Capturing Sun for Heat

Potential, Vision and Action Plan for Decentralised Solar Thermal Technologies and Application in India

Greentech Knowledge Solutions Pvt. Ltd.

SHAKTI SUSTAINABLE ENERGY FOUNDATION

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Potential, Vision, and Action Plan for Decentralised Solar Thermal Technologies and Applications in India

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Greentech Knowledge Solutions Pvt. Ltd

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SHAKTI SUSTAINABLE ENERGY FOUNDATION

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Shakti Sustainable Energy Foundation works to strengthen the energy security of India by aiding the design and implementation of policies that support energy efficiency and renewable energy.

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Foreword

सत्यमेव जयते

भारत सरकार
नवीन और नवीकरणीय ऊर्जा मंत्रालय
GOVERNMENT OF INDIA
MINISTRY OF NEW AND RENEWABLE ENERGY

Tarun Kapoor, IAS
Joint Secretary

India's energy demand and supply deficit makes it a challenge for the country to drive economic growth and meet its human development goals. It is expected that by 2032, India's primary energy demand will be three times that of the 2012 level. Currently, more than 80% of our energy demand is met through fossil fuels. In 2012, India imported 30% of its primary energy supply. This amounted to INR 8,800 billion- 33% of our total import bill and about 9% of our gross domestic product (GDP).

The heavy reliance on imports poses a threat to India's energy security and exerts enormous pressure on balance of payments. Moreover, it makes the emission reduction target distant.

It is interesting to note that 57% of our energy is consumed for applications such as residential cooking, industrial process heat, water heating, space cooling etc. The good news is that solar thermal technologies, which directly convert solar energy into heat, offer an excellent opportunity to harness locally and abundantly available solar energy for such applications. Further, it is well-established that direct conversion of solar energy into heat is one of its most efficient uses. Thus, solar thermal can contribute significantly to achieving India's solar target of 100 GW by 2022.

Globally, solar thermal is the second largest source of renewable energy after wind in terms of installed capacity. By 2013, solar thermal had reached an annual production of ~280 TWh_{th}, which was 1.75 times the annual energy generation from solar photovoltaic (PV) technology. China has realised the relevance of solar thermal and leads its deployment with 180.4 GW_{th} in 2012.

India was able to achieve 4.5 GW_{th} by 2012. For India, wide-scale adoption of decentralised solar thermal technologies can contribute significantly in meeting the goals of enhanced energy security, improved energy access, reduced electricity demand, better environmental quality, and socio-economic development. But to achieve such scale, this sector requires urgent attention.

In this context, this comprehensive report is the first of its kind. It estimates the technical, economic, and market potential of the solar thermal in India. It also analyses current market trends, manufacturing and supply status, and policies and regulations adopted worldwide. It then recommends strategies along with a long-term action plan for the accelerated development of the solar thermal sector in India.

This report, guided by a group of sector experts and practitioners, will inform MNRE's solar thermal programme under the Jawaharlal Nehru National Solar Mission. I believe that this report will initiate efforts that make India a global leader in solar thermal deployment and will be of interest to policy makers, professionals in the solar thermal industry, research institutions, and other relevant stakeholders.

Tarun Kapoor
Joint Secretary, Ministry of New and Renewable Energy
Government of India

Preface

Fifty-seven percent of final energy consumption in India is used for thermal applications. Industrial process heat, residential cooking and water heating are the main thermal applications, accounting for more than 90% of thermal energy requirements. These are primarily being met through coal, biomass and petroleum fuels.

Solar thermal technologies convert solar energy to heat for use in heating water, domestic and commercial cooking, agricultural and industrial drying, water desalination, low and medium temperature industrial process heat, space conditioning (space heating, cooling) and refrigeration. India can harness the potential offered by decentralized solar thermal technologies to meet the goals of reduced dependence on imported fossil fuels, enhanced energy security, improved energy access, reduced electricity demand, better environmental quality, and socio-economic development.

Stakeholders at the central and state levels are acknowledging the need for appropriate interventions to scale-up deployment of solar thermal technologies. In this context, this first of its kind study, undertaken by Greentech Knowledge Solutions Pvt. Ltd. with support from Shakti Sustainable Energy Foundation, is particularly timely. The study estimates the India-wide potential of solar thermal. It also analyses current market trends, manufacturing processes and supply chain linkages, and policies and regulations adopted worldwide. It then recommends strategies along with a long-term action plan for the accelerated development of the solar thermal sector in India.

The study is based on primary and secondary research, and extensive interactions with senior officials from the Ministry of New & Renewable Energy, State Nodal Agencies, urban development authorities, financial institutions and industry.

I trust that this study will be of use to policy makers, regulators, the solar thermal industry, educational institutions as well as different consumer groups in India, and that its recommendations will be translated into action. The practical nature of this study makes this work highly relevant for policy-making.

Krishan Dhawan

Krishan Dhawan
Chief Executive Officer
Shakti Sustainable Energy Foundation

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Two stakeholder workshops were conducted during the course of the project, the first at Pune in April 2014 and the second at New Delhi in October 2014. We are grateful to all the participants for their valuable inputs and recommendations. We would also like to acknowledge the valuable inputs of Dr Sanjay Bajpai, Associate Head, Tech Mission Cell – Water and Solar Energy, Department of Science and Technology, and Mr Mahendra Chetia, Director (R&D), Petroleum Conservation Research Association, during the second stakeholder workshop at New Delhi in October 2014.

A meeting of an expert group comprising Prof. Shireesh Kedare (Professor, IIT Bombay), Dr V V N Kishore (Formerly, Professor and Head of Department of Energy and Environment, TERI University), Dr Veena Joshi (Formerly, Sr Advisor, Swiss Agency for Development and Cooperation), Mr Mangal Akole (Chairman, Solar Thermal Federation of India), Dr Vishal Sardeshpande (ATE Enterprises and Adjunct Faculty, IIT Bombay), Mr Bhupinder Marwaha (Intersolar Systems Pvt. Ltd), Ms Swati Bhogle (Technology Informatics Design Endeavour — TIDE), and Mr Rahul Bhardwaj (L&T, Solar Thermal Initiative) was held on 13 June 2014 in New Delhi. We are grateful to the members of the expert group for their valuable insights and for guiding the project team in formulating the strategies for the roadmap.

Acronyms and Abbreviations

ASSOCHAM	The Associated Chambers of Commerce and Industry of India
BAU	business as usual
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
boe	barrels of oil equivalent
CAGR	compound annual growth rate
CII	Confederation of Indian Industry
COP	coefficient of performance
CPC	compound parabolic concentrator
CSIR	Council of Scientific and Industrial Research
CSTEP	Center for study of Science, Technology and Policy
CUF	capacity utilisation factor
DNI	direct normal irradiance
DST	Department of Science and Technology
ESCO	energy service companies
ETC	evacuated tube collector
FICCI	Federation of Indian Chamber of Commerce and Industry
FPC	flat-plate collector
GEF	Global Environment Facility
GHI	global horizontal irradiance
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GRIHA	Green Rating for Integrated Habitat Assessment
GW_p	gigawatt Peak
GW_{th}	gigawatt thermal
HH	households
IGBC	Indian Green Building Council
IIT	Indian Institute of Technology
IREDA	Indian Renewable Energy Development Agency
ITI	Industrial Training Institute
JNNSM	Jawaharlal Nehru National Solar Mission
kcal	kilocalorie
kWh	kilowatt-hour
kW_p	kilowatt peak
kW_{th}	kilowatt thermal
LEED	Leadership in Energy and Environment Design

LPD	litres per day
LPG	liquefied petroleum gas
MJ	mega joule
mmbtu	million metric British thermal unit
MNRE	Ministry of New and Renewable Energy
MoEFCC	Ministry of Environment and Forests and Climate Change
MoF	Ministry of Finance
MoUD	Ministry of Urban Development
Mtoe	million tonnes of oil equivalent
MW	megawatt
MWh	megawatt hour
NABARD	National Bank for Agriculture and Development
NGO	non-governmental organisation
NISE	National Institute of Solar Energy
NIT	National Institute of Technology
NSDC	National Skill Development Corporation
OECD	Organisation of Economic Cooperation and Development
PCRA	Petroleum Conservation Research Association
PNG	piped natural gas
PV	photovoltaic
R&D	research and development
RESCO	renewable energy service companies
SHC	Solar Heating and Cooling Programme
SNA	state nodal agency
SoPro	solar process heat
STDN	Solar Thermal Development Network
STFI	Solar Thermal Federation of India
SWH	solar water heater
TERI	The Energy and Resources Institute
TWh	terawatt hour
ULB	urban local body
UNDP	United Nations Development Programme
USD or US$	US Dollar
VAM	vapour absorption machine

Executive Summary

Background

Fifty-seven per cent (i.e., 240 Mtoe) of the final energy consumption in India is used for thermal applications. Industrial process heat, residential cooking, and water heating are the main thermal applications accounting for more than 90% of the thermal energy requirement (Figure 1). Presently, our thermal energy demand is primarily being met through coal, biomass, and petroleum fuels.

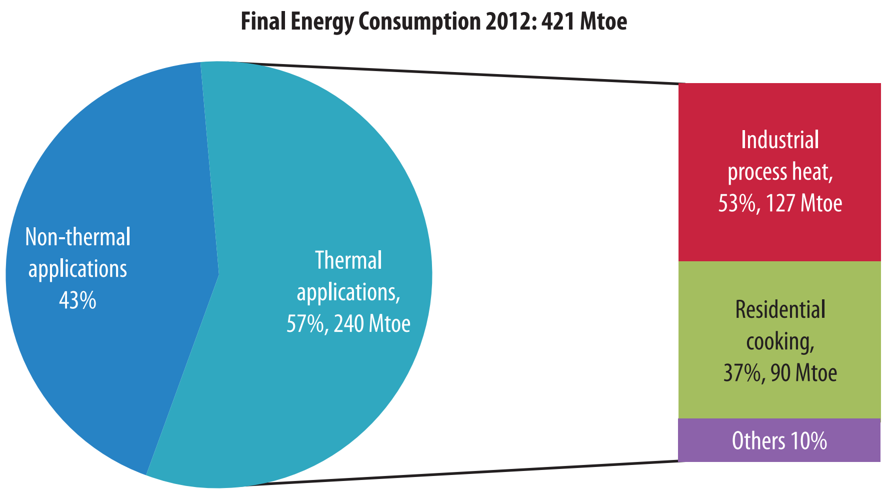


Figure 1 Energy used for thermal applications in final energy consumption - 2012

Solar Energy for Thermal Applications

Solar energy technologies can be broadly classified into two categories: (a) solar thermal technologies that deliver heat, and (b) solar photovoltaic (PV) technologies that produce electricity.

Solar thermal technologies convert solar energy to heat for use in heating water, domestic and commercial cooking, agricultural and industrial drying, water desalination, low and medium temperature industrial process heat, space conditioning (space heating, cooling), and refrigeration.

Conversion of solar energy into thermal energy offers much better efficiency as compared to conversion to electricity using solar PV technology. Hence, the useful energy yield per unit of land area is higher for conversion to thermal energy than to electricity.

India can harness the potential offered by decentralised solar thermal technologies to meet the goals of reduced dependence on imported fuels, enhanced energy security, improved energy access, reduced electricity demand, better environmental quality, and socio-economic development.

Status of Solar Thermal Technologies and Applications in India

Deployment: As of March 2014, the total installed capacity of all solar thermal technologies in India was at 5.8 GW_{th}. The annual energy from solar thermal is estimated to be 0.6 Mtoe, accounting for only 0.25% of the energy consumption for thermal applications (240 Mtoe). Solar water heaters (SWHs) account for 97% of the installed capacity of solar thermal in India. Among the SWHs, 82% of the installed capacity is estimated to be in residential buildings, 14% in commercial and institutional buildings, and 4% in industries.

Stages of Development: Solar thermal technologies are at different stages of development (Figure 2). Except SWHs for residential, commercial and institutional buildings, which are in the growth stage, all other technologies and their applications are either in the development or introduction phase.

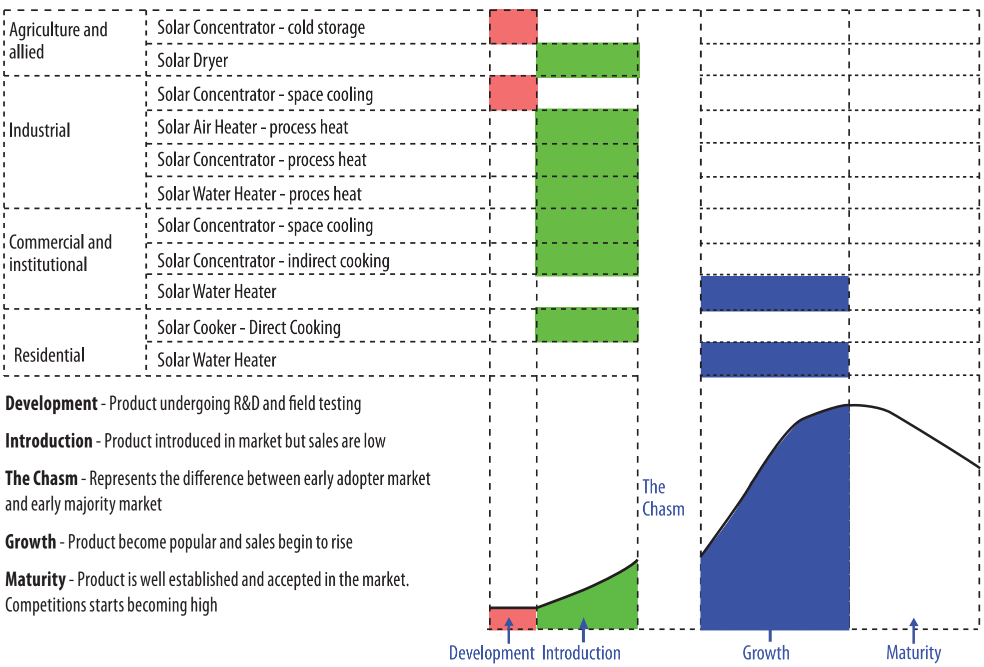
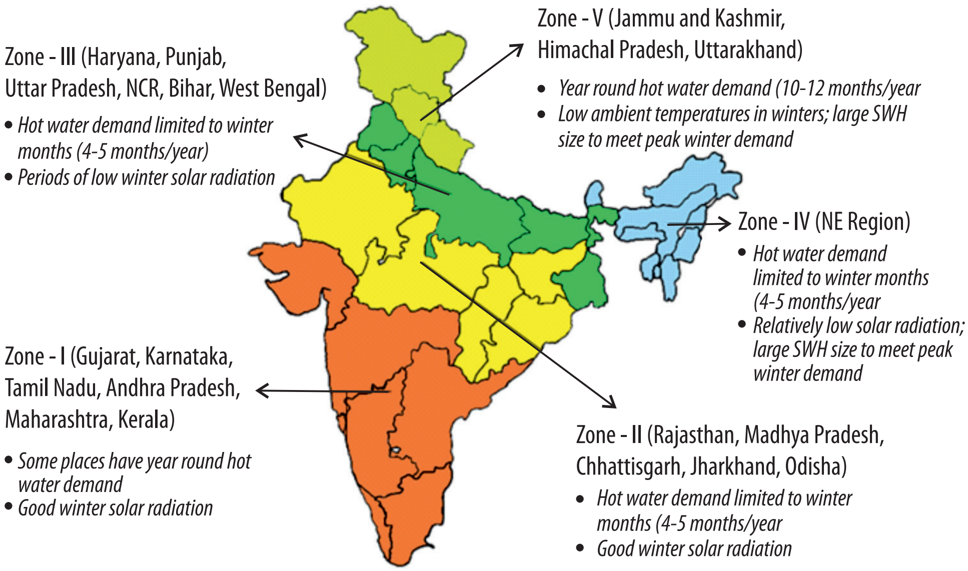


Figure 2 Status of solar thermal technologies and applications in India

Market: The annual sales of solar thermal systems are around 0.9 GW_{th} in 2013/14. SWHs in residential, commercial, and institutional buildings contribute more than 98% of the sales. More than 80% of the market is concentrated in the southern and western states (Zone I) of India. (Box 1 refers to the regional market segmentation of SWHs in the residential sector.)

Box 1 Regional market segmentation of SWHs in the residential sector



Manufacturing and Supply: The manufacturing base of solar thermal technologies is fragmented and dominated by small and medium enterprises. There are around 260 manufacturers/system integrators of solar thermal technologies empanelled with the Ministry of New and Renewable Energy (MNRE). More than 80% of them are concentrated in southern and western India. During the last decade, the number of manufacturers empanelled with the MNRE has increased rapidly. While some of them have set up manufacturing facilities, others act more as traders, importing evacuated tubes or complete SWH systems from other countries. Lack of a well-developed system to test and enforce quality norms has led to concerns about the quality of solar thermal systems.

Policy Framework: The policy focus on deployment of solar thermal applications has been limited so far in the existing policies and programmes. Provision of capital subsidies and soft loans has been the main policy tools used to promote solar thermal technologies in India. Recently, MNRE announced the withdrawal of central capital subsidies for SWH, but capital subsidies are still available for other solar thermal technologies.

At the municipal level, nearly 100 municipal corporations have incorporated the mandatory regulations for SWHs for certain building types in their building bye laws. However, only a few of the municipal corporations have been able to effectively implement the mandatory regulations. Other solar thermal technologies/applications require a fillip to scale up.

Potential Assessment and Market Projections

A summary of the results for potential assessment shows that:

1. The market potential for SWHs in buildings (Residential + Commercial and Institutional) is expected to grow 10-fold between 2014 and 2032, and is expected to reach 133 GW_{th} by 2032 (Figure 3).
2. Most of the future market potential will come from smaller towns and rural areas. In 2014, rural areas accounted for <10% of the market potential; they are expected to account for >50% of the market potential by 2032.

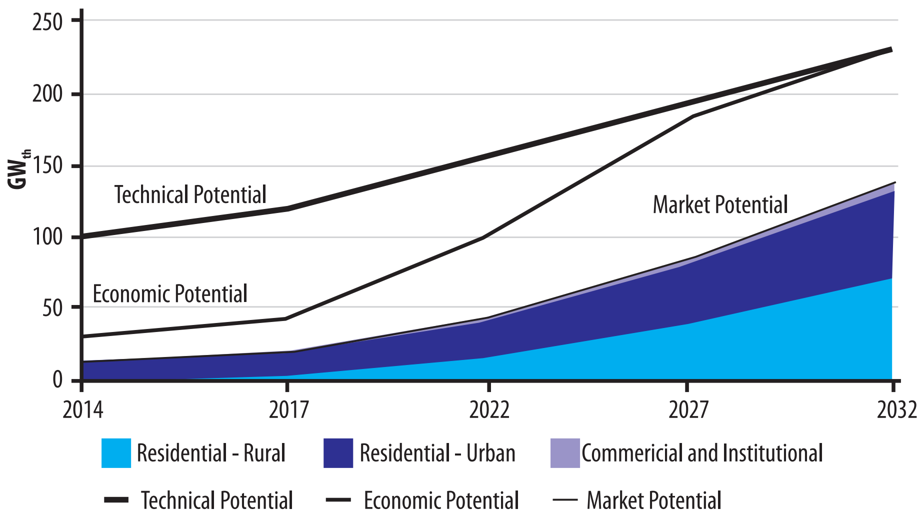


Figure 3 Technical, economic, and market potential of SWH in Buildings

3. The annual electricity savings in final energy consumption from fully exploiting the market potential (2032) for SWH in buildings is expected to be equivalent to the annual electricity generated from ~64 GW_p of solar PV installations (Figures 4 and 5).

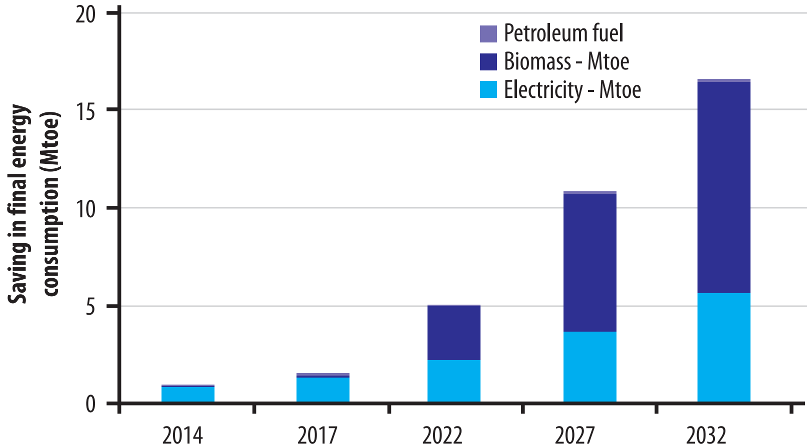


Figure 4 Savings in final energy consumption from realisation of market potential

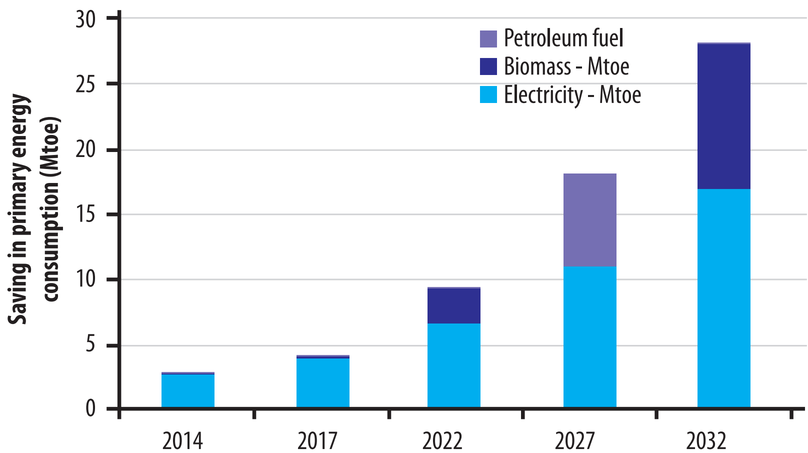


Figure 5 Savings in primary energy consumption from realisation of market potential

4. In 2014, the technical potential of solar cookers in terms of primary energy saving was at 11.7 Mtoe, with the rural sector accounting for ~90%. In 2032, this potential reduces to 10.6 Mtoe, with the rural share at ~86%. The rural sector should be targeted for solar cooking as it has very good potential, mainly due to space availability and lower cooking efficiency (Figure 6).

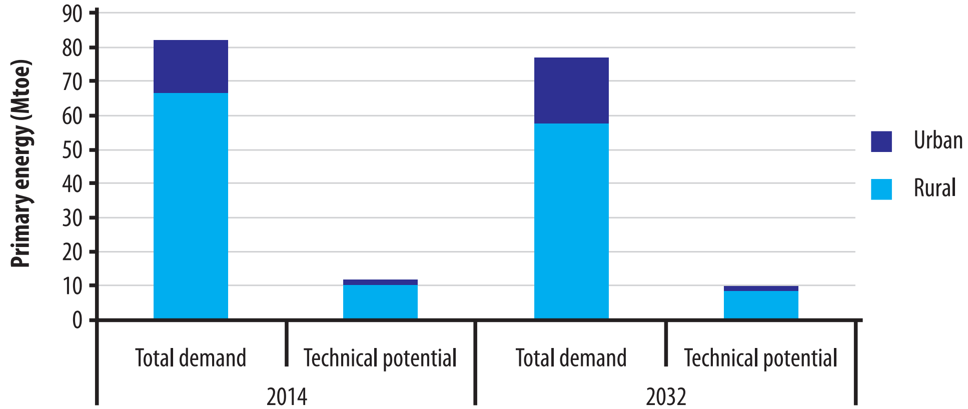


Figure 6 Technical potential of solar cookers

5. The technical potential of solar thermal technologies for industrial process heat applications (<250 °C) in terms of primary energy savings was estimated to be ~8.3 Mtoe in 2014 and ~16.5 Mtoe in 2032.

A summary of results of market projections under the two scenarios (business-as-usual [BAU] scenario and aggressive effort scenario] shows that:

6. The cumulative installation of solar technologies for each sector for 2032 under the BAU scenario and the aggressive effort scenario is expected to reach 41 GW_{th} and 106 GW_{th}, respectively (Figure 7).

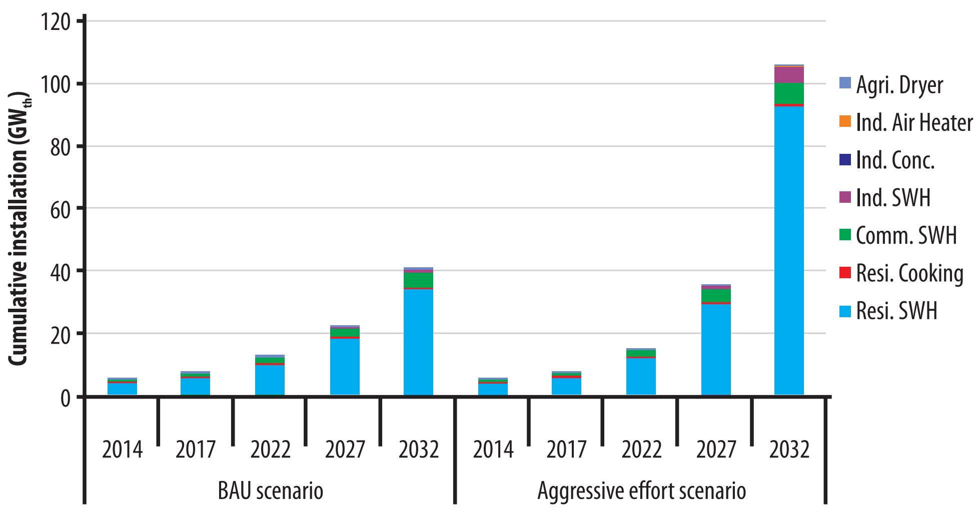


Figure 7 Projections of solar thermal technologies under BAU and aggressive effort scenario

Under the aggressive effort scenario, the cumulative installation of solar technologies is ~2.5 times as compared to the BAU scenario. Under the aggressive effort scenario, the total useful energy delivered by solar technologies is ~70 TWh/y (~6 Mtoe/y).

7. Under both the scenarios, SWH in the residential sector was noted to be the dominant application. SWH applications for all sectors (residential, commercial and institutional, and industrial) contribute to ~99% of installed solar thermal capacity in 2032 under both the scenarios (Figure 7).

Goal and Strategies

Goal 2032: The roadmap envisages decentralised solar thermal technologies and applications to follow an aggressive effort path to reach a cumulative installed capacity of 100–120 GW_{th}, delivering 65–80 TWh energy, annually, by the year 2032. A large part of the cumulative installed capacity (almost 90%) is expected to be met through the accelerated deployment of the mature solar thermal technology, i.e., SWHs in buildings. Solar industrial heat (<250 °C) is expected to cross the chasm and reach the growth phase during this period.

Achieving the goal of aggressive effort path (~106 GW_{th}) by 2032 would result in:

1. Annual savings of around 68,000 GWh of electricity at the consumer level or around 85,000 GWh[1] at the point of generation, i.e., at the power plant. This translates to equivalent avoided thermal power plant capacity of around 14,000 MW.[2] Generation of equivalent amount of electricity per year through solar PV would require around 50 GW_p of solar PV power plant capacity.
2. Annual savings of 1 Mtoe of oil and gas, resulting in an import bill reduction of ~Rs 5000 crore/year.[3]

Six strategic focus areas have been identified to achieve this goal, namely:

1. *Expansion of SWHs in the residential sector:* The aim of the strategy is to achieve accelerated deployment of SWHs in residential buildings by:
   a. Amending the building bylaws by urban local bodies (ULBs) for mandatory provision of SWHs (as a part of adoption of green building codes) and their effective implementation.
   b. Consolidation of the SWH market in the urban areas of Zone I through targeted market promotion and development activities, particularly in low- and medium-density population cities and towns.
   c. Expansion of the SWH market to urban areas of Zones II to V and rural areas of all zones by identifying the best suited regions for SWHs and further developing the market and strengthening the manufacturing and supply network in the identified regions. For exploiting rural markets, the roadmap recommends developing bundled solutions containing not only the SWH product but also its services and access to financing.

[1] *Considering transmission and distribution losses of 20%.*
[2] *Considering plant load factor of 75%.*
[3] *At world energy outlook prices 2012 (USD 136/boe (barrels of oil equivalent) and USD 11.8/mmbtu (million metric British thermal unit); 1 USD = Rs 60).*

d. Efforts in applied research and development (R&D) for developing reliable and integrated SWH solutions for multi-storey residential buildings and developing product variants suitable for rural requirements.

e. Developing standards, testing procedures, and testing facilities for SWHs and launching a quality labelling scheme, particularly for residential SWH systems.

2. *Development of the industrial process heat (<250 °C) market:* The strategy aims at developing the market of solar thermal technologies for industrial heat application to reach the growth phase by 2027. The main elements of the strategy include:

   a. Focussed market development and strengthening of the industrial solar thermal solution supply chain targeting selected industrial sectors to achieve a critical mass of industrial solar thermal installations.

   b. Applied R&D for developing standardised technology packages, and increasing reliability, functionality, efficiency and cost-competitiveness of industrial solar thermal solutions.

   c. Undertaking independent field performance assessment based on standard methods for benchmarking performance of different types of industrial solar thermal systems.

      i. Move towards regulations and market-based mechanisms for solar industrial heat after reaching a critical mass.

3. *Focussed research, development, and deployment:* Focussed R&D effort should be aimed at making existing solar thermal packages more efficient, reliable, and cheaper as well as developing new solar thermal technology packages for high potential end-use applications. A national-level solar thermal R&D programme should be started. The programme should promote collaborative R&D projects involving the solar thermal industry, academic institutions, and specialised research labs.

4. *Promoting indigenous and quality manufacturing:* The aim is to enhance the competitive advantage of the Indian solar thermal industry globally. The main elements of the strategy are:

   a. Strengthening and promoting indigenous manufacturing by establishing a solar thermal manufacturing park, providing a special dedicated line of credit to solar thermal manufacturers, providing tax and duty exemptions on indigenous manufacturing, and facilitating technology transfer and manufacturing tie-ups between Indian and international companies.

   b. Quality control and continuous quality upgradation by developing standards, testing procedures, and testing facilities for all types of solar thermal technologies, products, and systems, and launching a labelling scheme for mature technologies like residential SWHs.

   c. Building human capacities through developing vocational courses in industrial training institutes (ITIs) for the solar thermal sector and collaborating with the National Skill Development Corporation to devise skill development programmes.

5. *Strengthening the institutional network:* The aim is to put in place an institutional network for the implementation of the solar thermal roadmap. The main element of the strategy is the formation and operationalisation of a Solar Thermal Development Network

(STDN). STDN will take the overall leadership in the implementation of the solar thermal roadmap. This will be done by undertaking tasks in the following areas:

a. Applied R&D: To facilitate collaborative applied R&D projects involving multiple partner institutions to find solutions to the priority research.
b. Market and policy research: To undertake or facilitate market and policy research and engage with key stakeholders
c. Performance monitoring and testing: Coordinate work related to the development of performance monitoring and testing protocols, and dissemination of performance data of various solar thermal systems.
d. Technical training: Provide support for the development of curriculum for the training of technicians and engineers.
e. Knowledge sharing: STDN will organise an annual flagship knowledge event (seminar and exhibition) to promote information and knowledge exchange among the stakeholders.

6. *Policy framework redesign:* The roadmap suggests re-designing the existing policy framework for the solar thermal sector. Two different approaches are suggested, depending on the status of the technology in the product life cycle.
   a. Policy framework for mature technologies: The technologies that have crossed the chasm and are in a growth phase, i.e., mature technologies, require a policy framework that supports the rapid deployment of the technology.
   b. Policy framework for technologies that are under development: The main elements of the policy framework for technologies that have not crossed the chasm consist of supporting R&D, providing incentives to facilitate demonstration and reaching a critical mass, and providing support for performance benchmarking and technology appraisal.

CHAPTER 1

Introduction

1.1 Indian Energy Scenario and Potential for Solar Thermal Technologies

India faces several challenges in the energy sector. Some of the most important challenges that India might face in meeting its energy requirements include the following:

- Primary energy demand is expected to increase three-fold in the next two decades, from the current 601 Mtoe (million tonnes of oil equivalent) to 1859 Mtoe in 2032.[1]
- Currently, 77% of oil and 31% of primary energy are imported. By 2032, 93% of oil will need to be imported and a massive increase in coal imports will lead to almost 70% of primary energy being met through imports.[2]
- As a large part of India's energy comes from fossil fuels, particularly coal, the CO_2 emissions are expected to rise by more than three-fold.

In the context of these challenges, harnessing local renewable energy sources becomes critically important.

An analysis of the energy consumption pattern[3] in India shows that 57% (240 Mtoe) of final energy consumption is used for thermal applications (Figure 1.1). Industrial process heat, residential cooking, and water heating are the main thermal applications, accounting for more than 90% of the thermal energy requirement. At present, most of this thermal energy demand is being met through coal, biomass, and petroleum fuels.

[1] *Planning Commission, Government of India. The India Energy Security Scenarios 2047 (IESS 2047), www.indiaenergy.gov.in, 25 April 2014*
[2] *Ibid*
[3] *Analysis carried out under this study used the data from The India Energy Security Scenarios 2047 (IESS 2047), by the Planning Commission, Government of India, 25 April 2014.*

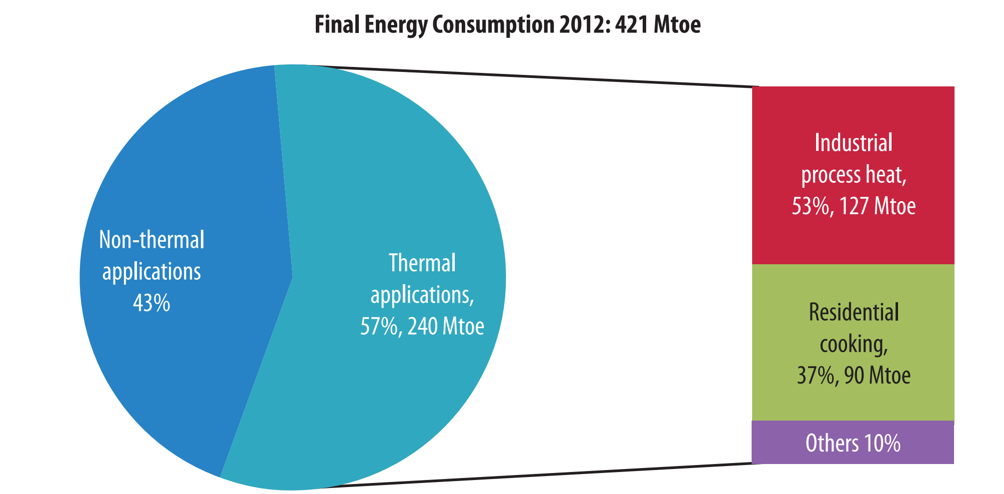


Figure 1.1 Share of thermal energy in final energy consumption[4]

Solar thermal technologies convert solar energy to heat, and can be applied to water heating, domestic and commercial cooking, agricultural and industrial drying, water desalination, low and medium temperature industrial process heat, space conditioning (space heating, cooling), and refrigeration.

Globally, solar thermal heat is the second largest source of renewable energy in the world after wind energy. Of the available solar thermal technologies, only the solar water heater (SWH) technology has been able to achieve significant deployment at the global level. By 2013, solar thermal heat had reached an annual production of ~280 TWh_{th}, which was 1.75 times the annual energy generation from solar photovoltaic (PV) technology[4] (Figure 1.2[5]).

[4] *Mauthner F, Werner W. Solar Heat Worldwide, Markets and Contribution to Energy Supply 2012, Edition 2014. IEA Solar Heating and Cooling Programme, June 2014.*

[5] *Ibid*

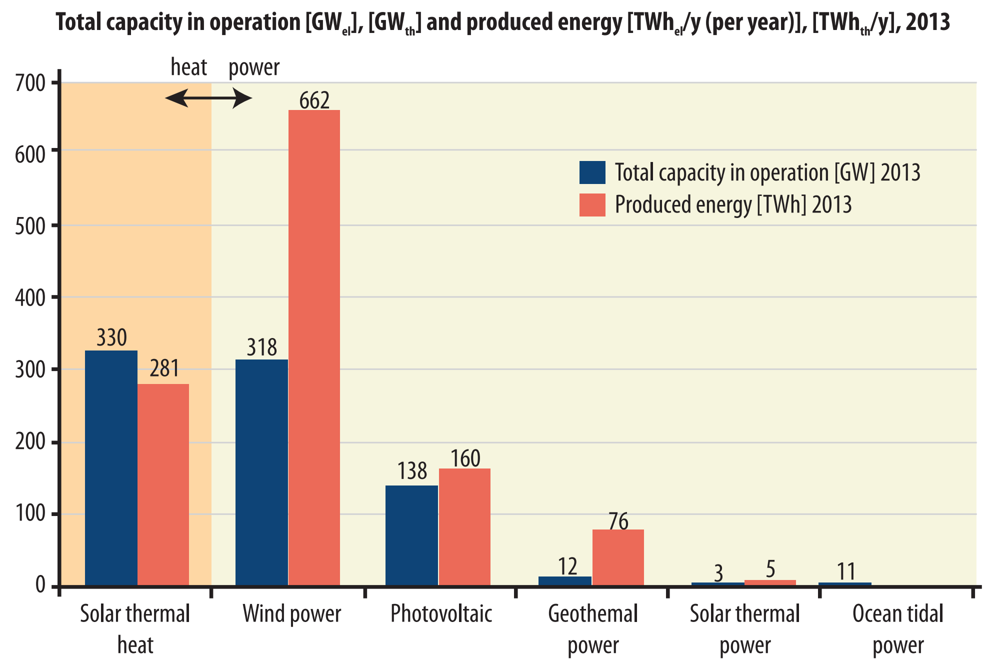


Figure 1.2 Comparison of estimated energy produced from various renewable energy sources by 2013

Solar thermal technologies for supplying low and medium temperature process heat in industries, for cooling, refrigeration and space conditioning, and for domestic and commercial cooking applications are, however, yet to be deployed at any significant scale. By the end of 2012, compared to China, which had an installed solar thermal capacity of 180.4 GW$_{th}$, India was able to achieve only 4.5 GW$_{th}$,[6] which is an indicator of a huge potential for growth.

Decentralised solar thermal technologies can contribute in meeting the goals of reduced dependence on imported fuels, enhanced energy security, improved energy access, reduced electricity demand, better environmental quality, and socio-economic development.

To harness the full potential of decentralised solar thermal technologies, an integrated approach, in the form of a roadmap for decentralised solar thermal technologies, is required. The roadmap will provide a vision, a goal, and a framework for the development of the sector and will help in accelerating the deployment of solar thermal technologies.

[6] *Mauthner F, Werner W. Solar Heat Worldwide, Markets and Contribution to Energy Supply 2012, Edition 2014. IEA Solar Heating and Cooling Programme, June 2014.*

1.2 International Examples of Solar Thermal Roadmaps

Internationally, solar thermal roadmaps have been developed that estimate the potential of solar thermal technologies and present strategies and action points to achieve this potential. In the following sections, brief information on two such roadmaps are provided.

1.2.1 IEA Technology Roadmap for Solar Heating and Cooling (2012)

The Solar Heating and Cooling (SHC) Programme of the International Energy Agency (IEA) was established in 1977 to promote the use of all aspects of solar thermal energy. The programme prepared a technology roadmap for solar heating and cooling in 2012.[7] As per the roadmap, by 2030, the deployment of solar thermal technologies will be mainly for (a) heating water in buildings, and (b) low-temperature solar industrial process heating. However, by the year 2050, in addition to the above two applications, deployment is expected to become significant for (a) solar space heating in buildings, (b) solar space cooling in buildings, and (c) heating water in swimming pools.

Overall, the roadmap envisages that by 2050, solar energy could annually produce 16.5 EJ of solar heating, more than 16% of total final energy use for low temperature heat; and 1.5 EJ solar cooling, nearly 17% of total energy use for cooling (Figure 1.3[8]).

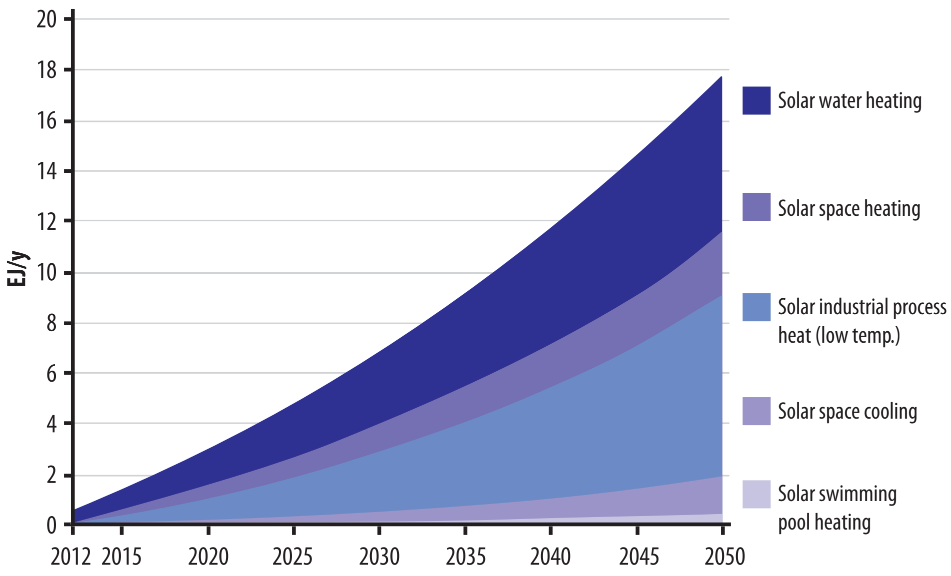


Figure 1.3 IEA roadmap for solar heating and cooling (EJ/y)

[7] *International Energy Agency. Technology Roadmap: Solar Heating and Cooling. Paris: OECD/IEA, 2012. http://www.iea-shc.org/data/sites/1/publications/2012_SolarHeatingCooling_Roadmap.pdf*

[8] *Ibid*

The roadmap recommends concerted action by all stakeholders to realise the vision. Among the various stakeholders, it specifically points out the actions that should be taken by governments in the next 10 years. These actions include:

- Create a stable, long-term policy framework for solar heating and cooling; establish medium-term targets to maximise the effective use of mature and nearly mature technologies, and long-term targets for advanced technologies that are yet to reach the market.
- Introduce differentiated economic incentives on the basis of competitiveness per technology by means of transparent and predictable frameworks to bridge competitive gaps.
- Address barriers such as information failures, up-front investment in technologies, lack of quality standards, and the 'split-incentive' problem (where the investor in solar heating and cooling technology does not reap the benefits of reduced energy costs).
- Provide RD&D (research, development, and demonstration) funding and support mechanisms to enable promising pre-commercial solar heating and cooling technologies to reach high volume commercial production within the next 10 years.

1.2.2 German Solar Heating Roadmap (2012)

In an initiative supported by the German Solar Industry Association, a solar heating roadmap was prepared for Germany in 2012. The study concluded that heating requirements account for over 50% of total end energy needs in Germany and a substantial part of this need could easily be met through solar energy. The roadmap sets up a vision aimed at attaining the goal of installing around 70 GW (gigawatts) of solar heating capacity (which is seven times the installed capacity in 2010), or around 100 million m^2 of collector surface on German rooftops by the year 2030.

The roadmap identified six strategic thematic priorities to meet the goals:

1. Accelerated expansion of solar water heating in the established market segments of single-family and dual-family homes
2. Development of additional market segments by gaining new expertise
3. Development of the market for 'industrial process heat up to 100 °C'
4. Enhanced competitiveness through cost-effective system solutions
5. Prioritizing of research towards development of inexpensive solutions in established segments and in the area of industrial process heat
6. Actively communicate the necessary framework conditions for growth of solar heating sector

An analysis of both roadmaps indicate that both are setting a goal of increasing the installed capacity by six to eight times during 2010–2030. Also, both roadmaps conclude that up to the year 2030, the largest deployment potential lies in the residential solar water heating and industrial process heating segments.

1.3 Objective

The overall objective of this study is to prepare a roadmap for decentralised solar thermal technologies and applications in India. The roadmap is for the period 2014–2032 and consists of analysis of the current situation (baseline assessment); assessment of the technical, economic and market potential of various solar thermal applications; market projection scenarios; goals to be achieved by 2032; and strategies and an action plan to achieve the goals.

1.4 Methodology

The methodology followed while formulating the roadmap is as presented in Figure 1.4

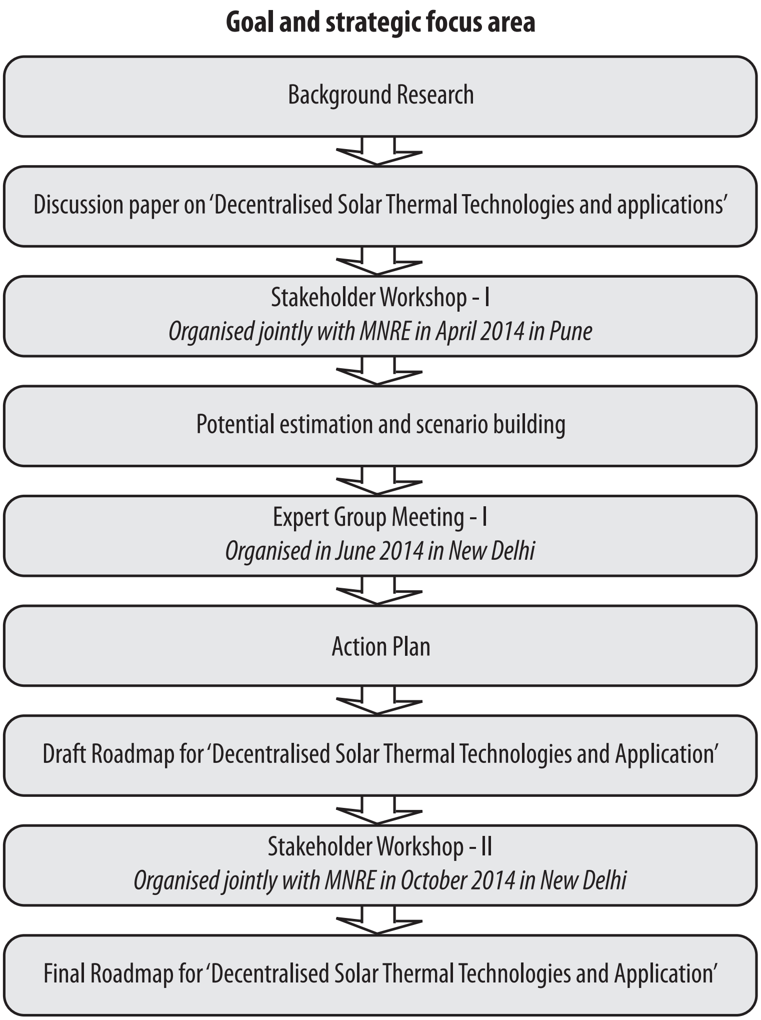


Figure 1.4 Methodology followed for preparation of roadmap for decentralised solar thermal technologies and applications in India

1.4.1 Background Research

The background research consisted of a literature review and covered aspects such as:

- current state of decentralised solar thermal in India, including information on technologies, applications, policies, manufacturing capabilities, market, and performance;
- global status of decentralised solar thermal technologies, applications, policies, market, and performance;
- case studies of Indian and global success stories; and
- examples of roadmaps that have been developed in other countries

In addition to a desk review, as a part of the background research, the project team conducted interviews with 10 key stakeholders, including policy makers, manufacturers, researchers, end-users, and state and national-level programme managers/implementers. The objective of these interviews was to collect additional and missing information on specific topics; collect different viewpoints on solar thermal technologies and their potential; and prepare a list of key issues.

1.4.2 Discussion Paper on 'Decentralised Solar Thermal Technologies and Applications in India'

The background research led to the preparation of a discussion paper, which covered topics as listed below:

- Relevance of solar thermal for India in the context of energy supply and access, climate change, emission reduction, and the low carbon growth objectives of the Government of India
- Status of solar thermal development and deployment in India:
    - Technology and applications (water heating, cooking, air heating, drying, industrial processes, etc.)
    - Market segment, current penetration, and geographical distribution
    - Policies at the central, state, and municipal levels

1.4.3 Stakeholder Workshop – I

A stakeholder workshop was organised on 29–30 April 2014 in Pune. The workshop was attended by more than 40 participants, including representatives from the Ministry of New and Renewable Energy (MNRE), the Solar Thermal Federation of India, solar thermal manufacturers, research organisations, state nodal agencies, non-governmental organisations (NGOs), industry, architects, and builders.

The main objectives of the workshop were to:

1. present the findings of the discussion paper;
2. present and receive input on the methodology for preparing the roadmap; and
3. discuss emerging trends and future scenarios of solar thermal technologies and applications.

1.4.4 Potential Assessment and Scenario Building

An assessment was carried out to quantify the potential (in terms of solar collector area, energy generation, and fuel substitution) of solar thermal technologies for different end-use applications. Potential assessment was carried out at three levels: technical, economic, and market potential. Two scenarios – business as usual (BAU) and aggressive effort – were developed to predict the growth path of solar thermal technologies during the period 2014–2032.

1.4.5 Expert Group Meeting

To guide the formulation of this roadmap, particularly with goal setting and strategic focus areas, an expert group was constituted. The members of the expert group consisted of representatives from the solar thermal industry, academia, and professionals working in the research areas of solar thermal technologies and energy policy. A meeting of the expert group was convened on 13 June 2014 in New Delhi.

1.4.6 Action Plan

A phased action plan specifying the activities and responsibilities of different stakeholders for each of the strategic focus areas was prepared.

1.4.7 Draft Roadmap

A draft roadmap containing the present baseline, the results of the potential assessment and scenario building, and the strategies and action plan was prepared for review by the stakeholders.

1.4.8 Stakeholder Workshop – II

With the objective of (a) presenting the main elements of the roadmap and (b) receiving inputs and comments on each of the identified six strategic focus areas, a second stakeholder workshop was organised in October 2014 in New Delhi. The workshop was attended by more than 35 participants, including representatives from MNRE, Department of Science and Technology, National Institute of Solar Energy, manufacturers, industry associations, academia, and research organisations.

1.4.9 Final Roadmap

The inputs and comments received from the second stakeholder workshop were analysed and relevant points were incorporated into the final roadmap.

1.5 Outline of the Report

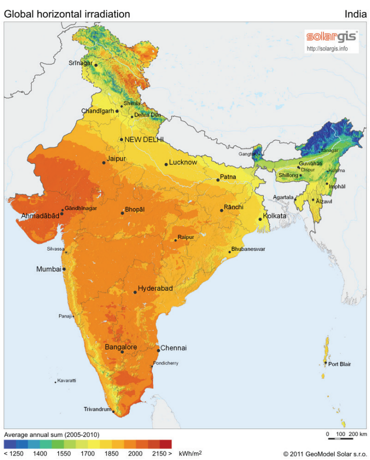
The next chapter, Chapter 2, provides a description of various solar thermal technologies and their applications. Chapter 3 provides the status of solar thermal technologies and applications in India. Chapter 4 explains both the methodology as well as results of the exercise to evaluate technical, economic, and market potential for various solar thermal applications. The goals and the strategic focus areas and action plan to achieve the goals are presented in Chapter 5.

CHAPTER 2

Solar Energy for Thermal Applications

2.1 Solar Energy Resource in India

On an average, India receives high solar radiation (GHI ~1900 kWh/m^2.y and DNI ~1500 kWh/m^2.y), but there are significant variations within the country; Gujarat, Rajasthan, parts of Maharashtra, and Ladakh receive high solar radiation (GHI >2000 kWh/m^2.y and DNI >1800 kWh/m^2.y) whereas, parts of north and northeast India receive low solar radiation (GHI <1300 kWh/m^2.y and DNI <1100 kWh/m^2.y). Figure 2.1[1] and Figure 2.2[2] show the annual global horizontal irradiation (GHI) and annual direct normal irradiation (DNI) of India.[3] Several of the solar thermal technologies used for low temperature applications (refer Section 2.4) utilise both direct and diffuse solar radiation (global solar radiation); however, medium to high temperature solar thermal technologies require concentration and hence are limited to using direct solar radiation.



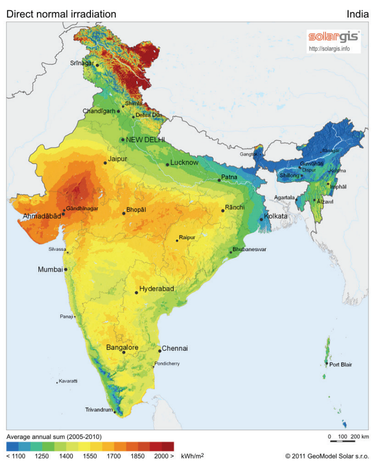


Figure 2.1 Annual global horizontal irradiance, India **Figure 2.2** Annual direct normal irradiance, India

[1] *http://solargis.info/doc/_pics/freemaps/1000px/ghi/SolarGIS-Solar-map-India-en.png*

[2] *http://solargis.info/doc/_pics/freemaps/1000px/dni/SolarGIS-Solar-map-DNI-India-en.png*

[3] *Solar radiation received at the earth's surface without change of direction (i.e., in line with the sun) is called direct radiation, while the radiation received from all parts of sky hemisphere (after subject to scattering in the atmosphere) is called diffuse radiation. The sum of direct and diffuse is called total or global radiation. (Source: S P Sukhatme. Solar Energy: Principles of Thermal Collection and Storage, Second Edition. New Delhi: Tata McGraw-Hill Publishing Company Limited, 2003.)*

2.2 Solar Energy Conversion

Solar energy technologies can be broadly classified into two categories: (a) solar thermal technologies that deliver heat, and (b) solar photovoltaic (PV) technologies that produce electricity. The heat delivered from solar thermal technologies can be used either for thermal applications or for generating electricity using a turbine and a generator. This study covers only the solar thermal technologies that are used for thermal applications.

Solar thermal technologies offer several advantages, some of these are listed below.

- Conversion of solar energy into thermal energy offers much better efficiency as compared to conversion to electricity using solar PV technology. For instance, while the efficiency of a flat-plate collector or solar concentrator usually ranges from 35%–70% (refer Box 2.1 and Box 2.2), the efficiency of commercially available crystalline solar PV panels is 10%–15%. Hence, the useful energy yield per unit of land area is higher for conversion to thermal energy than to electricity.
- Unlike grid-connected solar PV systems, where the generated electricity is transmitted through the grid, the thermal energy generated using solar energy is consumed locally, which minimises loss in the transmission of energy.
- Solar thermal technologies offer opportunities for local manufacturing and employment.

However, harnessing solar radiation for generating heat has challenges. Some of these include:

- Solar energy is a low energy density source that requires a large shadow-free area when the energy requirements are high.
- Due to diurnal and seasonal variations in solar radiation, the energy output from solar thermal systems is variable and hence they require sufficient storage systems and effective hybridisation with other sources of energy to meet the thermal energy demand.
- Solar radiation is available only during daytime and varies seasonally, therefore the capacity utilisation factor (CUF)[4] of solar systems are low.

2.3 Solar Thermal Technologies

2.3.1 Non-concentrating Solar Thermal Collectors

Collectors in which no optical concentration of radiation is done are called non-concentrating solar thermal collectors. They work on the principle of exposing a dark surface to solar radiation so that the radiation is absorbed. Non-concentrating collectors absorb both direct and diffuse radiation. The absorbed radiation is then transferred to a fluid, like air or water. There are two main types of non-concentrating solar thermal collectors: flat-plate collectors and evacuated tube collectors.

[4] *Capacity utilisation factor (CUF) = energy produced (kWh)/(365 x 24 x installed capacity of the system in kW)*

2.3.1.1 Flat-plate Collector

A flat-plate collector consists of an absorber used for collecting the incoming solar radiation (near infrared and visible range). To enhance absorption, the absorbers are dark in colour and are sometimes coated with selective coating.[5] Generally, the absorbers are made of metals that have high thermal conductivity, such as copper or aluminum. The absorber is enclosed in a box, covered on the top with a glass sheet (glazing), and insulated on the back and sides (Figure 2.3[6]). The absorbed heat is transferred to a heat transfer fluid (liquid or air) through a heat exchange circuit. A flat-plate collector with liquid heat transfer medium is used for solar water heating, whereas air-based flat-plate collectors are used in solar air heating.

Increasing the cost-effectiveness and the efficiency of the collector have been the two main areas of research and development (R&D). Developing newer materials to replace costly metals like copper, with little or no reduction in efficiency, have the potential to increase the cost-effectiveness of the collector. Recently, polymer-based flat-plate collectors with special coatings have been developed and introduced in the market. R&D is also under way to increase the efficiency of the flat-plate collector by minimising the losses. For example, an evacuated flat-plate collector was recently developed that has a vacuum between the absorber sheet and the glazing.

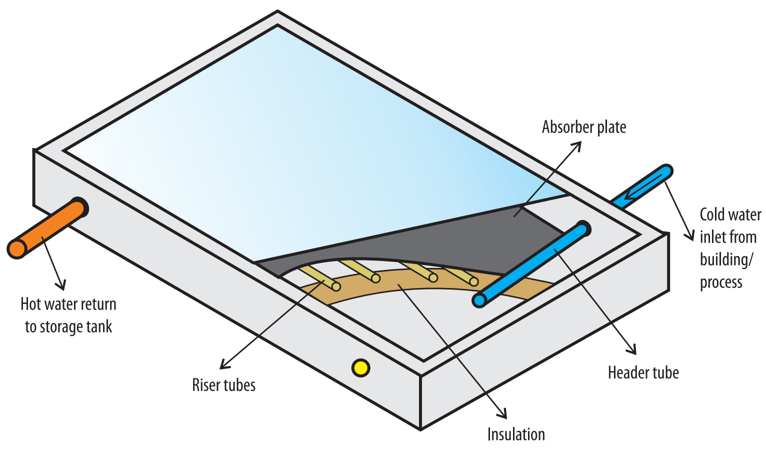


Figure 2.3 Cross-section of a typical flat-plate collector

2.3.1.2 Evacuated Tube Collector

Similar to a flat-plate collector, an evacuated tube collector also consists of an absorber to absorb solar radiation. The collector has two glass tubes fused together with a vacuum in between. The

[5] *Selective coating materials are special materials that have a high absorptance (and emittance) for short wavelength (visible) light and have low average absorptance and emittance for long wavelength radiation (thermal or infrared radiation). The absorber surface, after coated with selective coating, absorbs solar energy well but does not radiate thermal energy well.*

[6] *Master Plumbers' and Mechanical Services Association of Australia and Sustainable Victoria. Large Scale Solar Thermal Systems Design Handbook, First Edition. December 2009. http://bit.ly/1vrYl8m*

absorber is placed at the outer layer of the inner glass tube (Figure 2.4[7]). Generally, only liquid heat transfer medium is used and therefore they find application only in SWHs. Evacuated tube collectors can be further classified as direct flow tubes and heat pipe tubes.

In the direct flow tube, the liquid to be heated is directly circulated in the inside tube, whereas, in a heat pipe tube, the pipe (usually made of copper) is filled with a fluid of low boiling point and housed inside the evacuated tube (Figure 2.5[8]). When the pipe is heated by solar radiation, the fluid boils and rises up the pipe. At the top, the heat pipe is connected to a header pipe where the heat is transferred to the liquid flowing through the header pipe. The fluid in the heat pipe condenses on cooling and flows back to the bottom of the heat pipe.

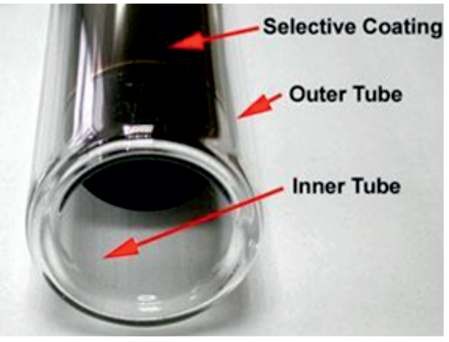


Figure 2.4 Evacuated tube collector

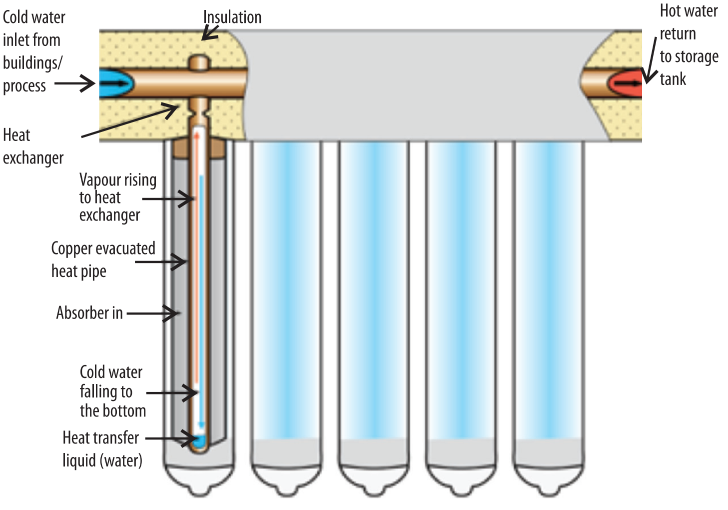


Figure 2.5 Evacuated tube heat pipe

[7] *Master Plumbers' and Mechanical Services Association of Australia and Sustainable Victoria. Large Scale Solar Thermal Systems Design Handbook, First Edition. December 2009. http://bit.ly/1vrYl8m*

[8] *Ibid.*

2.3.2 Concentrating Solar Thermal Collectors

Solar concentrator collectors work on the principle of focussing the DNI falling on a large area (reflector) onto a small area (absorber) to achieve higher temperatures of the working fluid. Generally, lenses or mirrors are used to focus the radiation. Except for the compound parabolic concentrator collector, all other collectors track the sun, either on one or two axes. Concentrating solar thermal collectors can be categorised based on their type of tracking.

2.3.2.1 Non-tracking Concentrators

Non-tracking concentrators have low concentration ratios (generally concentration ratio <2) and therefore cannot achieve higher temperatures. A compound parabolic concentrator (CPC) reflector used in combination with an evacuated tube collector (also known as a non-imaging collector) is the most prevalent type of non-tracking solar concentrator. In a CPC, an evacuated tube is placed at the focal plane of two parabolic shape reflectors (Figure 2.6[9]). The axis of the two reflectors is inclined so that the focus of one parabola lies on the axis of the other and vice-versa. The angle between the two axes of the parabola is known as the acceptance angle of the CPC. Light with an incidence angle of less than one-half the acceptance angle will be reflected to the receiver opening, while light with an incidence angle greater than one-half the acceptance angle will not be reflected to the receiver and will eventually be reflected back through the aperture of the CPC. Generally, the reflector is made of materials having high reflectance such as mirrors or specially coated aluminum sheets.

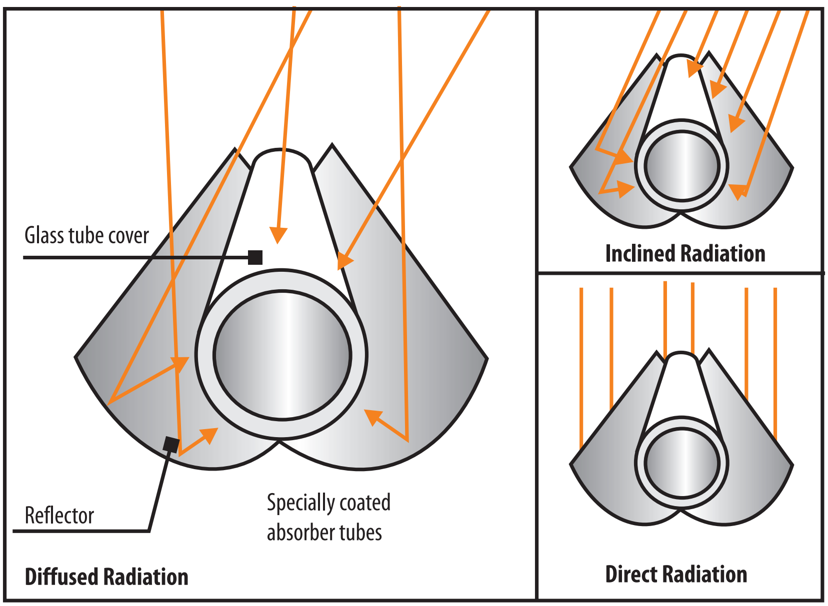


Figure 2.6 Schematic of a typical compound parabolic collector

[9] *MNRE. Non-Imaging Solar Concentrator: For Medium Temperature Thermal Applications. http://www.cshindia.in/images/pdf/Non-Imaging%20Concentrator.pdf*

Box 2.1 Performance characterisation of flat-plate, evacuated tube, and compound parabolic collectors

Figure 2.7 compares the instantaneous efficiency of flat plate, evacuated tube, and compound parabolic collectors.[10] While the ***y*** axis represents the instantaneous efficiency of the collector, the ***x*** axis of the figure represents the difference between average fluid temperature in the collector (t_m) and the ambient air (t_a), divided by the incident solar radiation (G). It can be seen that for a given solar radiation, when the temperature difference ($t_m - t_a$) is low, flat-plate collectors have better efficiency than evacuated tube collectors. As the temperature difference increases, evacuated tube collectors or CPC collectors performs better than flat-plate collectors.

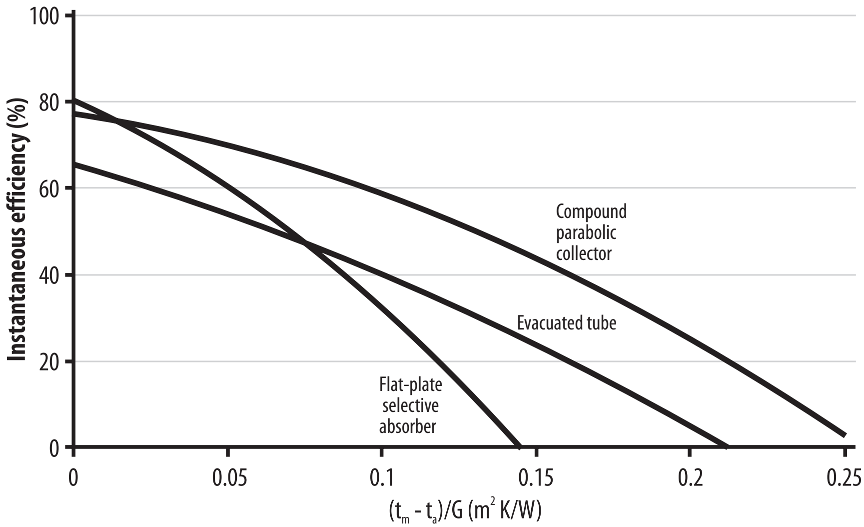


Figure 2.7 Instantaneous efficiency curve of flat plate and evacuated tube collectors

2.3.2.2 Single-axis Tracking Concentrators

Single-axis tracking concentrators consist of reflectors with a line or point focus. The reflectors can be either parabolic or plain reflectors with east-to-west sun tracking. Single-axis concentrators can be categorised by the type of focus. Line focus collectors having parabolic reflectors known as parabolic trough collectors (Figure 2.8[11]), while plain reflectors with line focus are known as linear fresnel collectors (Figure 2.9[12]). Parabolic elliptical reflectors are used to concentrate solar radiation on fixed point focus, commonly known as a fixed focus elliptical solar dish, e.g., Scheffler dish (Figure 2.10).

[10] *Source: Master Plumbers' and Mechanical Services Association of Australia and Sustainability Victoria. Large Scale Solar Thermal Systems Design Handbook, First edition. December 2009. http://bit.ly/1vrYl8m*

[11] *http://www.jc-solarhomes.com/COLLECTORS/concentrators_vs_flat_plates.htm*

[12] *http://solar.kgisl.com/*

Figure 2.8 Parabolic trough collectors

Figure 2.9 Compact linear fresnel collector system

Figure 2.10 Fixed focus elliptical dish (Scheffler dish)

A high performance parabolic trough collector usually has a large curved reflector made up of solar grade mirrors with automatic single axis tracking that concentrates solar radiation on an evacuated tube receiver with selective coating. The tube is filled with working fluid and can reach a maximum temperature of 400 °C. Other variants of parabolic trough collectors of lower performance are also available, with smaller curvature, aluminum-based reflectors and a non-evacuated tube receiver.

Linear fresnel reflectors use long, thin segments of mirrors to focus DNI onto a fixed absorber located at a common focal point of the reflectors. The reflectors are typically aligned in a north–south orientation and turn about a single axis using an automatic solar tracker system. An absorber runs parallel to the reflecting mirrors, and is located above them. The absorber consists of an inverted air cavity with a glass cover, enclosing insulated steam pipes. In a typical linear fresnel collector, only a single absorber is used for even a large mirror field. A variant of the linear fresnel reflector, known as a compact linear fresnel reflector, uses multiple absorbers for a single mirror field.

A fixed focus elliptical dish (Scheffler dish) consists of mirrors as reflectors to concentrate radiation on a fixed focus, which contains the working fluid to be heated. The most commonly available dish has automatic continuous east-to-west tracking with a provision of manual adjustment for seasonal variation in the north–south position of the sun. A dish with an automatic system for north–south adjustment has recently been developed.

2.3.2.3 Double-axis Tracking Concentrators

A double-axis tracking concentrator consists of reflectors that track the sun and concentrate direct normal radiation to a moving point focus. The concentrator has the shape of a paraboloid dish with a receiver fixed with respect to the reflector. The paraboloid dish can be made either with small plain mirrors arranged in a shape of a paraboloid dish, known as a fresnel paraboloid dish (Figure 2.11[13]), or with parabolic shape mirrors, known as paraboloid dish (Figure 2.12[14]). Generally, a cavity receiver is used to collect the radiation at the focus of the dish. A cavity receiver allows the reflected radiation to be intercepted by a small aperture or opening. The inside of the cavity is specially coated to increase the absorption of the radiation. The receiver is insulated on the outside to prevent heat losses. The entire structure, including the reflector and the receiver, moves continuously to track the sun.

Figure 2.11 Fresnel paraboloid dish

Figure 2.12 Paraboloid dish

[13] http://www.cliquesolar.com/
[14] http://megawattsolutions.in/

Box 2.2 Anticipated heat delivery of concentrating collectors[15]

Performance of concentrating collectors depends on various parameters, including direct radiation at the location, operating temperature, ambient temperature, wind speed, and other factors. This is due to higher heat losses.

Table 2.1 presents thermal efficiency and anticipated heat delivery at 150 °C operating temperature from various concentration collectors at different locations in India. It clearly shows that performance of double-axis tracking collectors is higher than single-axis tracking collectors. The efficiency will reduce marginally for higher working temperatures due to higher heat losses.

Table 2.1 Anticipated heat delivery from various type of concentrating collectors in different regions of India

Sl no.	Region	Indicative average DNI (kWh/m^2.day)	Fixed focus elliptical dish*/ parabolic trough collector with non-evacuated receiver		Parabolic trough collector with evacuated receiver/ linear Fresnel collector		Fresnel paraboloid dish/ paraboloid dish	
			Efficiency @ 150 °C	Annual heat delivery (lakh kcal/m^2)	Efficiency @ 150 °C	Annual heat delivery (lakh kcal/m^2)	Efficiency @ 150 °C	Annual heat delivery (lakh kcal/m^2)
1.	Leh, Ladakh	6.5	35%	6.26	40%	7.15	60%	10.73
2.	Gujarat, Rajasthan, and western Madhya Pradesh	6.0	40%	6.20	45%	6.97	65%	10.10
3.	Northwest including Himalayas	4.5	35%	3.39	40%	3.87	60%	5.81
4.	Northeast and eastern part of Orissa and Andhra Pradesh	4.0	40%	3.44	45%	3.87	65%	5.59
6.	Southern and central	5.0	40%	4.82	45%	5.42	65%	7.83

* Average effective aperture area of commercially available 16 m^2 fixed focus elliptical dish for receiving normal radiation during the whole year is to be taken as 11 m^2. The heat delivery from a 16 m^2 elliptical dish in a year in different regions will, therefore, be 11 multiplied by figures given in the above table. Also, dual-axis automatic tracked elliptical dishes may have higher heat delivery by about 5% in comparison to single-axis tracked dishes, due to avoided errors in manual north–south adjustments.

2.3.3 Thermal Storage

The intermittent and variable nature of solar radiation leads to a mismatch between the rate and time of solar energy collection and the load for the thermal application. Hence, a storage system is used that can store the solar energy when the collected amount is in excess of the requirement,

[15] MNRE. http://mnre.gov.in/file-manager/UserFiles/heat-delivery-from-CST-based-system.pdf, 15 October 2014.

and discharge energy when the collection amount is inadequate. The various types of thermal storage systems used for solar thermal applications are as described below.

2.3.3.1 Sensible Heat Storage

Sensible heat storage uses the heat capacity of the material to store heat. When the heat storage material is heated, its temperature increases. Water is the most common heat storage and transfer medium used for storing heat less than 100 °C. For heat greater than 100 °C, pressurised hot water or other material, such as concrete or molten salts are commonly used. Rock beds are often used to store heat from air collectors.

2.3.3.2 Latent Heat Storage

Latent heat storage utilises the phase change properties, either melting or evaporation, of the materials. The amount of heat stored depends on the mass and latent heat (fusion or evaporation) of the material.

2.3.3.3 Sorption Heat Storage

Sorption heat storage systems use water vapour uptake by a sorption material, either through adsorption or absorption. These technologies are largely in their development phase. Sorption heat storage technologies have much higher heat storage density than sensible heat storage.

2.3.3.4 Thermochemical Heat Storage

Thermochemical heat storage uses heat to produce a certain chemical reaction and then stores the product. The heat is released when the reverse reaction is made to occur. Such chemical reactions usually occur at a constant temperature; however, the temperatures of forward and reverse reactions are usually different.

2.3.4 Heat-driven Cooling Technologies

Heat-driven cooling technologies use heat as the source of energy to produce cooling. There are two main types of heat-driven cooling technologies:

1. Closed cycle systems use a refrigerant, which undergoes the thermodynamic cooling cycle in a closed loop, and a sorption chiller, to produce chilled water for cooling or refrigeration purposes. The sorption process could be either absorption or adsorption. Presently, the absorption chiller is the most commonly used heat-driven cooling technology. Common absorption cooling pairs are ammonia–water and water–lithium bromide. The coefficient of performance (CoP) of the absorption chiller depends on the type of absorption machine. A single-stage absorption machine[16] requires low temperature grade heat (70 °C–100 °C) to produce a CoP of about 0.7. Double-effect absorption chillers achieve higher CoP through a series arrangement of two thermal regenerators working at different temperatures. The CoP of a double-effect chiller ranges from 1.1 to 1.2 and requires a higher driving temperature, in

[16] *In single-stage absorption, machine regeneration of refrigerant and absorbent takes place in a single step.*

the range of 150 °C–180 °C. Recently, triple-effect absorption machines have been developed, achieving a CoP of 1.6–1.9 with driving temperatures of 200 °C–250 °C. Adsorption chillers work at lower temperature (around 55 °C) to produce lower CoP (~0.6).

2. Open cycle systems use evaporative cooling system in combination with a desiccant for dehumidification. These systems are also known as desiccant evaporative cooling systems. The term 'open' indicates that the refrigerant is not regenerated after producing the cooling effect. Hence, only water can be used as a refrigerant in such systems.

2.4 Solar Thermal Technology Applications

2.4.1 Buildings Sector

So far, the largest application of solar thermal technologies has been in buildings. A variety of solar thermal technologies are used for the purpose of heating water, cooking, and space conditioning in both residential and commercial buildings.

2.4.1.1 Solar Water Heating

Solar water heating systems use non-concentrating solar collectors (flat plate or evacuated tube), in combination with hot water tanks, as a sensible heat storage device. A schematic of SWH is shown in Figure 2.13. Solar water heating systems designed for buildings produce hot water up to 80 °C for bathing and other utilities. Solar water heating systems can operate either on the thermosiphon principle (natural circulation) or through pumped circulation (forced circulation). In India, thermosiphon systems are more prevalent in buildings (Figure 2.13[17]).

Domestic SWHs for individual houses are smaller systems with a collector area ranging from 1.5 m^2 to 10 m^2, and hot water storage capacity ranging from 100 to 500 litres. These systems have integrated backup heating systems in the form of an electrical resistance heating element in the water tank, to provide a complete hot water solution to the user.

[17] *Courtesy: Nuetech Solar System Pvt. Ltd, Bengaluru, Karnataka, India*

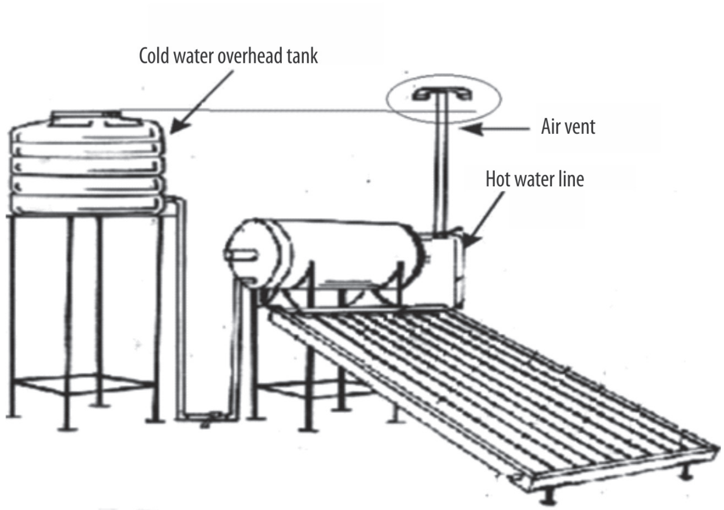


Figure 2.13 Schematic of a thermosiphon-based solar water heating system

2.4.1.2 Solar-assisted Cooking

2.4.1.2.1 Direct Cooking: Solar Cookers

Solar cookers convert solar radiation to heat for cooking food. Solar cookers can be broadly divided into two categories: (1) box-type and (2) concentrator-type.

(1) *Box-type cookers* utilise solar heat with little or no concentration of radiation. They consist of a well-insulated box, the inside of which is painted dull black and is covered by one or more transparent covers (Figure 2.14). The vessels used for cooking are also painted black on the outside. These covers allow the radiation from sun to come inside but do not allow the heat from the hot black absorbing plate to come out of the box. Because of this, the temperature of the blackened plate inside the box increases and can heat up the closed space inside the box up to 140 °C. Typical cooking time is about 1.5 to 3 hours, depending upon the food being cooked and the solar radiation intensity. Besides regular cooking, the solar box cooker can be used to bake cakes, roast nuts, dry grapes, etc. It is limited, however, in that it cannot be used for preparing *chapattis* or for frying purposes.

(2) *Concentrator-type solar cookers* use concentrator collectors to achieve higher temperatures for cooking (Figure 2.14). Concentrator cookers offer several advantages over box-type cookers and they come in many designs. They are classified according to whether they concentrate solar radiation on the cooking area from above or from below. Parabolic dish-type solar cooker is an example of a solar cooker that concentrates radiation from below. Cookers concentrating the heat on the bottom of the heating pad provide a cooking experience very similar to regular modes of cooking.

Panel-type and funnel-type solar cookers concentrate radiation from above onto the cooking pot and hence are not very efficient. In a solar panel cooker, a small bracket of reflectors unfold around a central space, where a cooking vessel sits in a transparent container of heat-resistant plastic. These cookers are simple to construct and are low-cost products.

Box type

Concentrator type

Panel type

Figure 2.14 Solar cooker technologies

2.4.1.2.2 Indirect Cooking: Solar Concentrators for Community Cooking

In an indirect cooking system, the heat produced from solar collectors is stored outside of the kitchen. The heat is then transferred to the kitchen for cooking. The system consists of a solar heat generation system with an arrangement to transfer heat to the food to be cooked. Solar concentrator systems are used to produce heat either as steam or heated thermic fluid.

In steam-based systems, steam vessels are used to pass steam through the food to be cooked, mainly by boiling. Jacketed vessels are used to extract heat from thermic fluid. Thermic fluid-based systems have the advantage of performing a wider range of cooking operations, including boiling and frying.

2.4.1.3 Solar Space Conditioning – Heating and Cooling

2.4.1.3.1 Solar Space Heating Using Non-concentrating Collectors

Solar water heating or solar air heating systems can be used for space heating applications in buildings. Generally, two types of space heating mechanisms are prevalent. Heating the fresh air to be circulated in the building through air handling unit is the most common method of space heating. Hot air can be produced either by using a solar water heating system in combination with an air–water heat exchanger or directly through solar air collectors. Another method is to heat the slab of the building to provide radiant heating. A solar water heater system is used to produce hot water, which is then circulated in a closed loop through the radiant heating pipes installed in the slab of the building.

2.4.1.3.2 Solar Cooling

Solar collectors can be used to produce heat to drive a thermal cooling machine (see Section 2.3.4). The temperature of the heat required to operate a single-effect vapour absorption machine is low, therefore, non-concentrating collectors can also be used to drive them. Whereas a double- or triple-effect vapour absorption machine requires higher temperatures that can only be supplied through concentrating collectors.

2.4.2 Industrial Sector

2.4.2.1 Solar Industrial Process Heat

Solar thermal technologies can be used to deliver medium to low temperature process heat (<250 °C) for industrial applications. Prominent industrial sectors with thermal applications of less than 250 °C include textile, pulp and paper, food and tobacco, pharmaceutical, chemical, dairy, and auto component manufacturing.

Non-concentrating collectors are primarily used for delivering heat less than 80 °C. Pre-heating of boiler feed water, producing hot water for process applications using SWHs, and hot air generation using air collectors for drying and pre-heating of air are the most common applications of non-concentrating collectors. Concentrating collectors can be used to provide process heat greater than 80 °C through steam generation, pressurised hot water generation, or thermic fluid heating. Main industrial applications include steam generation and thermic fluid heating for pasteurisation, effluent evaporation, cooling, laundry, desalination, cleaning, and degreasing.

Providing a reliable heat supply for industrial processes through hybridisation with conventional or other sources of energy has been one of the main challenges. Further development is required, particularly in hybridisation and integration, to effectively exploit the potential of industrial process heat.

2.4.3 Agriculture and Allied Sector

2.4.3.1 Solar Dryers

A traditional application of solar energy has been for drying agricultural products directly in the sun. The drying process removes the moisture and helps preserve the product. Solar dryers are devices that can either be used to improve the efficiency of solar drying in the open, or replace fossil fuels for drying. There are two general types of solar dryers: direct and indirect. Direct solar dyers expose the substance to be dehydrated to solar radiation, and indirect solar dryers heat the air and then pass the heated air over the substance to be dehydrated.

There are three main types of solar drying technology:

1. Solar conduction dryer (direct)
2. Solar greenhouse dryer (direct)
3. Solar air heater-based dryers (indirect)

Solar conduction dryer | Solar greenhouse dryer | Solar air heater-based dryers

Figure 2.15 Solar dryer technologies[18]

2.4.3.2 Solar Cold Storage Solutions

Similar to solar cooling, solar thermal technologies, in combination with thermal cooling machines, can be used to provide refrigeration solutions for cold storage or cold room purposes. Detailed information regarding the technology application is provided in Section 2.4.1.3.2.

2.4.4 Other Solar Thermal Technology Applications

2.4.4.1 Solar Swimming Pool Heating

Non-concentrating collectors can be used to provide heat for maintaining the water temperature in swimming pools, usually at 27 °C–28 °C. Non-concentrating solar collectors are ideal for this application as operating efficiency is high due to the low temperature difference between inlet and surrounding temperatures (10 °C–15 °C).

2.4.4.2 Solar Distillation

Solar stills consist of a black surface (collector) enclosed in an air-tight box with a sloping transparent cover on top of the box. The collector is coated with special material to increase its surface area and absorption properties. Saline water is spread evenly over the collector, then solar radiation heats the collector so that the water vapourises. The vapourised water rises and condenses as distilled water on the inside of the transparent cover, which then flows into a condensate collection channel.

2.4.4.3 Solar Steam Irrigation Pumps

A solar stream irrigation pump has two components: a solar collector and a steam engine pump. The solar collector produces heat to generate steam, which is used to drive a steam engine connected to a pump. This technology is in the initial phase of development. Currently, evacuated tube collectors and concentrating collectors are being tested as solar collectors for steam irrigation pumps.

[18] *Bayer Material Science Pvt. Ltd, Social Business Initiative*

2.5 Stage of Development of Solar Thermal Technologies

As per the diffusion of innovation theory of *Everett Rogers,* the lifecycle of the product can be segmented into five main stages, where the product is adopted by five different groups of consumers. The five stages and their respective adoption group are described in brief below.

1. *Development stage.* The product is undergoing R&D and field testing. At this stage, the product is adopted by customers who are enthusiastic about new technologies and are willing to try unproven products. This group is called *innovators*.
2. *Introduction stage.* The product has been introduced in the market and is commercially available, but the sales are low. This stage has few customers and little competition. For the technology to grow to the next stage, rapid technology improvement, sustained promotion, and market development activities are essential. The customer group adopting the product at this stage has the highest degree of opinion leadership and is called *early adopters*.
3. *Growth stage.* The product starts becoming popular with consumers and sales begin to rise. Penetration levels increase and companies can benefit from economies of scale. The customer segment opting for the product at this stage is called *early majority.*
4. *Maturity stage.* The product is well established and widely accepted in the market and costumers are satisfied. Competition is high. The customers for this segment are typically skeptical about the innovation and are called *late majority.*
5. *Decline stage.* Sales starts falling due to changes in consumer requirements, or because new technologies or choices are available to the consumer. These customers have an aversion towards change and are called *laggards*.

Geoffrey A. Moore expanded the diffusion of innovation theory for disruptive innovations[19] to suggest that there is a chasm between early adopters of innovations and the early majority (Figure 2.16). The chasm represents the differences between the two distinct marketplaces; the early market is dominated by early adopters and insiders who are quick to speculate about the benefits of the new development, and the early majority is the conservative mainstream market where financial returns can be delivered. The chasm indicates that aggressive efforts are required, particularly in aligning the technology/products to suit the needs of the mainstream market to cross the chasm.

[19] *A disruptive innovation is an innovation that helps create a new market and value network, and eventually disrupts an existing market and value network (over a few years or decades), displacing an earlier technology. (Source: www.wikipedia.org)*

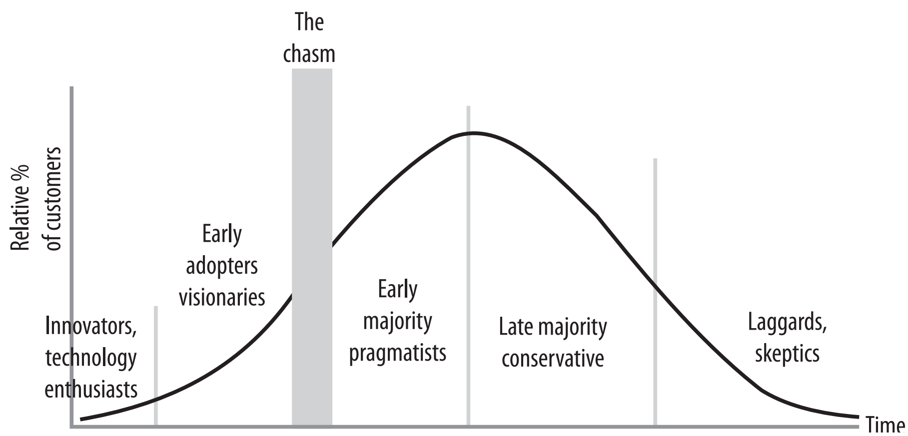


Figure 2.16 Moore's technology adoption lifecycle curve

Various solar thermal technology application packages are at different stages of development in their product lifecycles. Figure 2.17 captures the stage of development of solar thermal technology applications.

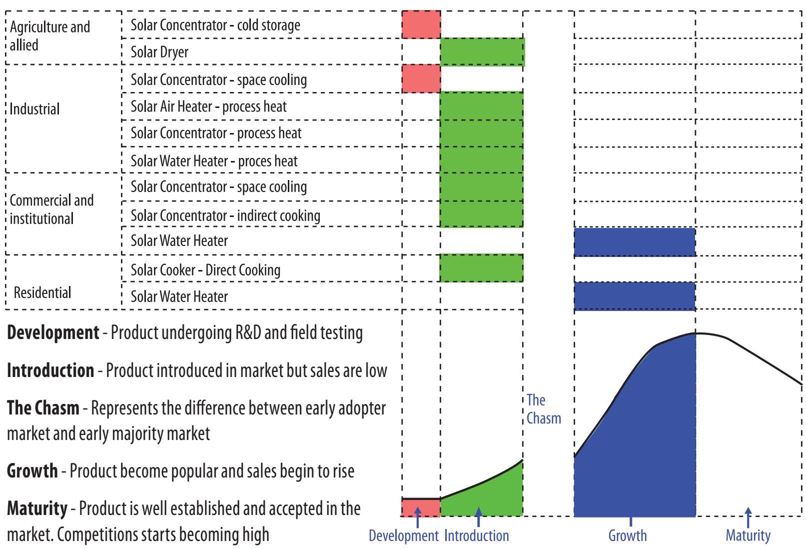


Figure 2.17 Solar thermal technology application packages, by product lifecycle

Currently, only SWHs in buildings (residential and commercial) have been able to reach the mainstream market (growth phase). A majority of the solar thermal technology applications, including solar assisted cooking, solar industrial process heat, and solar dryers are still in the introduction phase. Solar thermal-based cooling is in the development stage where there are a few demonstration projects being tested for field performance.

CHAPTER 3

Status of Solar Thermal Technologies and Markets

3.1 Global Status of Solar Thermal Technologies

3.1.1 Global Experience

Of the available solar thermal technologies, only solar water heating technology has been able to achieve significant deployment at the global level. Initiatives to promote solar cooking, especially in Africa and Asia, have not been able to increase adoption significantly. Other solar thermal technology applications, like solar industrial process heat and solar space conditioning, are still in the development and introduction stage, and it is too early to talk about them in terms of penetration.

Most of the solar water heating market expansion has happened in the last decade (2000–2012). The total installed capacity of solar water heating has grown from 66 million m^2 (46.2 GW_{th}) in 2000[1,2] to 385 million m^2 (269.3 GW_{th}) in 2012,[3] which is approximately a six-fold increase in 12 years (Figure 3.1). China and Europe have been the major growth drivers. This rapid expansion of the solar water heating market, especially in China (with a compound annual growth rate [CAGR] of 21%) and Europe (with a CAGR of 15%) has made solar thermal heat the second largest source of renewable energy in the world after wind energy. By 2013, solar thermal heat has reached an annual production of ~280 TWh_{th}, which was 1.75 times the annual energy generation from solar PV technology[4] (Figure 1.2).

The major breakthrough in solar water heating technology adoption was caused by the development and large-scale production of evacuated tube collectors. These collectors offer better efficiency at low cost as compared to flat-plate collectors. China is the world leader in solar water heating markets with 67% of the total installed capacity (Figure 3.2[5]). Out of the total installed capacity of 385 million m^2, 65% are evacuated tube type collectors.

[1] *Werner W, Faninger G. Solar Thermal Collector Market in IEA Member Countries. IEA Solar Heating and Cooling Programme, December 2002.*
[2] *Runqing H, Peijun S, Zhongying W. An Overview of Development of Solar Water Heater Industry in China. Energy Policy 2012l51:46–51.*
[3] *Mauthner F, Werner W. Solar Heat Worldwide, Markets and Contribution to Energy Supply 2012. IEA Solar Heating and Cooling Programme, June 2014.*
[4] *Ibid.*
[5] *Ibid.*

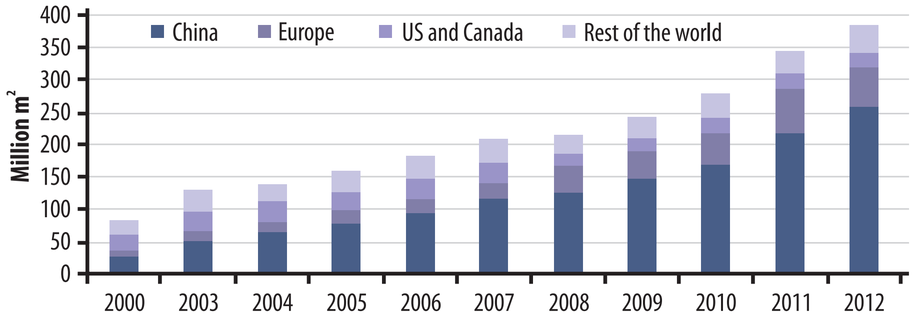


Figure 3.1 Cumulative global installed capacity of solar water heating, by year

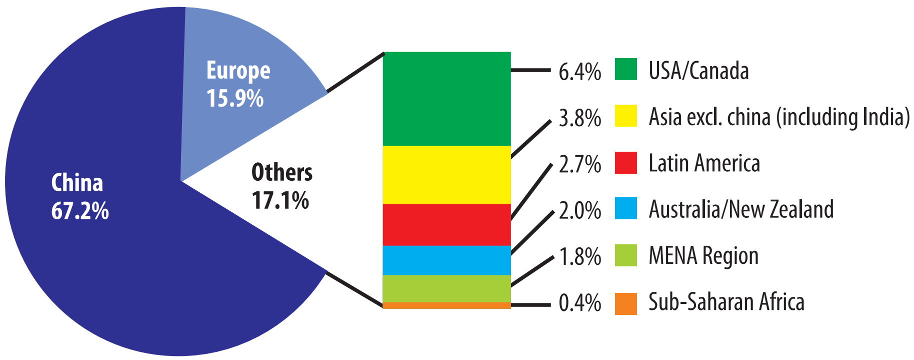


Figure 3.2 Share in total installed capacity by country/region, 2012

China is focussing on evacuated tube collectors, whereas Europe is still dominated by flat-plate collectors. Although China has the largest installed capacity of SWHs, European countries are leading in terms of penetration. Cyprus has the highest penetration of SWHs (548 kW_{th}/1000 inhabitants) followed by Austria (420 kW_{th}/1000 inhabitants) and Israel (385 kW_{th}/1000 inhabitants).[6]

The market for solar cooling systems is developing. By the end of 2013, around 1050 solar cooling systems were installed worldwide. Around 80% of the solar cooling installations are concentrated in Europe, particularly in Spain, Germany, and Italy. A majority of the solar cooling systems installed in Europe are based on non-concentrating collectors (flat-plate and evacuated tube collectors), whereas installations in India, Australia and Turkey are dominated by concentrated collectors.

Solar industrial process heat is still a niche[7] market, but due to the vast demand for thermal energy in a variety of industrial processes, the sector seems promising for solar thermal

[6] *Mauthner F, Werner W. Solar Heat Worldwide, Markets and Contribution to Energy Supply 2012. IEA Solar Heating and Cooling Programme, June 2014.*
[7] *Ibid.*

technologies. By the end of 2013, around 124 solar thermal installations were reported for industrial process heat application worldwide.[8]

3.1.2 China Experience

Some of the factors responsible for the high growth of SWHs in China are described below (Figure 3.3).

- *Hot water demand:* Most of the regions of China require year-round hot water. With the growing economy, the demand for hot water for urban and rural residents has increased significantly.
- *Manufacturing base:* The China experience clearly shows that indigenous manufacturing provides a large impetus for the growth of the industry. By 2009, China had around 1800 SWH manufacturers and more than 1200 units supplying ancillaries to the manufacturers.[9]
- *Policy*: Mandatory provisions for installing SWHs in new buildings at the municipal and provincial level have been the main market driver in urban areas of China. The SWH mandatory provisions have two parts: (a) administrative documents containing general guidelines of the policy and (b) technical specifications of the system. Most of the mandatory provisions are applicable only to new buildings up to 12 stories high. Multistorey buildings greater than 12 stories have been kept out of the purview of mandatory requirement. Economic incentives to counter the investment barrier are being provided only to rural households.[10]
- *Improving quality* (Standards and Certification): China has taken steps towards establishing a quality guarantee system for SWHs. To date, China has issued and implemented more than 20 national standards for solar heat collectors and hot water systems, and four national SWH quality testing centers have been established. In addition, China has developed voluntary certification systems for product quality and the impact of SWH on the environment. The certification systems assign labels such as Gold Sun Mark and Ten-Ring Mark to show the quality of the product.[11]

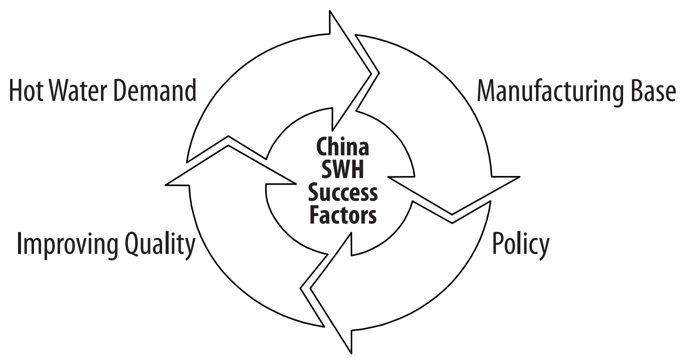


Figure 3.3 Factors responsible for high growth of SWHs in China

[8] Mauthner F, Werner W. Solar Heat Worldwide, Markets and Contribution to Energy Supply 2012. IEA Solar Heating and Cooling Programme, June 2014.
[9] Hu Runqing, Sun Peijun, Whang Zhongying 'An overview of development of solar water heater industry in China'; Energy Policy, 51, 46–51, 2012
[10] Ibid.
[11] Ibid.

3.2 Status of Solar Thermal Technologies and Applications in India

3.2.1 Total Installed Capacity of Solar Thermal in India

As of March 2014, the total installed capacity of all solar thermal technologies in India was estimated at 5.8 GW_{th}. The annual energy from solar thermal is estimated to be 0.6 Mtoe (Table 3.1). Out of the total thermal requirement of 240 Mtoe, presently only 0.6 Mtoe (0.25%) is being met through solar thermal technologies.

Table 3.1 Total installed capacity and energy delivered from installed solar thermal technologies

Sector	Solar thermal technology	Installed capacity		Energy delivered (GWh/year)
		Collector area/no.	GW_{th} [12]	
Residential	Solar water heaters[13]	6.5 million m^2	4.600	5,562
	Solar cookers[14, 15]	0.64 million (nos)	0.134	32
Commercial and institutional	Solar water heaters[16]	1.1 million m^2	0.800	941
	Solar concentrators[17]	19,000 m^2	0.013	14
Industrial	Solar water heater[18]	0.35 million m^2	0.240	299
	Solar concentrators[19]	10,000 m^2	0.007	9
	Solar air heater[20]	10,000 m^2	0.007	9
Agriculture	Solar dryer[21]	3,200 m^2	0.002	3
Total			5.803	6,869 (0.59 Mtoe)

Solar water heating accounts for 97% of the installed capacity. Among SWHs, 82% of the installed capacity is estimated to be in residential buildings, 14% in commercial and institutional buildings, and 4% in industries (Figure 3.4).

[12] *Collector area to capacity (in GW_{th}) conversion has been calculated considering 0.7 kWth/m^2.*

[13] *Standard output of solar water heater collectors is taken as 855.7 kWh/m^2.y (Source: Mauthner F, Werner W. Solar Heat Worldwide, Markets and Contribution to Energy Supply 2012. IEA Solar Heating and Cooling Programme, June 2014).*

[14] *Standard size of box type (540 x 540 mm, i.e. 0.3 m^2) of solar cooker is used for area calculation.*

[15] *Standard cooking energy output of the cooker is assumed to be 50 kWh/box/year (Source: Ishan P, Purohit P, Negi BS. Design and Testing of Box Type Solar Cookers Employing Non Tracking Planar Reflectors. Granada, Spain: Solar Cookers International (SCI), 2006).*

[16] *Standard output of solar water heater collectors is taken as 855.7 kWh/m^2.y (Source: Mauthner F, Werner W. Solar Heat Worldwide, Markets and Contribution to Energy Supply 2012. IEA Solar Heating and Cooling Programme, June 2014).*

[17] *Most of the solar concentrator installations in the commercial and institutional sector are Scheffler dishes and its output is taken as 6.2 lakh kcal/m^2.y (721 kWh/m^2.y) (Source: MNRE, Government of India, http://mnre.gov.in/file-manager/UserFiles/heat-delivery-from-CST-based-system.pdf, 15 October 2014)*

[18] *Standard output of solar water heater collectors is taken as 855.7 kWh/m^2.y (Source: Mauthner F, Werner W. Solar Heat Worldwide, Markets and Contribution to Energy Supply 2012. IEA Solar Heating and Cooling Programme, June 2014).*

[19] *The industrial solar concentrator sector is mainly dominated by dual-axis tracking dish-type collectors. The output is estimated to be 932 kWh/m^2.y (Source: MNRE, Government of India, http://mnre.gov.in/file-manager/UserFiles/heat-delivery-from-CST-based-system.pdf, 15 October 2014).*

[20] *Solar air heaters and solar dryers are taken to be equivalent in power and output to solar water heaters.*

[21] *Ibid.*

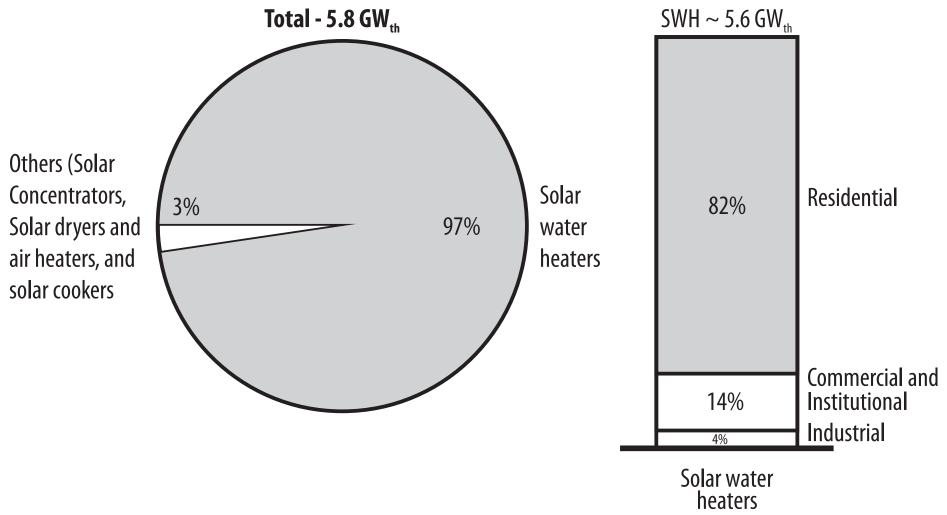


Figure 3.4 Total installed capacity of solar thermal technologies in India

3.2.2 Market Status of Solar Thermal Technology Applications

3.2.2.1 Residential Sector

As per the 2011 census, the residential sector in India comprises ~250 million households, of which 70% are in rural areas.[22] It is the second largest energy consuming sector after industrial, with a share of 27% of the total final energy consumption in India.[23]

Approximately 90% of the residential energy consumption is for thermal applications (Figure 3.5), and cooking is the largest energy end use, consuming ~80%. Cooking is dominated by petroleum fuels in urban areas and biomass fuels in rural areas. This trend is likely to continue even to 2032. Around 400 million people are exposed to the negative health impact of indoor air pollution from burning of biomass for cooking. Providing clean and modern energy for cooking to all is one of the major challenges for the Government of India.

SWH and solar cooker technology are used in the residential sector. The market status of these two solar thermal technology applications is discussed in detail in the subsequent sections.

3.2.2.1.1 Solar Water Heaters

By March 2014, approximately 2.1 million households (6.5 million m^2) were using SWH in India, and more than 90% of those households are located in urban areas. In terms of penetration levels, around 2% of the total urban households are currently using SWHs while only 0.1% of rural households use SWHs.

[22] *Census of India, 2011.*

[23] *Planning Commission, Government of India. The India Energy Security Scenarios 2047 (IESS 2047), www.indiaenergy.gov.in, 25 April 2014.*

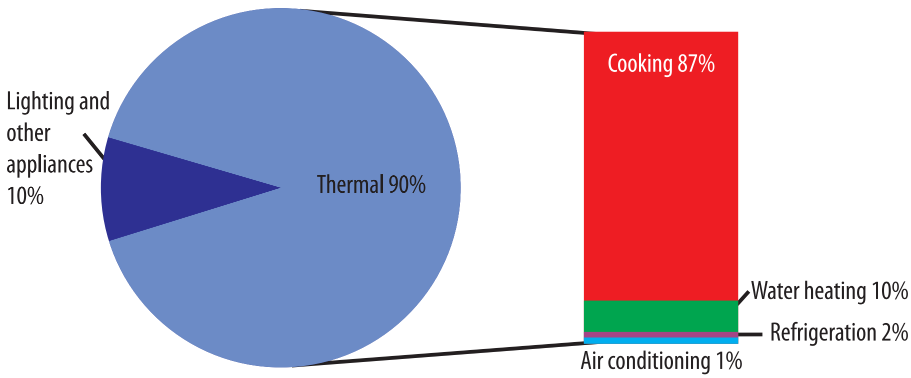


Figure 3.5 End-use type energy consumption in the residential sector (114 Mtoe)

At present, the market size of SWHs is approximately Rs 1000 crore/year (USD 165 million), with 80% of the market in the residential sector.

Recently, a shift towards evacuated tube systems has been observed in the residential SWH market. In 2010, flat-plate collectors used to contribute 65% of the sales of SWHs in the residential sector, while recent estimates of 2013 sales show that the share of evacuated tube systems has reached 65% of the sales.

Regional Market Segmentation: The market for SWHs in the residential sector depends on several factors, such as hot water demand, cost of hot water generation, availability of solar radiation, and supply chain of SWH technology. Based on these factors, the market of SWHs can be divided in to five geographical regions (Figure 3.6).

Presently, 85% of the residential sector sales of SWHs is in Zone I, while Zones II and III contribute around 4% and 9%, respectively. In Zones IV and V, the market is negligible.[24]

[24] *Based on SOLARWHIN (online monitoring system of solar water heater installations by MNRE) data for the duration of April 2012 to September 2013.*

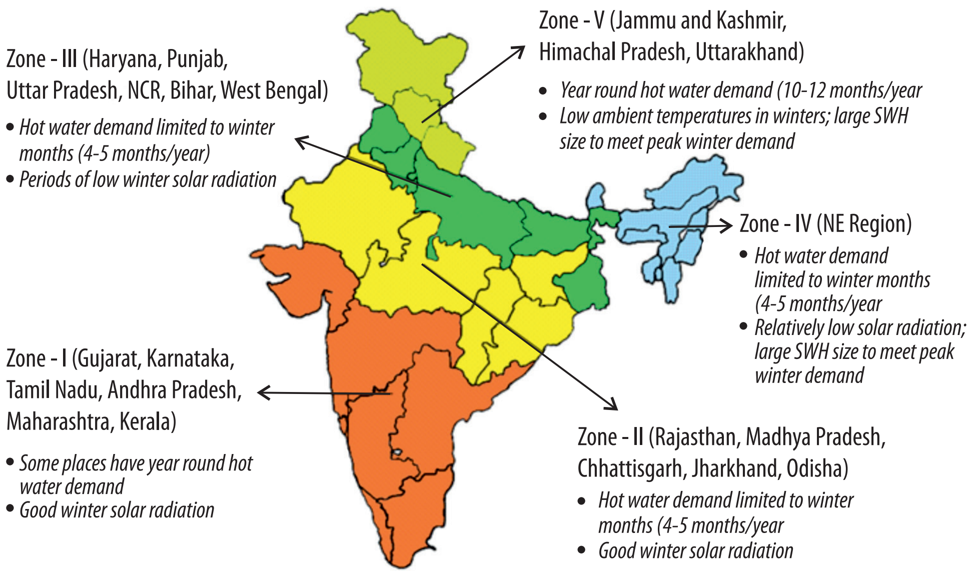


Figure 3.6 Regional market segmentation of SWHs in residential sector

Box 3.1 Regional market segmentation of SWHs in the residential sector

- Zone I comprises the western and southern states of Karnataka, Maharashtra, Tamil Nadu, Andhra Pradesh, Gujarat, and Kerala. The solar resource is adequately available year round and the region has high urban population.
- Zone II comprises the states of Rajasthan, Madhya Pradesh, Chhattisgarh, Jharkhand, and Odisha, having 4–6 months of hot water requirement and adequate solar radiation during the hot water requirement season.
- Zone III, consisting of Punjab, Haryana, Delhi NCR, Uttar Pradesh, Bihar, and West Bengal, has 4–6 months of hot water requirement but suffers from poor solar radiation (due to fog) during the peak hot water demand season (December–January).
- Zone IV consists of states of the northeastern region and is characterised by low hot water requirement and relatively poor solar radiation.
- Zone V is made up of the northern states of Jammu and Kashmir, Himachal Pradesh, and Uttarakhand; the region has a cold climate and therefore has high hot water demand and most of the region does not suffer from fog during peak winter months.

Detailed analysis of Zone I reveals that within the western and southern zone, a large segment of the market is concentrated in a few urban centres like Pune and Bengaluru. Also, recent sales data of channel partners indicate that within the residential sector of Zone I, ~20% of the sales of SWHs are in multistorey apartments.

3.2.2.1.2 Solar Cookers

According to the Ministry of New and Renewable Energy (MNRE), approximately 0.64 million solar cookers have been sold and/or distributed through government channels up to the end of the 11th Five Year Plan (2012). No data are available on the actual number of solar cookers that are operational at present. A majority of the solar cookers sold/distributed through government channels are of the box type. Recent data from the MNRE states that the sales in 2013/14 through the channel partner scheme has been a total of 1741 of box-type cooker and 1311 numbers of dish-type cookers.[25]

3.2.2.2 Commercial and Institutional Sector

The commercial and institutional sector comprises all the commercial and institutional establishments, including hotels and restaurants, hospitals, hostels, public buildings, offices, shopping complexes, malls, clubs, religious institutions, and all other types of institutional buildings.

This sector consumed ~3% (11.6 Mtoe) of the total energy consumed in India in 2012. The fuel mix of this sector shows that ~52% of the energy is consumed in the form of electricity, while ~46% is consumed in the form of liquid and gaseous petroleum fuels. Cooking is the main application attributed to liquid and gaseous petroleum fuels. HVAC is the main electricity consuming application, accounting for ~66% of the total electricity consumption of the sector.[26] The energy consumption of this sector is estimated to grow by 5 times, with electricity growing at an even higher rate of 7.5 times by 2032.[27]

Both SWHs and solar concentrators are used for water heating, cooking, and space conditioning applications in the commercial and institutional sector. SWHs are also used for swimming pool heating applications.

3.2.2.2.1 Solar Water Heaters

The commercial and institutional sector has the second highest installed capacity of SWHs at 1.1 million m^2. This constitutes approximately 14% of the overall installed capacity. The main application is for providing hot water for bathing, kitchen, and laundry, and in some cases for space heating. The economics of SWHs for this sector is attractive as it replaces costly energy sources like electricity and petroleum fuels. The hospitality sector, i.e., hotels, guesthouses and service apartments, are a major market for SWHs.

The geographic distribution of the SWH market in this sector is similar to the residential sector. More than 75% of the market is in Zone I; Zones II, III, and V each account for ~8% of the market; and the market in Zone IV is negligible.

There have been some installations (~10–15) of space heating applications using SWH collectors in Zone V. And approximately 20–30 swimming pools have installed SWHs, mainly in Zones III and IV.

[25] *MNRE, Government of India. Minutes of the third review meeting with manufacturers, suppliers and channel partner of box and dish type solar cookers held on 12 September 2014 at MNRE, New Delhi, http://mnre.gov.in/file-manager/UserFiles/minutes-cooker.pdf, 15 October 2014.*

[26] *Planning Commission, Government of India. The India Energy Security Scenarios 2047 (IESS 2047), www.indiaenergy.gov.in, 25 April 2014.*

[27] *Ibid.*

3.2.2.2.2 Solar Concentrators

Solar concentrators are used in cooking and space cooling applications in this sector. By December 2013, there were ~130 solar concentrator installations (~19,000 m^2 collector area) in the commercial and institutional sector. More than 95% of the installations (75% of the installed capacity) are for solar steam-based cooking applications. The majority of those are based on the fixed focus elliptical dish (Scheffler dish). India has emerged as the global leader in solar steam cooking systems (with more than 120 installations). Solar steam-based cooking applications seem to be the most promising application for solar concentrators in the commercial and institutional sector.

Solar space cooling is still in its development and demonstration phase; there have been only two installations for solar cooling in this sector.

3.2.2.3 Industrial Sector

The industrial sector is the largest consumer of energy, accounting for ~46% (196 Mtoe) of the overall energy consumption. Within the industrial sector there are seven sub-categories that have been identified as the largest consumers of energy: aluminum, cement, chlor alkali, fertiliser, iron and steel, and textiles. Together they account for more than 60% of industrial energy consumption. Other sub-sectors like brick, glass, chemical and petrochemical, food and tobacco, pharmaceutical, and auto and auto components, account for the remaining 40% of industrial energy consumption.[28]

Coal is the main source of energy for the industrial sector, contributing ~42%, followed by petroleum fuels ~27%, and electricity ~18%.

The energy demand in industries is expected to triple in the next two decades. Demand for coal, and oil and gas for industrial energy use is expected to reach 4 times and 2.5 times of 2012 level by 2032, respectively.[29]

According to the project team estimates, more than 65% of the total industrial energy consumption is used for supplying industrial process heat, and most of that is supplied by fossil fuels used in furnaces, boilers, and heaters. It is estimated that out of the total energy consumed for process heat, about 25%–30% is used for low and medium temperature process heating (<250 °C) applications. More than 80% of this demand is being met using diesel, furnace oil, and natural gas. It is also expected that by 2032, less than 250 °C industrial process heat demand will double 2012 levels. The industries that require less than 250 °C process heat are textiles, pulp and paper, food and tobacco, pharmaceutical, chemical, dairy, and auto component manufacturing.

Both concentrating and non-concentrating collectors are used for providing heat up to 250 °C in the form of hot water, hot air, steam, or hot thermic fluid.

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[28] *Planning Commission, Government of India. The India Energy Security Scenarios 2047 (IESS 2047), www.indiaenergy.gov.in, 25 April 2014.*
[29] *Ibid.*

3.2.2.3.1 Non-concentrating Collectors (Solar Water Heater)

Non-concentrating collectors are used by industry either for boiler water pre-heating or for supplying process heat below 80 °C. By March 2014, around 0.35 million m^2 of collector area with a few hundred installations had been installed in the industrial sector. These installations were for boiler water pre-heating, hot water for cleaning, process heat for pasteurisation, and electroplating. The dairy, textiles, pharmaceutical, food processing, chemical, and automobile industries are the main industrial sub-sectors that are presently using SWHs.

The annual market for non-concentrating collectors in the industrial sector is estimated to be 10,000 m^2 of collector area, which is equivalent to 1% of the SWH market.[30]

3.2.2.3.2 Solar Concentrators

Application of solar concentrator technologies in the industrial sector is relatively new. By December 2013, there were ~20 solar concentrator installations (~10,000 m^2 collector area) in industries. More than 50% of the installations are for process heat applications, followed by more than 40% for solar space conditioning applications. Scheffler technology has garnered more than 50% of the cumulative installed capacity.

The simple payback period (after accounting for subsidy and depreciation benefits) for process heat applications replacing petroleum fuels (diesel, furnace oil, natural gas) ranges from 3–4 years, while for coal and biomass it can go up to 7–9 years.[31,32] It is important to note that the simple payback period is sensitive towards the output of solar technology, and the lack of independent third-party audited performance data of existing installations introduces uncertainty in the estimation. Apart from the issue of credible performance data, technical constraints of inadequate roof/land space similar to that of SWH technology also exist for solar concentrator technology.

3.2.2.3.3 Solar Air Heaters

Although solar air heaters have a long history of R&D, very limited penetration has been achieved so far. At present, there are around 50 installations (~10,000 m^2 collector area) of solar air heaters for industrial applications. Pulses and cereals, latex, tea, auto components, salt, ceramics, mattresses, and paper are the industries where solar air heating technology has been applied. Most of the air heating applications in the above listed industries are conventionally carried out either through diesel or electricity.

The annual sales for solar air heaters for industrial application is ~2000 m^2 collector area.

[30] *Sales data from SOLARWHIN for the period April 2012 to September 2013.*

[31] *Greentech Knowledge Solutions Pvt. Ltd, Awareness and Preparation of DPR for Pilot Projects on Solar Energy Applications in Selected Pharmaceutical Sector. Commercialization of Solar Energy Project, GIZ, 2013.*

[32] *Greentech Knowledge Solutions Pvt. Ltd, Awareness and Preparation of DPR for Pilot Projects on Solar Energy Applications in Selected Food Processing Sector. Commercialization of Solar Energy Project, GIZ, 2013*

3.2.2.4 Agriculture and Allied Sector

Within the agriculture sector, solar dryer technology is the only established solar thermal technology in India. With the experience of more than two decades and a few hundred installations, solar dryer technology has established its technical viability in niché applications.

Other solar thermal applications that are still in the R&D and testing phase are solar thermal-based cold storage/cold rooms and solar thermal-based water pumps for irrigation.

3.2.2.4.1 Solar Dryer

Solar dryer industry estimates note that around 2000 m^2 of air heater-based dryers have been installed up to March 2014. Additionally, there are around 300 installations of solar conduction dryers, which is one-third of the conventional solar air heater-based dryers.

Solar dryer technology finds its best fit with products that are dried in a controlled environment to create value-added products. The main advantages of drying in a controlled environment are better hygiene, better quality, and wastage reduction. The value addition of controlled drying varies a lot with different products and in different market segments. Two niché applications have been identified so far, these include:

- Solar drying of horticulture products (fruits and vegetables)
- Solar drying of fish

Some of the other products that may offer high value addition through solar drying are bitter gourd, bottle gourd, herbs for Ayurvedic factories, arecanut, and banana.

Fish drying is a temperature sensitive process that requires fast drying. Solar air heater-based dryers for fish drying applications have been demonstrated successfully at several places in the country.

3.2.2.4.2 Solar Thermal-based Cold Rooms

A large part of the horticulture produce is wasted and therefore providing adequate cold storage facilities is one of the top most agenda of the government. Several ministries are providing support for establishing cold rooms; this involves the Ministry of Agriculture, the Ministry of Food Processing Industries, and the MNRE. Support in the form of subsidy is also available under the National Horticulture Mission through NABARD for cold rooms.

Solar PV-based vapour compression machines for small cold rooms are emerging as a viable option.

In its present form, solar thermal-based cooling applications for cold storages/cold rooms are under development. At present, there is only one installation under a research project, involving MNRE, TERI, and Thermax to demonstrate solar thermal-biomass energy-based cold storage.

3.2.3 Manufacturing and Supply

3.2.3.1 Solar Water Heater (Non-concentrating Collectors)

As of October 2014, there are 63 BIS-approved flat-plate manufacturers in India.[33] There are no manufacturing facilities for evacuated tube collectors in India. Most of the evacuated tubes are imported from China. Preliminary estimates indicate that the total import bill of evacuated tubes is ~Rs 200 crore/year. There are around 213 suppliers of evacuated tube-based SWH systems empanelled by the MNRE.[34] The MNRE has issued a notification on the mandatory use of indigenously manufactured balance of system (storage tank and other parts) in evacuated tube-based SWH systems.

The number of suppliers of SWH systems, particularly of evacuated tube-based systems, increased rapidly after the announcement of the subsidy under Jawaharlal Nehru National Solar Mission (JNNSM) in 2010. However, a significant number of newly added suppliers can be classified as traders as they do not have their own manufacturing/assembly facilities.

There are large regional imbalances in the manufacturing and supply network of SWH systems. Approximately 95% of the flat-plate manufacturing facilities, and 80% of the MNRE empanelled suppliers of SWH systems are located in Zone I.[35]

The Indian SWH industry is fragmented, consisting of mainly small- and medium-sized enterprises. There are very few manufacturers operating at the pan-India level. No single manufacturer has dominance in the market and the top five manufacturers hold only 25% of market share.

3.2.3.2 Solar Cookers

As of May 2013, there are 20 manufacturers of solar cookers, of which only four have BIS certification for their product.[36] Fifteen of these manufacturers are enrolled as channel partners for supplying solar cookers under JNNSM.[37] All manufacturers of solar cookers are small-scale fabricators.

[33] *MNRE, Government of India. List of BIS Approved Manufacturers of FPC-based Solar Water Heating Systems. http://mnre.gov.in/file-manager/UserFiles/list_fpc_manufacturers.pdf, 21 October 2014.*

[34] *63 flat-plate approved manufacturer also supply evacuated tube systems and therefore are included in the list of evacuated tube system suppliers. Source: MNRE, Government of India, List of Manufacturers of Evacuated Tube Collector-based Solar Water Heating Systems, http://mnre.gov.in/file-manager/UserFiles/list_etc_m.pdf, 21 October 2014.*

[35] *Ibid. p. 54.*

[36] *MNRE, Government of India. List of Box Type and Dish Type Solar Cookers Manufacturers, http://mnre.gov.in/file-manager/UserFiles/list_solar_box_cooker_manufacturer.htm, 21 October 2014.*

[37] *MNRE, Government of India. List of Channel Partners Accredited by the Ministry for Off-Grid and Decentralize Solar Application Under JNNSM for Supplying/installation/Distribution of Box and Dish Type Solar Cookers as on 17th July 2014, http://mnre.gov.in/file-manager/UserFiles/list_channelpartners_st_dish_box_solar-cooker_jnnsm.pdf, 21 October 2014.*

3.2.3.3 Concentrating Collectors

As of October 2014, there are 20 manufacturers of solar concentrating collectors empanelled by the MNRE, of which nine manufacture Scheffler dish technology (fixed focus elliptical dishes) .[38] Seventeen of the 20 manufacturers are based in Zone I.

3.2.3.4 Flat Plate Collector-based Solar Air Heaters and Solar Dryers

There are only eight manufacturers of flat-plate collector-based air heating systems and solar dryers empanelled by the MNRE.[39] All of these manufacturers are based in Zone I. There is only one manufacturer of solar conduction dryers.

3.2.4 Policy and Regulations

3.2.4.1 Subsidies and Incentives

Worldwide, providing subsidies and incentives has been one of the primary tools for promoting solar thermal technologies. The MNRE started providing capital subsidies for SWHs in the early 1990s. In 1994, the capital subsidy scheme was abolished and the provision of soft loans was introduced through the Indian Renewable Energy Development Agency (IREDA) and other designated banks.[40]

In 2010, the MNRE launched the JNNSM under which capital subsidies were introduced for all solar thermal technologies (except for the solar conduction dryer, which is still not empanelled by MNRE). In September 2014, the MNRE announced the withdrawal of central capital subsidies for SWHs, however, capital subsidy is still available for other solar thermal technologies.

For commercial establishments, accelerated depreciation benefits are also available on all solar thermal technologies, except solar cookers and solar conduction dryers.

Some state governments and municipal corporations have introduced special incentives and subsidies for promoting SWH systems, particularly in residential buildings:

- *Electricity bill rebates:* Some of the state governments (Uttarakhand, Rajasthan, Karnataka, and Jammu and Kashmir), through their electricity distribution companies, are providing electricity bill rebates to domestic SWH users.[41]
- *Property tax rebates:* Some of the urban local bodies (Rajkot, Thane, Durgapur, etc.) provide property tax rebates to property owners using SWHs.[42] Maharashtra alone has 13 municipal corporations providing the property tax rebate.
- *Additional capital subsidy by state governments:* Some of the states/union territories like Chandigarh, Chhattisgarh, Jharkhand, Jammu and Kashmir, Kerala, West Bengal, Haryana,

[38] *MNRE, Government of India. List of Manufacturers Empanelled by MNRE, as on 9th October 2014, for Installation of Solar CST-based Systems for Process Heat, Cooling or Cooking Application, http://mnre.gov.in/file-manager/UserFiles/list_scs_sadc.pdf, 21 October 2014.*

[39] *MNRE, Government of India. List of Known Manufacturers/Suppliers/Institutions Involved in Installation of Flat Plate Collector-based Solar Dryers/Air Heating Systems, http://mnre.gov.in/file-manager/UserFiles/list_ahs.pdf, October 21, 2014.*

[40] *OPET-TERI & HECOPET. Status of Solar Thermal Technologies and Markets in India and Europe. 2002*

[41] *WWF-India and Council for Energy Environment and Water. Renewables Beyond Electricity, 2013.*

[42] *Ibid.*

Delhi, and Madhya Pradesh are providing capital subsidies mainly to residential, government, semi-government, and institutional SWH users. The amount of this additional subsidy varies between 10%–25% of the system cost.[43]

3.2.4.2 Regulations

The MNRE worked with the Ministry of Urban Development (MoUD) to make the use of SWHs mandatory in various categories of buildings, through amendments in the building bye laws. Accordingly, the MoUD circulated a Government Order and model bye laws to all the states and union territories in 1999. Since then, 20–21 states and union territories have issued similar orders/notifications and the building bye laws of at least 100 municipal corporations have been amended. SWH systems have also been incorporated into the National Building Code 2005 developed by the Bureau of Indian Standards, and the Energy Conservation Building Code developed by the Bureau of Energy Efficiency, Government of India.

Only a few municipal corporations, like Bengaluru, Rajkot, Thane, Pune, and Chandigarh, have been able to effectively implement the mandatory regulations.

Most of the municipal corporations which have amended their building bye laws have included group housing societies/apartments (multistorey buildings) and high-rise commercial and institutional buildings within the purview of mandatory regulations. However, in a majority of the municipal corporations, the regulations do not provide any technical guidelines for hot water requirement norms for various categories of buildings, technical specifications for ensuring quality of the system and installation, or guidelines for equitable hot water distribution in multistorey apartments. High-rise buildings (>12 storeys) also face issues of insufficient space for adequately sized SWH systems. This issue is not addressed by the regulations.

The capacities at the municipal level, particularly of human resources and technical know-how, are inadequate, which impedes the effective implementation of regulations. The regulations in their present form also do not apply to existing buildings.

3.2.5 Quality, Testing, and Certification

3.2.5.1 Testing Standards

The Bureau of Indian Standards (BIS) has set standards for flat-plate collector-based SWHs and box-type solar cookers. The details of the BIS standards are provided in Table 3.2.

[43] *WWF-India and Council for Energy Environment and Water. Renewables Beyond Electricity, 2013.*

Table 3.2 Details of BIS standards for flat-plate SWHs and box-type solar cookers

Standard number	Year	Title
IS 12933	2003	Solar Flat Plate Collector (Part 1: Requirements, Part 2: Components, Part 3: Measuring instruments, Part 4: Test Methods)
IS 13429	2000	Solar Cooker – Box Type (Part 1: Requirements, Part 2: Components, Part 3: Test Methods)
IS 13129	1991	Solar Heating – Domestic Water Heating Systems (Part 1: Performance Rating Procedure Using Indoor Test Methods, Part 2: Procedure for System Performance Characterisation and Yearly Performance Prediction, Part 3: Procedure for System Component Characterisation and Prediction of Yearly Performance Using Component Performance Data, Part 4: Determination of Durability and Reliability)
IS 12976	1990	Solar Water Heating Systems – Code of Practice

In May 2013, MNRE issued standards for evacuated tube collectors (MNRE STD01:2013),[44] storage water tanks for evacuated tube collectors,[45] and evacuated tube SWH systems.[46] However, MNRE is yet to notify mandatory obligation of these standards on evacuated tube-based solar water heater system suppliers. There are no BIS standards for solar concentrators, dish-type solar cookers, flat-plate collector-based air heating systems, solar dryers, or other balance of systems.

3.2.5.2 Testing Facilities

The MNRE has established six test centres for BIS certification of flat plate collectors and box-type solar cookers.[47] With support from the UNDP–GEF Market Development and Promotion of Solar Concentrator-based Process Heat Applications' project, the MNRE is establishing a testing centre for concentrated solar thermal technologies at the School of Energy Studies, University of Pune.

3.2.5.3 Quality and Certification

In addition to standards for component testing, standards for system performance testing and field performance data are necessary for ensuring the quality of solar thermal technologies. Once the individual technologies start to mature, quality standards for components and quality labels for technologies need to be developed.

China has taken a leading position in establishing a quality guarantee system for SWHs. To date, China has issued and implemented more than 20 national standards for solar heat collectors

[44] *MNRE, Government of India. MNRE Standard – All Glass (Glass in Glass) Evacuated Solar Collector Tubes, http://mnre.gov.in/file-manager/UserFiles/MNRE-STD-AGESCT.pdf, 21 October 2014.*

[45] *MNRE, Government of India. MNRE Standard – Storage Water Tank for All Glass (Glass in Glass) Evacuated Solar Collectors, http://mnre.gov.in/file-manager/UserFiles/MNRE-STD-SWTAGETSC.pdf, 21 October 2014.*

[46] *MNRE, Government of India. MNRE Standard – All Glass (Glass in Glass) Evacuated Tubes Solar Water Heating System, http://mnre.gov.in/file-manager/UserFiles/MNRE-STD-AGETSWHS.pdf, 21 October 2014.*

[47] *MNRE, Government of India. Authorized Testing Laboratories for Solar Thermal Applications, http://mnre.gov.in/file-manager/UserFiles/authorized-testing-laboratories-for-Solar-Thermal-Applications.pdf, 21 October 2014.*

and hot water system. China has established four national testing centres (three of them were supported through the UNDP) for SWH product quality testing, supervision, and inspection for both components and the SWH system.

The first voluntary certification system for solar water heaters was developed in Europe – Solar Keymark (Box 3.2). China has also developed voluntary certification systems for product quality and influence of SWHs on the environment. The certification systems assign labels like Gold Sun Mark and Ten-Ring Mark to show the quality of the product.[48] At present, there are no quality certification/label schemes for any of the solar thermal technologies in India.

Box 3.2 Solar Keymark

Solar Keymark is the first voluntary third-party certification system for SWHs. It was developed in Europe by the European Solar Thermal Federation and the European Committee for Standardisation, in close coordination with leading European test laboratories. The Solar Keymark signifies that a product conforms to the relevant European standards and fulfils additional requirements. The Solar Keymark label produced under the European certification system has gained widespread prevalence in European markets. By January 2014, more than 1700 solar thermal products had been certified by the Solar Keymark.

Solar Keymark has 29 recognised testing laboratories located all over Europe to provide certification through 14 accredited certification bodies.

[48] *Runqing H, Peijun S, Zhongying W. An Overview of Development of Solar Water Heater Industry in China. Energy Policy 2012;51:46–51.*

CHAPTER 4

Potential Assessment and Market Projection

The objective of potential assessment is to quantify the potential (solar collector area, energy generation, and fuel substitution) of solar thermal technologies for different end-use applications. The framework, detailed methodology, and results of potential assessment and market projection are discussed in this chapter.

4.1 Framework for Potential Assessment

Figure 4.1 shows the framework for potential assessment.

- Step 1: Estimation of the thermal energy demand for each end-use application.
- Step 2: Evaluation of technical potential of the technology taking into account the geographic, demographic, and technical constraints of the technology.
- Step 3: Estimation of economic potential considering maximum acceptable payback period.
- Step 4: Estimation of market potential considering market-related factors like payback acceptance schedule, laws, regulations, and competing technologies.

A complete potential assessment exercise (estimation of technical, economic, and market potential) has been carried out only for SWHs in residential, and commercial and institutional sectors, as these applications have crossed the chasm in their product lifecycle and there is enough data available to conduct the assessment with reasonable accuracy. For other technologies and applications, wherever possible, an indicative technical potential assessment based on the demand pattern and technology constraints has been carried out.

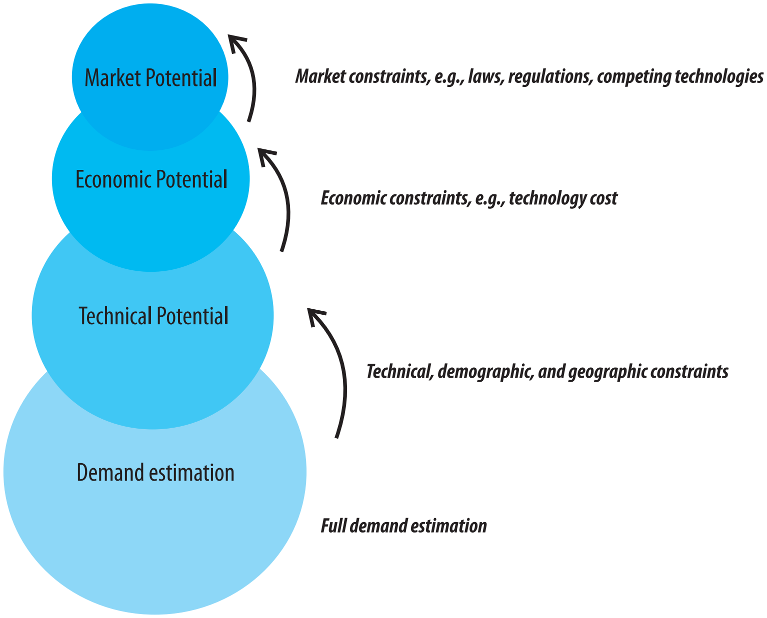


Figure 4.1 Framework for potential assessment[1]

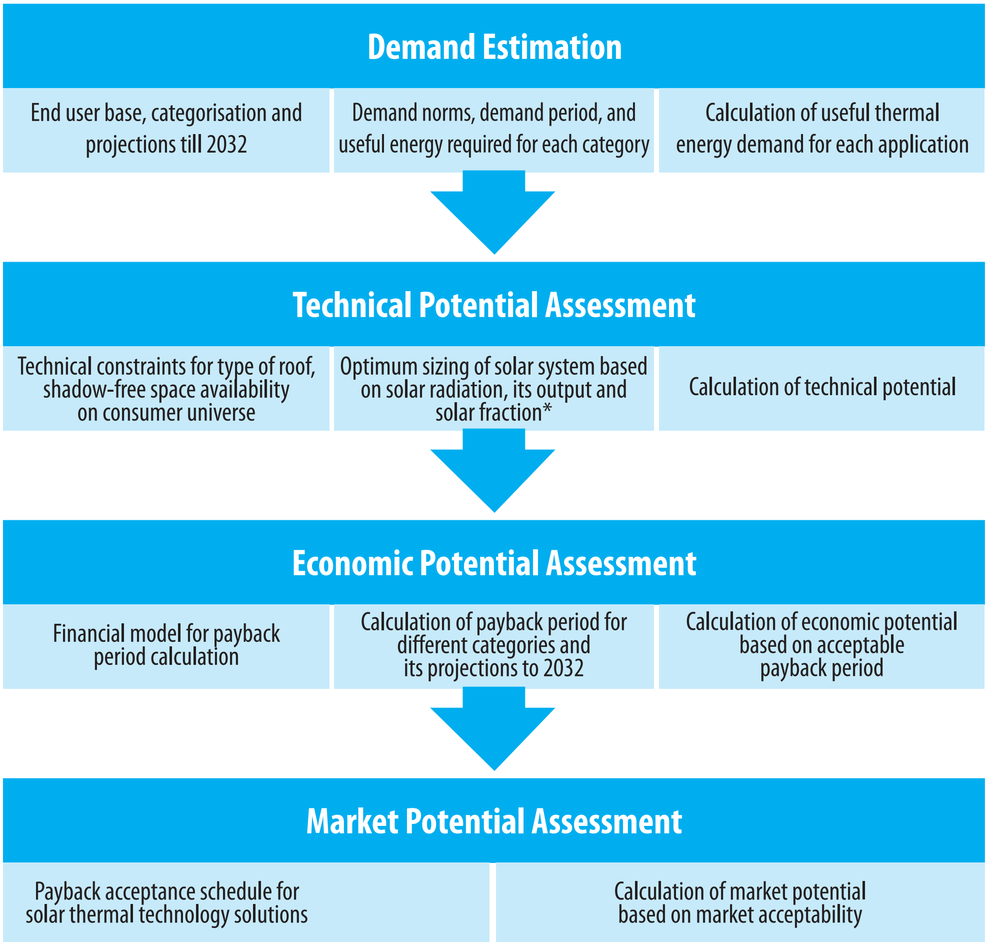
4.2 Methodology for Potential Assessment

The general methodology for potential estimation including demand estimation, technical, economical, and market potential was adapted from Pillai *et al.*[2] and is shown in Figure 4.2. The details are given in sub-sections.

[*All assumptions made and data sources referred to are given in Annexure I.*]

[1] *Adapted from Kreycik C, Vimmerstedt L, Doris E. A Framework for State-Level Renewable Energy Market Potential Studies. National Renewable Energy Laboratory, January 2010.*

[2] *Pillai IR, Banerjee R. Methodology for Estimation of Potential for Solar Water Heating in a Target Area. Solar Energy 2007;81:162–172.*



*Solar fraction is the fraction of annual energy demand met by the solar system. For example, if 100 units of energy is required annually for heating water, and out of this 60 units of energy is provided by the SWH system, then the solar fraction would be 60%.

Figure 4.2 Methodology for demand estimation and potential assessment

4.2.1 Demand Estimation

4.2.1.1 End User Base, Categorisation, and Projections till 2032

The first step for demand estimation was assessment of end user population for different sectors and different thermal applications. Projections of end user base were made till 2032. The data sources used for different sectors are listed in Annexure I. Further categorisation based on the location and consumer segment was performed (Figure 3.6 and Figure 4.3).

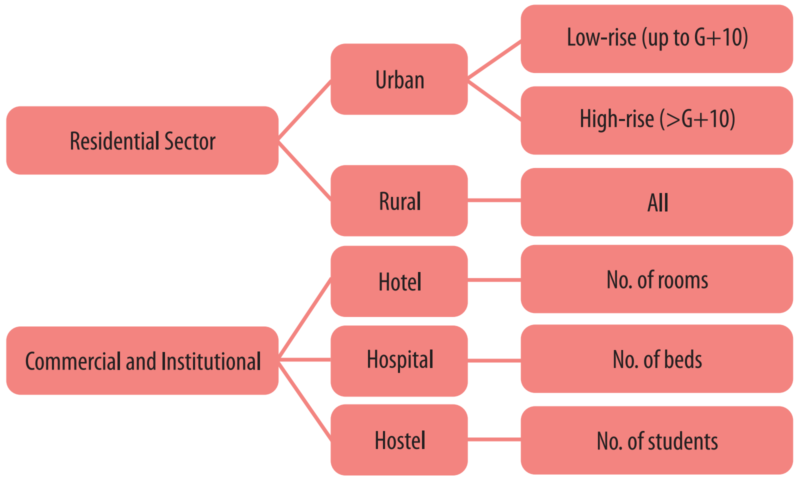


Figure 4.3 Categorisation based on consumer segments

4.2.1.2 Demand Norms, Demand Period and Useful Energy Required for each Category

The energy requirement for hot water generation has been estimated based on hot water consumption norms and its requirement months for different zones of the country. RETScreen[3] software was used to calculate the useful energy[4] required for hot water generation for 21 cities[5] in five zones. Average values for each zone is presented in Table 4.1.

Table 4.1 Demand norms, demand period, and useful energy required for each category

Zone	Type	Requirement months	Demand norm[6,7] @ 40 °C		Useful energy requirement	
			Value	Unit	Value	Unit
1	Residential - Rural	August–April	40	Lpd/person	0.86	MWh/HH
	Residential - Urban	August–April	65	Lpd/person	1.40	MWh/HH
	Hotel*	January–December	60	Lpd/room	0.85	MWh/room
	Hospital	August–April	65	Lpd/bed	0.28	MWh/bed
	Hostel	August–April	65	Lpd/person	0.28	MWh/person

table contd....

[3] RETScreen 4 is developed by Natural Resources Canada. It is an Excel-based clean energy project analysis software tool that helps decision-makers to quickly and inexpensively determine the technical and financial viability of potential clean energy projects.

[4] Useful energy is the energy available to the consumer after equipment conversion losses.

[5] The locations are: Ahmedabad, Bengaluru, Chennai, Hyderabad, Mumbai, Pune, Thiruvananthapuram, Bhubaneshwar, Indore, Jaipur, Raipur, Ranchi, Chandigarh, Delhi, Kolkata, Patna, Agartala, Guwahati, Shillong, Shimla, and Srinagar.

[6] International Copper Promotion Council (India). User's Handbook on Solar Water Heaters, UNDP–GEF and MNRE, 2010.

[7] Greentech Knowledge Solutions Pvt. Ltd. Solar Water Heater (SWH) Market Assessment Studies and Surveys for Different Sectors and Demand Segments. UNDP–GEF and MNRE, 2010.

Table 4.1 Contd...

Zone	Type	Requirement months	Demand norm[6,7] @ 40 °C		Useful energy requirement	
			Value	Unit	Value	Unit
2	Residential - Rural	November–February	40	Lpd/person	0.43	MWh/HH
	Residential - Urban	November–February	65	Lpd/person	0.70	MWh/HH
	Hotel*	January–December	60	Lpd/room	0.88	MWh/room
	Hospital	November–February	65	Lpd/bed	0.14	MWh/bed
	Hostel	November–February	65	Lpd/person	0.14	MWh/person
3	Residential - Rural	October–March	40	Lpd/person	0.70	MWh/HH
	Residential - Urban	October–March	65	Lpd/person	1.14	MWh/HH
	Hotel*	January–December	60	Lpd/room	0.91	MWh/room
	Hospital	October–March	65	Lpd/bed	0.23	MWh/bed
	Hostel	October–March	65	Lpd/person	0.23	MWh/person
4	Residential - Rural	October–March	40	Lpd/person	0.80	MWh/HH
	Residential - Urban	October–March	65	Lpd/person	1.30	MWh/HH
	Hotel*	January–December	60	Lpd/room	0.97	MWh/room
	Hospital	October–March	65	Lpd/bed	0.26	MWh/bed
	Hostel	October–March	65	Lpd/person	0.26	MWh/person
5	Residential - Rural	January–December	40	Lpd/person	2.50	MWh/HH
	Residential - Urban	January–December	65	Lpd/person	4.06	MWh/HH
	Hotel*	January–December	60	Lpd/room	1.34	MWh/room
	Hospital	January–December	65	Lpd/bed	0.81	MWh/bed
	Hostel	January–December	65	Lpd/person	0.81	MWh/person

1. Hotel requirement norms are at 60 °C.
2. Average household size is five persons.

4.2.1.3 Calculation of Useful Thermal Energy Demand

Once the useful energy required per unit of population is prepared, calculation of thermal energy demand is done by multiplying it with the relevant population.

4.2.2 Technical Potential Assessment

4.2.2.1 Technical Constraints for Strength of Roof, Shadow-free Space Availability on End User Universe

SWH systems are usually installed on the roof of the building and therefore the structure of the roof should have sufficient load bearing capacity to support it. Hence, only the fraction of end user base having roof of sufficient strength are technically suitable for the solar water heater installation. The roof should also have enough shadow-free space for the solar collectors. Therefore, only the fraction of end user base having suitable roof structure and sufficient shadow-free space on the roof have technical feasibility for SWH installation on their building roofs.

Only *pucca* households are considered to have sufficient roof strength for SWH installations. And, it is estimated that 30% of *pucca* households in the urban sector (independent and low-rise houses) and 60% of the *pucca* households in the rural sector have sufficient shadow-free roof area.

4.2.2.2 Sizing of Solar System and Its Output

The sizing of SWHs is mainly dependent on the hot water demand and solar radiation of the location. RETScreen was used to estimate the optimum size of the SWH system, and the useful energy delivered by solar system for each category in each zone. For example, a 2 m^2 SWH system would deliver 0.94 MWh/year, which will meet 68% of the useful thermal energy requirement for an urban household located in Zone I. Table 4.2 provides optimum size and useful energy delivered in each category in each zone.

Table 4.2 Optimum size and useful energy delivered for SWHs

		Useful energy requirement		Optimum size	Energy delivered from SWH	
Zone	Type	Value	Unit	m^2/unit	Value	Unit
1	Residential - Rural	0.86	MWh/HH	2.00	0.77	MWh/HH
	Residential - Urban	1.40	MWh/HH	2.00	0.94	MWh/HH
	Hotel	0.85	MWh/room	0.80	0.50	MWh/room
	Hospital	0.28	MWh/bed	0.40	0.19	MWh/bed
	Hostel	0.28	MWh/person	0.40	0.19	MWh/person
2	Residential - Rural	0.43	MWh/HH	2.00	0.38	MWh/HH
	Residential - Urban	0.70	MWh/HH	2.00	0.47	MWh/HH
	Hotel	0.88	MWh/room	0.80	0.52	MWh/room
	Hospital	0.14	MWh/bed	0.40	0.09	MWh/bed
	Hostel	0.14	MWh/person	0.40	0.09	MWh/person
3	Residential - Rural	0.70	MWh/HH	2.00	0.60	MWh/HH
	Residential - Urban	1.14	MWh/HH	2.00	0.70	MWh/HH
	Hotel	0.91	MWh/room	0.80	0.53	MWh/room
	Hospital	0.23	MWh/bed	0.40	0.14	MWh/bed
	Hostel	0.23	MWh/person	0.40	0.14	MWh/person
4	Residential - Rural	0.80	MWh/HH	2.00	0.63	MWh/HH
	Residential - Urban	1.30	MWh/HH	2.67	0.88	MWh/HH
	Hotel	0.97	MWh/room	0.87	0.52	MWh/room
	Hospital	0.26	MWh/bed	0.53	0.18	MWh/bed
	Hostel	0.26	MWh/person	0.53	0.18	MWh/person

table contd....

Table 4.2 Contd...

Zone	Type	Useful energy requirement		Optimum size	Energy delivered from SWH	
		Value	Unit	m²/unit	Value	Unit
5	Residential - Rural	2.50	MWh/HH	2.00	1.48	MWh/HH
	Residential - Urban	4.06	MWh/HH	4.00	2.61	MWh/HH
	Hotel	1.34	MWh/room	1.13	0.76	MWh/room
	Hospital	0.81	MWh/bed	0.80	0.52	MWh/bed
	Hostel	0.81	MWh/person	0.80	0.52	MWh/person

4.2.2.3 Calculation of Technical Potential

Technical potential is calculated in three steps:

Step 1: End users technically qualified for SWH systems – TP_{HH}

$$TP_{HH} = (\text{end user base}) \times (\text{fraction with suitable roof type}) \times (\text{fraction with sufficient shadow-free area})$$

Step 2: Total collector area that can be installed in technically qualified buildings – $TP_{SWH\ area}$

$$TP_{SWH\ area} = (TP_{HH}) \times (\text{optimum size of SWH system})$$

Step 3: Total useful energy delivered by the collector area – TP_{MWh}

$$TP_{MWh} = (TP_{HH}) \times (\text{useful energy delivered by SWH system})$$

4.2.3 *Economic Potential Assessment*

4.2.3.1 Financial Model for Payback Period Calculation

A financial model was prepared to calculate the payback period. The following parameters were taken into account:

- Capital cost of the solar thermal system
- Annual savings from conventional fuels after accounting for annual escalation in fuel prices
- Operation and maintenance costs
- Degradation in output of the solar thermal system over time
- Accelerated depreciation benefit (if applicable)

With the help of the financial model, a relation was developed between the payback period and the ratio of annual savings to capital cost (Figure 4.9).

4.2.3.2 Calculation of Payback Period for Different Categories and Its Projections till 2032

The ratio of annual savings to capital cost was estimated for the combination of different fuels replaced for different categories of consumers. Thereafter, using the relation developed from the financial model, payback periods were calculated for each consumer category.

Savings from fuel substitution is expected to increase with increasing prices of conventional fuels, whereas uncertainty prevails on the trend for the cost of technology. The potential for cost reductions from mass-scale production and the change in prices of essential materials used are the two main factors that will drive the trend for the cost of technology. However, to estimate the economic change of the technology over time, it is assumed that the ratio of annual savings from fuel substitution to the capital cost of the technology will increase by 7% per annum.
For example, the payback period for a SWH system replacing electricity in a rural household located in Zone I in 2014 was estimated to be 3.1 years, which is expected to be reduced to 1 year by 2032.

4.2.3.3 Calculation of Economic Potential based on Maximum Acceptable Payback Period

The maximum acceptable payback period was considered as the criteria for calculating economic potential. The maximum acceptable payback period has been assumed to be eight years for the residential sector and five years for the commercial and institutional sector.

Economic potential = Fraction of technical potential meeting acceptable payback period criteria

4.2.4 Market Potential Assessment

Market potential has been estimated based on the fraction of consumers that may choose SWHs instead of conventional electric geysers at a given payback period. A study by the ICF International on estimating the potential of demand-side management[8] has developed payback acceptance curves for residential and non-residential consumers (Figure 4.4). The payback acceptance curves have been adapted for determining the market potential of SWHs. Consumer behaviour responding to the payback period is presented as a payback acceptance schedule. Payback acceptance schedules were also adapted for solar thermal technologies.

[8] *ICF International. Achievable Demand Side Management Potential Study. October 2012.*

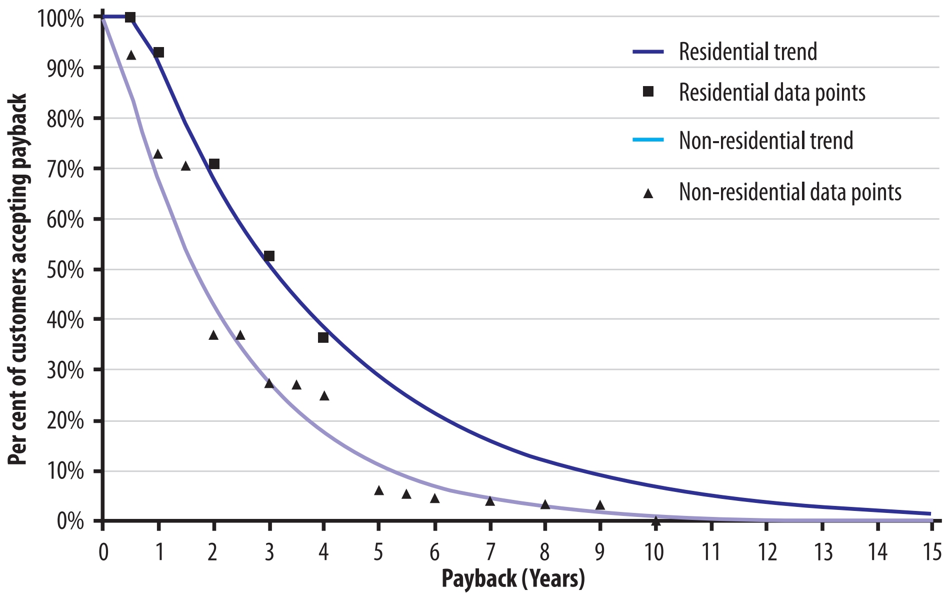


Figure 4.4 Payback acceptance schedule

Market potential is calculated as:

Market potential = *Economic potential* × *Percentage of consumers accepting payback*

Like, for example, if the payback period is two years for a residential sector solar system, ~70% of the consumers will accept it. For the same payback period in the non-residential sector, this fraction would be ~42%.

4.3 Results of Potential Assessment

4.3.1 Solar Water Heating in Residential, and Commercial and Institutional Sectors

4.3.1.1 Demand Estimation: Useful Energy for Hot Water Generation

Annual useful energy requirement for hot water generation in the residential, and commercial and institutional sectors was estimated at ~20.8 Mtoe in 2014, and is expected to reach ~32.7 Mtoe by 2032. The residential sector accounted for ~99% of this requirement in 2014, which is expected to reduce to 96% in 2032. Within the residential sector, 55% (in 2014) of the demand was noted to be from rural households (Figure 4.5). A large fraction of the rural demand is being met through non-commercial energy sources like fuel wood and dung cakes. Within the residential sector, 47% of the energy requirement is in Zone I, followed by Zone III with 31% (Figure 4.6).

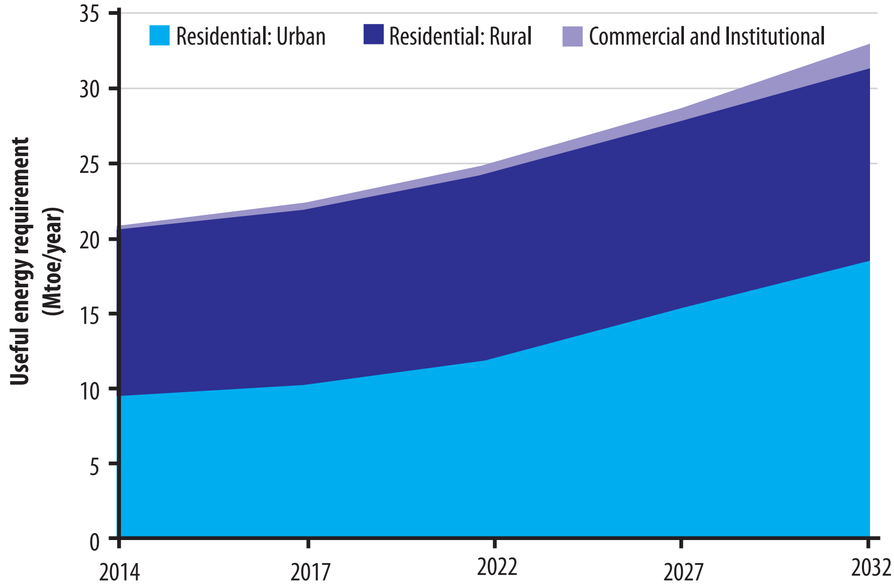


Figure 4.5 Projected useful energy requirement (2032)

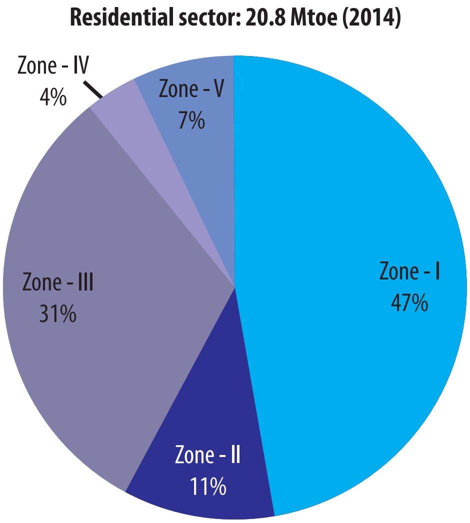


Figure 4.6 Distribution of useful energy requirement in the residential sector by zone

4.3.1.2 Technical Potential

The technical potential of SWHs in buildings (residential + commercial and institutional) was estimated to be 100 GW_{th} in 2014, which is expected to increase to 229 GW_{th} by 2032. Presently (2014), 99% of the technical potential of SWHs in buildings lies in the residential sector. The residential sector is expected to hold the majority (96%) of technical potential even by 2032. Within residential, rural households contribute to ~70% of the technical potential (Figure 4.7) in 2014. Zones I and III, because of their large populations, account for ~80% of the technical potential in the residential sector in both 2014 and 2032 (Figure 4.8).

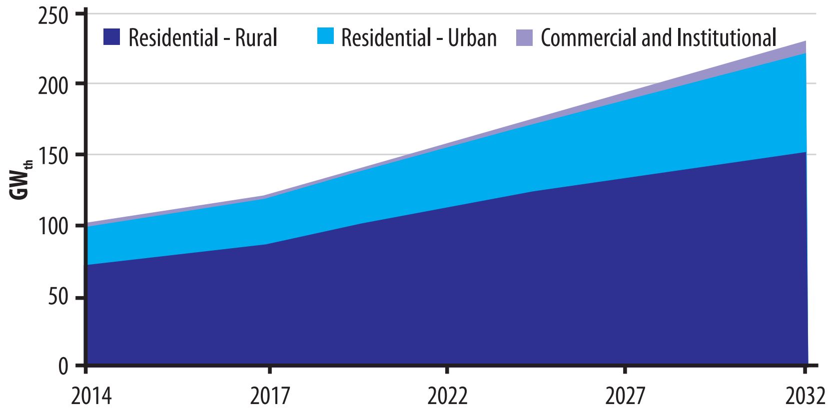


Figure 4.7 Technical potential of SWHs in buildings

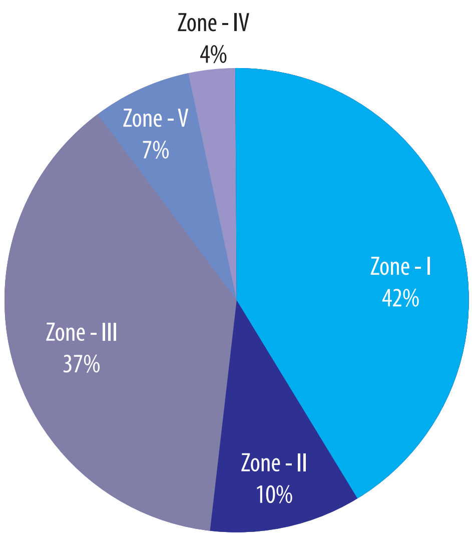


Figure 4.8 Distribution of technical potential in residential sector by zone

In 2014, 27% of the total households were noted to have a technical potential for SWHs, which is expected to rise to 41% by 2032 (Figure 4.14).

4.3.1.3 Economic Potential

Using the financial model for payback calculation, an empirical relation between the payback period and the ratio of annual savings to capital cost has been developed and shown in Figure 4.9.

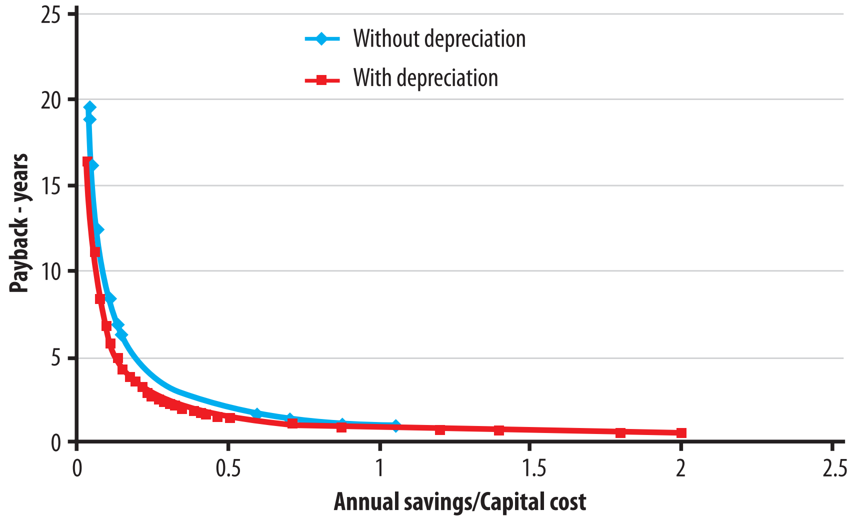


Figure 4.9 Relation of payback period with ratio of annual savings to capital cost

For calculating annual saving, it is assumed that the households that are technically qualified for installing SWHs in urban areas use electricity for hot water generation. Whereas, in rural areas, households using electricity-based heating systems has been estimated using secondary data.[9] The remaining technically qualified rural households are assumed to be using biomass for hot water generation. For the commercial and institutional sector, diesel and electricity have been assumed as the primary fuels for hot water generation.

The economic potential is estimated to be 25–32 GW_{th} in 2014, which rises to the level of technical potential (229 GW_{th}) by 2032. An important point to be noted is that in 2014, the rural sector share of the economic potential has been only 16%. This was mainly because a large proportion of households used a low cost fuel such as biomass for generating hot water. Also, penetration of electricity-based heating devices in rural areas is observed to be very low. With the increase in the price of biomass fuels and increased penetration of electric geysers, the share of rural sector in the economic potential is expected to increase to 66% in 2032 (Figure 4.10). It is estimated that the prices of conventional fuel will increase to the level where the entire technical potential will transform to economic potential by the year 2032 (Figure 4.14).

Within the residential sector, more than 90% of the economic potential in 2014 is concentrated in Zones I and III. By 2032, it is expected that the share of Zones I and III will reduce to ~78%, while the share of Zone II will rise to 14% (Figure 4.11).

[9] *McNeil M, Zhou N, Sathaye J, Letschert V, Can SD. Residential and Transport Energy Use in India: Past Trend and Future Outlook. Ernest Orlando Lawrence Berkeley National Laboratory, 2009.*

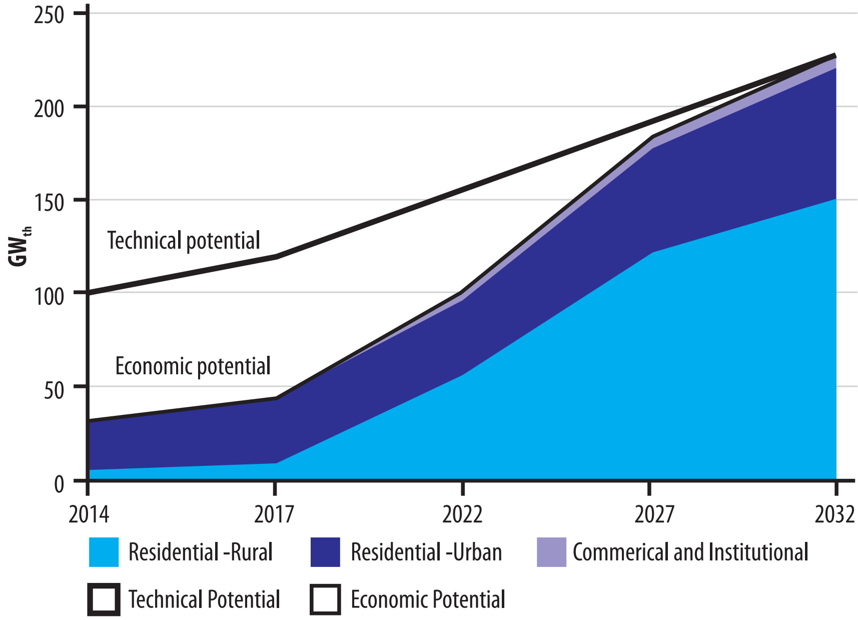


Figure 4.10 Economic potential of SWHs in buildings

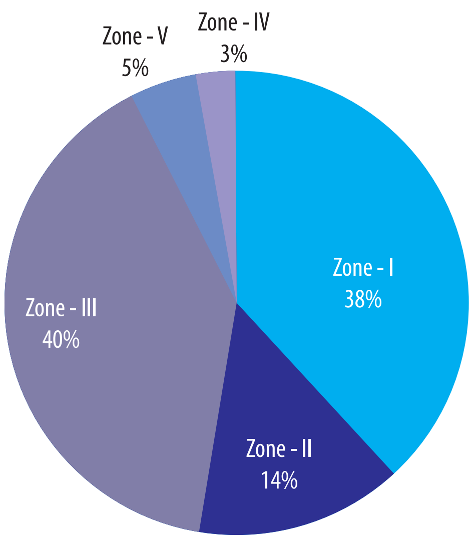


Figure 4.11 Zonal share of economic potential of SWHs in residential sector in 2032

4.3.1.4 Market Potential

The market potential of SWHs in buildings was estimated at 13.4 GW_{th} in 2014, which is expected to rise to 138.5 GW_{th} by 2032. In 2014, the rural sector share of the total market potential had been only 12%, and is expected to rise to 51% by 2032 (Figure 4.12). Realisation of the market potential of SWHs in the buildings sector can deliver ~8.6 TWh of useful energy for hot water generation in 2014, which is expected to rise to ~76.8 TWh in 2032 (Figure 4.13).

In the residential sector, households falling under market potential are expected to increase by a factor of ten by 2032 (Figure 4.14). Zones I and III, combined, will hold ~85% of the market potential of SWHs in buildings in 2032 (Figure 4.15 and Figure 4.16).

Realisation of the SWH market potential by 2032 has a potential of saving ~73 TWh/y of useful energy demand for hot water generation. This saving (in 2032) is equivalent to ~5.7 Mtoe of electricity, 0.1 Mtoe of petroleum fuels, and ~10.9 Mtoe of biomass in final energy consumption, which translates to ~28.1 Mtoe of primary energy (Figure 4.17 and Figure 4.18).

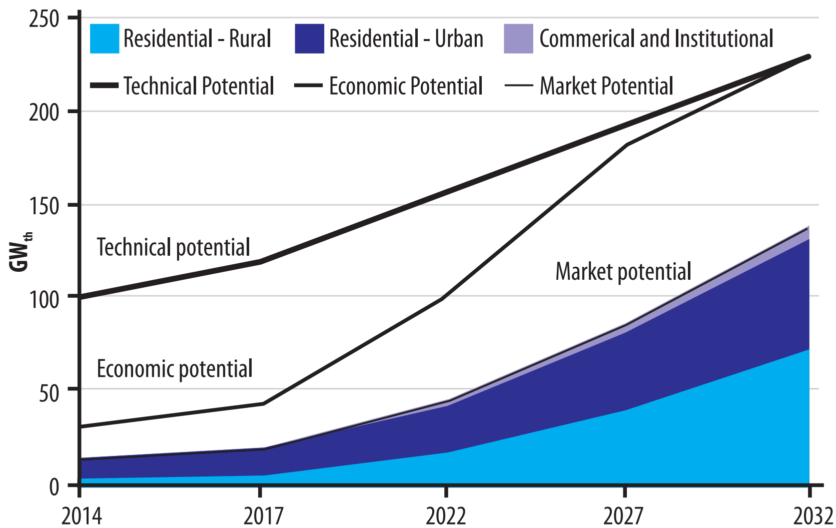


Figure 4.12 Market potential of SWHs in buildings (GW_{th})

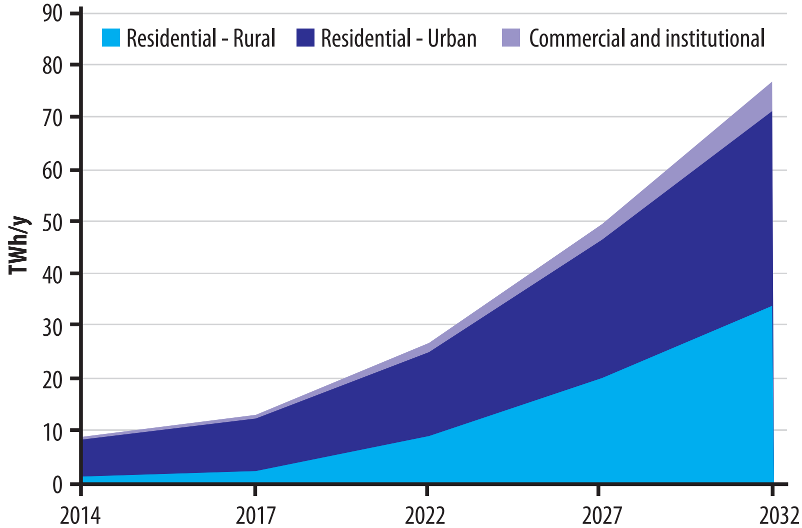


Figure 4.13 Useful energy delivered by realising the market potential (TWh/y)

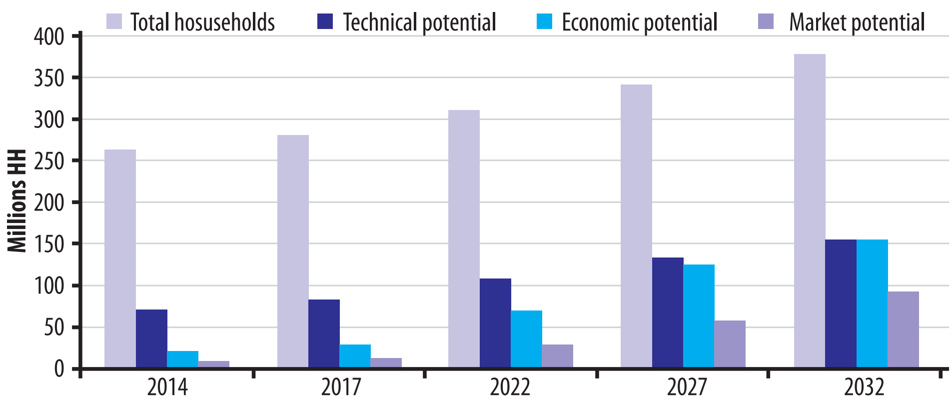


Figure 4.14 SWH potential households

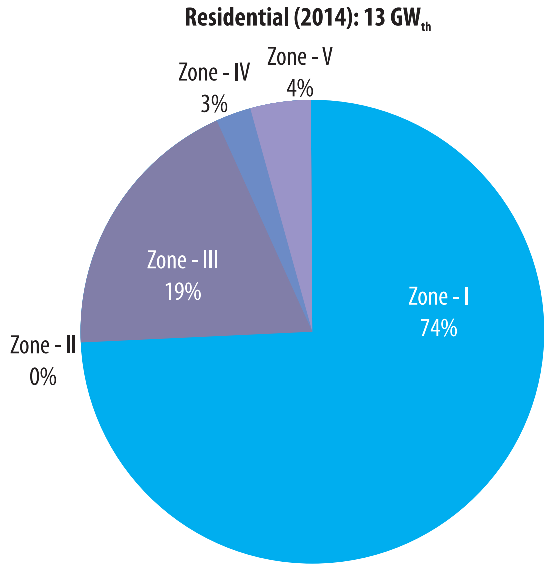


Figure 4.15 Zonal distribution of market potential in residential sector (2014)

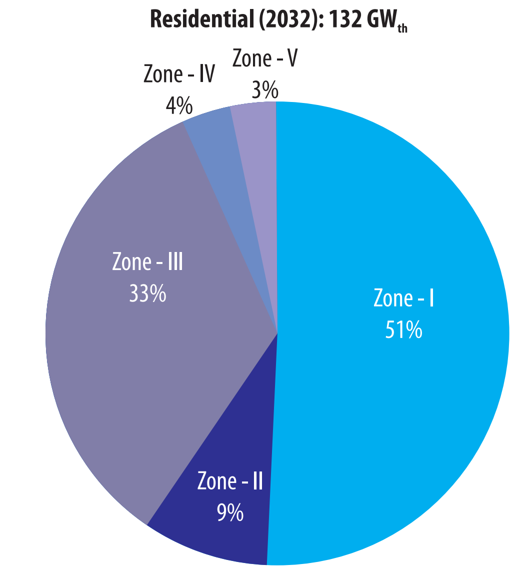


Figure 4.16 Zonal distribution of market potential in residential sector (2032)

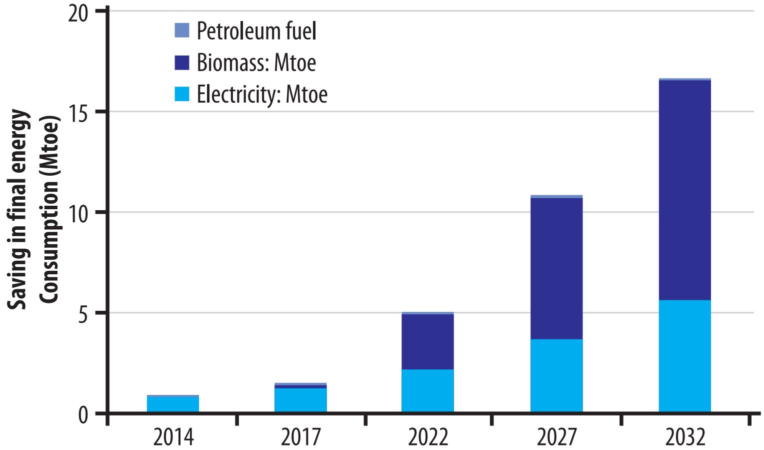


Figure 4.17 Savings in final energy consumption from realisation of market potential

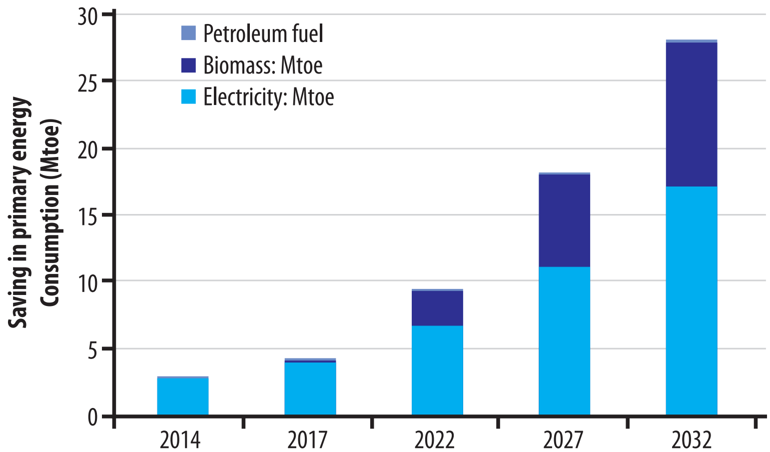


Figure 4.18 Savings in primary energy consumption from realisation of market potential

Box 4.1 Key findings of potential assessment of SWHs in buildings

- The market potential for SWHs in buildings is expected to grow 10 times between 2014 and 2032 and is expected to reach 138.5 GW_{th} by 2032.
- Most of the future market potential will come from smaller towns and rural areas. In 2014, rural areas accounted for ~12% of the market potential; they are expected to account for ~51% of the market potential by 2032.
- The annual electricity savings from fully exploiting the market potential (2032) for SWHs in buildings will be equivalent to annual electricity generation from ~64 GW_p of solar PV installations.

4.3.2 Solar Cookers in Residential Sector

The estimated technical potential for solar cookers in the residential sector is as described below.

4.3.2.1 Demand Estimation

Cooking energy demand was calculated using the following methodology:

- The distribution of rural and urban households using different fuels for cooking was determined. Average cooking efficiency for the respective fuels was also determined.[10]
- Average useful energy required for cooking was estimated to be 0.73 MJ/meal.[11]
- Primary energy demand for cooking has been estimated based on the weightage average cooking efficiency and the useful energy required for cooking.

Table 4.3 gives a summary of distribution of households among different fuels used for cooking with their respective fuel efficiency for cooking. Table 4.4 presents the primary consumption for cooking in the residential sector.

Table 4.3 Cooking efficiency and fuel used for urban and rural households

		Urban (%)		Rural (%)	
Fuel	Efficiency (%)	2014	2032	2014	2032
LPG	60	67.5	50.0	15.9	30.0
Electricity	71	0.4	2.3	0.5	2.0
PNG	60	2.9	35.0	0.0	1.0
Biomass	14	21.5	13.4	81.7	65.0
Coal	23	2.7	0.0	0.8	0.0
Kerosene	40	5.9	0.0	0.6	0.0
Biogas	45	0.0	0.0	0.6	1.0
Weighted average		34.0	42.0	16.2	19.0

Table 4.4 Primary energy demand norm for cooking

	Urban		Rural	
Primary energy demand	2014	2032	2014	2032
Useful cooking energy [MJ/(meal)]	0.73	0.73	0.73	0.73
Cooking efficiency weighted average (%)	34.0	42.0	16.2	19.0
Primary energy required [MJ/(meal.capita)]	2.1	1.7	4.5	3.8

[10] *Planning Commission, Government of India, The India Energy Security Scenarios 2047 (IESS 2047), www.indiaenergy.gov.in, April 25, 2014.*
[11] *Ravindranath NH, Ramakrishna J. Energy Options for Cooking in India. Energy Policy 1997:63–75.*

The useful energy required for cooking was estimated at ~16 Mtoe in 2014, which will increase to ~19 Mtoe in 2032. The total primary energy demand for cooking was estimated at ~82 Mtoe in 2014, which is expected to reduce to ~77 Mtoe in 2032. The reduction in primary energy is mainly due to the shift towards more efficient fuel and cooking technology.

4.3.2.2 Technical Potential

Technical potential has been calculated based on the estimated households having shadow-free area for solar cooker installations and the calculated solar fraction (assumptions for the calculation are provided in Annexure I.)

Figure 4.19 gives the technical potential of solar cookers in terms of number of households for urban and rural sectors. In 2014, ~132 million households are noted to have technical potential for solar cookers, with the rural sector accounting for ~80%. In 2032, households having technical potential is expected to increase to ~176 million with the rural share reducing to ~71%.

Figure 4.20 provides the technical potential of solar cookers in terms of primary energy for the urban and rural sectors. In 2014, technical potential of solar cooker in terms of primary energy saving was estimated to be at 11.7 Mtoe with the rural sector accounting for ~90%. In 2032, this potential is expected to reduce to 10.6 Mtoe with the rural share being ~86%.

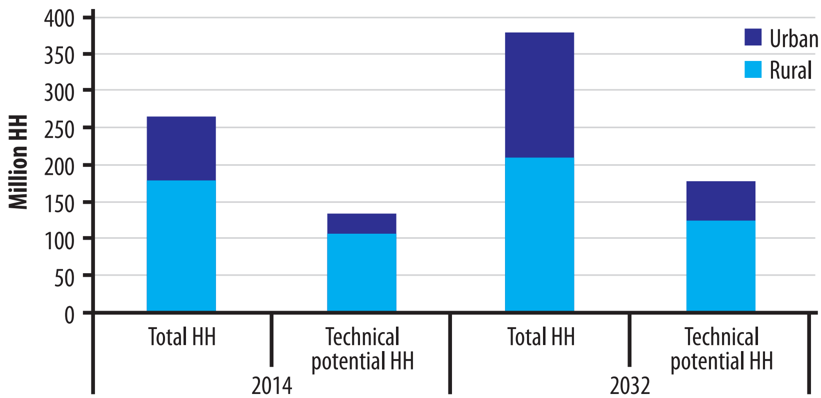


Figure 4.19 Technical potential of solar cooker (number of households)

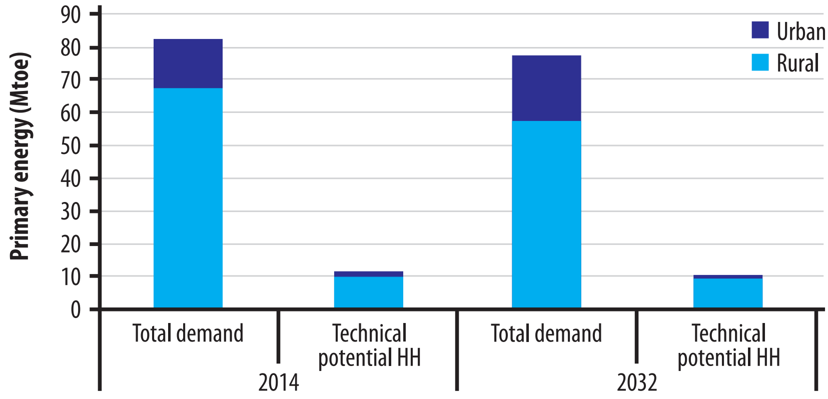


Figure 4.20 Technical potential of solar cooker (primary energy, Mtoe)

The technical potential of solar cookers was estimated in terms of number of solar cookers considering the box-type solar cookers. The estimated technical potential in 2014 was 132 million solar cookers, which is expected to increase to 176 in 2032.

The rural sector should be targeted for solar cooking as it has great need and potential, mainly because of space availability and low cooking efficiency.

4.3.3 Process Heat Applications in the Industrial Sector

4.3.3.1 Demand Estimation

The analysis has been carried out on a macro level, as explained in Chapter 2. Estimated primary thermal energy demand is shown in Figure 4.21.[12] Total primary thermal energy demand in 2014 was estimated at ~158 Mtoe, which is expected to increase to ~429 Mtoe in 2032. This thermal energy demand has been further divided between the process heat applications that require temperatures <250 °C and >250 °C.

[12] *GKSPL estimates based on data from: Planning Commission, Government of India, The India Energy Security Scenarios 2047 (IESS 2047), www.indiaenergy.gov.in, 25 April 2014.*

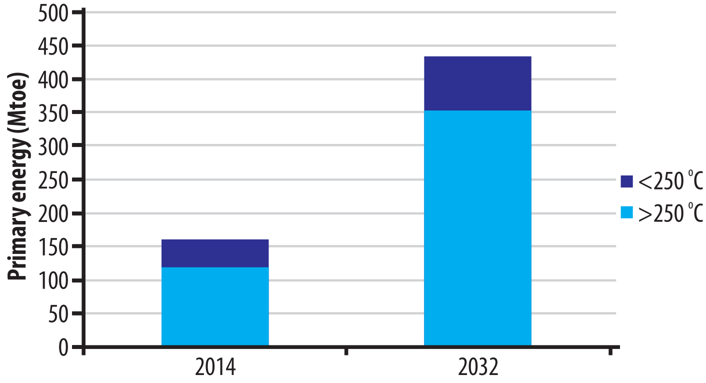


Figure 4.21 Primary thermal energy demand for industrial sector

4.3.3.2 Potential Estimation

For the industrial sector, the potential estimation was calculated based on data from past studies[13,14,15] for solar thermal applications. Twenty-three relevant feasibility reports have been referred to here and the industries include: pharmaceutical, food processing, textile, metal furniture, and chemicals. Table 4.5 gives a summary of thermal energy requirement for these industries and the solar fraction of proposed solar technologies calculated in the feasibility reports. The average solar fraction for these industries is pegged at 21%.

Table 4.5 Thermal energy demand and solar fraction for industries

Industry	Thermal energy demand (million kcal/y)	Equivalent steam demand[16] @10 kg/cm^2 and 365 d/y (t/d)	Solar fraction (%)
Chemicals 1	3,995	17	16
Food Processing 1	2,997	13	3
Food Processing 2	24,280	102	1
Food Processing 3	9,504	40	7
Food Processing 4	44,087	186	1
Food Processing 5	3,700	16	25
Food Processing 6	26,400	111	7

table contd....

[13] *Greentech Knowledge Solutions Pvt. Ltd. Awareness and Preparation of DPR for Pilot Projects on Solar Energy Applications in Selected Pharmaceutical Sector, Commercialization of Solar Energy Project, GIZ, 2013.*

[14] *Greentech Knowledge Solutions Pvt. Ltd. Awareness and Preparation of DPR for Pilot Projects on Solar Energy Applications in Selected Food Processing Sector. Commercialization of Solar Energy Project, GIZ, 2013.*

[15] *UNDP, GEF, MNRE. Project Document for 'Market Development and Promotion of Solar Concentrator Based Process Heat Applications in India (India CSH).' 2011.*

[16] *Total thermal energy demand is converted into equivalent steam demand considering the steam is generated 10 kg/cm^2 pressure and there is requirement for steam 365 days of the year.*

Table 4.5 Contd...

Industry	Thermal energy demand (million kcal/y)	Equivalent steam demand[16] @10 kg/cm^2 and 365 d/y (t/d)	Solar fraction (%)
Food Processing 7	1,250	5	35
Food Processing 8	1,048	4	35
Food Processing 9	2,136	9	22
Food Processing 10	10,950	46	3
Metal Furniture 1	8,909	38	19
Metal Furniture 2	847	4	50
Pharmaceutical 1	5,545	23	7
Pharmaceutical 2	1,212	5	45
Pharmaceutical 3	7,470	31	17
Pharmaceutical 4	10,228	43	17
Pharmaceutical 5	3,205	14	34
Pharmaceutical 6	1,685	7	46
Pharmaceutical 7	1,276	5	32
Pharmaceutical 8	710	3	39
Pharmaceutical 9	26,857	113	1
Textile 1	2,400	10	16

Figure 4.22 gives an indication about the relationship between the thermal energy requirement and the solar fraction. Solar thermal technologies have good potential (solar fraction up to 50%) in the smaller industries, which have lower steam requirement (<50 tonnes/day). Bigger industries having a steam demand >100 t/d have lower potential (<10% solar fraction). If we consider the average solar fraction (21%) as a representative for the industrial sector having thermal energy demand <250 °C, then the potential of solar thermal technologies is ~8.3 Mtoe in 2014 and ~16.5 Mtoe in 2032.

Detailed assessments of thermal energy demand for the whole industrial sector, with similar feasibility studies, could be done to estimate better the potential of solar thermal technologies in the industrial sector.

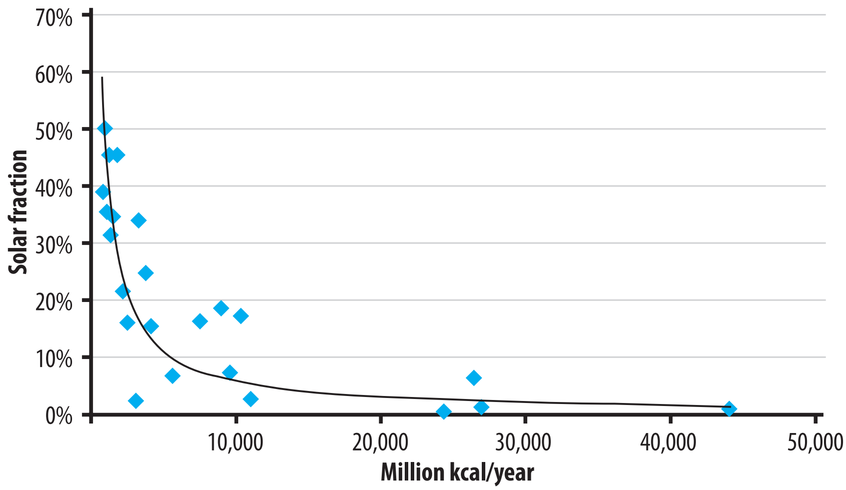


Figure 4.22 Relationship between the thermal energy demand and solar fraction

4.4 Market Projection

While the potential assessment indicates the maximum possible deployment of solar thermal technologies, market projection indicates the potential that can be realised with respect to time. Market projections have been done for all the sectors, solar technologies, and their applications using two scenarios: business-as-usual (BAU) case and aggressive effort case.

4.4.1 Business-as-Usual Scenario

Under this scenario, it is assumed that the past and present market trend would continue in the future. However, the views of key stakeholders on the future market and key decisions (e.g., removal of capital subsidy for SWHs) have been taken into account under this scenario.

4.4.2 Aggressive Effort Scenario

Under this scenario, it is assumed that there would be aggressive effort to improve solar thermal technology deployment. Improved economic viability over time (due to increase in fuel prices and corresponding increase in overall saving), more policy regulation and enforcement, improvements in supply chain for solar thermal technologies, and availability of financial mechanisms have been considered to accelerate the market deployment of solar thermal technologies.

[Key assumptions made for both the scenarios are given in Annexure I.]

4.4.3 Results of Market Projection

The status (in 2014) of solar thermal technologies is shown in Table 3.1 (Chapter 3) and Figure 4.23 gives the cumulative solar technologies installation for 2014, 2017, 2022, 2027, and 2032 for both the scenarios. Under both the scenarios, solar water heating in the residential sector is the dominant application and contributes ~80% in 2014, and remains the largest application in 2032 (~84% and ~88% under BAU and aggressive effort scenario, respectively). Solar water heating applications for all sectors (residential, commercial and institutional, and industrial) contribute to ~99% in 2032 under both the scenarios.

The cumulative installation of solar technologies for each sector for 2032 under the BAU scenario (Table 4.6) and the aggressive effort scenario (Table 4.7) is presented. Under the aggressive effort scenario, the cumulative installation of solar technologies is ~2.5 times as compared to the BAU scenario. Under the aggressive effort scenario, the total useful energy delivered by solar technologies is ~70 TWh/y (~6 Mtoe/y).

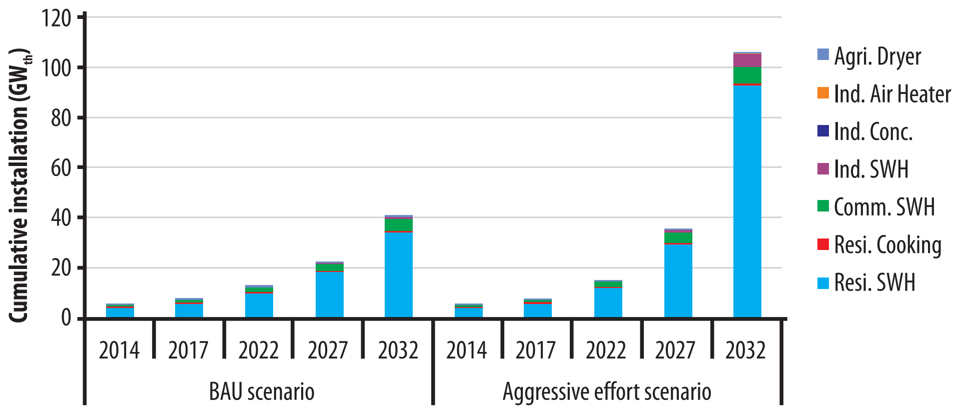


Figure 4.23 Cumulative solar technologies installation under BAU and aggressive effort scenario

Table 4.6 Cumulative installations of solar technologies in 2032 under BAU scenario

Sector	Solar thermal technology	Installed capacity		Energy delivered (GWh/y)
		Collector area/no.	GW_{th}	
Residential	Solar water heaters	50 million m^2	34.800	22,080
	Solar cookers	0.72 million	0.151	36
Commercial and institutional	Solar water heaters	6.5 million m^2	4.600	3,691
	Solar concentrators	114,300 m^2	0.080	82
Industrial	Solar water heater	2.2 million m^2	1.500	1,217
	Solar concentrators	285,000 m^2	0.200	266
	Solar air heater	85,000 m^2	0.060	73
Agriculture	Solar dryer	19,000 m^2	0.013	16
Total			**41.404**	**27,461**
				(2.36 Mtoe)

Table 4.7 Cumulative installations of solar technologies in 2032 under aggressive effort scenario

Sector	Solar thermal technology	Installed capacity		Energy delivered (GWh/year)
		Collector area/no.	GW_{th}	
Residential	Solar water heaters	133 million m^2	92.800	58,908
	Solar cookers	1.36 million	0.286	68
Commercial and institutional	Solar water heaters	9.6 million m^2	6.700	5,415
	Solar concentrators	336,100 m^2	0.235	242
Industrial	Solar water heater	7.4 million m^2	5.200	4,202
	Solar concentrators	689,000 m^2	0.483	642
	Solar air heater	196,000 m^2	0.137	168
Agriculture	Solar dryer	43,000 m^2	0.030	37
Total			**105.872**	**69,683** (5.99 Mtoe)

CHAPTER 5

Goal, Strategies, and Action Plan

5.1 Goal 2032

The roadmap envisages decentralised solar thermal technologies and applications to follow aggressive effort path (refer to Section 4.4.2 for details) to reach a cumulative installed capacity of 100–120 GW_{th}, delivering 65–80 TWh energy annually, by the year 2032. A large part of the cumulative installed capacity (almost 90%) is expected to be met through the accelerated deployment of mature solar thermal technology, i.e., solar water heaters in buildings. Solar industrial heat (<250 °C) is expected to cross the chasm and reach the growth phase during this period.

Achieving the goal of aggressive effort path (~106 GW_{th}) by 2032 would result in:

1. Annual savings of around 68,000 GWh of electricity at the consumer level, or around 85,000 GWh[1] at the point of generation (i.e., at the power plant). This translates into an equivalent avoided thermal power plant capacity of around 14,000 MW.[2] Generation of an equivalent amount of electricity per year through solar PV would require around 50 GW_p of solar PV power plant capacity.
2. Annual savings of 1 Mtoe of oil and gas, resulting in an import bill reduction of ~Rs 5000 crore/year.[3]

5.2 Strategies

To achieve the goal of 100–120 GW_{th} by 2032, the roadmap has identified six strategic focus areas. These include:

1. Accelerated deployment of SWHs in the residential sector
2. Development of the solar industrial heat market (<250 °C)
3. Focussed research, development, and deployment
4. Promoting indigenous, quality manufacturing, and human resource development
5. Strengthening the institutional network
6. Policy framework redesign

[1] *Considering transmission and distribution losses of 20%.*
[2] *Considering plant load factor of 75%.*
[3] *At World Energy Outlook Prices 2012 (USD 136/boe and USD 11.8/mmbtu; 1 USD = Rs 60).*

Each of these six strategies are described in brief in the subsequent sections.

5.2.1 Expansion of SWH in the Residential Sector

Aim: The aim is to achieve accelerated deployment of SWHs in residential buildings by overcoming the challenges identified in the previous chapters (Table 5.1).

Table 5.1 Key challenges for SWH market expansion in residential buildings

Area	Challenges
Technology and product	• Better solar water heater solutions are needed for multistorey residential buildings to address issues of: equitable distribution of hot water, efficient backup heating, effective utilisation of the roof area, and installation on vertical surfaces. • Rural households are expected to constitute more than 50% of the market potential in 2032. SWH product variants to meet specific requirements of the rural areas are needed to tap this market.
Manufacturing and supply chain	• More than 80% of the MNRE empanelled suppliers of SWH systems are located in Zone I. The manufacturing and supply network is weak outside of Zone I, which is expected to contribute to ~50% of the market potential in 2032. • Inadequate quality standards and the lack of a labelling programme for residential SWH systems results in significant market share taken up by poor quality systems.
Building regulations	• Out of more than 3000 urban local bodies, only around 100 have amended their building bylaws making the use of SWHs mandatory. • Among the 100 urban local bodies that have amended their bye laws, only a few have been able to effectively implement them. • The scope of mandatory regulations is limited to new buildings; existing buildings are not covered.

The main elements of the strategy are listed below.

I. **Amendment in building bylaws by urban local body (ULB) for mandatory provision of solar water heaters (as a part of adoption of green building codes) and their effective implementation.** Mandatory provision of SWHs for new buildings has been one of the most effective strategies for popularising SWH use in buildings, worldwide. The urban population in India is set to rise from 31% of the total population in 2010 to around 50% by 2050, adding 441 million new urban habitants.[4]

Given the existing housing shortage in urban areas and the addition of new population, a large expansion in residential building stock is expected. Sustainability concerns have given rise to the demand for amending the building bye laws of ULBs to include provision of sustainable construction (green buildings). Faster adoption of green building codes has been one of the key recommendations of the 'Expert Group on Low Carbon Strategies for

[4] *United Nations. World Urbanisation Prospects: The 2014 Revision. New York: United Nations Department of Economic and Social Affairs, 2014.*

Inclusive Growth' and a focus activity during the 12th Five Year Plan.[5] The earlier attempt by the MNRE to persuade ULBs (through the Ministry of Urban Development) to amend bye laws to include mandatory provision for SWHs, has resulted in limited success.

It is suggested that the MNRE and the SWH industry work jointly with other agencies (e.g., Ministry of Urban Development, Bureau of Energy Efficiency, and green building rating systems like GRIHA, IGBC, and LEED) involved in pushing for adoption of green building codes by ULBs to ensure that the provision of SWHs is included as one of the measures. In addition, the ULBs should be provided necessary technical support for operationalising the mandatory regulations. Some of the ULBs (e.g., Thane, Rajkot, Bengaluru) have already implemented such regulations. Their knowledge and experience should be disseminated to other ULBs.

II. **Consolidation of the SWH market in urban areas of Zone I.** Zone I constitutes around 50% of the market potential in 2032 and hence should be the prime focus for expanding the SWH markets. Some of the key features of Zone I that make it the focus region for market expansion are given below.

- The zone already has an established manufacturing and supply network of SWHs in all major cities and towns.
- Penetration of SWHs in certain urban areas, like Bengaluru and Pune, has already reached a satisfactory level. These cities can act as a node for market development and promotion activities in the zone.
- Knowledge and experience for operationalising and implementing mandatory regulations already exist in the zone as some of the municipal corporations in Zone I, like Rajkot, Bengaluru, and Pune, have already implemented the mandatory regulation.

The main recommendations for expanding and consolidating the SWH market in Zone I are to:

- Operationalise and implement mandatory regulation strategy in all major ULBs of Zone I.
- Undertake targeted market promotion and development activities, particularly in low- and medium-density population cities and towns.
- Provide access to financing to overcome the barrier of high upfront cost for medium- to low-income households.

III. **Expansion of SWH market to urban areas of Zones II to V and rural areas of all zones.** Although Zone I constitutes 50% of the market potential of SWHs in the residential sector, the rest of the 50% lies outside of Zone I (Figure 4.16). The rural market is expected to constitute more than 50% of the market potential. The main recommendations for expanding and consolidating the SWH market in other zones and rural areas are listed below.

- *Phase-wise implementation:* To begin with, the best suited regions (urban centres or rural areas) for SWHs should be identified for market development and strengthening of manufacturing and supply networks in Zones II, III, IV, and V. After reaching a

[5] *Planning Commission. Faster, More Inclusive and Sustainable Growth, Twelfth Five Year Plan (2012–2017). Government of India, 2013.*

certain critical penetration, these identified regions will act as nodes for further market expansion to nearby regions.

- *Bundled offering for rural markets:* Providing access to financing and developing a network for service and maintenance will also play a critical role in exploiting the rural markets. The roadmap recommends developing bundled solutions for rural markets containing not only the SWH product but also its service and access to financing.

IV. **Applied R&D.** Developing reliable and integrated SWH solutions for multistorey residential buildings and developing product variants suitable for rural requirements are the two priority areas for applied engineering in SWHs.

R&D should focus on increasing the cost-competitiveness of SWHs. At present, developing new materials for efficient and low-cost solar energy collection and advancement in thermal storage technologies appears to be the focus area for R&D.

V. **Improving quality: standards and labels.** International experience shows that focus on improving the quality of solar thermal systems is a prerequisite for sustaining the growth of the market in the long term. Lessons should be drawn from China, which has taken a leading position in developing quality improvement mechanisms. In India, lessons can also be learned from the BEE labelling programme for appliances, which has resulted in developing a market for higher star-labelled products.

Standards, testing procedures, and testing facilities for SWHs should be established, and a labelling scheme should be launched. The quality label will provide differentiation and higher visibility, and help in increasing the market share of better quality products.

5.2.2 Development of Industrial Solar Heat Market (<250 °C)

Aim: The strategy aims at developing the market for solar thermal technologies for industrial heat application to reach the growth phase by 2027.

A recap of the key challenges in the development of the industrial solar heat market is presented in Table 5.2.

Table 5.2 Key challenges for the development of industrial process heat (<250 °C)

Area	Challenges
Technology and product	• Lack of audited performance data on industrial solar thermal systems results in increased risk perception among potential industrial customers. • The output from industrial solar thermal systems varies depending on the solar radiation, and on their own they are able to meet only part of the industrial thermal demand. Thus there is a need for solar thermal-based hybrid solutions that are able to meet the industrial thermal demand (in both quantity and quality), taking into account integration with the main/backup heat generation systems, the end-use industrial process, and thermal storage.

table contd....

Table 5.2 Contd...

Area	Challenges
Reference systems	• The number of existing industrial solar thermal systems is small. These installations are scattered geographically.
Technology suppliers	• There are only a limited number (around 30–40) of solar thermal technology suppliers catering to the industrial sector. Most of them are located in Zone 1 and are small companies with limited resources and reach.
Cost, economics, and competing technologies	• The simple payback period[6] for replacing petroleum fuels (diesel, furnace oil, natural gas) and electricity ranges from 2–3 years for non-concentrating collectors[7] and 3–4 years for concentrating collector,[8] while for solid fuels like coal and biomass it goes up to 7–9 years for both concentrating and non-concentrating collectors. • Solar thermal solutions face competition from biomass-based systems for heat generation, waste heat recovery system, and heat pumps. For rooftop space, they face competition from solar PV systems.

The main elements of the strategy include the ones listed below.

I. **Focussed market development to achieve a critical mass of industrial solar thermal installations.** Based on the available information on existing solar thermal installations in industries available through the GIZ-supported SoPro project[9] and the UNDP–GEF concentrated solar heating project,[10] the main industrial sectors where solar thermal technologies have been used are pharmaceutical, dairy, food processing, chemical, textile, and auto sectors. Most of the industries that have adopted solar thermal solutions are using high-cost petroleum fuels.

The following actions are suggested for developing the market of solar thermal technologies in a focussed manner with an aim to achieve a critical mass in the identified industrial sectors and states.

- Undertake market development and strengthening of the industrial solar thermal solution supply chain targeted at selected industrial sectors in the identified states. A first list of sectors and states that can be targeted is provided in Table 5.3. However, this list needs to be updated and expanded by undertaking detailed market assessment studies.
- Energy Service Company (ESCO) is a potentially attractive business model to overcome the barriers related to financing of upfront costs and perceived risks of performance of the solar thermal solutions. A few examples exist for use of the ESCO concept for industrial solar thermal systems.[11] Action should be taken to promote the ESCO concept.

[6] *The payback periods have been calculated using the benchmark cost and performance quoted by the technology suppliers. It is important to note that the financial payback period is sensitive towards the output of the solar technology and at present apprehensions prevail in the market on the actual financial returns from the system due to lack of independent third party audited performance data from actual installations.*

[7] *After accounting for 80% accelerated depreciation benefit available from the MNRE.*

[8] *After accounting for capital subsidy and 80% accelerated depreciation benefit available from MNRE.*

[9] *http://www.soproindia.in/*

[10] *http://www.cshindia.in/*

[11] *Case study of Wheels India project with Aspiration Energy, details available at: http://solarthermalworld.org/content/india-esco-concept-wheel-producer*

Table 5.3 List of states and industrial sectors for undertaking focussed market development activities

Pharmaceuticals	Food processing	Dairy	Auto	Textile
States having major pharmaceutical clusters	States having two or more operational/ under implementation mega food parks[12]	Five top states in terms of milk production[13]	States having major auto clusters[14]	Some of the important states having textile clusters (involved in wet processing)
Andhra Pradesh Maharashtra Gujarat Madhya Pradesh Punjab Himachal Pradesh	Andhra Pradesh Maharashtra Gujarat Uttarakhand Bihar Chhattisgarh	Uttar Pradesh Rajasthan Andhra Pradesh Gujarat Punjab	Maharashtra Haryana Tamil Nadu Gujarat	Rajasthan Gujarat Tamil Nadu Punjab Haryana

II. **Applied R&D.** Development of standardised technology packages for different industrial applications should be a priority. R&D should focus on increasing reliability, functionality, efficiency and cost-competitiveness of industrial solar thermal solutions. Development of thermal storage solutions for industrial applications should be a focus area of research.

III. **Performance assessment and benchmarking.** Independent field performance assessment based on standard methods should be undertaken for industrial solar thermal systems. The results of performance assessment would be useful in benchmarking performance of different types of industrial solar thermal systems. Ensuring quality and benchmarking performance will help in establishing the credibility of solar thermal technologies for industrial applications. In this respect, a beginning has already been made by the GIZ-sponsored SoPro project (for monitoring of industrial solar thermal systems) and the UNDP–GEF concentrated solar heat project (for the monitoring of industrial solar concentrator heat systems). There is a need to build upon the work initiated in these projects.

BIS standards, testing procedures, and testing facilities for all types of products and systems for industrial heat should be established.

IV. **Moving towards regulations and market-based mechanisms for solar industrial heat.** Once a critical mass of industrial solar thermal systems have been reached and industrial solar thermal technologies are able to cross the chasm, a move towards mandatory regulation for specific industrial applications and/or market-based mechanisms (e.g., BEE's Performance Achieve and Trade [PAT] scheme) to promote solar thermal across industrial sectors and geographies should be considered.

[12] *http://mofpi.nic.in/mfp_graph.aspx, 23 October 2014.*
[13] *http://www.nddb.org/English/Statistics/Pages/Milk-Production-States.aspx, 23 November 2014.*
[14] *http://en.wikipedia.org/wiki/Automotive_industry_in_India, 23 October 2014.*

5.2.3 Focussed Research and Development

Aim: Focussed research and development at making existing solar thermal packages more efficient, reliable and cheaper, as well as developing new solar thermal technology packages for high potential end-use applications.

The main elements of the strategy are listed below.

I. **Applied R&D to improve existing solar thermal technology packages.** Some of the key R&D topics for existing solar thermal technology applications are provided in Table 5.4.

Table 5.4 Key R&D topics for existing solar thermal technology application packages

Solar thermal technology application	Key R&D topics
Solar water heating for buildings	• Developing better SWH packages for multistorey residential buildings, addressing the issue of equitable hot water generation, efficient space utilisation, and integration of efficient backup heating systems. • New product variants focussing on the needs and requirements of rural areas. • Newer materials (e.g., polymeric materials) for solar collectors for cost reduction. • Collectors and systems that can work in areas having poor water quality.
Solar cookers for residential and institutional sectors	• Residential solar cookers with higher efficiency, lighter weight, and ease of use. • Integration of solar thermal storage to extend the number of hours of usage for both residential and institutional solar cookers.
Solar cooling systems	• Advancing the VAM technology to maintain efficiency and output for variable heat input, and to lower heat temperatures. • VAM systems of smaller capacities. • Effective integration and hybridisation of vapour absorption/adsorption technology with solar thermal collectors, other heat sources, and other cooling technologies. • Thermal storage solutions for storing heat or cold.
Solar industrial heat	• Development of standardised technology packages for different industrial applications. • Increasing reliability, functionality, efficiency, and cost-competitiveness of industrial solar thermal solutions. • Development of thermal storage solutions for industrial applications.

II. **Applied R&D to develop new solar thermal technology packages.** New solar thermal technology solutions should be developed, particularly for thermal applications that have a significant share in energy consumption or are likely to become large energy consumers in the near future. Some of the identified thermal applications include:

- *Space conditioning in residential sector:* The electricity demand for fulfilling the air conditioning loads of room air conditioners is expected to increase by a factor of 40 by 2032 from 2012 levels. In 2032, room air conditioners are expected to hold ~4% share in the final energy consumption of the country. There is a need to develop solar thermal solutions that can cater to small space conditioning loads.

- *Water pumping for irrigation:* In 2012, water pumping for irrigation consumed 17% of the total electricity consumption of India. Some prototypes have been developed and tested for solar steam-based irrigation pumps (refer to Section 2.4.4.3). Further R&D and technology developments are needed for developing solar thermal-based water pumping solutions.
- *Desalination for providing potable water to households:* Providing safe drinking water is one of main priorities to ensure the health of citizens. Recently, solar desalination collectors based on solar stills technology have been developed for providing potable water at the household level. There is large potential in developing newer technologies and products for solar-based desalination.

III. **National Solar Thermal R&D Programme.** It is suggested that the research funds available from the Department of Science and Technology (DST) and the MNRE should be pooled together and a 'National Solar Thermal R&D Programme' should be started. The programme should identify time-bound projects based on the inputs provided above as well as in discussion with stakeholders. The programme should promote collaborative R&D projects involving the solar thermal industry, academic institutions (IITs, NITs, and other engineering and science universities and colleges), and specialised research labs (e.g., research labs working on newer materials). The funding available from the Government of India should be supplemented by contributions from industry for specific projects as well as funds/in-kind support that may be available from international agencies.

5.2.4 Promoting Indigenous, Quality Manufacturing, and Human Resource Development

Aim: The aim is to promote indigenous manufacturing and improve the quality of indigenously manufactured solar thermal systems and products to provide better products in the local market as well as to enhance the competitive advantage of the Indian solar thermal industry globally.

A recap of the key challenges in the manufacturing and quality of solar thermal technologies and products is presented in Table 5.5.

Table 5.5 Key challenges in the manufacturing and quality of solar thermal technologies and products

Area	Challenges
Solar thermal industry	• There are large regional imbalances in the manufacturing and supply networks of SWH systems, with a large concentration in Zone I. • Except for SWH technology in Zone I, the number of manufacturers and supply chain capacities of solar thermal industry is low. • A majority of the SWH suppliers/system integrators lack the technical competency required for executing large/industrial projects.

table contd....

Table 5.5 Contd...

Area	Challenges
Import content	• There is no operational manufacturing facility for evacuated tube collectors in India. Most of the evacuated tubes are imported from China. Preliminary estimates indicate that the total import bill of evacuated tubes is ~Rs 200 crore/year. • The low iron solar mirrors used in solar concentrator collectors are imported.
Quality and performance	• There are no BIS standards for evacuated tube collectors, solar concentrator collectors, dish-type solar cookers, flat-plate collector-based air heating systems, solar dryers, or other balance of systems. • At present, there is no quality certification/labelling scheme for any of the solar thermal technologies in India. • There is a lack of independently collected performance data of medium- to large-scale solar thermal systems. Performance benchmarks for various solar thermal technology applications are also missing.
Finance	• Most of the solar thermal manufacturers are small- or medium-scale firms and they find it difficult to raise funds for expansion or implementation of large projects.
Trained manpower	• The lack of trained and skilled manpower is a major problem witnessed by solar thermal manufacturers/technology providers across the country. Installation and commissioning of solar thermal technologies requires manpower with plumbing, electrical, electronic, and mechanical skills.

The main elements of the strategy are listed below.

I. **Strengthening and promoting indigenous manufacturing.** The following actions are suggested to promote indigenous manufacturing in India:
   - As most of the solar thermal manufacturers are small- and medium-scale enterprises, and there is a case for them being located at a common location to utilise common facilities for testing and manufacturing as well as trained manpower, the feasibility of having one or more than one solar thermal manufacturing park should be tested. As Zone I already has a manufacturing base for solar thermal systems, it may be more useful to explore setting up such a manufacturing park outside of Zone I. Incentives and benefits in line with those provided for other similar facilities, e.g., mega food parks, textile parks, may be considered for these new facilities.
   - Provide a special line of credit for solar thermal manufacturers that simplify the process of availing credit, and if possible, provide lower interest rates for meeting the requirements of solar thermal manufacturers for upgrading, expansion, etc.
   - Provide tax and duty exemptions on indigenous manufacturing.
   - Facilitate technology transfer and manufacturing tie-ups between Indian and international companies. This could be done by involving industry associations like Confederation of Indian Industry (CII), Federation of Indian Chambers of Commerce and Industry (FICCI), Associated Chambers of Commerce and Industry of India (ASSOCHAM), through the Solar Thermal Federation of India (STFI) or other similar organisations.

II. **Quality and performance.** Quality control and continuous quality upgradation is important for sustaining the long-term growth of the industry. Performance testing and developing performance benchmarks are essential for reducing the perceived risk of performance, particularly for large or industrial systems. The following actions are suggested.

- Developing standards, testing procedures, and testing facilities for all types of solar thermal technologies, products, and systems.
- A labelling scheme should be launched for mature technologies like residential SWHs. The quality label will provide differentiation and higher visibility, and will help increase the market share of better quality products.
- Independent field performance assessment should be undertaken for large-scale or industrial solar thermal systems. Ensuring quality and benchmarking performance will help in establishing the credibility of solar thermal technologies for large-scale or industrial heat applications.

III. **Human capacity building.** The following actions are suggested to build human capacities for the solar thermal sector:

- Develop vocational courses in industrial training institutes (ITIs) for the solar thermal sector. ITIs should collaborate with the solar thermal industry to develop the courses and for direct placement of the candidates after completing the courses.
- Solar thermal industry associations should collaborate with the National Skill Development Corporation to devise their own training and skill development programme. The programme could focus on skill improvement for the existing workforce as well as developing a new skilled workforce for the sector.
- The decentralised nature of the solar thermal sector demands local-level entrepreneurs for installation, commissioning, and maintenance. An entrepreneurship development centre could run special programmes to promote entrepreneurship in the solar thermal sector.

5.2.5 Strengthening the Institutional Network

Aim: To strengthen institutional capacities in the solar thermal sector and put in place an institutional network to implement the solar thermal roadmap.

A recap of the main institutional challenges in the solar thermal sector is as follows:

- The capacities for solar thermal (R&D, policy research, market research, training, etc.) are limited and are distributed over different institutions.
- There are very few collaborative projects/initiatives to pool expertise available across different institutions for development of solar thermal sector.
- The solar thermal industry is fragmented. The Solar Thermal Federation of India (STFI) is a new organisation and mainly represents the solar water heating industry.
- The link between academic and industrial R&D is weak and there is a lack of coordinated R&D efforts.

- Due to initiatives under the projects supported by the UNDP–GEF and GIZ, knowledge exchange in the form of newsletters and through dedicated websites has started. However, there is no platform (in the form of an annual event/forum) for exchanging knowledge and discussing issues of common interest.

The main element of the strategy is to strengthen the institutional network through the formation and operationalisation of a Solar Thermal Development Network (STDN). The key features of this network would be that:

- STDN would be a collaborative, membership-based network having members from various stakeholders interested in the development of the solar thermal sector, such as the following:
  - Government and public sector institutions involved in policy-making, implementation of programmes, and financing (MNRE, SNAs, IREDA, SECI, BEE, PCRA, etc.).
  - Research organisations involved in technology and policy research.
  - Academic organisations involved in research, teaching, and training (IITs, NITs, other engineering colleges and universities).
  - Solar thermal industries and their associations (e.g., STFI).
  - Consulting organisations.
  - Non-government organisations.
  - Others.

- The network would have a lean and efficient secretariat, preferably housed in one of the network institutions (e.g., IIT Bombay). The secretariat will be funded through a grant available for the first five years, preferably from the MNRE or one of the development cooperation agencies. The secretariat would have the following staff:
  - Executive director
  - Solar thermal specialist
  - Market and policy specialist
  - Knowledge specialist
  - Secretarial assistant

Apart from the executive director and the secretarial assistant, the staff can be located at different places and may be hosted by other key stakeholders.

- STDN will provide the overall leadership to implement the solar thermal roadmap. This will be done by undertaking tasks in the following areas.
  - **Applied R&D**: To facilitate collaborative applied R&D projects involving multiple partner institutions to find solutions to the priority research needs identified in Section 5.2.3. STDN will also develop a research atlas to map past and ongoing solar thermal research projects in the country.
  - **Market and policy research**: To undertake or facilitate market and policy research, and engage with key stakeholders to communicate the results of these studies.

- **Performance monitoring and testing**: Coordinate work related to the development of performance monitoring and testing protocols, and dissemination of performance data of various solar thermal systems.
- **Technical training**: Provide support for the development of curriculum for the training of technicians and engineers.
- **Knowledge sharing**: Organise an annual flagship knowledge event (seminar and exhibition) to promote information and knowledge exchange among the stakeholders. The event will also be a forum to discuss the key issues, and for interacting with international players.

The specific initiatives would submit proposals and secure funding from MNRE, DST, industry, development agencies, and others.

5.2.6 Policy Framework Redesign

The roadmap suggests a redesign of the existing policy framework for the solar thermal sector. Two different approaches are suggested, depending on the status of the technology in the product life cycle.

I. **Policy framework for mature technologies.** The technologies that have crossed the chasm and are in a growth phase, i.e., mature technologies (e.g., SWH systems for buildings) require a policy framework that supports the rapid deployment of the technology. The main policy instruments for these technologies are listed below.
   - *Support for quality labels:* The policy framework should support a labelling programme for mature technologies. The quality label will provide differentiation and higher visibility, and help to increase the market share of better quality products.
   - *Mandatory regulations:* The policy framework should support the introduction of regulations to make the installation of solar thermal systems mandatory, e.g., amend building bye laws to make the use of SWHs mandatory.
   - *Market-based mechanism:* The policy should support market-based mechanisms like Perform Achieve and Trade (PAT) for energy-efficiency or renewable energy certificates.

II. **Policy framework for technologies that are under development.** The main elements of the policy framework for technologies that have not crossed the chasm include the following:
   - Support for R&D to improve efficiency and reliability, and reduce costs.
   - Incentives in the form of grants, subsidies, etc. to facilitate demonstration and to reach a critical mass.
   - Support for technical appraisal and performance monitoring.
   - Support for market assessment studies.
   - Support to manufacturers to access financing.

5.3 Action Plan and Stakeholders

Activities under each of the strategies have been mapped with its respective timeline and relevant stakeholders in Table 5.6.

Table 5.6 Action plan for activities under the six identified strategies

S. no.	Strategy and sub-activities	Phase 0 (2015–17)	Phase 1 (2018–22)	Phase 2 (2023–27)	Phase 3 (2028–32)	Primary stakeholders	Stakeholders whose support will be essential
1	**Expansion of SWHs in Residential Sector**						
1.1	Amendment to building bye laws by ULBs for mandatory provision of SWHs and their effective implementation					- Urban local bodies - State urban departments - Utilities - BEE	- Ministry of Urban Development - State nodal agencies
1.1.1	*Urban local bodies of Zone I*						
1.1.2	*Urban local bodies of Zones II–V*						
1.2	Consolidation of SWH in urban areas: Zone I					- Solar thermal industry - STDN - State nodal agencies - MNRE - Financial institutions - BEE	- Urban local bodies - Utilities - Development agencies - Foundations - NGOs - PCRA
1.2.1	*Market promotion and development activities in low- and medium-population density urban centres*						
1.2.2	*Provide access to financing to overcome the barrier of high upfront cost*						
1.3	Expansion of SWH to all zones in urban and rural areas					- Solar thermal industry - STDN - State nodal agencies - MNRE - Financial institutions - BEE	- Urban local bodies - Utilities - Development agencies - Foundations - NGOs - PCRA
1.3.1	*Identify best suited urban centres and rural areas*						
1.3.2	*Market promotion and development activities in identified urban centres and rural areas*						
1.3.3	*Bundle offerings (technology, service, incentives, and financing) for rural markets*						
1.3.4	*Provide access to finance to overcome the barrier of high upfront cost for urban areas*						

Table contd...

Table 5.6 Contd...

S. no.	Strategy and sub-activities	Phase 0 (2015–17)	Phase 1 (2018–22)	Phase 2 (2023–27)	Phase 3 (2028–32)	Primary stakeholders	Stakeholders whose support will be essential
1.4	Applied R&D					- Solar thermal industry - STDN - DST - Academic/research institutions - NISE	- Urban local bodies - NGOs - Development agencies - MNRE
1.4.1	*Develop reliable and integrated SWH solutions for multistorey residential buildings*						
1.4.2	*Develop product variants suitable for rural requirements*						
1.4.3	*Focus on increasing the cost-competitiveness of SWHs*						
1.5	Improve quality: standards and certificates					- BIS - Testing centres - Solar thermal industry - Academic/research institutions - NISE	- STDN - BEE - PCRA - Development agencies - MNRE
1.5.1	*Develop BIS Standards, testing procedures, and testing facilities for all types of SWH products, components, and systems*						
1.5.2	*Develop a third-party quality certification scheme in the form of quality labels*						
2	**Develop Industrial Process Heat Market (<250 °C)**						
2.1	Focussed market development to achieve a critical mass of industrial solar thermal installations					- Solar thermal industry - STDN - MNRE and SECI - Financial institutions - BEE - ESCO/RESCOs	- Industry associations - PCRA
2.1.1	*Identify selected industrial clusters/segments best suited for solar thermal technologies*						
2.1.2	*Undertake market development and strengthening of the industrial solar thermal solution supply chain*						
2.1.2	*Promote ESCO/RESCO models*						

Table 5.6 Contd...

S. no.	Strategy and sub-activities	Phase 0 (2015–17)	Phase 1 (2018–22)	Phase 2 (2023–27)	Phase 3 (2028–32)	Primary stakeholders	Stakeholders whose support will be essential
2.2	Applied engineering and R&D					- Solar thermal industry - STDN - DST - Academic/research Institutions - NISE	- Urban local bodies - NGOs - Development agencies - MNRE
2.2.1	*R&D for effective hybridisation of solar thermal technologies with other heat sources, and integration with thermal storage*						
2.2.2	*Develop standard technology packages for industrial applications*						
2.2.3	*R&D for advancing thermal storage for heat >100 ºC*						
2.3	Performance assessment and benchmarking					- BIS - Testing centers - Solar thermal industry - Academic/research institutions - STDN	- BEE - PCRA - Development agencies - MNRE
2.3.1	*Develop BIS standards, testing procedures, and testing facilities for all types of products and systems for industrial heat*						
2.3.2	*Undertake independent third-party field performance assessments for industrial solar thermal systems for technology appraisal and performance benchmarking*						
2.4	Move towards regulations and market-based mechanisms for solar industrial heat					- MNRE - BEE - PCRA - MoEF - Industry associations	- Solar thermal industry - Utilities

Table contd...

Table 5.6 Contd...

S. no.	Strategy and sub-activities	Phase 0 (2015–17)	Phase 1 (2018–22)	Phase 2 (2023–27)	Phase 3 (2028–32)	Primary stakeholders	Stakeholders whose support will be essential
3	**Focussed Research, Development, and Demonstration**						
3.1	Applied R&D to improve existing solar thermal technology packages					- Solar thermal industry - STDN - DST - Academic/research institutions - NISE	- Urban local bodies - NGOs - Development agencies - MNRE
3.1.1	*SWHs for buildings*						
3.1.2	*Solar cookers for residential and institutional sectors*						
3.1.3	*Solar cooling systems*						
3.1.4	*Solar industrial heat*						
3.2	Applied R&D to develop new solar thermal technology packages					- DST - Academic/research institutions - NISE	- Solar thermal industry - MNRE
3.2.1	*Space conditioning in residential sector*						
3.2.2	*Water pumping for irrigation*						
3.2.3	*Desalination for providing potable water to households*						
3.3	National solar thermal R&D programme					- DST - Academic/research institutions - NISE - Solar thermal industry	- MNRE
3.3.1	*Identify time-bound projects for R&D*						
3.3.2	*Collaborative R&D projects involving solar thermal industry, academic institutes, and research laboratories*						

Table 5.6 Contd...

S. no.	Strategy and sub-activities	Phase 0 (2015–17)	Phase 1 (2018–22)	Phase 2 (2023–27)	Phase 3 (2028–32)	Primary stakeholders	Stakeholders whose support will be essential
4	**Indigenous, Quality Manufacturing**						
4.1	Strengthen and promote indigenous manufacturing					- Ministry of Industries - MNRE - Solar thermal industry - Financial institutions - Ministry of Finance	- Development agencies
4.1.1	*Establish a solar thermal manufacturing park outside of Zone I*						
4.1.2	*Provide a special line of credit to solar thermal manufacturers*						
4.1.3	*Provide tax and duty exemptions*						
4.1.4	*Facilitate technology transfer and manufacturing tie-ups*						
4.2	Quality and performance					- BIS - Testing centres - Solar thermal industry - Academic/research institutions - STDN - NISE	- BEE - PCRA - Development agencies - MNRE
4.2.1	*Develop BIS standards, testing procedures, and testing facilities for all types of solar thermal technologies*						
4.2.2	*Develop a third party quality certification scheme in the form of quality labels*						
4.2.3	*Undertake independent third-party field performance assessment for industrial solar thermal systems*						
4.3	Human capacity-building					- Solar thermal industry - National skill Development Council - Entrepreneurship development centres - ITIs	- MNRE - Industry associations - Incubation centres
4.3.1	*Develop vocational courses in ITIs for the solar thermal sector*						
4.3.2	*Develop programme for skill improvement of existing workforce as well as a new skilled workforce for the sector*						
4.3.3	*Special programmes by an entrepreneurship development centre in the solar thermal sector*						

Table contd...

Table 5.6 Contd...

S. no.	Strategy and sub-activities	Phase 0 (2015–17)	Phase 1 (2018–22)	Phase 2 (2023–27)	Phase 3 (2028–32)	Primary stakeholders	Stakeholders whose support will be essential
5	**Strengthening the Institutional Network**						
5.1	Formation of a Solar Thermal Development Network					- All relevant stakeholders	
5.1.1	*Formation of the network having members from various stakeholders*						
5.1.2	*Creation of a lean and efficient secretariat of the network*						
5.2	Operationalisation of the Solar Thermal Development Network					- Solar Thermal Development Network members	
5.2.1	*Launch initiatives on applied R&D, market and policy research, performance monitoring and testing, technical training, and knowledge sharing*						
5.2.2	*Develop proposals for activities under each initiative*						
5.2.3	*Secure funding for each initiatives through MNRE, DST, industry, or development agencies*						
5.2.4	*Carry out activities under each of the initiatives*						
6	**Policy Framework Redesign**						
6.1	Policy framework for mature technologies					- MNRE - BEE - ULBs - PCRA	- Solar thermal industry - Industry associations - Utilities
6.1.1	*Support for quality labels*						
6.1.2	*Mandatory regulations for buildings*						
6.1.3	*Market-based mechanisms for industries*						

Table 5.6 Contd...

S. no.	Strategy and sub-activities	Phase 0 (2015–17)	Phase 1 (2018–22)	Phase 2 (2023–27)	Phase 3 (2028–32)	Primary stakeholders	Stakeholders whose support will be essential
6.2	Policy framework for technologies that are under development					- DST - MNRE - Financial institutions - STDN - BEE - PCRA	- Solar thermal industry - Industry associations Utilities
6.2.1	*Support for R&D to improve efficiency and reliability, reduce costs, and develop new technology packages*						
6.2.2	*Provide incentives in the form of grants, subsidies, etc. to facilitate demonstration and to reach a critical mass*						
6.2.3	*Support for technical appraisal and performance monitoring*						
6.2.4	*Support to manufacturers for providing access to financing*						
6.2.5	*Support for market assessment studies*						

Annexure

Annexure I
Assumptions and Data Sources for Potential Assessment and Market Projection

1. Residential sector potential assessment

Data sources for population, households, high-rise buildings:

- National Commission on Population. Census of India 2011. Government of India, 2011.
- Technical Group on Population Projections of the National Commission on Population. Population Projections for India and States 2001–2006. Office of the Registrar General & Census Commissioner, 2006.
- National Commission on Population. Census of India- 2001. Government of India, 2001.
- Emporis Pvt. Ltd. Emporis GMBH. 2013. Retrieved 2014, from www.emporis.com: http://www.emporis.com/country/india

Data sources for developing norms for water heating and cooking demand and technical analysis:

- International Copper Promotion Council (India) (2010). *User's Handbook on Solar Water Heaters.*
- Indu R, Pillai RB. **Methodology for Estimation of Potential for Solar Water Heating in a Target Area.** *Solar Energy,* 2007; 81: 162–172.
- Ravindranath NH, Ramakrishna J. **Energy Options for Cooking in India.** *Energy Policy,* 1997; 25(1): 63–75.
- Purohit I, Purohit P, Negi BS. *Design and Testing of a Box Type Solar Cooker Employing Nontracking Reflectors,* 2004.
- Planning Commission of India. India Energy Security Scenario. New Delhi, 2014.
- Ernest Orlando Lawrence Berkeley National Laboratory. *Residential and Transport Energy Use in India: Past Trend and Future Outlook*, 2009.

Assumptions made for calculations

- Minimum SWH for household: 2 m^2
- Household considered as 'pucca' house with roof
  - Concrete
  - Burnt brick
- Percentage of household meeting space availability criteria
  - Rural pucca: 60%
  - Urban independent and low-rise pucca: 30%
  - Urban high-rise pucca: 80%
- Assumptions for replaced fuel considered for water heating: electricity
  - Range of zonal average residential tariff for all states of India is taken (http://www.bijlibachao.com/news/domestic-electricity-lt-tariff-slabs-and-rates-for-all-states-in-india-in-2014.html)
  - Efficiency: 85%
  - Escalation in electricity price: 7% per year
- Assumptions for replaced fuel considered for water heating: biomass
  - Price in 2014: Rs 2 per kg
  - Efficiency: 15%
  - Escalation in fuel price: 7% per year
- Price of 2 m^2 of SWH system in 2014: Rs 25,000
- Acceptable payback period considered for economic potential: 8 years
- Technical potential for solar cooking
  - All households 'with cooking' are considered
  - Number of meals per day: 2
  - Calculated utilised energy in cooking: 0.73 MJ/meal.capita
  - Weighted average efficiency for cooking in 2014–2032
    - Urban: 34%–42%
    - Rural: 16%–19%
  - Energy demand met by solar cooker: 70% of one meal per day
  - Calculated solar fraction: 17%–29%
  - Percentage of household meeting space availability criteria
    - Rural: 60%
    - Urban independent and low-rise: 30%
    - Urban high-rise: 25%

2. Commercial and Institutional sector potential assessment

Data sources for hotel rooms, hospital beds and hostel students

- Ministry of Tourism. India Tourism Statistics. Government of India, 2011.
- Ministry of Health and Family Welfare. India Healthcare Statistics. Government of India, 2011.
- Greentech Knowledge Solutions Pvt. Ltd. Solar Water Heater (SWH) Market Assessment Studies and Surveys for Different Sectors and Demand Segments. New Delhi: UNDP–GEF, 2010.
- Greentech Knowledge Solutions Pvt. Ltd. Market Assessment of Solar Water Heating Systems in Five Potential States/NCR Region. New Delhi: UNDP–GEF, 2011.
- Greentech Knowledge Solutions Pvt. Ltd. Market Assessment of Solar Water Heating Systems in the Himalayan Region. New Delhi: UNDP–GEF, 2011.
- Planning Commission of India. India Energy Security Scenario. New Delhi, 2014.
- PHD Chamber of Commerce and Industry. An Analysis of Power Tariffs Across India, February 2013.

Assumptions made for calculations:

- Hot water demand norm
  - Hotel: 60 lpd/room @60 °C
  - Hospital: 65 lpd/bed @40 °C
  - Hostel: 65 lpd/student @40 °C
- Percentage of hotel, hospital and hostels meeting space availability criteria: 75%
- Solar fraction
  - Hotel: 53% to 59%
  - Hospital: 61% to 68%
  - Hostel: 61% to 68%
- Assumptions for replaced fuel considered for water heating: electricity
  - Zonal average commercial tariff for 2013
    - Zone 1: Rs 6.48/kWh
    - Zone 2: Rs 5.90/kWh
    - Zone 3: Rs 6.10/kWh
    - Zone 4: Rs 5.40/kWh
    - Zone 5: Rs 4.37/kWh
  - Efficiency: 85%
  - Escalation in electricity price: 7% per year
- Assumptions for replaced fuel considered for water heating: diesel
  - Price in 2014: Rs 59 per litre

  - Efficiency: 65%
  - Escalation in fuel price: 7% per year
- Price of 2 m^2 of SWH system in 2014: Rs 25,000

3. Assumptions for market projection

The key parameter considered for market projection is the growth in the annual sales of the solar technology product for each application and sector. The table below gives the summary of these assumptions for both the scenarios.

Sector/technology	BAU scenario	Aggressive effort scenario
Residential: Solar water heater	2015: 0% (Subsidy removal) 2016–2023: 5% to 15% (linear growth) 2024–2032: 15%	2015: 0% (Subsidy removal) 2016: 5% 2017–2023: 15% to 25% (linear growth) 2024–2030: 25% to 30% (linear growth) 2031–2032: 30%
Residential: Solar cooker	2015–2021: 0% 2022–2032: 0% to –15% (linear growth)	2015: 0% 2016–2023: 5% to 25% (linear growth) 2024–2030: 25% to 30% (linear growth) 2031–2032: 30%
Commercial and institutional: Solar water heater	2015–2023: 10% 2024–2029: 7.5% 2030–2032: 5%	2015–2023: 15% 2024–2029: 10% 2030–2032: 7.5%
Commercial and institutional: Solar concentrators	2015–2032: 10%	2015–2017: 10% 2018–2023: 15% to 25% (linear growth) 2024–2030: 25% to 30% (linear growth) 2031–2032: 30%
Industrial: Solar water heater	2015–2032: 10%	2015: 10% 2016–2023: 15% to 25% (linear growth) 2024–2030: 25% to 30% (linear growth) 2031–2032: 30%
Industrial: Solar concentrator	2015–2032: 15%	2015–2023: 15% to 25% (linear growth) 2024–2030: 25% to 30% (linear growth) 2031–2032: 30%
Industrial: Solar air heaters	2015–2032: 10%	2015–2018: 10% to 15% (linear growth) 2019–2023: 15% to 20% (linear growth) 2024–2030: 20% to 25% (linear growth) 2031–2032: 25%
Agriculture: Solar dryers	2015–2032: 10%	2015–2018: 10% to 15% (linear growth) 2019–2023: 15% to 20% (linear growth) 2024–2030: 20% to 25% (linear growth) 2031–2032: 25%

About the Study

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About Shakti Sustainable Energy Foundation (www.shaktifoundation.in)

Shakti Sustainable Energy Foundation works to strengthen the energy security of India by aiding the design and implementation of policies that support energy efficiency and renewable energy.

About Greentech Knowledge Solutions Privat ve Limited (www.gkspl.in)

Greentech Knowledge Solutions is a Clean Energy Research and Advisory firm which offers services across Renewable Energy, Energy Efficiency, and Green Buildings domains.

Our robust research practices and insights can be applied across sectors, industries, buildings and urban and rural communities.

Our approach integrates both technology and business expertise. We combine our science and engineering knowledge to provide optimal solutions to real-world problems.

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