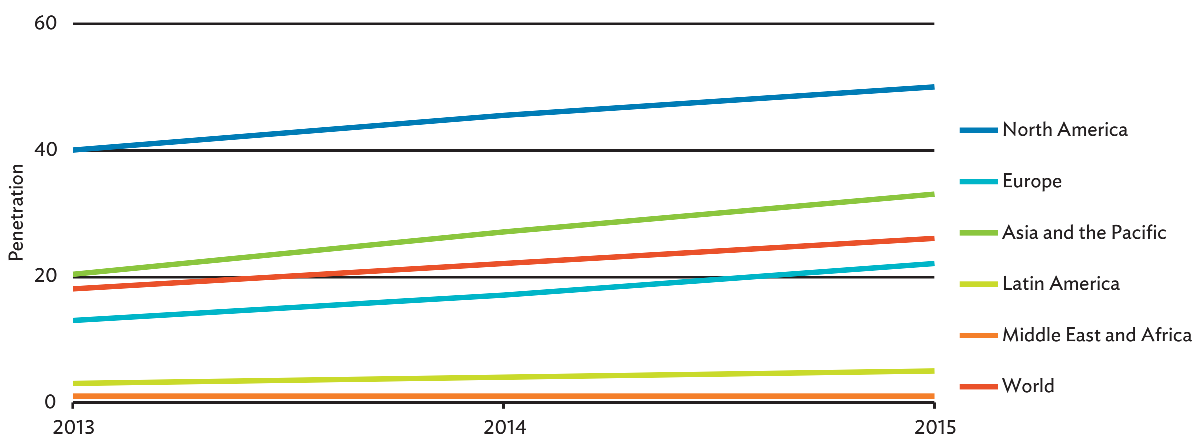
93. Essential to all of the abovementioned technologies and domains is operations. Operations refer to the management and use of the communication systems, which are the backbone of the smart grid. Systems such as these can be compromised and the results may be devastating, which is why security is of the utmost importance in these systems and may be one of the greatest factors in time taken to roll out a smart grid. Data analysis and visualization refers to how all of the data collected may actually be used to take informed action. The study of this data and the associated control systems is an area of intense research and, again, will be key to having a true implementation of the smart grid.

94. Another important domain of the smart grid is the service provider. The service provider is responsible for the enablement of consumer's power supply and even equipment such as distributed power generators. The service provider sets the tariff for the consumer and negotiates the price from the providing plants. However, in a smart grid scenario, generation and use become very complex variables and the traditional set tariff becomes very variable in nature. Important to the realization of a smart grid future must be the development of business models for such a scenario and the enablement of service providers through government assistance.

95. How these markets will evolve over the decades depends on various factors that are not limited to available/new/disruptive technology, available fuels and cost, government and industry interest and regulation, consumer interest, and financial markets.

96. Figure 10 illustrates the penetration of smart meters, an essential component of smart grid, in the regions. The biggest growth in the last 2 years, approximately 13%, takes place in the Asia and Pacific region. In North America, it increases by 10% and in Europe by 9%.

Figure 10: Smart Meter Penetration by Regions
(%)



Source: International Energy Agency (IEA). 2016. *Tracking Clean Energy Progress 2016*. Paris: Organisation for Economic Co-operation and Development / IEA.

97. Smart grid incorporates smart end use based on home and community area networks, rooftop solar (RTS) PV systems, smart metering and control systems in households, and electric vehicles. Smart end use presupposes end user education and participation both in urban and nonurban settings.

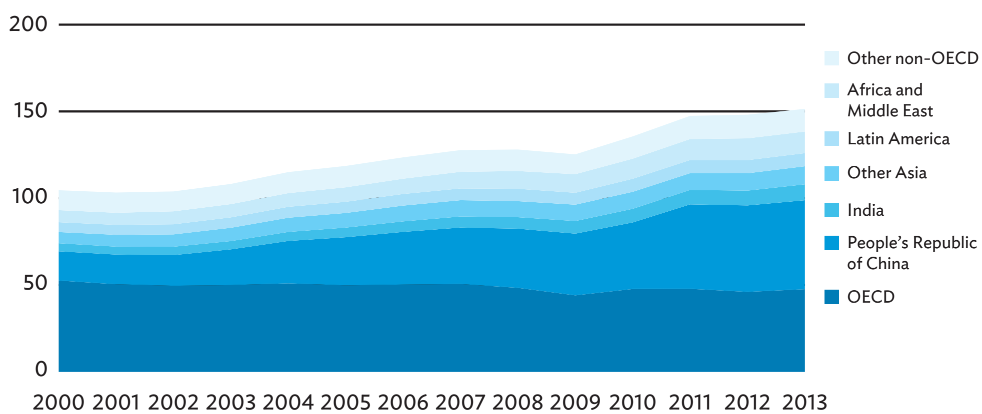
98. In general, smart grid provides opportunities for GESI integration in the following key aspects: (i) demand management in households and community; and (ii) mini-grid-based systems with GESI-inclusive consideration related to women's participation as producers and entrepreneurs, managers, technicians, and consumers.

99. The experience in Europe has shown that the main motivational factors winning consumer support for smart grids are environmental concerns and control and reduction of electricity bills. Interestingly, environmental concerns are a greater motivator than the control and reduction of electricity bills. Successful projects have involved proactive consumer engagement strategies. A major concern has been privacy and data retention. The "privacy by design principle" and other mechanisms can be used to limit the collection and retention of personal data. In Europe, these concerns are covered by the EU data protection framework. However, other jurisdictions have less stringent privacy laws than the EU. Cyber security and potential external attack are related concerns. Another concern has been the potential health risks, "although evidence to date suggests that exposure to radio wave produced by smart meters do not pose a risk to health" (Mengolini and Vasiljevska 2013).

3.6 Industry

100. The long-term trend of increasing industrial energy demand continued from 2000 to 2013, with an annual average growth in energy use of 3.4%, except for some temporary drops due to economic downturns. Industrial final energy consumption has increased since 2000 in Africa, Asia, Latin America, and the Middle East, while in OECD economies overall industrial energy consumption has decreased slightly (0.7% on average per year) (Figure 11).

Figure 11: Global Industrial Energy Use
(exajoule)



OECD = Organisation for Economic Co-operation and Development.
Source: International Energy Agency (IEA). 2016. *Tracking Clean Energy Progress 2016*. Paris: Organisation for Economic Co-operation and Development / IEA.

101. In India, industry energy use almost doubled, from 4,644 exajoules (EJ) in 2000 to 9,154 EJ in 2013. In the PRC, industry energy use in 2013 was more than three times that of 2000, rising from 16,839 EJ to 51,241 EJ. In the rest of Asia, it increased by more than 60%, from 6,440 EJ in 2000 to 10,422 EJ in 2013 (Figure 11).

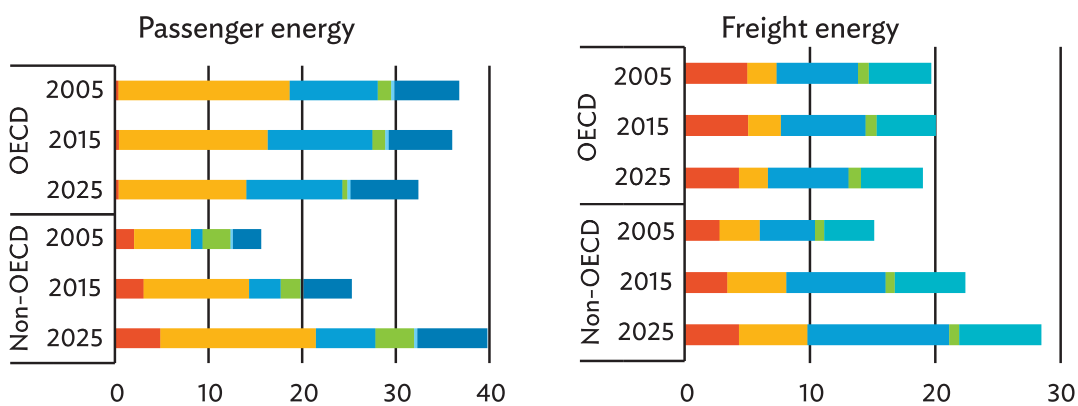
102. The distribution of energy use across industry sectors has not changed significantly since 2000; energy consumption in energy-intensive industry (chemicals and petrochemicals, cement, iron and steel, aluminum, and pulp and paper) has grown by 49% since 2000, while non-energy intensive sectors' consumption grew by 37%. Energy-intensive industry now makes up 68% of all industrial energy use, compared with 66% in 2000.

3.7 Transport

103. Transport is the least diversified sector in relation to sources of energy supply, and has not noticeably changed in more than 3 decades. Petroleum-based fuels continue to be more than 90% of the total final consumption (TFC) of energy in the transport sector. For instance, in 2015, more than 93% of the TFC was still sourced from petroleum-based fuels. However, biofuels and natural gas have made some inroads with biofuels now providing 2.5% of TFC in transport, and natural gas providing 2.8%. Electric vehicles are also beginning to offer a viable alternative to conventional internal combustion engine road vehicles, particularly In certain markets that provide a strong and consistent portfolio of fiscal and regulatory policies. Most of the growth in transport energy over the past 15 years is attributable to non-OECD economies.

104. There is a 60% increase in non-OECD countries in passenger energy consumption over the last decade (2005–2015), with a slight decrease in OECD passenger energy consumption over the same period (Figure 12). Non-OECD passenger energy consumption is expected to be larger than OECD consumption in the coming decade (2016–2025). However, this greater energy use is not necessarily an indication of superior mobility because it can also indicate inefficiencies in providing adequate access to mobility and goods. Freight energy consumption in non-OECD countries has experienced an increase of 53%, overtaking OECD energy consumption. OECD freight energy consumption is expected to decline in 2016–2025 while that of non-OECD continues to increase.

Figure 12: Transport Energy Use Trends
(exajoule)



OECD = Organisation for Economic Co-operation and Development.
Source: International Energy Agency (IEA). 2016. *Tracking Clean Energy Progress 2016*. Paris: OECD / IEA.

3.8 Electric Vehicles

105. As of 2015, there were over 1 million electric vehicles on the road, a growth of 70% from 2014. The PRC was the largest market for electric vehicles, followed by the US, the Netherlands, and Norway. In order to remain on track with 2°C scenario (2DS)[4] targets however, the worldwide market will require sustained annual average sales of 66% until 2020 and 39% until 2025.

106. The installation of fast chargers is considered important to the growth of the electric vehicle industry. Once again, the PRC was the lead developer here with 450% growth in fast direct current (DC) chargers from 2014 to 2015. The worldwide total was 57,000 installations. The more common alternating current (AC) slow charger grew from 94,000 to 148,000 installations.

107. Interestingly, electric cars do not make up the majority of electric vehicles on the road. There are over 200 million electric two-wheelers in the PRC. Electric buses and other delivery vehicles are also growing in number; this is considered a major step in reducing pollution in urban areas. The number of electric buses grew from 29,500 to 170,000 in the PRC in 2015, and the national mail carrier of France has electrified its fleet with 5,000 Renault Kangaroos (due to double by 2020).

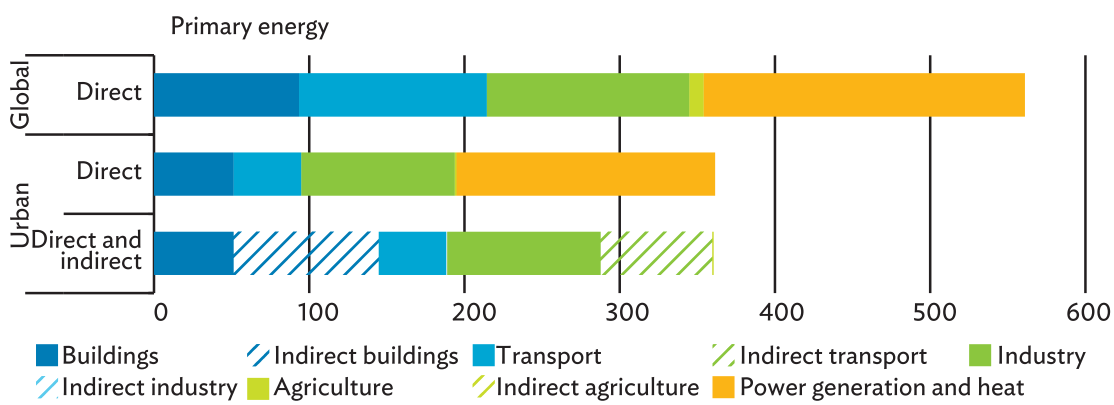
[4] The 2DS scenario used by the International Energy Agency (IEA) lays out an energy system deployment pathway and an emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C.

3.9 Urban Energy

108. Urban areas dominate global primary energy use and carbon dioxide (CO_2) emissions. In 2013, the world's urban areas accounted for 64% of global primary energy use (approximately 365 EJ) and 70% of the global CO_2 emissions (24 gigatons). Much of the population growth and urban GDP growth will occur in developing economies. This growth, combined with continued economic development, will increase demand for energy services as both affluence and basic energy access levels rise. The PRC will become highly urbanized, with 76% of its population projected to live in cities by 2050, compared to 53% in 2013. Pronounced population shifts will also occur in India, where the urban population will rise from 33% in 2013 to 50% in 2050, and in Africa, from 39% in 2013 to 55% in 2050. By 2050, the urban populations in India, the PRC, and Africa will account for approximately one-third of the projected world's population and 70% of projected urban GDP growth. Large urban populations, combined with rapidly developing per capita demand for energy services, will make the transition to sustainable urban energy systems particularly important in these economies. Most urban growth is projected to occur in small and medium-sized cities, with populations of less than 500,000 and 1 million people, respectively, where weaker resources present even greater challenges to put in place sustainable urbane energy systems.

109. Within urban areas, major sources of final energy demand are residential and services buildings, industrial processes, transport systems, and generation of electricity and heat. In 2013, direct fuel use by the power sector (for electricity and heat generation) accounted for the largest share of urban primary energy use, followed by direct fuel use by the buildings (residential and services combined), industry, and transport sectors within urban areas (Figure 13). When direct fuel use by the power sector is distributed to end use sectors on the basis of their consumption of electricity and heat, the buildings and industry sectors emerge as the largest total (direct plus indirect) contributors to urban primary energy use, followed by the transport sector.

Figure 13: Global Urban Primary Energy Use, 2016
(exajoule)



Source: International Energy Agency (IEA). 2016. *Energy Technology Perspective 2016: Towards Sustainable Urban Energy Systems.* Paris: Organisation for Economic Co-operation and Development / IEA.

110. The IEA identified the main components of urban energy systems: buildings (residential and services); transport (passenger and freight); heat and power; industry, water, and waste; and small-scale urban farms augmenting urban food supply. Efficient buildings and transport systems, and low-carbon integrated networks all play an important role in sustainable urban energy systems. The IEA also put forward the following framework to analyze urban energy use based on the following key drivers: (i) drivers linked to the geophysical environment—the constraints imposed by a city's location, the prevailing climate conditions, or the resources at its disposal, including proximity to other economic centers; (ii) sociodemographic drivers—from the social and economic structure to household occupation, to cultural aspects that drive the growth of a city; (iii) drivers linked to the built-infrastructure—the energy and transport infrastructure, the design and density of buildings, and the degree of connection of socioeconomic activity; and (iv) institutional drivers—the architecture of urban governance, including the governance of the energy system.

111. According to IEA definitions, sustainable urban energy systems are broadly those that meet demand for urban energy services while (i) protecting the environment, including mitigating climate change, reducing air pollution, and avoiding natural resource depletion; (ii) improving the resilience of urban energy infrastructure to external shocks; and (iii) achieving economic and human development goals. The human development goals need to address the continuing lack of access to clean and quality energy sources in the urban areas of developing countries in Asia. A transition to sustainable urban energy systems will require addressing the continuing energy poverty in urban areas.

112. Cities are vast sources of energy demand, and supply sources within cities are limited. The rooftop areas or facades of buildings can be used to produce electricity with solar PV systems (or to warm water with solar thermal modules). Restricted supply implies that cities will have to rely to a great extent on energy imports to meet their total energy needs. Electricity imports can come from distant centralized sources or more decentralized local sources on the city periphery. Peri-urban areas could have a critical role to play. Centralized supply options, such as large power plants, may provide benefits in terms of economies of scale, but may require transmission infrastructure. Fuel sources close to cities reduce transmission needs but may result in higher specific generation costs if plant sizes are smaller. The choice between centralized or decentralized supply options may be influenced by considerations other than cost, such as resilience against supply disruptions. How urban infrastructure is designed, built, and operated can yield vastly different outcomes for energy delivery. On the technology side, new developments in distributed energy resources are changing the technical and economic conditions of energy networks. Distributed PV and storage are creating new opportunities for agile local energy systems—community or even "personal" energy. Urgent action is needed to find sustainable urban energy solutions before cities are locked in inefficient urban energy systems as they face rapid urbanization.

3.10 Buildings, Appliances, and Lighting

113. In 2013, buildings accounted for half of the electricity demand globally and over 30% (120 EJ) of total final energy consumption. About 55% of the total energy load is cooling and heating needs. Since 1990, the use of coal in the electrical energy mix has decreased, but the use of natural gas has increased by 40%, meaning that fossil fuel consumption has still grown by 8%. In total, although floor space has doubled since 1990, building energy performance per unit area has improved by 1.5% per year.

114. The energy use per capita chart (Figure 14) gives a snapshot of country energy use since 1990. India and ASEAN countries are still well below the US, the EU, and the PRC, but have seen steady growth over 23 years.

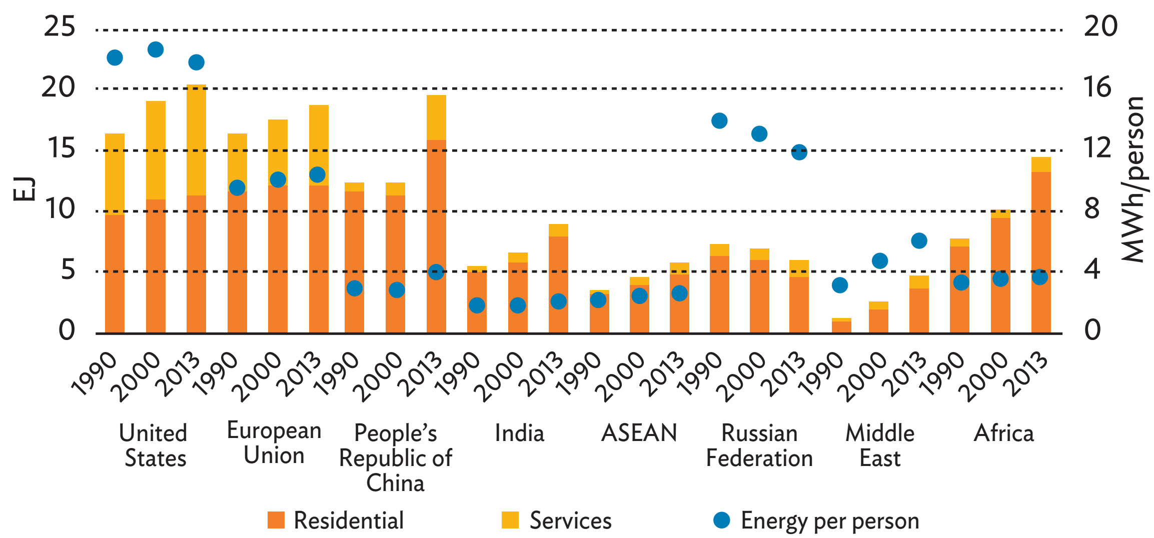
115. Countries with energy efficiency standards and labeling programs have seen efficiency improvements in major appliances at 3%–4%, and some of the more mature programs are estimated

to have saved up to 25% energy consumption. As of 2015, member states of ASEAN have agreed to a harmonization of lighting standards and policy that is expected to have annual savings of 35 terawatts-hour per annum.

116. In rapidly developing countries such as India and the PRC, it is considered of the utmost importance to implement energy efficiency policies now to prevent the lock-in of inefficient building investments. In India, they are achieving this with the Energy Conservation Building Code, which has been adopted by 23 of 36 states nationally (IEA, 2016a).

117. In developed countries, it is necessary to improve energy performance at 2.5% each year until 2025. In addition, globally, deep energy improvement building renovations need to be at 2%–3%. The potential for energy savings in the building sector is significant. It is estimated that with use of the right policies and existing technology energy savings of 50 EJ per year could be achieved by 2050.

Figure 14: Total and Per Capita Energy Use in Buildings



ASEAN = Association of Southeast Asian Nations, EJ = exajoule, MWh = megawatt-hour.

Source: International Energy Agency (IEA). 2016. *Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems*. Paris: Organisation for Economic Co-operation and Development / IEA. p. 111.

3.11 Energy Storage

118. Globally, pumped hydro accounts for the vast majority of store energy (149 GW or 96%), however, battery storage implementations were strong in 2014 with 400 MW of additions (double the previous year). This is due to the spread of distributed power sources and countries updating policy and regulations to ensure that this power from these sources is captured effectively (e.g., in the US, Europe, and key markets in Asia).Yet hydro can be particularly vulnerable to climate change given its dependence on water for power generation. According to Hamududu and Killingtveit (2012), the key resource for hydro generation is runoff, which is dependent on precipitation. The future global climate is uncertain and thus poses some risk for the hydro generation sector. The crucial question and challenge then is what the impact of climate change will be on global hydro generation and what the resulting regional variations are in hydro generation potential (p. 305). Changing precipitation patterns, increases in temperature, more frequent or intense incidence of droughts, extreme weather events, sea level

rise, and resulting flooding and landslides can all affect hydroelectricity generation capacity, damage infrastructure, and disrupt service.

119. Building large capacity power storage grew more than 50% in 2014. The commercialization of the Tesla Powerwall has driven other producers to lower prices, hence the increased uptake of the technology. Since 2010, lithium-Ion battery costs have dropped at about 22%, but this is expected to balance out and so the market will flatten again.

120. It is possible that flow batteries could help improve large-scale energy capture in the future, with 40 MW of planned deployments as of 2016. However, high upfront costs still remain one of the biggest obstacles to integrating battery storage technologies with the grid.

3.12 Fostering Innovation: Disruptive Technologies

121. Do some technologies have the potential to disrupt the status quo and change entirely the way people live and work and even think? An area of study has emerged, which assesses the potential of certain technologies and their development over the next 25 years, to do just that. These technologies are described as disruptive technologies.

122. Renewable energy has been identified as having the potential, at least, to be a disruptive technology (Manyika et al. 2013) due to the following general characteristics:

- **Rapidly advancing technology.** Since 2000, the growth in solar PV and wind generation has grown significantly while costs have declined (the price of a solar PV cell has decreased by 85% since 2000).
- **Broad potential scope of impact.** It can change the quality of life, health, and environment, and, if coupled with developing energy storage technologies (also identified as potentially disruptive), can provide energy access to millions of poor people.
- **Economic impact, which could dramatically change the status quo.** Renewable energy technologies can potentially change the comparative advantage of developing nations, such as the case of the PRC and India, with ambitious plans for solar and wind adoption that could further enable rapid economic growth while mitigating negative environmental impacts (Manyika et al. 2013).

123. Evans (2014) assessed that the convergence of disruptive technologies has the potential to have profound societal impacts, and gives examples of renewable energy sources, when combined with sensing and analytic networks, having the potential to provide “personalized” green energy via smart grids. While the paths of technological change cannot always be predicted and impacts are highly uncertain, there are some clearly emerging trends that point to real possibilities of steering technology in the direction of addressing critical societal issues.

124. Some of the key issues related to climate change, adaptation, risk mitigation, and enhancing resilience can be tackled through green power development, smart grids, and improved quality of response, based on the following technology convergences. Smart grids, with distributed generation, are also emerging as an optimal solution to provide energy access solutions for low-income communities in developing countries.

- *Renewable Energy Sources + Extensive Sensing + Networking + Analytics + Extensive Distributed Energy Sources = Smart Grid, with “Green Power” and Improved Energy Access*
- *Extensive Sensing + Analytics + Networking = Improved Quality of Response, Enhanced with Robotics and Unmanned Aerial Vehicles*

125. The problems associated with increasing urbanization (such as eroding urban ecology and air quality) and the increasing pressure on infrastructure and services can be addressed through the following technology convergences.

- *Smart and Agile Energy Systems + Extensive Sensing + Analytics + Networking + Autonomous Electric Vehicles = Safe, Green, Sustainable (Smart) Cities.*

126. Impacts include the following:

- Smart and agile energy systems—community power generation, storage, and sharing
- Low-cost-effectiveness—reducing the relative cost of infrastructure, improved access, and social equity
- Data-driven decision-making—strengthened governance and improved planning and design
- Improved urban ecology, biodiversity, and air quality
- The development of smart traffic light grids that predict traffic flow

The following system and technology convergences will also be a feature of these smart cities.

- *Computing Power + Robotics = Further Automation of Manual Work*
- *Cyclic Economies, Increased Recycling*

However, automation brings dangers of job losses, particularly in manual labor, which could have serious negative effects including in South Asia.

127. Disruptive technologies, such as renewable energy technologies and systems, have the potential to transform how energy is produced, distributed, and consumed and to foster technology innovation. Smart and agile power systems based on distributed energy sources, such as mini-grids, can result in community energy systems for smart cities or smart communities, simultaneously providing solutions for inclusive energy access. Hand in hand with these developments is the dark side of disruptive technologies, i.e., the possibility for enhanced and wide-scale surveillance of human activities. The concerns of smart systems being used for surveillance and other societal issues can be addressed through democratic safeguards on data ownership and data access, as well as through addressing broader issues such as ownership and control of technologies.

3.13 Community Energy

128. Community energy in broad terms refers to the involvement of local communities and citizens in the energy transition. In developing Asia, community energy programs based on small hydro systems have been historically driven by the need to provide a basic level of energy access through rural electrification. More recently, community energy systems have been driven by a combination of technology and socioeconomic considerations. Renewable energy technologies, especially solar PV and wind, and the rapid decline in costs have made the implementation of community energy systems viable in many local areas. For some communities, the ability to generate revenue from renewable energy systems is an important incentive in participating in community energy programs. Communities, especially in developed countries, that are dissatisfied with the traditional centralized models of energy production and wanting to have control over their own energy supply based on local resources, generating local employment and stimulating local economies, are also driven to support community energy programs.

129. Community energy systems, with the emphasis on end users, community-based structures, and end user participation, have important implications for addressing GESI challenges. IRENA provides a

useful definition of community energy systems, which includes the following common characteristics: (i) citizens running projects through communities, such as cooperatives or development trusts; (ii) a cooperative, democratic, or noncorporate structure in which individuals participate actively in decision-making; (iii) tangible local benefits to people living or working close to projects; and (iv) profits returning to the community or being reinvested in other community energy schemes. This definition helps provide entry points for GESI.

130. Energy access continues to be an ongoing challenge in developing countries, with significant differences among countries and between urban and rural gaps (Table 2).

131. In developing technology solutions, there is an opportunity for a more consultative process where the voices of women are heard in the design and dissemination of solutions.

Table 2: Electricity Access, 2014
(%)

Region	Population without Electricity (million)	Electrification Rate	Urban Electrification Rate	Rural Electrification Rate
Transition economies and OECD	1	99.9	100.0	99.7
Developing countries	1,185	79.0	92.1	67.4
Developing Asia	512	86.4	96.2	78.9
Bangladesh	60	62.0	84.4	50.7
Nepal	7	76.3	97.0	71.7
Sri Lanka	0	98.6	99.6	98.4

OECD = Organisation for Economic Co-operation and Development.
Source: Data compiled from International Energy Agency (IEA). 2016. *World Energy Outlook 2016*. Paris: Organisation for Economic Co-operation and Development / IEA.

3.14 ADB Mainstreaming High-Level Technology

132. The following ADB working definitions for high-level technology (HLT) provide important entry points for GESI mainstreaming (Table 3):

(i) Uses smart grid

(ii) Creates or improves ways of serving client needs in terms of efficiency and productivity, e.g., smart grids, information and communication technology (ICT)

(iii) Addresses climate mitigation, and adaptation and resilience to disaster risks, e.g., smart grids, mini-grids with storage, offshore wind, concentrated solar, early warning systems

(iv) Innovates processes, methods, or techniques and uses new or improved equipment and materials in construction and operations

(v) Reduces environmental and social costs, e.g., negative impacts on air and water quality, noise, natural capital

(vi) Improves economic efficiency, durability, long-term performance efficiency, e.g., more efficient energy and materials consumption, reduce–reuse–recycle

(vii) Creates market opportunities for scaling up, e.g., innovative business opportunities based on renewable energy penetration

(viii) Maximizes energies and increases scale and impact through cross-sectoral collaboration, e.g., an integrated infrastructure approach, smart and safe cities

Table 3: Gender Equality and Social Inclusion Integrated High-Level Technology Definitions

ADB Definition	GESI Entry Points
a. Uses smart grid	In general, smart grid provides opportunities for GESI integration in the following key aspects: • Demand management in households and community • Mini-grid-based systems with GESI-inclusive consideration related to women's participation as producers and entrepreneurs, managers, technicians, and consumers.
b. Creates or improves ways of serving client needs in terms of efficiency and productivity	• Services should aim to achieve at least tier 3 levels of energy access based on the Global Tracking Framework multi-tier levels of access: - >365–1,000 kWh/annual threshold - Operate medium-power appliances—food processing, water pumps, washing machine, air coolers, refrigeration, rice cooker - A minimum of 8 hours of supply - Quality of supply—no quality or reliability issues with significant impact - At least 50% of MSMEs working hours - At least 50% of the neighborhood covered by street lamps, lit daily for at least 50% of nigh time - No perceived health and safety risks—no accidents in the last 12 months that have been fatal, resulted in disability, or required professional medical attention • Prioritize energy intensity and efficiency for BPL end users • Include GESI-inclusive end user awareness programs for households, MSMEs, industry, and agriculture • Household programs to be sensitive to gender-differentiated patterns of energy use and target women consumers
c. Addresses climate mitigation, adaptation, and resilience to disaster risks	• Smart mini-grids and GESI-inclusive community energy solutions • Storage to enhance community livelihoods, e.g., refrigeration, cooling, and heating systems • Early warning systems with GESI integration • Smart energy solutions to enable the reconstruction and rehabilitation of systems in the quickest possible time in vulnerable communities
d. Innovates processes, methods, or techniques and uses new or improved equipment and materials in construction and operations	• Include the integration of social and GESI analysis and criteria in processes, methods of analysis and design, techniques, etc. • Use energy systems modeling based on social considerations and GESI as an additional pillar, along with technology, least cost, environmental factors, and CO_2 reduction • Identify materials for lighter and mobile systems (such as lightweight solar PV materials)
e. Reduces environmental and social costs	BLEENS for improved cooking solutions to reduce indoor air pollution • Technology solutions based on energy–water nexus to provide pumped water • Indigenous women's knowledge harnessed to preserve and enhance natural capital • GESI mainstreamed risk mitigation strategies • GESI indicators for impact evaluation

continued on next page

Table 3 *continued*

ADB Definition	GESI Entry Points
f. Improves economic efficiency, durability, long-term performance efficiency	• Cyclic economies—smart cities and smart communities based on increased recycling • Gender-inclusive smart recycling processes targeting women end users • Waste to energy systems development
g. Creates market opportunities for scaling up	• Independent and small power producers based on renewable energy systems—include targets for women-owned and women-led producers • Women-led MSMEs development based on uptake of new technologies
h. Maximizes energies and increases scale and impact through cross sectoral collaboration	• Integrated infrastructure approaches and frameworks to include a social pillar with GESI integration, prioritizing women's infrastructure needs, livelihoods, employment, and participation • GESI-inclusive bottom-up governance and planning processes • GESI-integrated smart and safe cities

ADB = Asian Development Bank; BLEENS = biogas, liquefied petroleum gas, ethanol, electricity, natural gas, and solar; BPL = below poverty line; CO_2 = carbon dioxide; GESI = gender equality and social inclusion; kWh = kilowatt-hour; MSMEs =micro, small, and medium-sized enterprises; PV = photovoltaic.

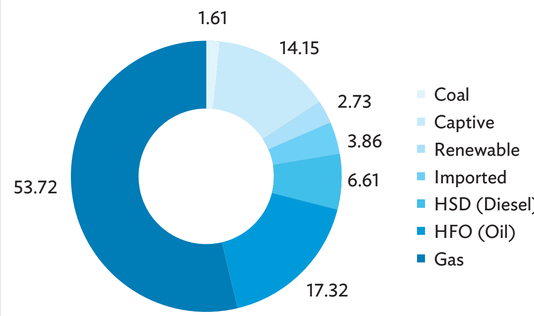
Source: P. Batra. 2017. *Inclusive Energy Solutions: Framing the Policy Challenges for Smart Grid*. Presentation for the Central Electricity Authority. Bhopal, Madhya Pradesh. 19 April.

4. TECHNOLOGY AUDIT—BANGLADESH

4.1 Introduction

133. The desk study includes collection of data on renewable energy technologies and systems deployed in the South Asia subregion—a technology audit. The audit was conducted to (i) identify the technology types and systems being deployed, (ii) understand the type of information being collected, and (iii) inform GESI-integrated system design. The technology audit was limited to Bangladesh, Nepal, and Sri Lanka, where data were available to inform a desk study.

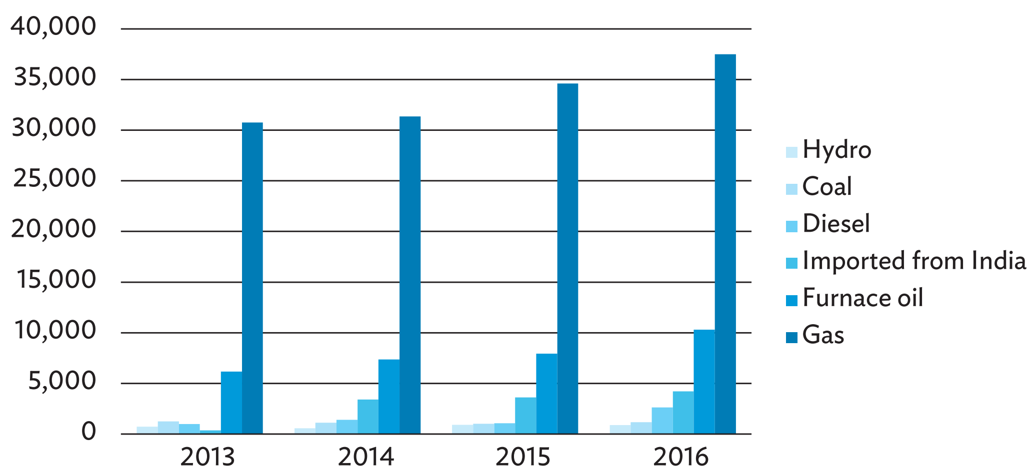
Figure 15: Bangladesh's Electrical Energy Overview 2017
(%)



HSD = high speed diesel, HFO = heavy fuel oil.
Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. http://www.sreda.gov.bd/index.php/site/re_present_status.

134. As of 2017, natural gas power plants produce the majority of power in the country, followed by oil plants, captive power plants, and diesel plants. Bangladesh has been importing power from India since October 2013, and this is only set to rise in the future. Gas power plants meet the base load demand, and rental power producers using diesel generators are contracted to meet peak demand in the summertime. The 7th Five Year Plan FY2016–2020 identifies that if the gas demand of Bangladesh continues to grow at 7% per annum (2015 growth), the present reserve would be fully depleted by 2023, unless new gas field exploration or gas import starts immediately. To make up for the shortfall (with peak demand ever increasing), the country has had to rely more on oil-fired electricity, which was up from 3.89% of generation in 2009 to 16.95% in 2015. Figures 15 and 16 give an overview of the electricity production balance and output for the past 5 years.

Figure 16: Bangladesh's Annual Power Generation
(GWh)

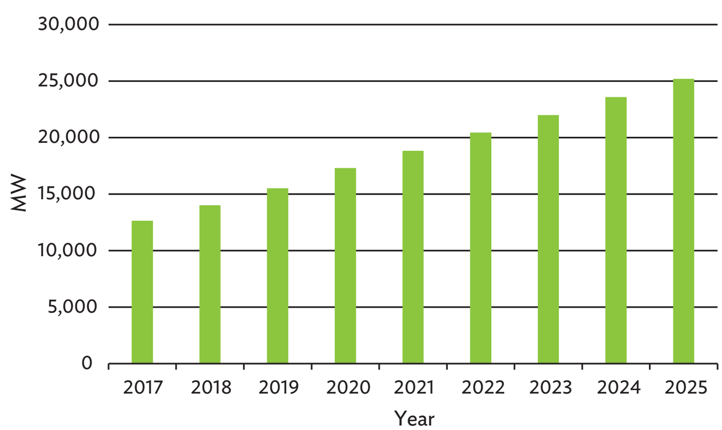


GWh = gigawatt-hour.
Source: Power Grid Company of Bangladesh Ltd. Operational Monthly Reports. https://pgcb.org.bd/PGCB/?a=pages/operational_monthly.php.

135. The 2016 Power Sector Master Plan set out targets for future power generation with 35% to be delivered by coal, 35% by natural gas, 15% by imported electricity and renewables, 10% by nuclear and 5% by oil.

136. Peak demand is forecast to increase at a constant rate well into the next 2 decades, and so a sustainable but reliable mix of energy sources is required to meet these demands. Figure 17 shows a prediction of future peak demands.

Figure 17: Bangladesh's Peak Demand Forecast



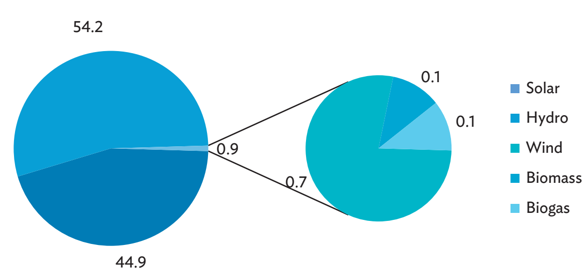
MW= megawatt.
Source: Bangladesh Power Development Board. Demand Forecast. http://www.bpdb.gov.bd/bpdb/index.php?option=com_content&view=article&id=12&Itemid=126 (accessed 1 October 2017).

4.2 The Grid—Bangladesh

137. As of 2017, access to electricity is at 90% in urban areas and only 40% in rural areas. Power Cell lists 2017 transmission and distribution losses at 12.19%, 9.98% of which is lost purely in distribution.

138. The Renewable Energy Policy of Bangladesh was created in 2008 and set out pathways for the country's adoption of such resources. The initial targets were 5% of all energy generated should be from renewable sources by 2015, and 10% by 2020. As shown in Figure 15, current production is only at 2.73%. Figure 18 gives an overview of the renewables balance, while Table 4 gives details of installed capacity over the last 7 years.

Figure 18: Bangladesh's Renewable Energy Overview 2017
(%)



Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. http://www.sreda.gov.bd/index.php/site/re_present_status.

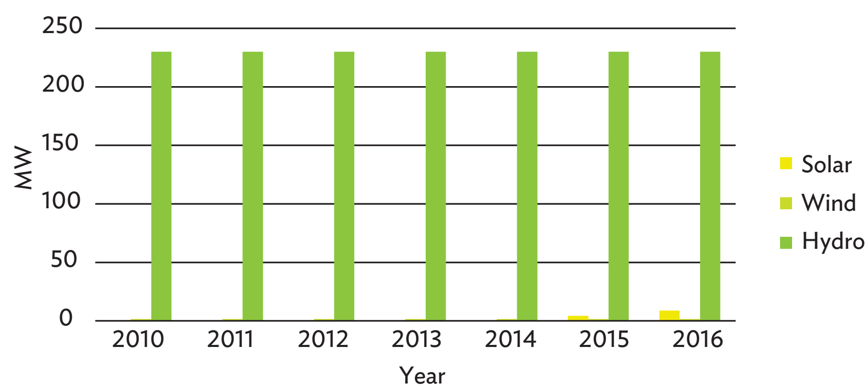
Table 4: Bangladesh's Installed Renewable Energy Production Capacity Overview (megawatt)

Capacity (MW)		Year						
		2010	2011	2012	2013	2014	2015	2016
Solar	On-grid	0.00	0.00	0.00	0.00	0.50	4.37	8.92
	Off-grid	0.10	49.11	76.26	110.40	140.18	168.48	181.70
	Sum	0.10	49.11	76.26	110.40	140.68	172.85	190.62
Hydro	On-grid	230.00	230.00	230.00	230.00	230.00	230.00	230.00
	Off-grid	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sum	230.00	230.00	230.00	230.00	230.00	230.00	230.00
Wind	On-grid	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	Off-grid	1.00	1.00	1.00	1.00	1.00	2.00	2.00
	Sum	1.90	1.90	1.90	1.90	1.90	2.90	2.90
Biogas	On-grid	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Off-grid	0.05	0.05	0.07	0.07	0.10	0.23	0.63
	Sum	0.05	0.05	0.07	0.07	0.10	0.23	0.63
Biomass	On-grid	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Off-grid	0.00	0.00	0.00	0.00	0.00	0.40	0.40
	Sum	0.00	0.00	0.00	0.00	0.00	0.40	0.40
Total		232.05	281.06	308.23	342.37	372.68	406.38	424.55

MW = megawatt.
Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. http://www.sreda.gov.bd/index.php/site/re_present_status.

139. The on-grid power generation breakdown is shown in Figure 19. The great majority of on-grid generation is from the 230-MW Kaptai Hydropower Plant, which has been running since 1988. Four turbines at Muhuri Dam have been supplying wind power to the grid since 2005. Only in the last few years has solar power made an appearance on the grid.

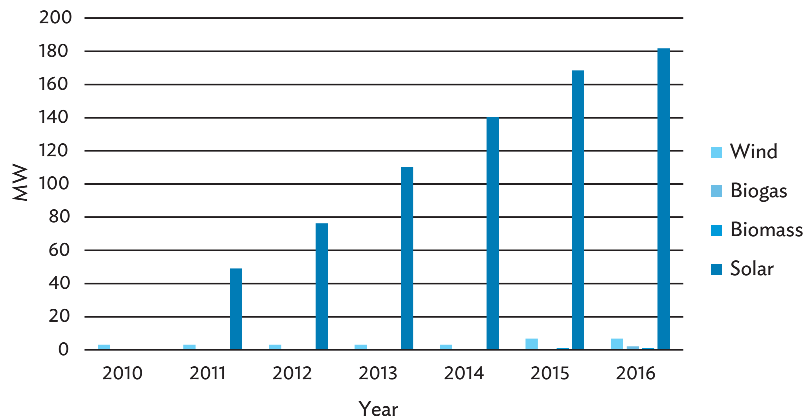
Figure 19: Bangladesh's Cumulative On-Grid Renewable Power Generation Capacity



MW = megawatt.
Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. http://www.sreda.gov.bd/index.php/site/re_present_status.Energy.

140. Since the implementation of the renewable energy policy, the large majority of investment in renewables has been in off-grid solar projects. Figure 20 gives an overview of how off-grid power generation has developed over the past 7 years.

Figure 20: Bangladesh's Cumulative Off-Grid Power Generation Capacity



MW = megawatt.
Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. http://www.sreda.gov.bd/index.php/site/re_present_status.

141. Sustainable And Renewable Energy Development Authority (SREDA), in conjunction with various organizations, published the information in Table 5 in their investment plan 2015. The table gives an overview of the full potential capacity of various renewable energy sources. Solar power is predicted to have the greatest potential, and this has affected investment across the board, as will be discussed in the ensuing sections.

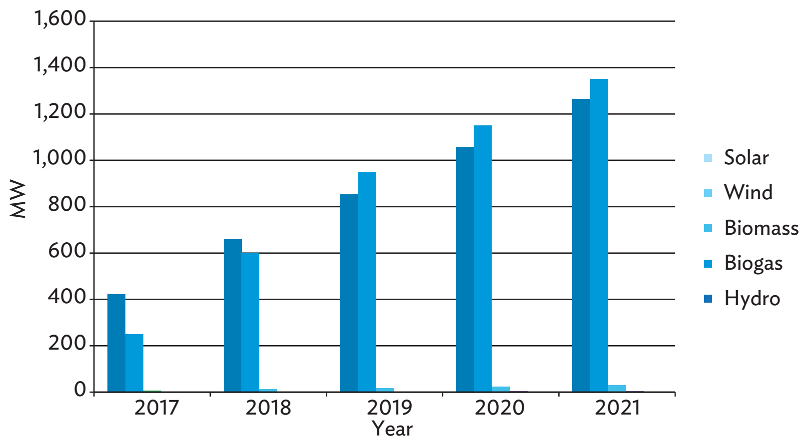
Table 5: Bangladesh's National Estimated Total Capacity and Generation by Technology

Technology	Resource	Capacity (MW)	"Annual Generation (GWh)"
Solar parks	Solar	1,400**	2,000
Solar rooftop	Solar	635	860
Solar home systems	Solar	100	115
Solar irrigation	Solar	545	735
Wind parks	Wind	637**	1,250
Biomass	Rice husk	275	1,800
Biogas	Animal waste	10	40
Waste to energy	Municipal waste	1	6
Small hydropower plants	Hydropower	60	200
Mini and micro-grids***	Hybrid	3***	4
Total		3,666	7,010

GWh = gigawatt-hour, MW = megawatt.
* Case 1 (agricultural land excluded) estimate.
** Case 1 (flood-prone land excluded) estimate.
*** Based on planned projects only, not a theoretical maximum potential, because there is potential overlap with grid solar systems. Either could be used to serve off-grid demand.
Source: Government of Bangladesh, SREDA. 2015. Scaling Up Renewable Energy in Low Income Countries (SREP): Investment Plan for Bangladesh. Dhaka.

142. The planned additions of renewables in Figure 21 was constructed from the SREDA renewable energy master database, which gives details of projects in progress and planned projects. It indicates that solar and wind power have received a lot of attention from government and even more so from industry, as contractors must commit to the projects.

Figure 21: Bangladesh's Cumulative Planned Additions of Renewables

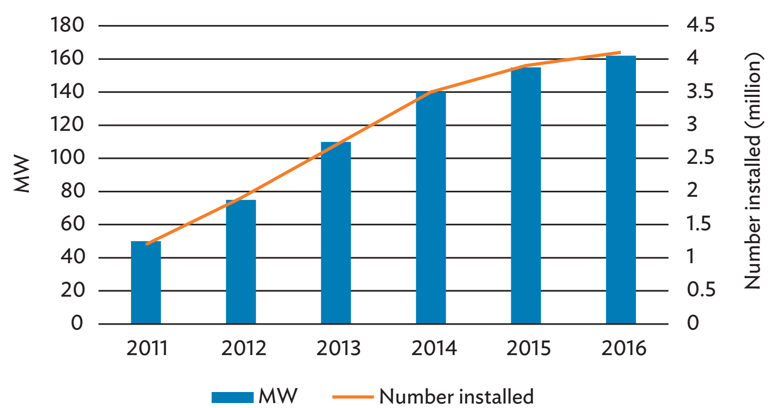


MW = megawatt.
Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. Renewable Energy Master Database. http://www.sreda.gov.bd/index.php/site/re_present_status.

4.3 Solar Power—Bangladesh

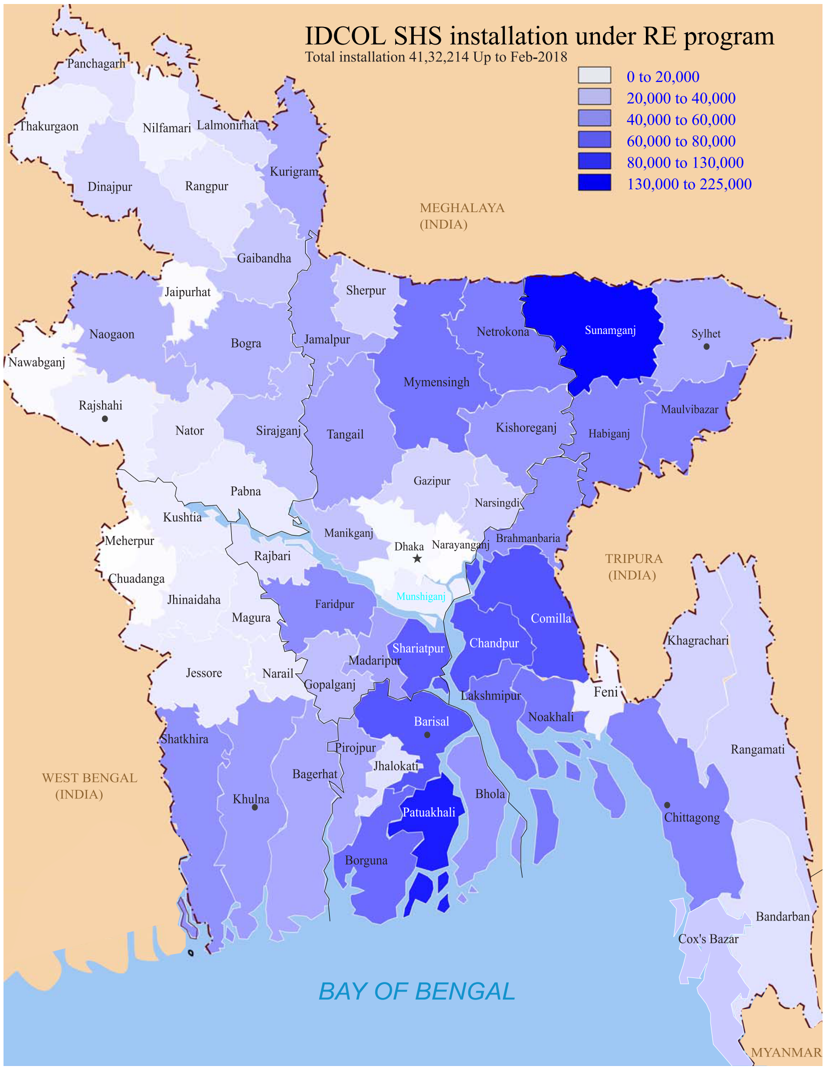
143. By far the largest producers of solar power are the solar home systems (SHSs). The number and total capacity of these systems are shown in Figure 22. These systems are low-cost solar battery systems installed on individual homes. Funded by government-owned Infrastructure Development Company Limited (IDCOL) (supported by other organizations), the SHS project ended on 30 June 2017 with a total expenditure of $1 million. At present, there are over 4 million systems installed with the final project goal of 6 million installed systems by 2018 (the current distribution of installed systems is shown in Figure 23). Households make a down payment at the installation of these systems and pay off the rest of the cost over 3 years.

Figure 22: Bangladesh's Cumulative Installed Solar Home Systems



Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. Renewable Energy/Energy Efficiency Status Report (Installed). http://www.sreda.gov.bd/index.php/site/re_present_status.

Figure 23: Bangladesh Infrastructure Development Company Limited Solar Home System Installations



IDCOL = Infrastructure Development Company Limited, RE = renewable energy, SHS = solar home system.
Source: IDCOL. http://www.idcol.org/old/bd-map/bangladesh_map/.

144. A typical SHS operates at 12 volts (direct current) and provides power for fluorescent/LED lights, radio-cassette players, a small black and white TV, or similar low-power appliance for about three to five hours a day (systems are generally 10 watts-peak to 21 watts-peak). The systems are modular in that the number of photovoltaic (PV) modules may be increased in the installation to provide greater output; however, only one 12V battery (18Ah at 10 hours) is included. The systems are protected by warranty: 20 years for the PV modules output (power output will not fall below 80%), supporting structures for 10 years, 3 years for components, 5 years for the battery, and only 2 years for the PV panels themselves.

145. Funding is not supplied directly to the end user by IDCOL, rather, IDCOL channels its loans through participating organizations, to which they give a $20 subsidy per SHS financed.[5] These participating organizations then supply loans to households and commercial establishments and install the systems. At present, there are 56 participating organizations implementing the program. Households are expected to make a down payment of 10%–15% to the participating organization, and the loan is to be paid off over 3 years at 12% interest. In addition, there is a buy back and replace program for batteries.

146. Since 2003, IDCOL has received its funding from 45 partner organizations. Most prominent among these are the World Bank and Global Environment Facility, which funded to start the program; and later, ADB, Department for International Development of the United Kingdom, GIZ, Global Partnership of Output-Based Aid, Inter-American Development Bank, Japan International Cooperation Agency, KfW, and United States Agency for International Development came forward with additional financial support for expansion of the SHS program. IDCOL supplies these funds as loans to participating organizations under a specific contract, the details of which are shown in Table 6.

5 Down from $90 in 2003.

Table 6: Bangladesh Infrastructure Development Company Limited to Participating Organization Loan Terms for Solar Home Systems

Particulars	Term Details	
Loan amount	Up to BDT 250M	80% of POs loans to households
	> BDT 250M	70% of POs loans to households
Tenure including grace	Up to BDT 250M	Up to 7 years
	> BDT 250M and <= BDT 500M	Up to 6 years
	> BDT 250M and <= BDT 100M	Up to 6 years
	> BDT 1000M	Up to 5 years
Interest rate	Up to BDT 250M	6% p.a.
	> BDT 250M	7% p.a.

BDT = Bangladesh taka, p.a. = per annum, PO = participating organization.
Source: Infrastructure Development Company Limited. Lending Terms: Solar Home System (SHS) Program. http://idcol.org/home/r_lending_terms.

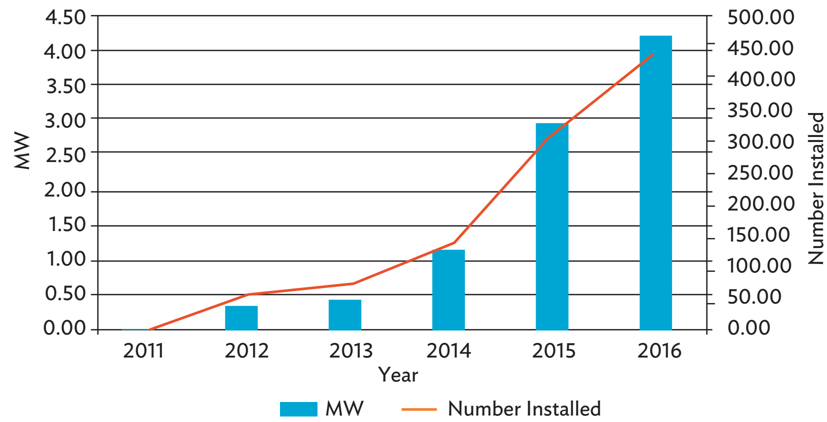
147. Solar rooftop systems are forecast to provide the bulk of Bangladesh's new solar power. SREDA reported that 12.04 MW of off-grid solar rooftop systems have been installed; however, these produce little energy and so future installations will all be grid tied. Only 8.93 MW of grid tied solar rooftop systems are installed, and a little more is scheduled for future installation. The renewable energy potential survey for Bangladesh indicates a potential of up to 635 MW for this type of system.

148. Households headed by women are more likely to acquire an SHS than the households headed by men. A majority of households see SHS as beneficial to children's education. Children's study time is increased by SHS adoption, 12.1 minutes per day on average for girls, 8.5 minutes for boys. SHS has allowed women to spend more time tutoring children and has increased their participation in social activities (Asaduzzaman et al. 2013).

149. SHS has also enabled increased economic opportunities for women. Grameen Shakti, a nongovernment organization that provides microfinance for SHS installation, reported: "Women are enjoying hazardless and hassle-free lighting systems in their daily life. They are getting the opportunities to earn extra income by utilizing their time after dusk by sewing, poultry farming or setting [up] home based industries" (Grameen Bank, 2008).

150. IDCOL also runs the solar irrigation program using a fee for service model, where they pay for 40% of the cost of the system and the customer pays the rest with a down payment and a loan to be paid off over 8 years. The target is to have 1,500 solar irrigation pumps installed by 2018. Additionally, IDCOL aims to have 50,000 solar pumps (11-kilowatts-peak [kWp]) installed by 2025. The current status of installed units is shown in Figure 24.

Figure 24: Bangladesh Cumulative Installed Solar Irrigation Systems

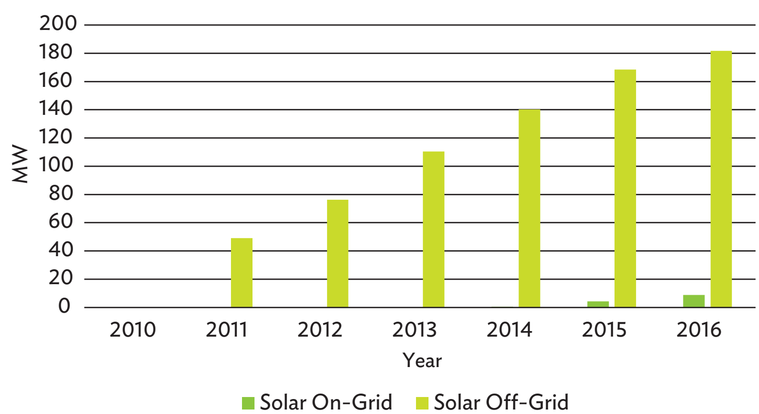


MW = megawatt.

Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. Renewable Energy/Energy Efficiency Status Report (Installed). http://www.sreda.gov.bd/index.php/site/re_present_status.

151. The 500-MW solar program was developed in 2012, the objective of which was to add 500 MW of solar power by 2016. As can be seen in Figure 25, capacity as of the end of 2016(181.7 MW) was still nowhere near 500 MW.

Figure 25: Bangladesh's Cumulative Solar Power Capacity



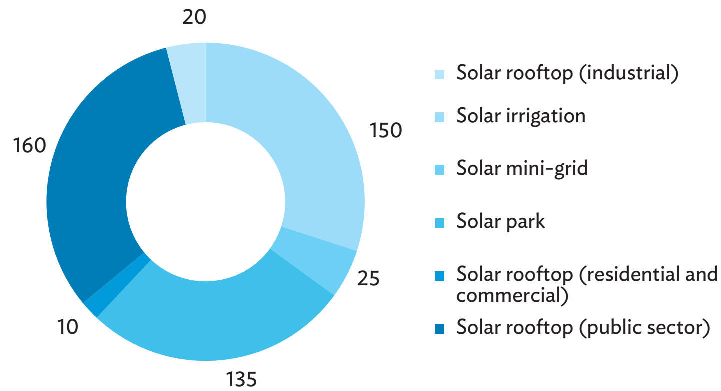
MW = megawatt.

Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. Renewable Energy/Energy Efficiency Status Report (Installed). http://www.sreda.gov.bd/index.php/site/re_present_status.

152. None of the scheduled 80-MW solar parks scheduled to be completed in 2016 are yet operating. There are 1,853 MW of solar parks listed as "implementation ongoing" or "under planning" in the renewable energy master database of SREDA.

153. Utility scale solar and rooftop solar (RTS) are ranked as highest priority in the Investment Plan for Bangladesh by SREDA. The breakdown of the 500-MW solar program is shown in Figure 26.

Figure 26: Bangladesh's 500-Megawatt Solar Program Breakdown
(megawatt)



MW = megawatt.

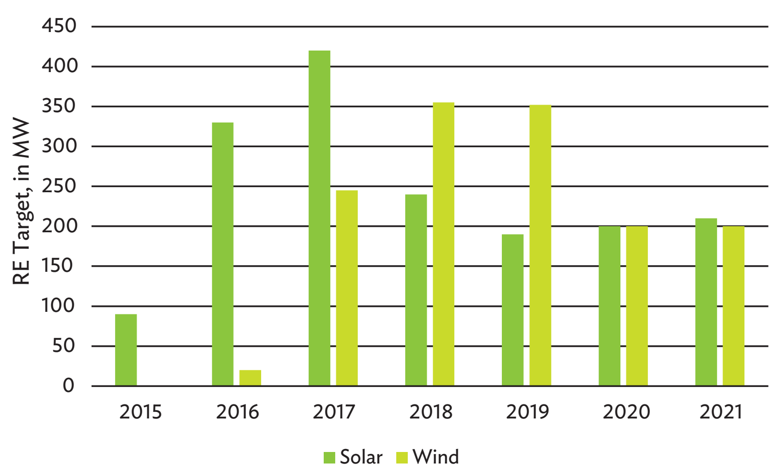
Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. 2015. *Scaling Up Renewable Energy in Low Income Countries (SREP): Investment Plan for Bangladesh.*

4.4 Wind Power—Bangladesh

154. As of 2015, there were only two grid-connected wind farms (900 kW and 1,000 kW).

155. The Government of Bangladesh has set yearly targets for installations of wind energy sources (Figure 27). It is planned to have 1,370 MW of new wind power plants installed by 2021, with the majority of these being privately owned. It should be noted that this target differs significantly from the published technical capacity assessment of Table 5. The use of a larger figure could indicate an overestimation or use of a different model by the government in setting their targets.

Figure 27: Bangladesh's Wind and Solar Yearly Installation Targets



RE = renewable energy, MW = megawatt

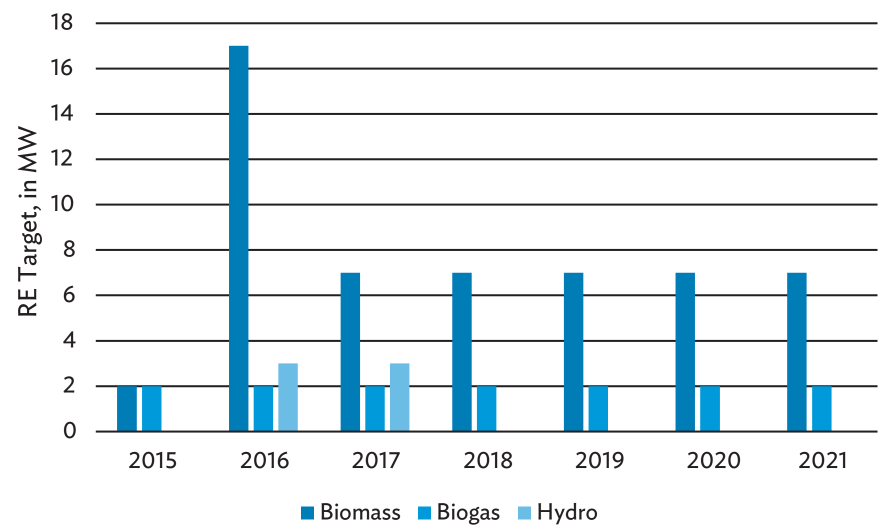
Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. 2015. *Scaling Up Renewable Energy in Low Income Countries (SREP) Investment Plan for Bangladesh.*

156. The renewable energy potential study in Table 5 indicates that Bangladesh has a total potential capacity for 637 MW of wind power, and wind has been ranked almost as high a priority by SREDA for implementation due to studies undertaken by the Government of Bangladesh and the United States Agency for International Development.

4.5 Biomass—Bangladesh

157. There are two biomass power plants in Bangladesh, which are off-grid projects with capacities of 0.4 MW and 0.25 MW. The 0.25 MW is mini-grid-connected and supposed to be able to supply power up to 200 households and 100 businesses but currently only operates at 56 kW and supplies 50 households. SREDA indicates that if rice husks are used for electrical energy production, there can be up to a 274-MW potential capacity. Biomass readiness of availability for electricity production is listed as medium by SREDA, and solar projects always take priority. Total future targets for biomass-based energy improvements are displayed in Figure 28 (biomass here includes both biomass [7 MW] and waste-to-energy [47 MW] power). There are plans to build a 1-MW waste-to-energy pilot power plant soon that uses household waste.

Figure 28: Bangladesh's Biomass, Biogas, and Hydro Yearly Installation Targets



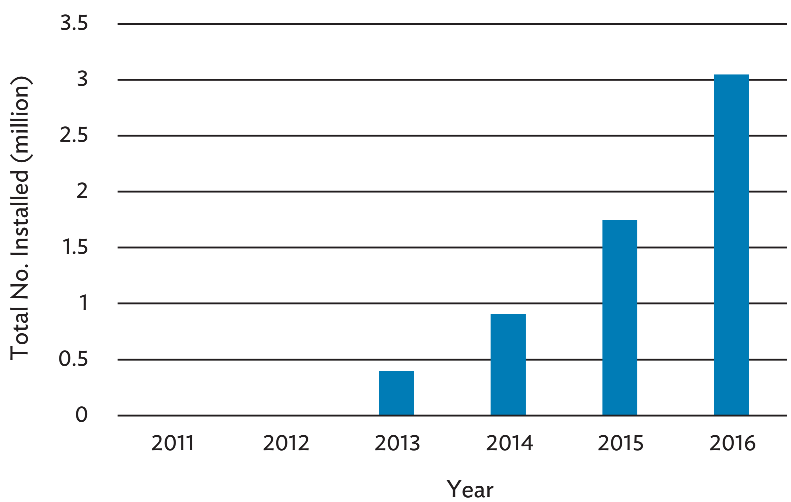
MW = megawatt, RE = renewable energy.

Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. 2015. *Scaling Up Renewable Energy in Low Income Countries (SREP) Investment Plan for Bangladesh.*

158. Biomass accounts for 50% of Bangladesh's energy supply, as many Bangladeshi households use biomass for cooking. This is a problem as biomass fuels are becoming less available and more expensive.

159. The Bangladesh Country Action Plan for Clean Cookstoves was implemented by the Government of Bangladesh in 2013 with the aim of achieving 100% (over 30 million households) clean cooking solutions by 2030 with financial support from GIZ Bangladesh, Global Alliance for Clean Cookstoves, SNV Netherlands Development Organisation, United States Agency for International Development, and the World Bank. IDCOL has recently established its own ICS program with help from the World Bank to disseminate one million ICS by 2018. SREDA reports that over 3 million ICS have been installed. The most common biomass ICS is the Chulha model which takes 1–2 hours to build and lasts approximately 3 years. Figure 29 shows the total number of ICS installed by SREDA over the last 6 years.

Figure 29: Bangladesh's Installed Improved Cookstoves

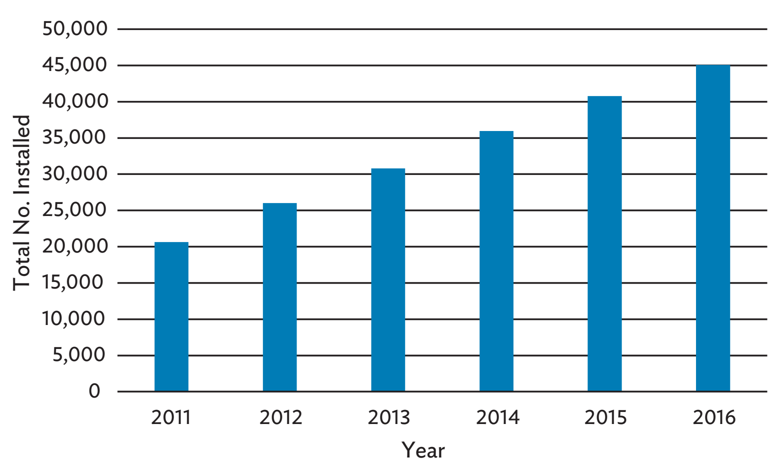


Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. Renewable Energy/Energy Efficiency Status Report (Installed): http://www.sreda.gov.bd/index.php/site/re_present_status.

4.6 Biogas—Bangladesh

160. The vast majority of biogas is produced by small-scale household plants and is used for cooking. These domestic biogas plants are anaerobic digesters 2.4–4.8 m^3 in size, which are operating using mostly animal waste and sometimes human waste. As of June 2018, over 48,300 of these systems have been installed. IDCOL funds the program and the systems are installed by Grameen Shakti (unit cost $330–$615).[6] The total number of small-scale biogas plants installed from 2011 to 2016 is shown in Figure 30.

Figure 30: Bangladesh's Cumulative Installed Biogas Plants



Source: Government of Bangladesh, Sustainable and Renewable Energy Development Authority. Renewable Energy/Energy Efficiency Status Report (Installed). http://www.sreda.gov.bd/index.php/site/re_present_status.

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6 With additional funding by KfW and the World Bank.

161. There are currently six IDCOL-funded biogas off-grid power plants in operation with a combined capacity of 0.63 MW. The estimated potential for production of electricity using biogas is 1,376 kW for cattle manure and 8,052 kW for poultry manure.

162. SREDA currently lists a 1-MW on-grid biogas plant due to come into operation at the end of 2017, and one 0.06-MW plant that was due to come online at the end of 216 but is not listed as operational. It lists biogas electricity production potential as moderate, and domestic biogas plant installation as medium-high with over 40+ organizations using the IDCOL model.

4.7 Hydropower—Bangladesh

163. Hydro provides the majority of renewable power supplied to the grid, but this is only from the single 230-MW Kaptai Hydropower Plant, which has been running since 1988 (although a 10-kW micro hydro plant does exist in Bamerchara).

164. Assessment of the potential of hydro energy was carried out in the country by Stream Tech (US). As of the end of 2015, SREDA officially stated that “Hydropower has limited potential in Bangladesh due to concerns about land use and flooding.” Grid-connected hydro has not been considered for SREDA funding, but they have hope that hydrokinetic energy may be useful: “Hydrokinetic generation may be well suited for future application in Bangladesh if viability is proven over the next ten years.”

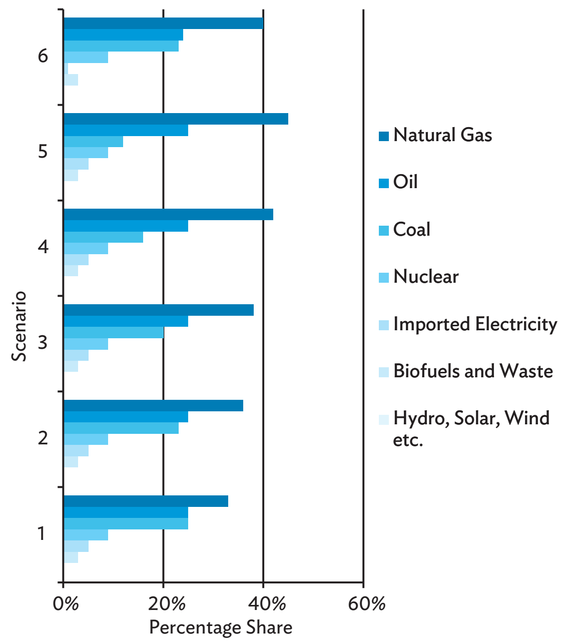
165. It is interesting to note, however, that the government does have a target of installing 4 MW of small hydro by 2021, but only with help from the Green Climate Fund.

4.8 A Realistic Look at the Future Energy Balance of Bangladesh

166. The future energy scenarios in Figure 31 and Figure 32 were put together by the Japan International Cooperation Agency in the People’s Republic of Bangladesh Survey on Power System Master Plan 2015.[7] The report considered economic, social, financial, and political constraints on the future of the primary energy supplies of the country. From all the scenarios, the average growth of renewable is expected to be about 4.38% per annum from 2014 to 2041, and the average expected output from renewables in 2041 is expected to be about 131.17 thousand tons of oil equivalent (1,525.51 GWh), which represents less than 1% of all energy produced. The targets set out in the Power System Master Plan 2016 for power generation, as mentioned in section 4.1, will further influence these forecasts as projects are completed and interim targets achieved.

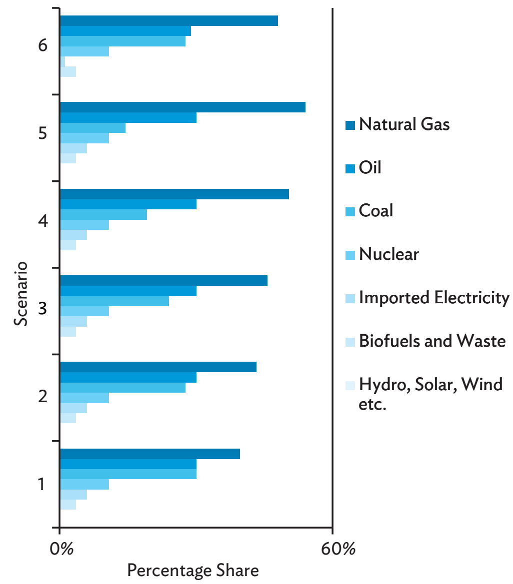
[7] There are six scenarios of fuel mix varying the composition of natural gas and coal for power generation, among which scenario 1 depends maximally on coal usage whereas scenario 6 relies maximally on natural gas, as well as some optional scenarios that stretch the promotion of renewable energy.

Figure 31: Bangladesh's Predicted Share of Energy Production by Resource by 2041



Source: Japan International Cooperation Agency. 2016. *People's Republic of Bangladesh Survey on Power System Master Plan 2015: Draft Final Report.*

Figure 32: Bangladesh's Predicted Growth of Energy Production Sources 2014–2041



Source: Japan International Cooperation Agency. 2016. *People's Republic of Bangladesh Survey on Power System Master Plan 2015: Draft Final Report.*

4.9 Conclusions

167. As the example of Bangladesh's SHS program demonstrates, distributed generation, driven by technology innovation, can be a pathway for providing energy access and rural electrification solutions. The SHSs are the biggest contributor to renewable energy penetration in the country. This has impacted women beneficiaries both through access to electricity and to livelihood and employment opportunities, including as technicians.

168. There is a trend toward more complex solar mini-grid systems. There are currently 11 operational mini-grid projects in Bangladesh and 15 under construction (Rashedul Alam 2017). This creates improved energy consumption levels through the inclusion of higher loads for productive activities, and has implications for the economic development of local communities. Furthermore, the IDCOL Solar Irrigation Program has a target of installing 50,000 solar irrigation pumps in rural off-grid areas by 2025 to aid the agricultural industry.

169. There is potential for small and micro power producers to emerge as the backbone of new mini-grid-related industries. With the right policy environment, strategies, and plans, women and marginalized groups can participate in these industries from their inception.

170. The collection of technology data needs to reflect the energy transition from the old grid to the new one. It needs to have a greater focus on information relevant for distributed generation in both on-grid and off-grid systems. This requires accurate information at the households and for small power producers. The shift is starting to be reflected in the technology data collected by energy agencies, which now includes some household data.

171. There is a lack of sex disaggregated technology uptake data collected by government agencies. However, nongovernment organizations do have programs that specifically target BPL women and households headed by women, and provide some data related to this.

172. Figure A2 in the Appendix is a proposed template for integrating GESI information in technology data collection.

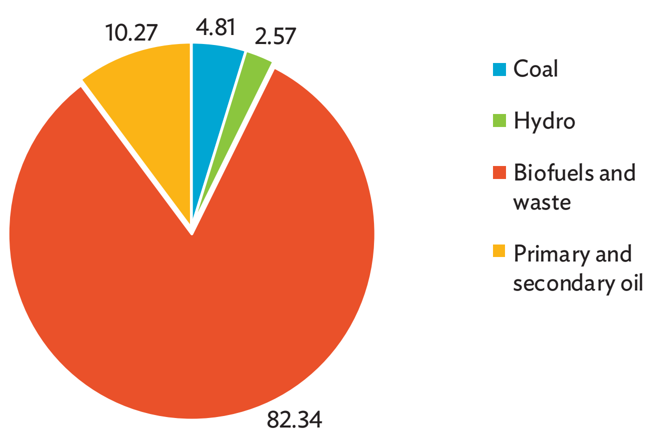
5. TECHNOLOGY AUDIT—NEPAL

5.1 Introduction

173. The primary source of energy supply in Nepal is biofuel (82.34%) (Figure 33). With respect to electricity generation, hydro is the primary source for supply at 3,453 GWh (both large and small), with 6 GWh of wind power, and 1 GWh of solar power making up the remainder.

174. Small off-grid hydro systems (up to 1 MW) have been a major source of electricity provision in remote rural communities, and it is estimated that more than 100 MW of electricity can be supplied by these systems. From July 2012, the various Alternative Energy Promotion Centre (AEPC) programs were consolidated under the National Rural and Renewable Energy Programme (NRREP). Table 7 contains the baseline values for renewable energy deployment at the time of the consolidation. Under the NRREP the following systems were operationalized: 8.6 MW of SHP; 289,523 units of solar PV home systems, and 64,074 units of domestic biogas systems. The devastation caused by the 2015 earthquake caused significant damage to the systems and impeded the implementation of the rural renewable energy program: approximately 249 SHP systems were destroyed, approval processes were delayed, and the transportation of equipment was severely hampered. Table 8 is a breakdown of recent and current government funded AEPC programs.

Figure 33: Nepal's Share of Total Primary Energy Supply
(%)



International Energy Agency. Nepal: Balances for 2014. https://www.iea.org/statistics/?country=NEPAL&year=2016&category=Key%20indicators&indicator=TPESbySource&mode=chart&categoryBrowse=false&dataTable=BALANCES&showDataTable=false (accessed 15 December 2017).

Table 7: 2012 Baseline of Nepal's Renewable Energy Deployment

Renewable Energy Technology	No.	Capacity	Unit	Districts Covered	Subsidized (%)
Hydro					
Mini hydro	42	16.34	MW	31	2.4
Micro hydro	1,287	24.60	MW	59	87.0
Pico hydro	1,634	3.70	MW	56	94.7
Improved water mill	9,015	-	kW	49	99.9
Biogas					
Household plant	277,226	-		74	100.0
Institutional plant	226	-		36	100.0
Community plant	74	-		20	100.0
Solar					
Solar PV home systems (20Wp and >)	329,849	8.43	MWp	74	100.0
Institutional solar PV	2,155	2,949.35	kWp	42	55.8
Solar pumps	111	116.65	kWp	22	100.0
Solar cookers and dryers	2,024	-		30	100.0
Small solar PV home systems (10Wp)	22,605	113.02	kWp	49	100.0
Improved cookstoves	746,223			52	1.0
Wind	24	26.70	kW	12	54.2

kW = kilowatt, kWp = kilowatt-peak, MW = megawatt, MWp = megawatt-peak, PV = photovoltaic, Wp = watt-peak.
Source: Government of Nepal, Alternative Energy Promotion Centre. Baseline for Rural and Renewable Energy Technologies (until 15 July 2012).

Table 8: Cumulative Physical Deployment of AEPC Systems (Number of)

System	Year				
	2012/2013	**2013/2014**	**2014/2015**	**2015/2016**	**2016/2017**
Mini/Micro Hydro	3,366	6,654	10,300	12,210	13,455
Solar Home System	96,495	183,533	286,694	343,464	359,548
Biogas Plant	17,635	49,147	79,225	95,931	116,467
Solar Dryer	140	342	372	394	394
Improved Water Mill	1,256	1,597	2,238	2,911	2,911
Improved Cook Stove	120,364	261,026	571,315	622,526	683,081

Source: Government of Nepal, Alternative Energy Promotion Centre Solar Home System. https://aepc.gov.np/statistic/solar-home-system# (accessed 4th September 4, 2018).

5.2 Tariffs and Subsidies—Nepal

175. The inclusion of statistics on subsidies is also an important feature of AEPC's data collection. Table 9 gives a breakdown of the cumulative progress on subsidies in Nepal.

Table 9: Analysis of Cumulative Progress on Subsidy in Nepal
(NRs '000)

SN	Program Target Areas	Total Budget for 1st to 3rd Year	Cumulative Achievement			
			1st and 2nd year	3rd year	Total	%
1.	Mini/micro hydropower	1,840,000	1,000,698	255,561	1,256,259	68.3
2.	Improved water mill	61,900	23,295	10,688	33,983	54.9
3.	Solar PV home systems and small solar PV home systems	2,165,000	1,293,236	505,920	1,799,156	83.1
4.	Institutional solar PV systems	780,000	128,959	124,283**	253,242	32.5
5.	Solar drinking water pumping system	210,000	65,343	26,243	91,586	43.6
6.	Solar dryer	60,150	1,749	0	1,749	2.9
7.	Solar cooker	6,000	0	0	0	0.0
8.	Metallic ICS	133,250	35,819	26,613	62,432	46.9
9.	Domestic biogas plants	2,436,000	1,012,617	813,685	1,826,302	75.0
10.	Institutional/community biogas/commercial plants	64,480	0	4,451	4,451	6.9
11.	Productive energy use (new and upgraded MSMEs)	189,000	26,263	42,634	68,897	36.5
	Total	**7,945,780**	**3,587,979**	**1,810,078**	**5,398,057**	**67.9**

ICS = improved cookstoves; ISPS = institutional solar photovoltaic systems; MSMEs = micro, small, and medium-sized enterprises; NRREP = National Rural and Renewable Energy Programme; PV = photovoltaic.
** This figure does not include the subsidy paid for 109 ISPS (paid against bank guarantee) and 122 ISPS (paid from Governments of Nepal budget)."
Source: National Rural and Renewable Energy Programme (NRREP) annual reports (July 2012–July 2015).

Table 10: Nepal's National Rural and Renewable Energy Programme Technology Uptake and Subsidies Disbursed

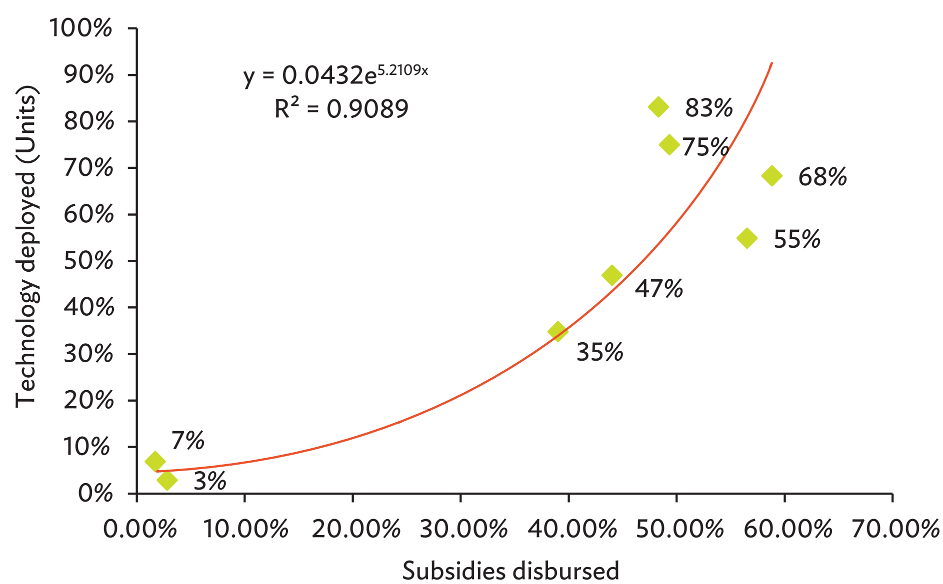
Technology/System Type	Units (% of Target)	Disbursed Amount (% of Budget)
Small hydropower (households)	59	68
Improved water mills	57	55
Solar PV home systems	48	83
Solar dryers and cookers	3	3
ICS (metallic)	44	47
Domestic biogas plants	49	75
Institutional, community, commercial biogas plants	2	7

ICS = improved cookstoves, PV = photovoltaic.
Source: National Rural and Renewable Energy Programme annual reports (July 2012–July 2015).

176. There is a strong correlation (R ~ 0.9) between the technology deployed, measured in number of units as a percentage of the overall target, and subsidies disbursed, measured as a percentage of the budget allocation. This is an indication that targeted subsidies can significantly influence the uptake of technologies, especially in low-income and BPL communities (Table 10 and Figure 34).

177. The Subsidy Policy for Renewable Energy 2012 would have guided the implementation of the government program for the period that the data was collected.[8] The purpose of these policies is to address problems of differential access based on remoteness, gender, ethnic, caste, and other social inequities to promote the uptake of renewable energy technologies in rural poor communities.

Figure 34: Correlation between Technologies/Systems Uptake and Subsidies in Nepal



Source: NRREP annual reports (July 2012–July 2015).

8 In 2016, a new subsidy policy replaced the 2012 policy.

178. Key social objectives of the Subsidy Policy for Renewable Energy 2012 are included in the following policy objectives:

- **Policy 7.1:** "To increase access to renewable energy technologies for low income households by reducing the initial upfront cost"
- **Policy 7.2:** "To maximize the service delivery and its efficiency in the use of renewable energy resources and technologies in the rural areas ... and minimize regional disparity"
- **Policy 7.3:** "To support use of energy for productive purpose thereby creating rural employment and enhancing livelihood of rural people particularly women, poor and socially excluded group, vulnerable community"
- **Policy 7.4:** "To ... reduce the growing gap of electricity supply, consumption between rural and urban areas"
- **Policy 7.7:** "To encourage rural households in the use of renewable energy services thereby contributing to better health and education conditions of people"

179. An additional subsidy category applies exclusively to socially disadvantaged groups such as marginalized castes and ethnic communities, as well as households headed by women.[9] For example, households in very remote communities connected to small hydro systems receive a subsidy of NRs20,000 and an additional subsidy of NRs2,000 if they are also headed by women. Solar PV pumps for pumping water, which are managed by the community, receive a subsidy of up to 70% to cover up-front costs. In the case of households headed by women, they qualify for an additional subsidy of NRs2,500. Single women wanting to start up or develop their small enterprises can receive an additional subsidy of up to NRs10,000, provided the enterprises use energy from renewable sources. Through the provision of such additional subsidies, the policy promotes a progressive system of subsidies, explicitly weighted toward enabling the most deprived, rural poor, and women to access renewable energy technologies.

180. Another unique and important feature of the AEPC statistics is the collection of information on beneficiaries, disaggregated by sex, caste, and religion (Table 11). This is a result of the GESI mainstreamed features of the NRREP, including the production of a toolkit to support GESI mainstreaming (Government of Nepal, AEPC 2014).

Table 11: Nepal's Beneficiaries Disaggregated by Sex, Caste, and Religion

S.N.	Programs/ activities	Benefited				Caste/Ethnicity/Religion (% of the benefited population)				
		Household	Population	Male	Female	Janjati	Dalit	Madhesi	Muslim	Others (B/C/T)
1	"Micro/ Mini/pico hydro"	22,733	110,937	53,804	57,133	15.2	4.8	10.6	4.4	65
2	IWM	27,866	135,986	65,953	70,033	15.2	4.8	10.6	4.4	65
3	SSHS	10,831	43,324	21229	22,095	NA	NA	NA	NA	NA
4	SHS	92,330	369,320	180,967	188,353	NA	NA	NA	NA	NA
5	PVPS	1,400	8,565	4378	4,308	66	9	0	0	25

continued on next page

[9] Households headed by women are referred to as "single women" in the subsidy policy.

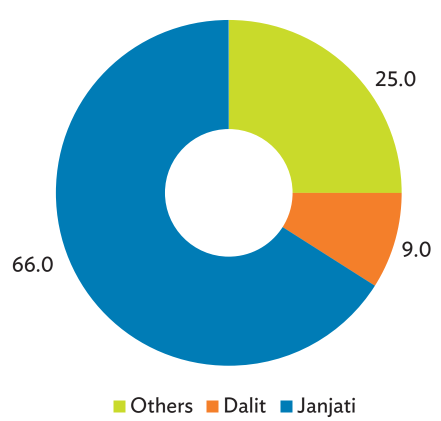
Table 11 *continued*

S.N.	Programs/ activities	Benefited				Caste/Ethnicity/Religion (% of the benefited population)				
		Household	Population	Male	Female	Janjati	Dalit	Madhesi	Muslim	Others (B/C/T)
6	Solar Dryer	26	130	64	66	46	0	0	0	54
7	Biogas-Domestic	30,196	150,980	14,492	15,704	52	1	1	0	46
8	ICS-Metal	6,746	32,380	16,123	16,257	59	9	0	0	33
9	ICS-Mud	281,469	1,550,683	782,318	766,537	30	17	27	7	19
10	MSMEs	1,054	5,144	900*	154**	38	6	NA	NA	56
11	IGA	3,217	15,699	1,245#	1,972##	47	18	NA	NA	35

ICS = improved cookstoves; IGA = income-generating activities; IWM = improved water mill; NA = not applicable; MSMEs = micro, small, and medium-sized enterprises; SHS = solar home system; SSHS = small solar home system; PVPS = photovoltaic pumping system.
* Number of man-owned MSMEs.
** Number of woman-owned MSMEs.
# Number of man-owned IGA.
Number of woman-owned IGA.
Source: National Rural and Renewable Energy Programme annual report (2014–2015).

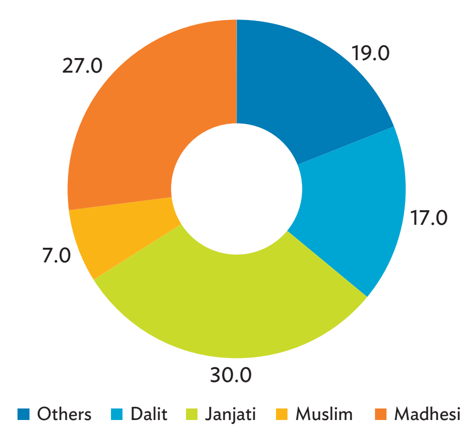
181. The following figures (Figures 35–38) are an indication of the uptake of new technologies among various sections of the population and the bearing of social inclusion considerations on the uptake of technologies. The marginalized caste and religions (Dalit and Muslims) consistently rank low in the beneficiaries. Gender differences between women and men are marked in the ownership of MSMEs, with men owning five times as many MSMEs as women under the program.

Figure 35: Nepal's Solar Photovoltaic Pumping Systems Uptake—Ethnic Composition
(%)



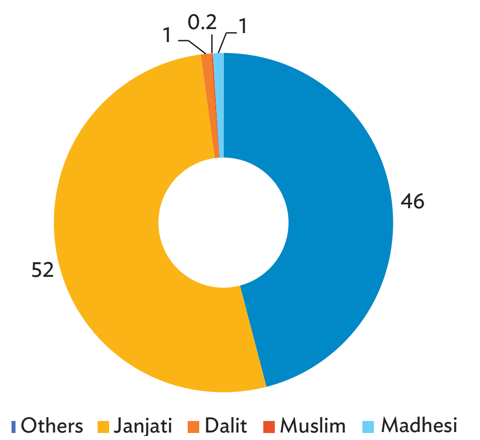
Source: National Rural and Renewable Energy Programme annual report (2014–2015).

Figure 36: Nepal's Improved Cookstoves Uptake—Ethnic Composition
(%)



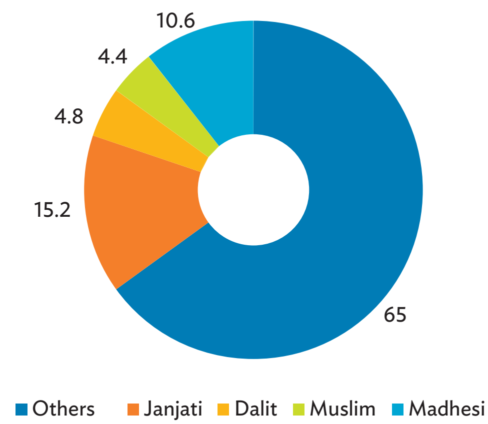
Source: National Rural and Renewable Energy Programme annual report (2014–2015).

Figure 37: Nepal's Domestic Biogas Plant Uptake—Ethnic Composition
(%)



Source: National Rural and Renewable Energy Programme annual report (2014–2015).

Figure 38: Nepal's Small Hydropower System Beneficiaries—Ethnic Composition
(%)



Source: National Rural and Renewable Energy Programme annual report (2014–2015).

5.3 Hydropower—Nepal

182. The installation of micro hydro systems in Nepal has a long history dating back to the use of water mills for agro-processing. With the addition of generators, micro hydro systems emerged as one of the primary means of providing rural electrification, primarily lighting. Various impact assessments have been conducted of the AEPC's micro hydro programs, which indicate important beneficial impacts in rural communities, ranging from increases in households' nonfarm incomes, improved outcomes in maternal health and respiratory illnesses, increase in children's schooling years, and reduction in women's labor time with the mechanization of agro-processing labor due to electrification (Banerjee et al. 2011, Legros et al. 2011, Pokharel 2006).

183. In Nepal, a micro hydro installation is defined as having a capacity less than 100kW, although the AEPC/NRREP provides support of up to 1 MW for installations. As of mid-2016, approximately 39.28 MW of micro hydro is installed; most of the plants, however, have low plant factors of 15%–40%. This is mainly due to marginal business opportunities in communities and so the systems are underutilized. Since mid-2012 the AEPC/NRREP has been installing these plants (Government of Nepal, AEPC 2016).

184. The potential micro hydro resource capability for Nepal is estimated at 100 MW. The country is moving forward with making full use of this capacity with approximately 617 technical staff (268 engineers, 349 technicians) across all sectors in micro hydro and approximately 35 manufacturers and 80 installation companies. Improvements in training programs are still necessary, however, as it is estimated that on average only one operator per micro hydro installation has been trained and attrition rates are high for these courses. In addition, the AEPC estimates that 30%–40% of operators who completed their courses in rural areas end up working abroad (Government of Nepal, AEPC 2016).

185. The NRREP commenced in July 2012. The target for installations of mini and micro hydro plants was 25 MW, providing electricity to about 150,000 rural households. As of September 2016, 8 MW has been achieved. At that stage, AEPC has supported 1,163 micro hydro enterprises, with another 353 projected. With respect to electrification, NRREP reported that from July 2014 to July 2015, 25,235 rural households were electrified through micro hydro projects (Government of Nepal, AEPC 2012; Government of Nepal, AEPC 2015; Government of Nepal, AEPC 2016).

186. Under the AEPC's Micro Hydro Debt Fund (and some of its other programs), a total of 26 micro/pico hydro projects have been funded by different banks (NRs63 million) as of October 2015. Most financial institutions have not lent because most installation designs are not project-specific and the quality of installation by undertrained technicians is often poor (Government of Nepal, AEPC 2015; Government of Nepal, AEPC 2016; Nepal Rastra Bank 2010).

187. Most micro hydro plants are community-owned; subsidies exist for off-grid community, cooperative, public–private partnership owned mini and micro hydro plants of 10–1,000 kW. An additional subsidy of NRs4,000 is provided to households headed by women with dependent children, earthquake victims, and endangered indigenous communities, identified by the government, and Dalit. Interestingly, for micro hydro projects that have not been completed due to inadequate finance, the government provides a subsidy of up to 80% of the cost of completion (Government of Nepal, Ministry of Population and Environment 2016).

5.4 Conclusions

188. The AEPC is a good practice case study of GESI mainstreaming in energy programs and of the collection of GESI data to monitor implementation.

189. Technology innovation is enabled by the policy and regulatory environment. This includes financial assistance and tariff incentives as demonstrated by the targeted subsidy policies in Nepal, in which household consumers and low-income and BPL consumers were targeted beneficiaries.

190. Nepal demonstrates that social criteria, including GESI criteria, can be effectively integrated to promote technology uptake for rural electrification solutions. The findings in the Nepal case show a strong correlation between targeted financial assistance and technology uptake in BPL and marginalized communities.

191. Distributed generation, driven by technology innovation, can be a pathway for providing energy access and rural electrification solutions. With the right policy environment, strategies, and plans, women and marginalized groups can be enabled to participate in these industries from their inception.

192. The collection of technology data needs to reflect the energy transition from the old grid to the new one. It needs to have a greater focus on information relevant to distributed generation in both on-grid and off-grid systems. This requires accurate information at the households and for small power producers. This shift is starting to be reflected in the technology data collected by energy agencies, which now includes some household data.

193. The proposed template (Appendix, Figure A2) is drawn from the Nepal case of data collection disaggregated by sex, caste, religion, and ethnicity.

6. TECHNOLOGY AUDIT—SRI LANKA

6.1 Introduction

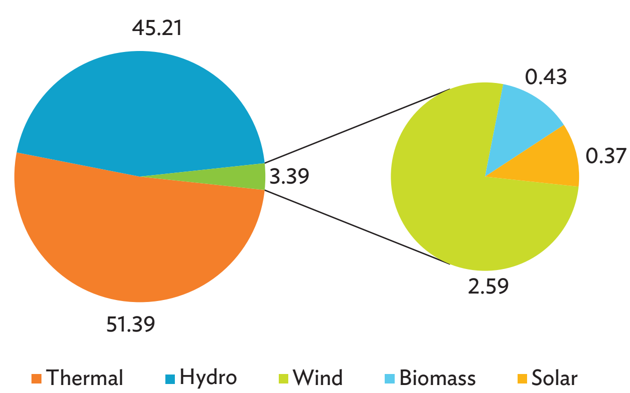
194. As of 2015, the major source of Sri Lanka's electricity production is fossil fuel-powered thermal plants, the majority of which are owned by the state-owned utility Ceylon Electricity Board (CEB). Coming in at a close second are hydro plants. The hydro resources of the country are almost at full utilization however, and so construction of new plants is not desirable (Government of Sri Lanka, Sri Lanka Sustainable Energy Authority [SLSEA] 2015). Table 12 gives the full breakdown of yearly generation by plant category, and Figure 39 gives a source overview.

Table 12: Sri Lanka's Total Power Generation Trends by Technology Type
(gigawatt-hour)

Total Generation		2011	2012	2013	2014	2015
Electrical board	CEB Hydro	3,972.67	2,726.72	6,010.10	3,649.72	4,904.41
	CEB Wind	2.66	2.32	2.32	2.13	1.07
	CEB Thermal	2,531.68	3,432.62	2,795.78	5,269.10	5,524.39
Private	IPP Thermal (Gross)	4,352.33	4,983.85	2,023.94	2,675.20	1,272.03
	SPP Hydro	600.57	564.69	908.39	902.17	1,064.72
	SPP Thermal	0.00	0.00	0.00	0.00	0.00
	SPP Solar	1.11	2.00	1.68	1.47	1.87
	SPP Biomass	31.63	22.17	26.39	41.39	57.31
	SPP Wind	88.95	144.48	232.26	270.32	342.13
Net solar	NMP Solar	0.00	0.00	4.69	18.60	38.84
Off-grid	Small Hydro, Industrial	7.07	7.07	7.07	7.07	7.07
	Small Hydro, Household	3.58	3.69	3.69	3.69	3.69
	Solar Photovoltaic, Household	7.60	8.01	8.01	8.01	8.01
	Wind Energy, Household	0.01	0.01	0.01	0.01	0.01
Gross Generation		11,599.87	11,897.62	12,024.32	12,848.88	13,225.54

CEB = Ceylon Electricity Board, IPP = independent power producer, NMP = net-metering project, SPP = small power producer.
Note: Numbers may not sum precisely because of rounding.
Sources: Public Utilities Commission of Sri Lanka. 2016. *Generation Performance in Sri Lanka 2016*. http://www.pucsl.gov.lk/english/wp-content/uploads/2017/07/GenPerformance-2016_Draft.pdf; Ministry of Power and Renewable Energy, Sri Lanka. http://powermin.gov.lk/english/.

Figure 39: Sri Lanka's Electrical Energy Produced by Source, 2015
(%)



Sources: Public Utilities Commission of Sri Lanka. http://www.pucsl.gov.lk/english/; Ministry of Power and Renewable Energy, Sri Lanka. http://powermin.gov.lk/english/.

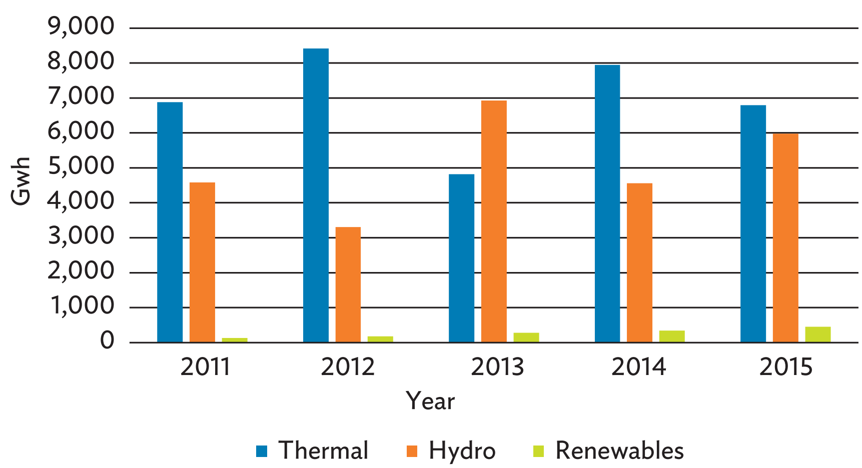
195. To address the issue of unsustainable hydropower construction the Ministry of Power and Energy published the National Energy Policy and Strategies of Sri Lanka in 2008. The objective was to reduce the amount of oil-based power supplied to the grid and use coal and renewable energy sources to cover the shortfall. As outlined in "Sri Lanka Energy Sector Development Plan for a knowledge-based Economy 2015–2025" coal, LNG, solar, wind, hydro, and biomass are the preferred fuel options for electricity generation with the reduction of oil-based power plants by converting them to gas a priority (Ministry of Power and Renewable Energy 2015). Figure 40 and Table 13 give overviews of the previous 5-year energy balance of the country.

Table 13: Sri Lanka's Primary Energy Supply by Source
(%)

Total Energy Share	2011	2012	2013	2014	2015
Biomass	43.7	42.8	43.3	42.5	38.8
Petroleum	43.4	45.9	36.9	39.4	38.9
Coal	2.9	4	4.3	8	9.9
Major Hydro	8.5	5.7	13	7.6	9.5
New Renewable Energy	1.6	1.6	2.6	2.6	2.9

Source: Government of Sri Lanka, Sri Lanka Sustainable Energy Authority. 2015. *Sri Lanka Energy Balance 2015*. Colombo. p. 19.

Figure 40: Sri Lanka's 5-Year Electrical Energy Production

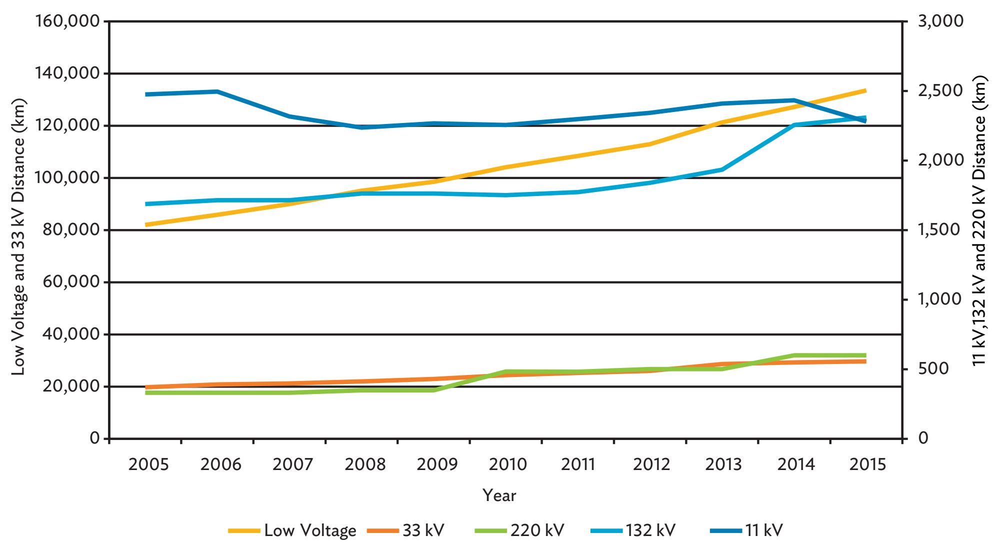


GWh = gigawatt-hour
Sources: Public Utilities Commission of Sri Lanka. http://www.pucsl.gov.lk/english/; Ministry of Power and Renewable Energy, Sri Lanka. http://powermin.gov.lk/english/.

196. The first coal fired power plant commenced operation in 2011 with a capacity of 300 MW, and as of 2015 the country operates a total of three 300-MW plants. The CEB operates these coal plants as the base load providers, and in 2015 coal power met 34% of all electricity generated and accounted for 95.6% of all Sri Lanka's total coal demand.

197. A quick look at the 5-year electrical energy production chart in Figure 41 shows that thermal power production has not been increasing in general, but, as discussed, power production from coal has been increasing at an accelerated rate—the lack of decline in yearly thermal power production is only due to the phasing out of oil power plants. Hydro has been variable due to weather patterns, and hydro and coal have been maintaining the base load. Of most interest, though, is that the production from renewable sources has been steadily increasing.

Figure 41: Sri Lanka's Transmission Line Length by Year



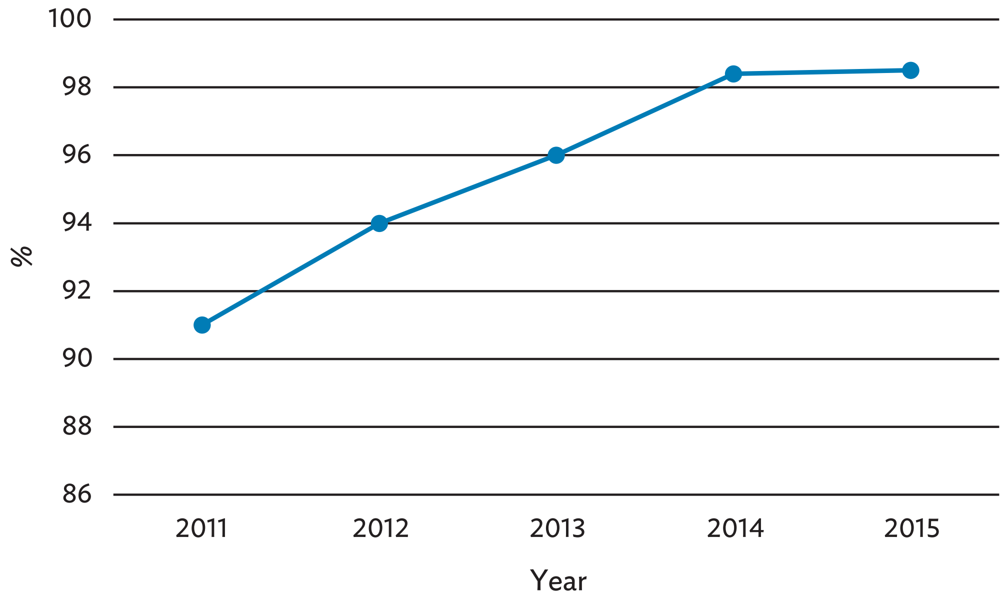
km = kilometer, kV = kilovolt.
Source: Ceylon Electricity Board Statistical Digest 2006–2015.

6.2 The Grid—Sri Lanka

198. The 10-year transmission line length trend shown in Figure 42 indicates relatively regular and stable grid development, except 2013–2014 when about 500 km of extra 132-kilovolt lines were installed. Also noteworthy is the relatively steady decrease of 11-kilovolt lines due to replacement with higher voltage lines.

199. As of 2015, Sri Lanka has 98.5% household electrification. This is a significant improvement over previous years, as shown in Figure 42.

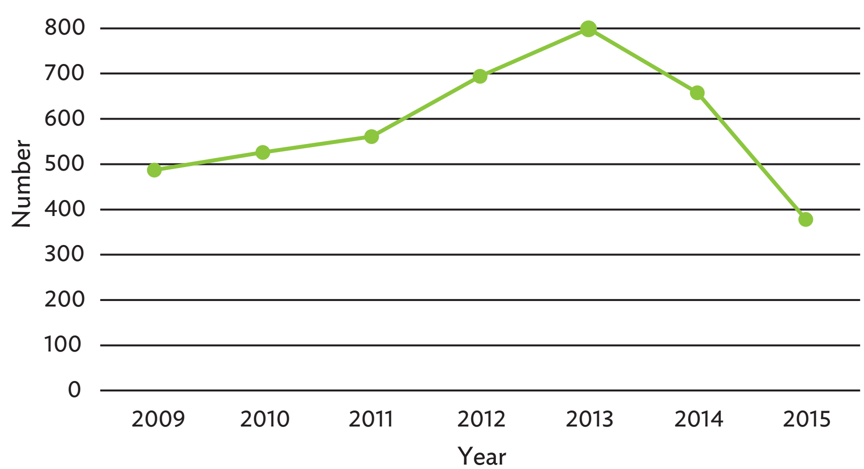
Figure 42: Sri Lanka's Households Electrified



Source: Ceylon Electricity Board Statistical Digest 2011–2015.

200. The northern and eastern parts of the country have least access to the grid. Rural electrification schemes have been steadily decreasing since 2013 (Figure 43) as the need for new schemes were not present. However, this is most likely due to the massive strides made in electrification during the past. There are still some noteworthy rural electrification projects in action. As of 2015, there was a Japanese-funded project to supply off-grid power to 600 families on Baththalangunduwa Island and a study in electrifying Uchchimunai Island has been completed.

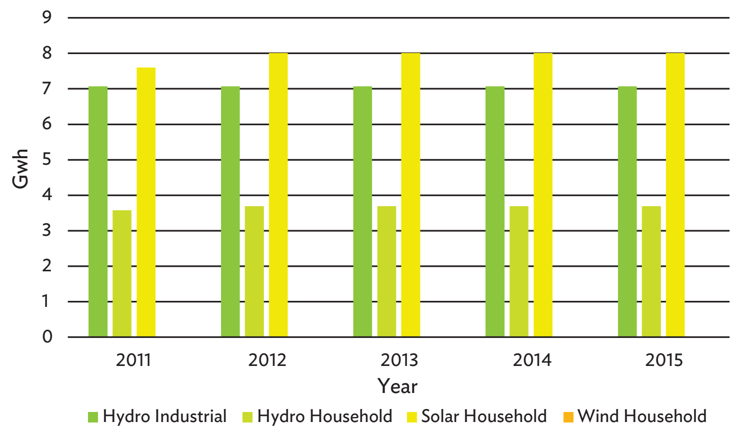
Figure 43: Sri Lanka's Rural Electrification Schemes



Source: Ceylon Electricity Board Statistical Digest 2009–2015.

201. In the arena of the off-grid system, the 2015 Sri Lanka Energy Balance Report indicated that there were 32 industrial off-grid hydro plants, all servicing the tea industry; 260 off-grid village level hydro plants, most of which were in disuse; a few dozen off-grid household wind power plants, most of which were in disuse; and widespread off-grid residential small-scale solar installations, which are used for lighting and agriculture. Figure 44 gives an overview of off-grid generation during 2011–2015.

Figure 44: Sri Lanka's Off-Grid Generation

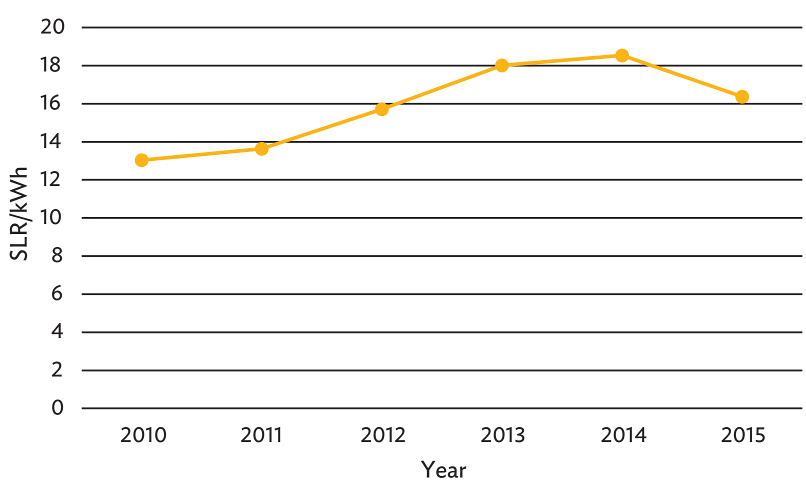


GWh = gigawatt-hour.
Sources: Public Utilities Commission of Sri Lanka. http://www.pucsl.gov.lk/english/; Ministry of Power and Renewable Energy, Sri Lanka. http://powermin.gov.lk/english/.

6.3 Tariffs and Subsidies—Sri Lanka

202. The average selling price of electricity in Sri Lanka was $0.118/kWh in 2015, and the average cost of actual generation was $0.074/kWh.[10] Figure 45 shows the trend since 2010.

Figure 45: Sri Lanka's Average Electricity Price



kWh = kilowatt-hour.
Source: Government of Sri Lanka, Sri Lanka Sustainable Energy Authority. 2015. *Sri Lanka Energy Balance 2015*. Colombo. p. 52.

10 Figures are calculated using a conversion rate of SLRs149 to the $, which approximated market rates in May 2017.

203. According to a 2016 ADB study, only small and medium domestic households and small-scale industry receive subsidies on their tariffs. Electricity cross subsidies, along with cost of supply are shown in Table 14.

Table 14: Sri Lanka's Subsidy Report 2016

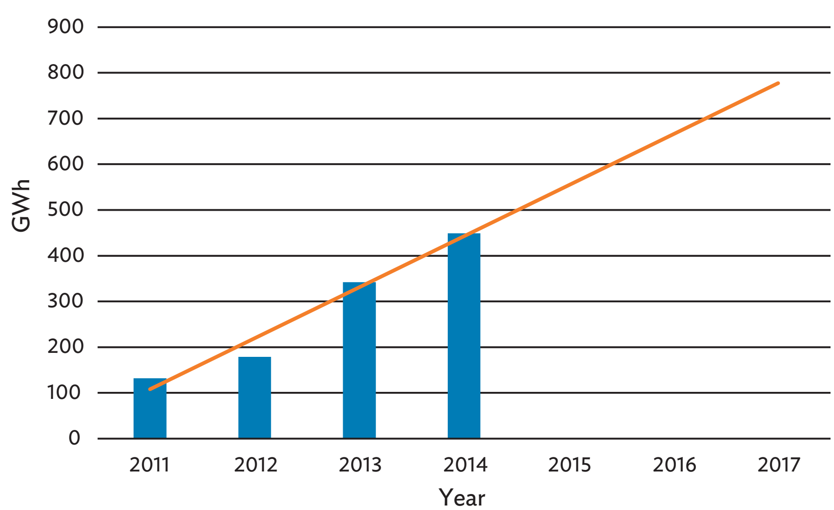
Customer	Class	Monthly Use (kWh)	Average Tariff (SLR/kWh)	Cost of Supply (SLR/kWh)	Subsidy (%)
Domestic	Small	30	3.50	27.93	87
	Medium	90	9.57	23.29	59
	Large	180	22.24	20.92	-6
	Very Large	600	38.27	19.07	-101
Commercial	Small	1,000	21.73	19.61	-11
Industrial	Small	5,000	12.24	17.19	29

Source: ADB. 2016. *Enhancing Gender Equality Results in South Asia Developing Member Countries*. Manila. p. 25.

6.4 Renewable Energy—Sri Lanka

204. The Sri Lanka Sustainable Energy Authority (SLSEA) was established in 2007 and was tasked with overseeing the implementation of the National Energy Policy and Strategies of Sri Lanka, which set a target of 10% of energy to be delivered by new renewable energy sources by the end of 2015. This target was exceeded, with the total share of power delivered by new renewable energy sources at 11.01% in 2015. The target, however, was still a low one, and this is most likely due to high production costs associated with renewables. Coal power is produced at a mere $0.053/kWh while new renewable energy power is produced at $0.123/kWh. In a way, the coevolution of these power sources has been necessary to maintain affordable electricity prices. The total output from renewable sources from 2011 to 2015 is shown in Figure 46.

Figure 46: Sri Lanka's Renewable Energy Generation



GWh = gigawatt-hour.
Note: Trend line shows projections for 2016 and 2017.
Sources: Public Utilities Commission of Sri Lanka. http://www.pucsl.gov.lk/english/; Ministry of Power and Renewable Energy, Sri Lanka. http://powermin.gov.lk/english/.

205. To achieve their renewable energy targets, the SLSEA adopted a policy of providing competitive tariffs for the purchase of power from small power producers and a net metering scheme for solar installations for business and home consumers.[11] The tariffs offered to small power producers are regulated by the PUCSL. As of 2015, there were 181 small power producers under the scheme. The PUCSL also regulates the net metering scheme (currently solar generation only, but can theoretically be used with wind, hydro, etc.). Excess power generated by customers under this scheme is stored as kW credits. Using these strategies, the SLSEA has the further goal that 20% of all electrical power supplied will be from renewable sources by 2020. The SLSEA offers free training and capacity building, pre-feasibility studies, and resource assessments to private sector developers as an incentive to invest in becoming installers for the program.

206. As of 2016, with the introduction of Soorya Bala Sangramaya (Battle for Solar Power) and as part of the net metering development, there are available "Net Accounting"[12] and "Net Plus"[13] options for rooftop solar installations. Under the program the government aims to install 1 million home solar units over the next 10 years (Government of Sri Lanka, Ministry of Power and Renewable Energy 2015). Until 2015, home solar power generation was only popular among upper and middle-class households, however, the Net Plus scheme targets low-income households and will purchase all solar power generated by users at SLRs22.00/kWh ($0.148/kWh) for the first 7 years of production and then at SLRs15.50/kWh ($0.104/kWh) until the 20th year.[14] The SLSEA has set a target of 20% (200,000) of the total installed units to be supplied to low-income families. In addition, the government proposes that the solar systems be purchased on low interest rate loans, to be paid off in 7 years, which the excess generation of solar power will cover. Thereafter, the customer can earn between SLRs2,500 and SLRs2,700 monthly.[15]

207. In December 2016, the PUCSL formally recognized through Gazette notification- the modalities to obtain electricity connections by low income households, in line with the Sri Lanka Electricity Act No. 20 of 2009. [16] The new rules state:

> "Any person who requires a supply of electricity under Section 25 of the Act, but does not have sufficient means to pay in total at once the expenses reasonably incurred by a Distribution Licensee in providing any electrical line or electrical plant or connection and supply of electricity to the person concerned, may request the Distribution Licensee to recover such expenses in reasonable monthly installments along with the tariff and any other charges levied by the Distribution Licensee as per the standard tariff agreement."

208. The criteria that determine whether the applicant has reasonable means to pay for electrical supplies/equipment are based on the following:

> "(i) the fact that the person requesting the supply of electricity (being the owner or occupier of the premises at which the supply is required) is a Divinaguma beneficiary; or

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11 "Net Energy Metering means the measurement of the difference between electrical energy supplied through the electricity distribution network of CEB to the Producer and the amount of electrical energy generated by the Producer's Generating Facility delivered to the electricity distribution network of CEB" (Government of Sri Lanka, CEB 2016).

12 "Net Accounting means the payment for the difference between electrical energy supplied through the electricity distribution network of CEB to the Producer and the amount of electrical energy generated by the Producer's Generating Facility through Solar PV delivered to the electricity distribution network of CEB" (Government of Sri Lanka, CEB 2016).

13 "Net Plus means the consumer generates electricity through Solar PV connected to the National grid with no linkage in-between the electricity consumption of the producer" (Government of Sri Lanka, CEB 2016).

14 The rate is the same for net accounting customers. After 7 years has elapsed, the rate drops to SLRs15.50/kWh (Government of Sri Lanka, Ministry of Power and Renewable Energy 2015).

15 This is up to 20 years from the installation date of the system.

16 Government of Sri Lanka. 2009. *Sri Lanka Electricity Act, No. 20 of 2009*. Colombo. This original document contains only one mandate to assist disadvantaged groups, which was the lifeline tariff implementation.

(ii) the fact that monthly household income of the occupants, including the owner or occupier requesting the supply of electricity at the premises where the supply of electricity is required, is less than 50% of the median income of households in Sri Lanka as specified by the Department of Census and Statistics from time to time based on the Household Income and Expenditure Survey (HIES)."

209. The distributor may then seek to recover the costs of installation with monthly installments, which shall

"(i) not be more than five percent of the declared household income with the maximum deduction being not more than SLRs1,500 (equivalent to five percent of the median income of households in Sri Lanka as specified by the Department of Census and Statistics from time to time based the Household Income and Expenditure Survey) ;

(ii) be recovered over a period of not less than 24 months; and

(iii) be synchronized with the seasonal variations of income patterns, such as the cultivation cycle, if applicable".

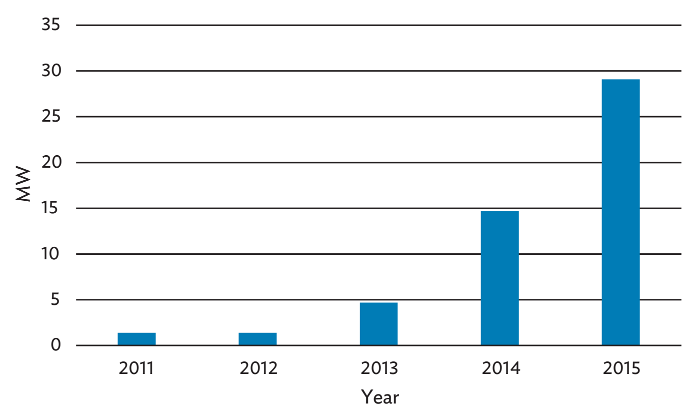
210. Distributors can also consider requests for this installment plan from "elderly persons over the age of 55 years, pensioners, disabled soldiers, whether the person requesting the supply of electricity is the owner of the premises, the extent of the premises as well as housing conditions etc."

6.5 Solar Power—Sri Lanka

211. There are only four commercial solar plants currently in operation. Two large-scale (737 kW and 500 kW) solar power plants were operated in 2015 as part of a pilot project. Unfortunately, the two plants only realized plant factors of 17.91% and 17.69%, respectively due to the failure of key components in the plants. The first new project since then was commissioned in 2016.

212. The 2015 Sri Lanka Energy Balance Report indicated that almost 28 MW of the available solar power production capacity was from micro power producers, which are small installments such as an array of solar panels on a customer's rooftop. As of 2015, there were 4,196 separate micro power installations operating. Figure 47 shows the total capacity of grid-connected solar power installations.

Figure 47: Sri Lanka's Grid-Connected Solar Power Production Capacity



MW = megawatt.
Sources: Generation Performance in Sri Lanka 2016. http://www.pucsl.gov.lk/english/wp-content/uploads/2017/07/GenPerformance-2016_Draft.pdf; Ministry of Power and Renewable Energy, Sri Lanka. http://powermin.gov.lk/english/.

213. The success of the net metering scheme in 2015 contributed in allowing the SLSEA to surpass its policy of supplying 10% of the country's power as renewable energy. To further increase installations as of 2017, all home solar systems are to be installed within 2 weeks from the date of application.

214. Proposed direct government funding for solar power in 2017 is shown in the Box below. A highlight of the 2016 budget was SLRs2 billion to power schools through solar or grid connections.

Box: Sri Lanka's Solar Highlights from the 2017 Budget Speech

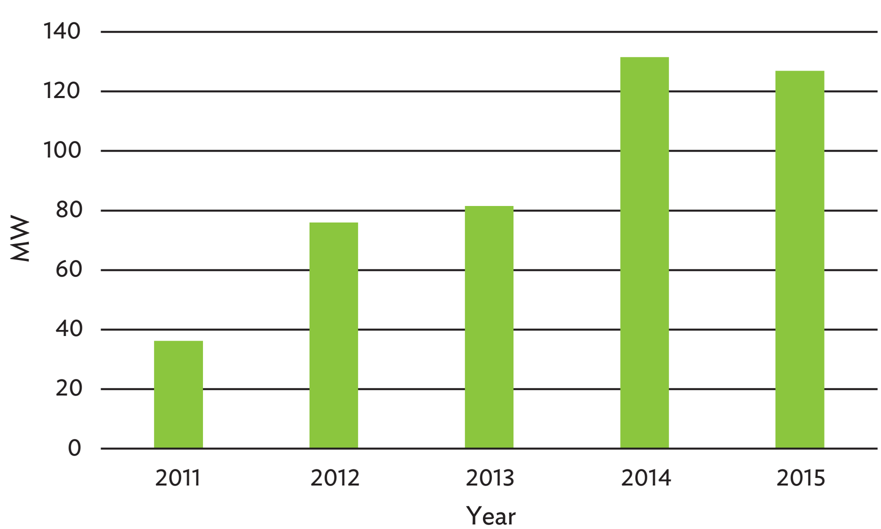
- All public sector buildings will be converted to green energy sources within 2 years—SLRs350 million.
- Households with a monthly electricity bill over SLRs2,500 will have access to loans of up to SLRs150,000 to transfer to solar energy, the government will cover half of the interest—SLRs1.5 billion.
- Solar panel modules and accessories will be exempted from the nation building tax.

Source: Government of Sri Lanka, Ministry of Finance. Budget Speech 2017: Accelerating Growth with Social Inclusion.

6.6 Wind Power—Sri Lanka

215. Figure 48 shows Sri Lanka's wind power production capacity. Sri Lanka has developed 127 MW of wind power capacity with feed-in-tariffs and standard power purchase agreements until 2015. In 2016, a 100-MW utility scale wind power project was proposed to pilot large scale wind power parks in the country.

Figure 48: Sri Lanka's Wind Power Production Capacity

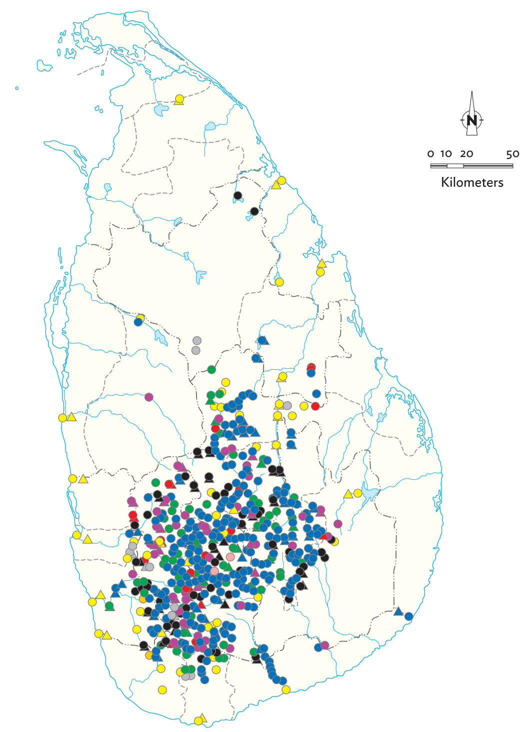


MW = megawatt.
Sources: Generation Performance in Sri Lanka 2016. http://www.pucsl.gov.lk/english/wp-content/uploads/2017/07/GenPerformance-2016_Draft.pdf; Ministry of Power and Renewable Energy, Sri Lanka. http://powermin.gov.lk/english/.

6.7 Hydropower—Sri Lanka

216. Figure 49 shows the distribution of hydro producers across the country (each marking represents a hydro plant). These producers lie in abundance in the central region. Many of the plants are off-grid. In 2015, over 10.5 gigawatt-hour (GWh) of power was produced by off-grid industrial and household hydro plants.

Figure 49: Sri Lanka's Geographic Information System Hydro Map



This map was produced by the cartography unit of the Asian Development Bank. The boundaries, colors, denominations, and any other information shown on this map do not imply, on the part of the Asian Development Bank, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries, colors, denominations, or information.

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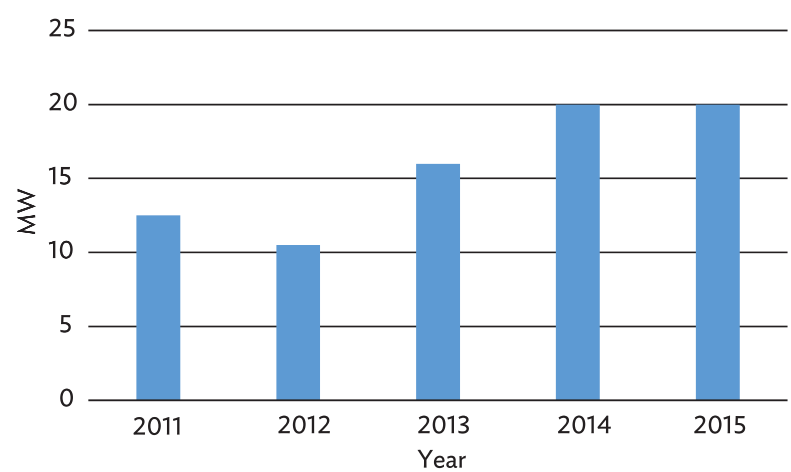
Source: Web Geographic Information System for Sustainable Energy Authority. http://www.gisserver.org/seagis/.

6.8 Biomass—Sri Lanka

217. The biomass power plant production capacity continued to grow even though the 2015 Sri Lanka Balance Energy Report indicates that no new fuel wood plantations are being developed to fuel the plants. Figure 50 gives an overview of biomass power production capacity and Figure 51 shows the distribution of this capacity.

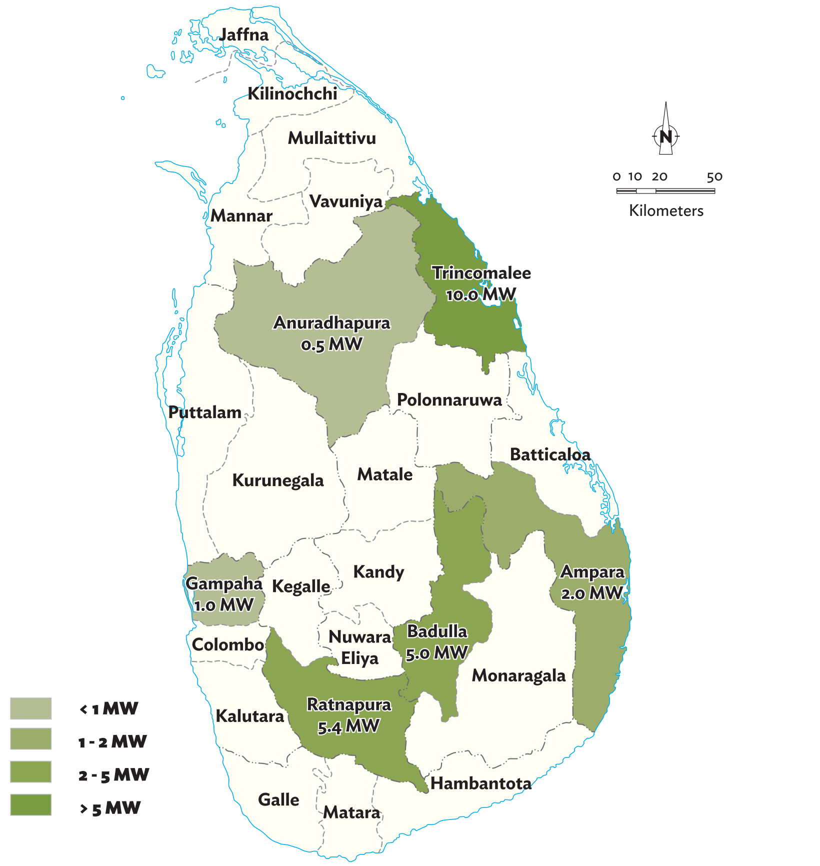
218. The government has introduced buying schemes so that communities can become involved in the production and sale of biomass materials for power plants. For the second time ever, sales of firewood to be used in biomass power plants and households dropped from 102,301 cubic meters (m^3) in 2014 to 83,041m^3 in 2015.

Figure 50: Sri Lanka's Grid-Connected Biomass Power Production Capacity



MW = megawatt.
Source: Ceylon Electricity Board. http://www.ceb.lk/.

Figure 51: Sri Lanka's Biomass Capacity by Province



This map was produced by the cartography unit of the Asian Development Bank. The boundaries, colors, denominations, and any other information shown on this map do not imply, on the part of the Asian Development Bank, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries, colors, denominations, or information.

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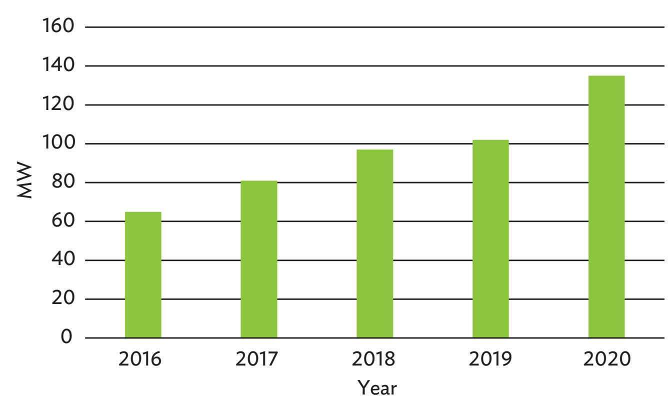
km = kilometer, MW = megawatt.
Source: Government of Sri Lanka, Sri Lanka Sustainable Energy Authority. 2015. *Sri Lanka Energy Balance 2015*. Colombo. p. 10.

219. Nevertheless, the SLSEA has ambitious targets for electricity produced using biomass as shown in the five-year plan in Figure 52.

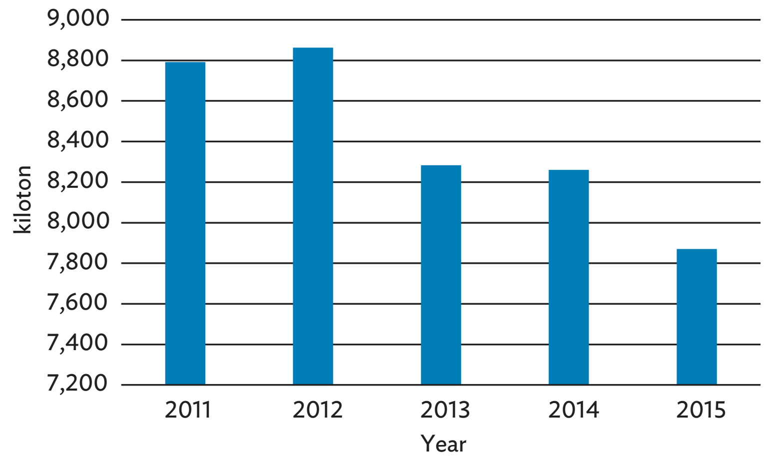
220. Biomass, along with petroleum, is the dominant source of energy in Sri Lanka, and is used mainly in households for cookstoves. In Figure 53, data from the past 5 years (2011–2015) shows a decrease in overall household firewood consumption; however, there is insufficient data to determine the root cause of this decreasing trend.

Figure 52: Sri Lanka's Biomass Power Production, Five-Year Plan



MW = megawatt.
Source: Ceylon Electricity Board. 2015. *Long Term Generation Expansion Plan 2015-2034*. http://www.ceb.lk/index.php?aam_media=4464.

Figure 53: Sri Lanka's Household and Commercial Firewood Consumption



Source: Government of Sri Lanka, Sri Lanka Sustainable Energy Authority. 2015. *Sri Lanka Energy Balance 2015*. Colombo. p. 78.

221. The Sri Lanka Department of Census and Statistics published data on the types of cooking fuel used in houses across the country. It is estimated that 4.03 million out of the 5.2 million households in Sri Lanka rely on firewood cookstoves, which can be harmful to health; the use of improved cookstoves (ICS) would great benefit to the population. The published data is shown in Table 15.

Table 15: Cooking Fuel by Sector in Sri Lanka
(%)

Sector	Cooking Fuel			
	Total	Firewood	LP Gas	Kerosene
Sri Lanka	100	77.5	19.0	3.5
Urban	100	35.2	55.5	9.2
Rural	100	85.7	12.0	2.3
Estate	100	95.3	2.4	2.3

Source: Government of Sri Lanka, Department of Census and Statistics. 2013. *Household Income and Expenditure Survey 2012/13.* Colombo.

222. As of 2017, approximately 19%–20% of the 8 million households (lower middle class) in Sri Lanka use liquefied petroleum gas for cooking.[17]

6.9 Cooking, Heating, and Cooling—Sri Lanka

223. As the cost of the liquefied petroleum gas rises and of firewood decreases, many look to the use of ICS to fulfill the balance between a cheap fuel source and efficient use of energy. There are currently around 30 different ICS models, most of which are produced locally and use either charcoal, pellets fuel wood, or wood chips as fuel (footnote 22). The SLSEA website states that Anagi stove, IDB stove, NERD

[17] Interview by Reihana Mohideen with Nazim Musafer. 14 March 2017. Skype phone interview.

center stove are the most common models seen in the country, with Anagi as by far the most common with around 300,000–400,000 units produced per annum.

224. From September 2015 to January 2016, the Integrated Development Association of Sri Lanka ran a program for the distribution of 500 Anagi stoves in Kilinochchi, Mullaitivu, and Batticaloa districts and trained individuals on constructing and/or using them. Also, the World Food Programme operates their Safe Access to Fuel and Energy initiative in the country, part of which is the distribution of ICS.

6.10 Conclusions

225. Technology innovation is enabled by the policy and regulatory environment. This includes financial assistance and tariff incentives as demonstrated by the net metering measures and Net Plus program in Sri Lanka. Household consumers and low-income and BPL consumers are targeted beneficiaries.

226. Distributed generation driven by technology innovation can be a pathway for simultaneously providing energy fostering high-level technology (HLT) innovation, such as that by small power producers in Sri Lanka.

227. Small and micro power producers are emerging as the backbone of new energy industries, such as the solar PV sector. With the right policy environment, strategies, and plans, women and marginalized groups can participate in these industries from their inception.

228. The collection of technology data needs to reflect the energy transition from the old grid to the new one. It needs to have a greater focus on information relevant for distributed generation in both on-grid and off-grid systems. This requires accurate information at the households and for small power producers. The shift is starting to be reflected in the technology data collected by energy agencies, which now includes some household data.

229. Figure A2 in the Appendix is a proposed template for integrating GESI information in technology data collection.

7. RURAL ENERGY TRANSITION PATHWAYS: GENDER EQUALITY AND SOCIAL INCLUSION MAINSTREAMED MODELING

7.1 Introduction

230. In this section, integrating GESI into energy systems modeling for rural electrification is proposed. Concepts, algorithms, and data collection templates to integrate GESI consideration into modeling processes and to enable the design of GESI integrated systems are proposed and discussed. GESI considerations are integrated into the work done by Nerini et al. (2014, 2016a and 2016b), which includes his algorithm for weighting criteria based on participatory processes and in identifying least-cost technology pathways for rural electrification. This work's key outcome metrics are the composite index for weighting criteria and the levelized cost of electricity (LCOE), which is linked to the World Bank Global Tracking Framework of multi-tier levels of access. A modified reference energy system integrating GESI criteria is proposed to fill a gap in the analytical toolbox available to the energy research community and energy planners, especially in developing countries.

7.2 Energy System Design Concept

231. There are key criteria that constitute the pillars that energy systems are designed upon—technology and technical criteria, and economic criteria related to cost (long-established); environmental criteria (recently established); social criteria (emerging); institutional criteria (included in this study).

232. The social criteria can integrate GESI considerations in the following way:

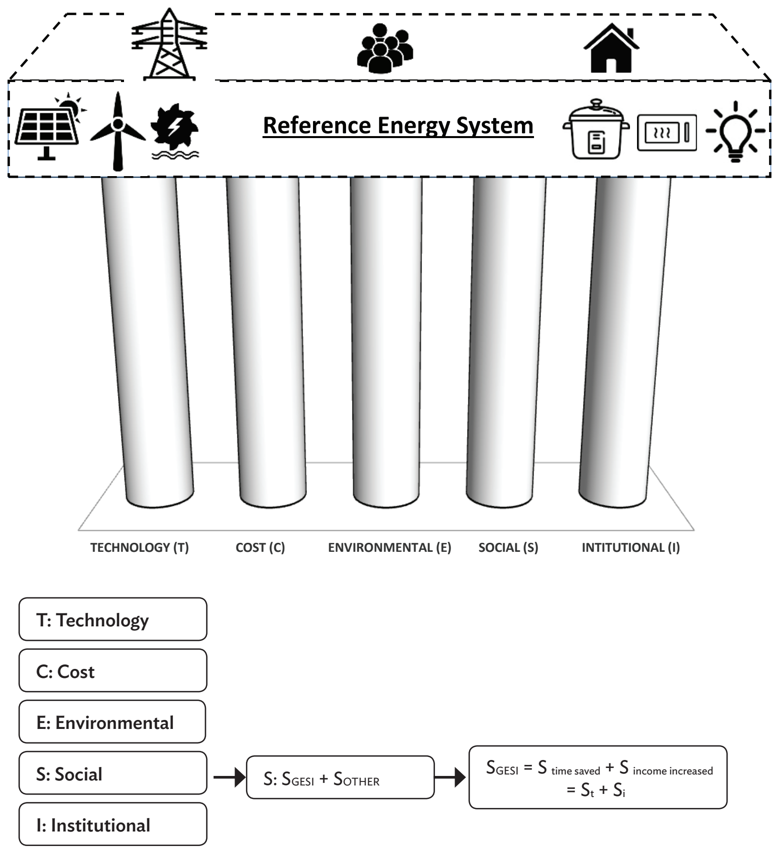
$$\text{Social } (S) = \text{Social GESI } (S_{GESI}) + \text{Social Other } (S_{Other})$$

233. S_{GESI} can be further broken down into subcriteria. This study identifies women's time saved (St) and income levels (Si) as the subcriteria for GESI:

$$S_{GESI} = S_t + S_i$$

234. The conceptual framework for this system is illustrated in Figure 54.

Figure 54: Conceptual Framework for the Design of Energy/Power Systems



Source: R. Mohideen and M. Thompson.

235. A criteria table has been devised (Table 16) with the integration of GESI criteria, building on Nerini's list of criteria and subcriteria applied in remote communities in the Amazon, Brazil (Nerini et al. 2014). The criteria and subcriteria can be weighted through a participatory process involving the stakeholders.

Table 16: Gender Equality and Social Inclusion Integrated Criteria and Subcriteria

Criteria	Subcriteria	Brief Description
Technical	Reliability	Point of failure assessment. Capability of the system to work in a specific region. Assessment of the life expectancy
	Resilience	The ability of the system to withstand, respond to, and recover rapidly from disruptions
	Resource availability	Availability of the source of energy within the local resources, and ease of access to those
	Scalability	Possibility of the system being scaled up (or down) as the
	O&M needs	Expert human resources needed on site for the system to work properly

continued on next page

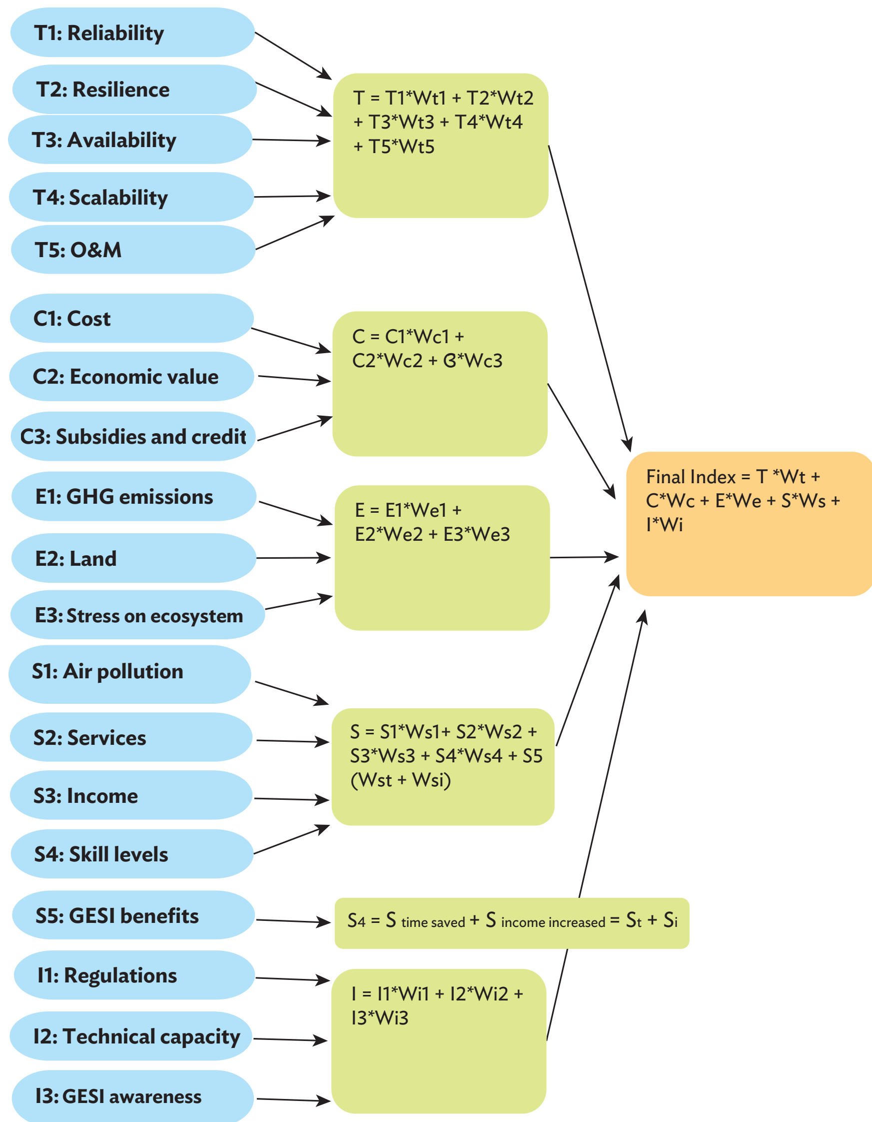
Table 16 *continued*

Criteria	Subcriteria	Brief Description
Economic	Cost	Total life span costs including capital cost required to set up a plant, considering labor, equipment, and installation, as well as O&M and fuel costs
	Economic value	Economic benefits for the community, or the concessionary providing energy services, for the considered system in the long term (e.g., Will the usage of a certain energy system benefit the overall economy of a village? Will a concessionary be at risk of incurring high debt levels due to the vast usage of a certain electrification option?). Price and economic output.
	Accessibility to credit, financial assistance, and subsidies	Possibility of access to credit, financial assistance, and subsidies for the realization of the project
Environmental	GHG emissions	Quantity of GHG emissions consequent to building and the operation of the compared energy systems
	Land requirement	Quantity of land necessary for system operation
	Stress on the ecosystem	Direct environmental impacts of the energy system on the ecosystem
Social	Presence of harmful emissions to health	Types and quantity of emission that can be hazardous for the health of rural communities—indoor household pollution related to cooking and outdoor air pollution
	Support to local productive activities/Job creation	Estimation of the amount of local jobs created and how the productive activities have been stimulated from a specific electrification option
	Skill levels	An estimation of the skill levels of the community and training needs assessment
	Services that are possible to provide to communities	New public services that can be supplied to a community (e.g., public lighting, electricity in schools and community centers, etc.)
Gender and Social Inclusion	Reduce women's time on household chores	Estimate how women's time on household chores can be reduced through mechanization of agri-processing and pumped water
Institutional	Improve women's livelihood and income	How women's livelihood activities will be improved through the creation of electricity-based small and micro enterprises
	Regulations	Which technologies are easier to introduce under the current regulatory framework
	Technical capacity	A needs assessment of capacity and what capacity development is required
	GESI awareness	What are the institutional policies, strategies, and plans addressing GESI and how effectively are these being implemented

Source: F. Nerini et. al 2014. Rural Electrification Options in the Brazilian Amazon: A Multi-Criteria Analysis. *Energy for Sustainable Development*. 20. pp. 36–48.

236. In Nerini's model, the criteria are weighted (with a weight Wi [%]) to form the respective macrocriterion—T, C, E, S, I. The macro criteria are in turn weighted, based on the subcriteria, to reach a final composite index. All the parameters are normalized in percentages so as to be aggregated in the final index (0%–100%). The weights Wi for the analysis have been chosen pursuing a participatory approach. This study integrates GESI considerations into Nerini's composite index (Figure 55). This model is based on achieving not the best technology solution, but the best fit for the "purpose," where purpose is identified by the weighted criteria.

Figure 55: Integrating Gender Equality and Social Inclusion in Nerini's Algorithm



GESI = gender equality and social inclusion, GHG = greenhouse gas, O&M = operation and maintenance.

Sources: F. Nerini, et. al. 2014 Rural Electrification Options in the Brazilian Amazon: A Multi-Criteria Analysis. *Energy for Sustainable Development*. 20. pp. 36–48, and Reihana Mohideen.

237. The strength of the model is that it promotes a participatory consultation process to assess what the community wants. In this sense the model addresses the question: "How much energy does a community want"? This study then disaggregates the question to assess "How much energy do women and men in the community want?"

238. Table 17 builds on Nerini's table enabling the collection of technology data related to agricultural production activities in rural communities. This study integrates a simple gender division of labor analysis into the table. Conversely, this can also be used as a template to integrate technical information in a gender division of labor analysis, which is a standard GESI practice. Table 16 and Table 17 can both be used as guides or tools to collect information on what the community wants, with an emphasis on productive energy use.

Table 17: Including Technical Information in the Analysis of the Gender Division of Labor

Processes	Tasks	Gender Division of Tasks	Traditional Methods and Technologies	Energy Sources	Modern Methods and Technologies	Energy Sources
Primary Production	Land preparation/ Tilling	Women and men	Hand hoe, animal drawn tiller	women, men, and animal	Power tiller/two-wheel tractor	Fossil fuels, biofuels
	Seeding	Women and men	Hand planting	Women and men	Bed planter, row planter/seed drill	Fossil fuels, biofuels
	Irrigation	Women and men	Container/bucket for lifting/ carrying water, wind pumps, rain fed	Women, men, and animal, traditional, renewable	Mechanical irrigation (with diesel pump, treadle pump, rope pump, ram pump, persian wheel, river turbine)	Fossil fuels, biofuels, electricity, mechanical energy, and direct usage of renewable energy (solar, wind, and hydro)
	Fertilizing	Women and men	Organic fertilizer	Women, men, and animal	Organic and inorganic fertilizer applied with modern technology	Energy embedded in the fertilizer, fossil fuels, biofuels
	Harvesting	Women and men	Scythe, animal drawn mower, manual practices	Women, men, and animal	Harvester, attached to a power tiller/tractor	Fossil fuels, biofuels
Crop Processing	Drying	Women	Hand-held fan, sun drying	Women, traditional, renewable	Artificial drying, powered fan	Electricity, fossil fuels
	Milling, Pressing	Women	Hand ground, flail	Women, traditional, renewable	Electric motors, direct mechanical supply, powered mill, oil expellers	Electricity, fossil fuels, biofuels, mechanical energy
	Cutting, shredding	Women	Knife	Women	Saw mills, power shredder	Electricity, fossil fuels, biofuels, mechanical energy
	Winnowing, decorticating	Women	Winnowing basket	Women	Powered shaker, grinders	Electricity, fossil fuels, biofuels, mechanical energy
	Spinning	Women	Manual Spin	Women	Powered spinner	Electricity, fossil fuels, biofuels, mechanical energy
	Packing	Women and men	Manual Packing	Women	Automated packing	Electricity
Crop Conservation and Distribution	Refrigeration (dairy products, fish, meat)	Women and men	None	-	Refrigerated storage	Electricity
	Distribution to local market		Walk and distribution with animal	Women, men, animal, bicycles, bus, etc.	Modern transportation by road	Fossil fuels, biofuels
	Transport to national and international market		-	-	Modern transportation by road, rail, sea, or air	Fossil fuels, biofuels, electricity

Note: "Gender division of task" is author's addition.
Source: Author, building on F. Nerini et al. 2016. Powering Production: The Case of the Sisal Fibre Production in the Tanga Region, Tanzania. *Energy Policy*. 98. pp. 544–556. Column 3.

7.3 World Bank Tier System Analysis

239. The conceptual framework of the five pillars and the index of weighted criteria can be used in conjunction with the World Bank Global Tracking Framework, which identifies six tiers of transitioning to advanced energy access, and applied to identify pathways for energy access (and the related energy transition) in rural communities.

240. Food processing and water pumping have an important bearing on women's labor time devoted to onerous household chores (also referred to as women's time poverty). Following the World Bank framework and multi-tier matrix for measuring access to household electricity services (Figure 56), tier 3 is an important threshold level of energy access to lay the basis for reducing women's labor time poverty.

Figure 56: World Bank Global Tracking Framework for Electricity Consumption

		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Tiers	Tier Criteria	-	Task lighting and phone charging	General lighting and fan (if needed)	Tier 2 and any medium power appliances	Tier 3 and any high power appliances	Tier 2 and any very high power appliances
Appliances	Indicative list of appliances		Very low power appliances	Low power appliances	Medium power appliances	High power appliances	Very high power appliances
	Lighting	-	Task Lighting	Multipoint general lighting			
	Entertainment and communication	-	Phone charging, radio	Television, computer	Printer		
	Space cooling and heating	-		Fan	Air cooler		Air conditioner, space heater
	Refrigeration	-			Refrigerator, freezer		
	Mechanical loads	-			Food processor, washing machine, water pump		
	Product heating	-				Iron, hair dryer	Water heater
	Cooking	-			Rice cooker	Toaster, microwave	Electric cooking

Source: International Bank for Reconstruction and Development/The World Bank and the International Energy Agency. 2017. *Sustainable Energy for All Global Tracking Framework: Progress toward Sustainable Energy 2017.* Washington, DC.

241. Tier 3 is also the threshold level of access to operate medium-power appliances. This indicates that it is an important level of access to provide electricity for productive use, such as establishing small enterprises, which can contribute to women's economic empowerment. According to the World Bank's multi-tier matrix for measuring access for productive activities (Figure 57), 1.0 kilowatt-hour (kWh) of daily supply capacity—or 365 kWh of annual supply capacity—is the minimum required to provide electricity coverage for at least 50% of working hours, that is, tier 3 level of access. A minimum of 3.4 kWh

of daily supply capacity—or 1,241 kWh of annual capacity supply—is required to cover "most of working hours", that is, tier 4 level of access. It is also assessed that tier 4 levels of access are more reliable, affordable, convenient, and safe, and therefore less likely to impact negatively on productive activities.

242. It can be argued that tier 3 to tier 4 access is important to address GESI criteria in energy access. Energy pathways and related models need to give special consideration to providing electricity to meet tier 3 levels of access—approximately 365–1,250 kWh of annual supply capacity—as a threshold to enable important GESI impacts.

243. However, there are also several caveats that apply. Figure 58 does not take into account affordability, reliability, resilience, or scalability. There is also an assumption that the grid or even mini-grid is based on conventional alternating current (AC) power and not direct current (DC)-powered mini-grids with DC appliances.[18]

[18] I. Mareels. 2017. In discussion with author. October.

Figure 57: Electricity Consumption for Productive Energy Use

			Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1. Capacity	Electricity	Power		Minimum 3 W	Minimum 50 W	Minimum 200 W	Minimum 800 W	Minimum 2k W
		“Daily Supply Capacity”		Minimum 12 Wh	Minimum 200 Wh	Minimum 1.0 kWh	Minimum 3.4 kWh	Minimum 8.2 kWh
		“Typical Source”		“Solar Lanterns”	“Solar Home Systems”	“Generator or Grid”	“Generator or Grid”	Grid
	Non-electric					“Available nonelectric energy partially meets requirements”	“Available nonelectric energy largely meets requirements”	“Available nonelectric energy fully meets all requirements”
	Both					“No relevant application is absent solely due to energy supply constraints.”		
2. Duration of Daily Supply	Electricity			“Minimum 2 hrs”	“Minimum 4 hrs”	“Minimum 50 percent of working hours”	“Most of working hours (Minimum 75 percent of working hours)”	“Almost all of working hours (Minimum 95 percent of working hours)”
	Nonelectric					“Available nonelectric energy partially meets requirements”	“Available nonelectric energy largely meets requirements”	“Available nonelectric energy fully meets all requirements”
	Both					Longer working hours are not prevented solely by lack of adequate energy (capacity or duration)		
3. Reliability							“No reliability issues that have severe impact”	“No reliability issues or little impact”

continued on next page

Figure 57 *continued*

			Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
4. Quality							"No quality issues that have severe impact"	No quality issues or little impact
5. Affordability							"Variable cost of energy is less than two times the grid tariff"	"Variable cost of energy is less than the grid tariff"
6. Legality							"Energy bill is paid to the utility, pre-paid card seller, authorized representative, or legal market operator"	
7. Convenience							"Time and effort in securing and preparing energy does not cause severe impact"	"No convenience issues or little impact"
"8. Health (Indoor air quality from use of fuels)"	PM (µg/m^3)			"[To be specified by competent agency such as WHO]"	"[To be specified by competent agency such as WHO]"	"[To be specified by competent agency such as WHO]"	< 35 (WHO IT-1)	"< 10 (WHO guideline)"
	CO (mg/m^3)						"< 7 (WHO guideline)"	"< 7 (WHO guideline)"
	"or Use of Fuels (BLEENS)"				"Use of non-BLEENS solutions (if any) for heating in the open or with smoke extraction"		Use of BLEENS or equivalent solutions only (if any)	
9. Safety							"Energy supply solutions have not caused any accidents over the last one year that required professional medical assistance."	"Energy supply solutions have not caused any accidents over the last one year."

BLEENS = biogas, LPG (liquefied petroleum gas), ethanol, electricity, natural gas and solar; CO = carbon monoxide; kW = kilowatts; kWh = kilowatt hours; PM = particular matter; W = watts; Wh = watt hours; WHO = World Health Organization.watts; Wh = watt hours; WHO = World Health Organization.

Sources: International Energy Agency and World Bank.

7.4 Nerini: Cost Comparison of Technology Approaches

244. Nerini et al. (2015) derived a simple tool for conducting a cost comparison of different electrification technologies for energy access, which is linked to the World Bank multi-tier matrix. Although Nerini does not directly integrate GESI criteria or indicators into his model, the results from the application of the tool to a general case is extremely illuminating. Nerini's model is based on calculating the levelized cost of electricity (LCOE) and the total household cost of electricity for each energy source and system over a 15-year time frame (2015–2030). The model is based on four parameter "families": (i) target level and quality of energy access; (ii) population density; (iii) local grid connection characteristics; and (iv) local energy resource availability, fuel, and technology cost.

245. The LCOE equation is the following:

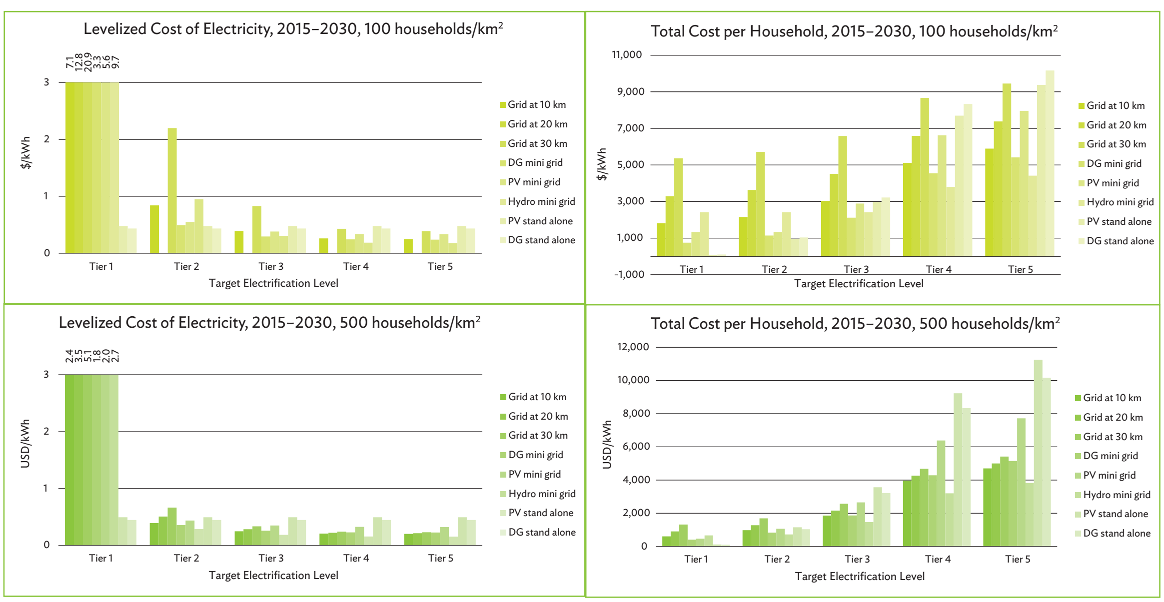
$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + O\&M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

246. The total cost per household is calculated by using the following equation:

$$Household_{(2015-2030)} = \frac{\sum_{t=1}^{n} \frac{I_t + O\&M_t + F_t - S_t}{(1+r)^t}}{hh}$$

[For a specific system in year *t*, I_t is the investment expenditure, $O\&M_t$ is the operation and maintenance (O&M) expenditure, F_t is the fuel expenditure, E_t is the electricity generation, *r* is the discount rate, *n* is the life expectancy of the system, S_t is the salvage cost of elements being dismissed in year *t*, *hh* is the number of households being served by the given energy system.]

Figure 58: Levelized Cost of Electricity and Total Costs for Different Levels of Energy Access



DG = diesel generator, PV = photovoltaic.

Source: F. Nerini et. al. 2016. A Cost Comparison of Technology Approaches for Improving Access to Electricity Services. *Energy*. 95 (15). pp. 255–265.

247. The results of Nerini's model indicate that the cost per kWh and the total cost per household to achieve tier 3 levels of energy access are lower (for remote households 30 km or further from the grid) or compatible (for households less than 30 km from the grid) in mini-grid systems—especially hydro mini-grids, and to a lesser extent solar PV and diesel generator driven mini-grids.

248. The cost of solar PV falling over time and low-carbon sources being prioritized will weigh in favor of solar PV, as well as including the criteria of scalability, given the modular structure of solar PV systems. Solar PV and diesel hybrid systems can and are being combined to improve reliability. Hydro mini-grid systems depend on the availability of the source for local generation. Scalability is also more complex.

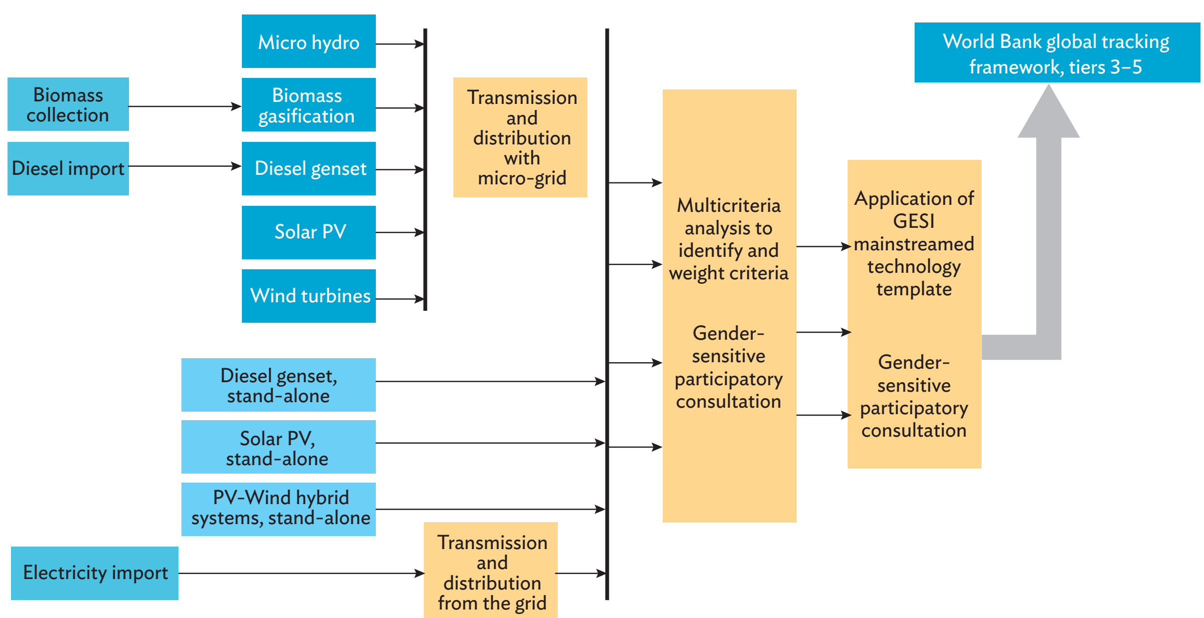
249. For smaller, remote communities (with smaller numbers of households also being a characteristic of remoteness), PV mini-grids are more competitive than the grid for T4 and T5 levels of access. All the factors in this section need to be taken into consideration in anticipating the future evolution of the system.

7.5 Gender Equality and Social Inclusion Integrated Reference Energy System

250. A revised GESI integrated reference energy system is proposed for modeling energy access pathways in the rural energy transition (Figure 59). The revised reference energy system builds on the system design piloted by Nerini et al. (2014) in the village of Suro-Craic in Timor-Leste. The revised system is based on the following approaches:

- including social and GESI considerations as a pillar in system design and modeling,
- including GESI criteria based on reducing women's time poverty and economic empowerment through increased income,

Figure 59: Gender Equality and Social Inclusion Integrated Reference Energy System



GESI = gender equality and social inclusion, PV = photovoltaic, genset = generation set.

Source: Author. Based on F. Nerini et al. 2015. Estimating the Cost of Energy Access: The Case of the Village of Suro Craic in Timor Leste. *Energy*. 79 (1). pp. 385–397. Nerini's reference energy system is developed from M. Beller. 1976. *Reference Energy System Methodology*. Upton, New York: Brookhaven National Laboratory. https://www.osti.gov/scitech/servlets/purl/7191575. ADB recognizes "Timor Leste" as Timor-Leste.

- implementing GESI-inclusive participatory processes,
- compiling technology data based on templates that include information on financial assistance and technology/systems ownership (or uptake) disaggregated by sex and ethnicity/caste/tribes and/or relevant categories to reflect marginalized individuals and groups,
- integrating technology information in data on gender roles in productive activities, and
- prioritizing tier 3 energy access levels as a minimum threshold level.

7.6 Conclusions

251. Chapter 7 draws together the various elements of the study. Conceptually, social and GESI elements have been integrated as a pillar in energy service systems design. The GESI pathways and the technology pathways have been identified and allocated specific criteria. The criteria have been integrated into a quantifiable algorithm (Figure 55), following Nerini's multicriteria analysis. The weighting of the criteria will be done through a participatory process of consultation with key stakeholders. GESI integrated guidelines have been provided—Table 30 and Table 32—to guide the consultation process.

252. The World Bank Global Tracking Framework tiers of access have been assessed in relation to the GESI criteria of women's labor time and income linked to productive energy use. Tier 3 levels of access or approximately 1 kWh of daily supply capacity has been identified as the minimum necessary level of access in relation to women's time saved (the provision of pumped water) and productive energy use for income generation (the use of medium-power appliances such as food processing equipment).

253. The section assesses technology pathways drawing on Nerini's general model based on LCOE calculations. The consideration here is the future evolution of the system over several decades, such that communities are not locked into technologies and low-capacity systems that are unable to evolve over time. Finally, all these elements are incorporated into a GESI integrated reference energy system that incorporates not only cost criteria, but also social and environmental criteria.

254. This model enables us to address the question: How much energy does a community want? A prerequisite here is to provide the community with the information they require to be able to make these decisions.

255. The next stage of the study will be the piloting of the model in the field. This needs to be accompanied by a monitoring and evaluation process, over several years, to further inform and develop the system design.

8. KEY CONCLUSIONS, AREAS FOR FURTHER STUDY, AND WAYS FORWARD

8.1 Gender Equality and Social Inclusion Pathways

256. Technology is not purely technological. Technology is a social product. The process of creating and producing technology is a sociotechnical process, where men and women, organizations, culture, and knowledge are combined. Gender is integral to this sociotechnical process. Technology shapes gender and gender shapes technology at every level. They are also historically contingent and context driven, situated in time and place.

257. While there is demonstrable evidence that energy services improve women's welfare, the question remains whether it transforms gender roles or leads to women's empowerment. Energy access itself is not necessarily sufficient, and other contextual factors such as policy and legal frameworks are needed to support women's empowerment.

258. There are multiple pathways to address gender equality considerations through energy provision, and these pathways are interdependent and overlap. Increasing the economic worth of women's labor (women's economic empowerment) could be more conducive than other pathways to enable the transformation of gender relations.

259. Energy system design and modeling should include a social pillar as an important component of the system design. GESI considerations can be integrated into this social component.

260. Gender considerations in energy system design and modeling need to prioritize two important general criteria: (i) reducing or saving women's labor time spent on household chores, and (ii) supporting women's economic empowerment. These criteria can also be quantified.

261. Prioritizing women's time and economic empowerment criteria also necessitates integrated solutions. This includes a nexus approach that links energy to water and sanitation, low-carbon transport, and communication, among others that is the basis for the development of smart communities.

8.2 Technology Pathways and Audit

262. Disruptive technologies, such as smart and agile power systems driven by innovation in renewable energy technologies, based on distributed energy sources such as mini-grids, can result in community energy systems for smart communities. These systems can simultaneously foster high-level technology (HLT) innovation and provide solutions for inclusive energy access. They necessitate interoperability with end users, women, and men, and are conducive to GESI-inclusive processes.

263. Smart grid incorporates smart end use based on home and community area networks, energy savings based on an optimal combination of renewable energy sources, storage of all energy vectors including battery storage and electric vehicles, the use of HLT on power electronics, control and digitization, smart metering, energy management systems, demand management, etc. Demand management and smart end use presupposes end user education and participation both in urban and nonurban settings, and is conducive to GESI-inclusive processes.

264. Demand management and distributed generation, specifically mini-grids, are important entry points for GESI integration in smart grid.

265. Small power producers are emerging as the backbone of new energy industries such as the solar PV sector. With the right policy environment, strategies, and plans, women and marginalized groups can participate in these industries from their inception.

266. Technology innovation is enabled by the policy and regulatory environment. This includes financial assistance and tariff incentives to promote technology uptake, especially in BPL households, women, and marginalized communities. Social criteria, including GESI criteria, can be effectively integrated to promote technology uptake.

267. The collection of technology data needs to reflect the energy transition from the old grid to the new one. It needs to have a greater focus on information relevant for distributed generation in both on-grid and off-grid systems. This requires accurate information at the community and household levels and for small power producers.

268. The study includes a proposed template for integrating GESI information in technology data collection, as well as a template for collecting technology data in analyzing the gender division of labor in a rural setting (Appendix, Figure A2).

269. The ADB working definition for HLT provides important entry points for GESI mainstreaming. The study includes a guideline/tool for integrating GESI in ADB's HLT definition (see Table 30 and Table 32 for GESI considerations or entry points).

8.3 Energy Systems Design and Modeling

270. The World Bank Global Tracking Framework with multi-tier levels of access is a useful tool to be used in energy system design and modeling. In order to effectively meet the GESI criteria of women's economic empowerment, a minimum of tier 3 levels of access must be met.

271. Energy systems modeling can integrate GESI criteria based on a reference energy system that integrates

- GESI considerations as a pillar in system design and modeling,
- GESI criteria based on reducing women's time poverty and economic empowerment through increased income,
- GESI-inclusive participatory processes,
- compiling technology data based on templates that include information on financial assistance and technology/systems ownership (or uptake) disaggregated by sex and ethnicity/caste/tribes and/or relevant categories to reflect marginalized individuals and groups,
- integrating technology information in data on gender roles in productive activities, and
- prioritizing tier 3–4 energy access levels as a minimum threshold level.

8.4 Areas for Further Study

272. The following topics have been identified as areas for further study:

(i) frameworks and definitions for smart grid models, including domains and sub-domains, that integrate GESI considerations to inform policy and planning;

(ii) GESI trends in employment in renewable energy industries in Asia; and

(iii) application in the field of multicriteria analysis taking into better account GESI considerations.

8.5 Ways Forward

273. Designing and implementing a pilot, a reference energy system, that mainstreams gender and social equity. This system should be linked to the ADB portfolio. The key elements of such a system are the following:

(i) renewable energy-based mini-grids;

(ii) designed for household consumption levels of at least tier 3 levels and more;

(iii) system design to include, as key criteria, reducing women's time burden and enabling women's economic empowerment;

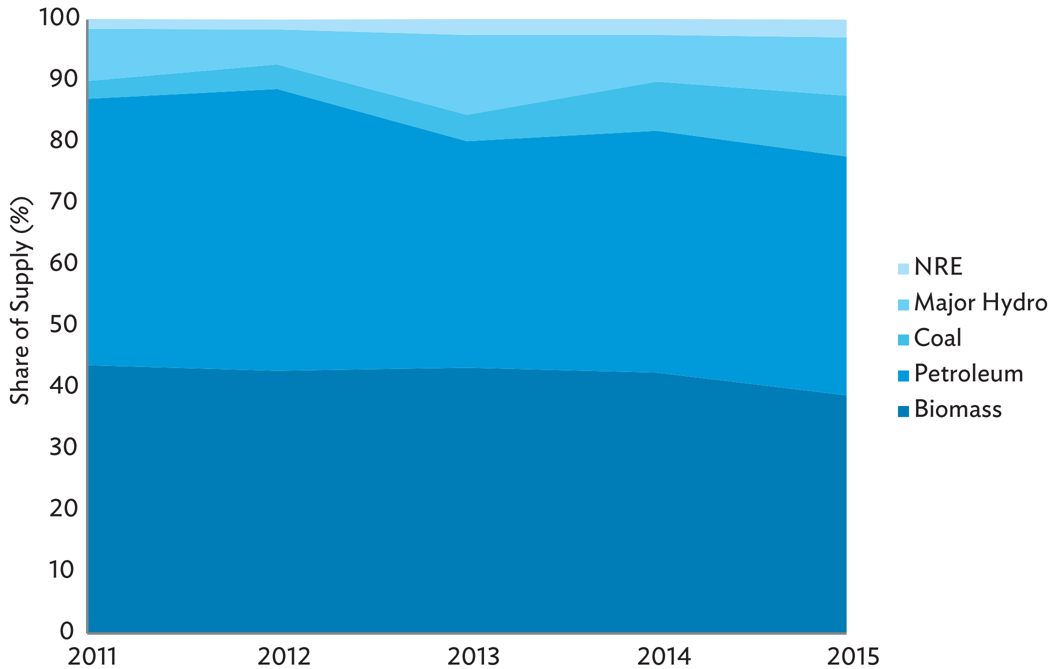
(iv) GESI-inclusive participatory processes; and

(v) integrated systems—local infrastructure, maternal health services, and water and sanitation.

274. The community energy system should be piloted in a community where the quality of supply and electricity consumption capacity needs to be improved to support local economic development. The system should be smart, that is simultaneously leap-frog the access and technology divide resulting from poverty, remoteness, and social marginalization. It should be adaptable to technological evolution over 2 decades or more. The pilot should be monitored over 2–3 years to further refine the GESI mainstreamed model.

APPENDIX

Figure A1: Sri Lanka's Energy Balance, 2015



NRE = new renewable energy.
Source: Government of Sri Lanka, Sri Lanka Sustainable Energy Authority. 2015. *Sri Lanka Energy Balance 2015*. p. 19.

Figure A2: Proposed Template—Energy/Renewable Energy Technology and Systems Information

Technology area/ Systems	FY 2017-18		Cumulative achievements	Financial Assistance					Technology update/ownership						
	Targets	Achievement		BPL	Rural	Industry			Government	Private			Cooperatives		
I. GRID-INTERACTIVE POWER (CAPACITIES)				Women/WHH/ Male/Marginalized		Large/ IPP	SME/ IPP/SPP	Micro/ SPP		Women	Male	Marginalized	Women	Male	Marginalized
Wind Power															
Large scale (MW)															
Mini-grid															
Solar power															
Large scale (MW)															
Mini-grid															
Small hydro power															
Bio-power (biomass and gasification and bagasse cogeneration															
Waste to power															
Total															
II. OFF-GRID/CAPTIVE POWER (UNITS, CAPACITIES)															
Waste to energy															
Biomass (non-bagasse) cogeneration															
Biomass gasifiers															
- Rural															
- Industrial															
Aero-generators/ hybrid systems															
SPV systems															
Water mills/ micro															
Total															
III. OTHER RENEWABLE ENERGY SYSTEMS (UNITS, CAPACITIES) (UNITS, CAPACITIES)															
Family biogas plants															
Solar water heating areas (square meters)															
Other technology areas															

BPL = below poverty level, IPP = independent power producer, MW = megawatt, SMEs = small and medium-sized enterprises, SPP = small power producer, SPV = solar photovoltaic, WHH = women headed households.

Source: Author.

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Energy Technology Innovation in South Asia

Implications for Gender Equality and Social Inclusion

This working paper addresses how energy systems and services in South Asia can improve women's economic empowerment and well-being. It focuses on integrating gender equity considerations into technology design and on drawing women into this process for equal employment opportunities. South Asia's low-carbon energy transition has significant implications for gender equality and social inclusion. The rising energy demand and the commitment to mitigate climate change are the driving force in energy technology innovation. This paper is the beginning of an ongoing research project that will also include a pilot program to field test a gender equality and social inclusion reference energy system.

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