SOLAR HEAT FOR INDUSTRY INDIA

Solar Payback

CONTENTS

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About Solar Payback

- The objective of the three-year Solar Payback project (from October 2016 to December 2020) is to promote the use of Solar Heat for Industrial Processes (SHIP) in four countries – South Africa, India, Mexico and Brazil.
- This project is financed by the International Climate Initiative (IKI).
- The Federal Ministry for Environment, Nature Conservation, and Nuclear Safety supports this initiative on the basis of a decision adopted by the German Bundestag (German parliament).
- The project raises awareness of the technical and economic potential of SHIP technologies through clear and transparent information about the costs and benefits of SHIP applications, and helps to create reference systems.
- Solar Payback also collaborates with financial institutions to develop models that assist different actors and investors in accessing financing.
- For more information, please consult www.solar-payback.com

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EXECUTIVE SUMMARY

Energy efficiency is an important accompaniment to renewable energy. Energy savings should be realised before implementing new-generation capacities. India's industrial sectors account for more than 50% of the country's energy needs, and are projected to grow massively during the next decades. So far, much of this energy has to be imported, whether oil and gas or high-quality coal, and a significant share of it goes towards fulfilling heating needs. However, many industries in India use only low to medium temperatures of below 400°C, which Solar Heat for Industrial Processes (SHIP) can easily provide. In this context, industries of particular importance are food and beverages and dairy, automotive, textiles, chemicals, and pharmaceuticals, where India is either a global leader or among the top. Incidentally, these industries are widely spread around the country and well established in regions with excellent insolation.

A mix of sources currently covers India's energy needs, including electricity, petroleum products as well as coal and biomass. Sources such as electricity and petroleum are often more expensive than SHIP, which makes a good potential business case for the latter. This is especially true in states with high irradiation, such as in the north western and central states, which can be supplied on a decentralised level.

While India has an already established industry of solar thermal companies and suppliers that have installed more than 78,000 m^2 of plants for SHIP, different solar technologies require quite a lot of space, which is often scarce at many industrial plants. In addition, these technologies have to be integrated into existing processes. In each case, such an integration requires careful analysis of technical and economic potential. For this, the Solar Payback Project illustrates market niches and applications in identified industries and provides a methodology as a basic tool to facilitate the economic calculation of SHIP projects.

CHAPTER 1

INTRODUCTION

India's energy consumption, heavily fossil-fuel dependent, goes hand-in-hand with the country's huge industrial demand for heat energy. However, this demand has limited representation from the excellent insolation that India receives, which in annual global horizontal irradiation (GHI) terms has a variation of 1,600-2,000 kWh/m^2 for almost 250-300 days a year.[1] The direct normal irradiance (DNI) value averages 5.5 kWh/m^2/day due to India's geographic position in the Equatorial Sun Belt of the earth[2] – which takes the country's equivalent energy potential to about 6,000 million GWh per year. Though this resource potential is the highest in India's north-western regions and desert wastelands, the central and southern industrialized states also receive fairly large amounts of direct as well as diffused radiation. Thus, using solar energy for heating processes at the industrial scale appears to be a logical solution.

To push the adoption of solar technologies, the Government of India, with its Ministry of New and Renewable Energy (MNRE), has launched the National Solar Mission (NSM) in 2010 and rolled out policy initiatives to incentivize the use of renewable energy technologies. Since 2014, this mission has highly ambitious targets for scaling up the implementation of solar technologies – to 100 GW out of the 175 GW total renewable energy capacity that India would have by 2022 – and to increase the installed solar thermal collector area by 20 million square metres (m^2), also by 2022.

While conventional energy production still suffers from traditional limiting factors such as raw-material availability and import dependency, the new renewable energy sector has leapfrogged technologically and seen capacity additions. With industries of all sizes looking at energy transitions, solar thermal technologies are not only perceived to be appropriate, but also feasible for heating applications. Technologically, India has been an early adopter of solar thermal systems, with many plants having proven their life and cost efficiencies. This study explores the prevailing market conditions and factors that can support the spread of solar thermal technologies in India.

Solar **H**eating for **I**ndustrial **P**rocess (SHIP) systems can be significant contributors to optimization of heat demand in process applications and meaningfully reduce greenhouse gas emissions (GHGs). One of the limiting factors for SHIP is that every installation needs detailed engineering, techno-commercial study and specialized installation, unlike for solar photovoltaic (PV), which is comparatively plug-and-play. Highly effective and rapidly scalable stationary and concentrator solar thermal technologies, such as parabolic trough and compound parabolic concentrator, are gaining momentum. This study, with a technological, commercial, and policy overview, aims to explore a variety of aspects that either favour or limit the large-scale adoption of SHIP.

1 GHI is the total amount of shortwave radiation received from above by a surface horizontal to the ground

2 DNI is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky

CHAPTER 2

ECONOMIC AND INDUSTRIAL POLICY IN INDIA

India's Gross Domestic Product (GDP) has seen tremendous growth since 1990 at 6.0-7.5% annually. Foreign direct investments have crossed USD 40 billion and trade barriers for economic and industrial development have diminished compared to 25 years ago.

The most important industries in India today are agriculture, bulk processing, manufacturing and the services. While agriculture constitutes all aspects of food production, processing and food security, the large manufacturing industry base constitutes of sectors such as cement, steel, automotive, textile, chemicals, and fertilizers.

Since India is a market-based economy for the most part, pricing of commodities is driven by non-linear demand and supply. Both state and central government public sector undertakings (PSUs) own bulk-processing industries. India also has public-private partnership ventures, including international joint ventures (JVs). The size of these industries varies from very small to very large. Most of these industries are resource intensive and have often faced obstacles in matching energy supply to demand because of availability, quality, and regulation-related issues. Recently, the government has pushed for large-scale infrastructure development.

Energy supply is the mainstay for the economy. In most sectors, coal, oil and natural gas have the highest penetration. Due to an overdependence on imported fossil fuel over a long period, recently, there has been a renewed impetus on deregulation of coal and for indigenous discovery of natural gas in the country.

2.1 Macro-Economic Outlook

The Indian economy moves based on a variety of factors such as political dispensation, international oil pricing, domestic inflation, and global economic conditions. As of 2018, India's GDP was measured at USD 2.716 trillion in nominal terms with an annual GDP growth of 7%.[3] Rising inflation, a challenge in the past 7-10 years, has seen a sharp decline of late. Figure 1 and Figure 2 depict important economic parameters, corresponding US dollar values, and provide an outlook.

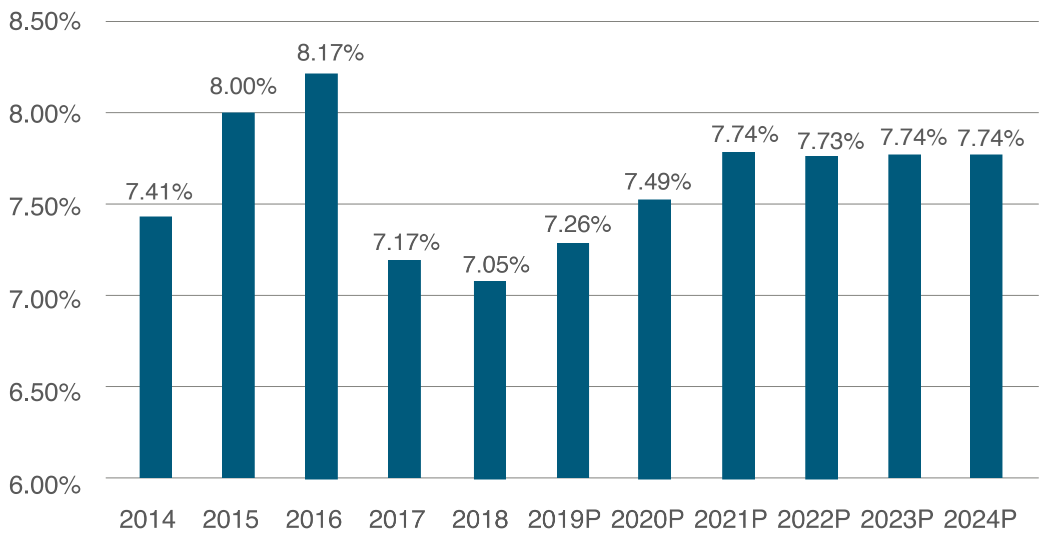

FIGURE 1: ECONOMIC DEVELOPMENT INDICATORS IN INDIA, ESTIMATIONS, AND OUTLOOK

Source 1: Statista.com[4]

3 https://www.statista.com/statistics/263771/gross-domestic-product-gdp-in-india/

4 https://www.statista.com/statistics/263771/gross-domestic-product-gdp-in-india/

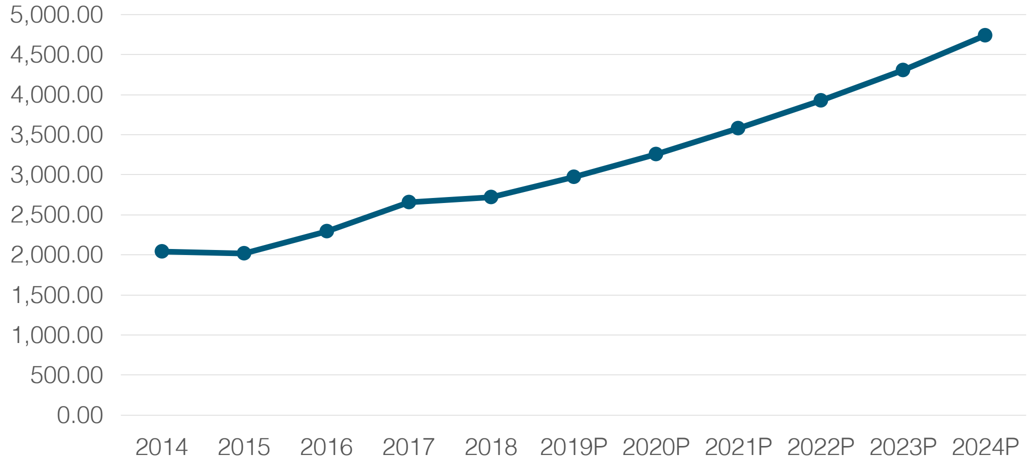

FIGURE 2: GROSS DOMESTIC PRODUCT (GDP) IN INDIA (IN BILLION USD)

Source 2: Statista.com[5]

Economic growth continues and has reached high levels. Overall economic indicators for India look promising, as visible in Table 1.

TABLE 1: Important Macroeconomic Indicators for India 2018

Parameter/Criteria	Definition	Value (2018)
GDP (current US$)	The total value of goods produced and services provided in the country during one year	2,71 trillion
GNI, PPP (current international $)	PPP GNI (formerly PPP GNP) is the gross national income (GNI) converted to USD using purchasing power parity rates	7.78 billion
GDP growth (annual %)	Annual growth rate of the GDP in per cent at market prices, based on constant local currency	7.0 %
Inflation, GDP deflator (annual %)	Inflation as measured by the annual growth rate of the GDP implicit deflator shows the rate of price change in the economy as a whole	3.8 %
Domestic credit provided by financial sector (% of GDP)	Domestic credit provided by the financial sector includes all credit to various sectors on a gross basis, with the exception of credit to the central government	76.14 %
Foreign direct investment, net inflows (BoP, current US$)	Foreign direct investment refers to direct investment equity flows in the reporting economy	40 billion

Source 3: The World Bank, OECD, Reserve Bank of India

2.2 Energy Policy in India

Along with economic growth, India's energy demand has grown steadily in the past decade. Figure 3 shows that India's energy consumption is set to grow by around 4.2% annually in the coming two decades, faster than all major economies of the world (IEA 2015,[6] BP 2018). India's consumption growth of fossil fuels will be the highest by 2035, and it will surpass China as the largest growth market for energy in volume terms by 2030. The country remains import dependent, despite an increase in production and exploration of conventional and renewable fuel sources. The role of renewable energies in limiting fuel imports will assume increasing importance, even as conventional energy sources continue to play a large part.

5 https://www.statista.com/statistics/263771/gross-domestic-product-gdp-in-india/

6 http://petroleum.nic.in/

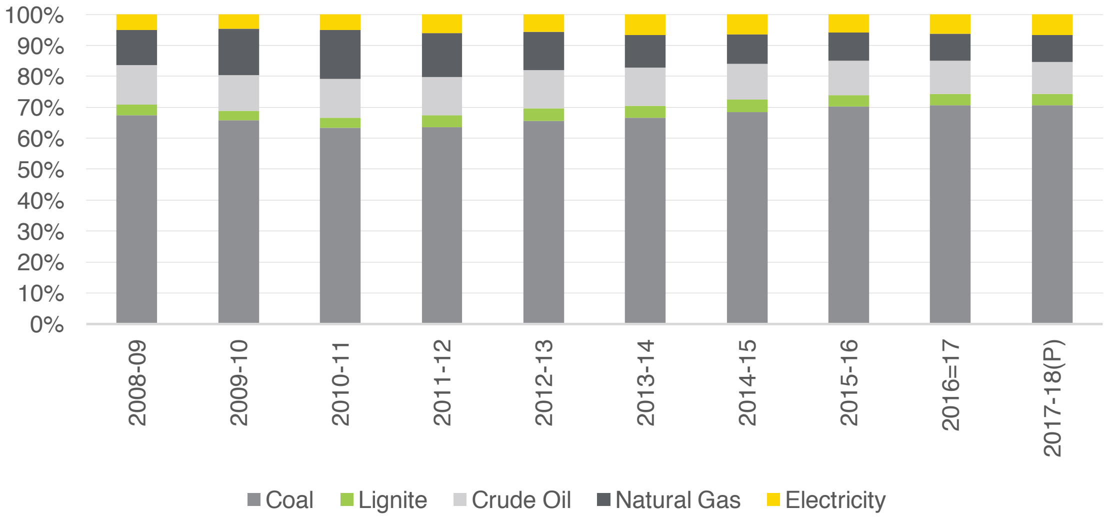

FIGURE 3: GROWTH OF ENERGY DEMAND FROM 2008 TO 2018 IN INDIA IN PETAJOULES

Source 4: Ministry for Statistics 2019[7]

2.2.1 Fossil Fuel Resources in India

India's Ministry of Petroleum and Natural Gas[8] estimated hydrocarbon resources in India at about 28.1 billion tonnes (oil and oil equivalent of gas). So far, close to 50% of resources could be covered through exploration. The estimated Coal Bed Methane (CBM) resources are at 2,600 billion Cubic Meters (BCM) or 91.8 trillion cubic feet (TCF), spread over 11 states in the country. The recoverable shale gas reserves are estimated to be 500-2,000 trillion cubic meters.

TABLE 2: Estimated conventional energy reserves

Energy source	Reserves as of 31 March 2018
Coal	319.20 billion tonnes
Lignite	45.66 billion tonnes
Crude oil	594.49 million tonnes
Natural gas	1,339.57 billion m³
Coal bed methane	2,600 billion m²

Source 5: Ministry of Statistics, 2018[9]

India remains a net importer of coal, crude oil, petroleum products and natural gas. In the electricity market, from being from an importer over the past 10 years as indicated in Figure 4, is has switched to becoming a significant exporter.

7 http://www.mospi.gov.in/sites/default/files/publication_reports/Energy%20Statistics%202019-finall.pdf

8 http://petroleum.nic.in/

9 http://www.mospi.gov.in/sites/default/files/publication_reports/Energy%20Statistics%202019-finall.pdf

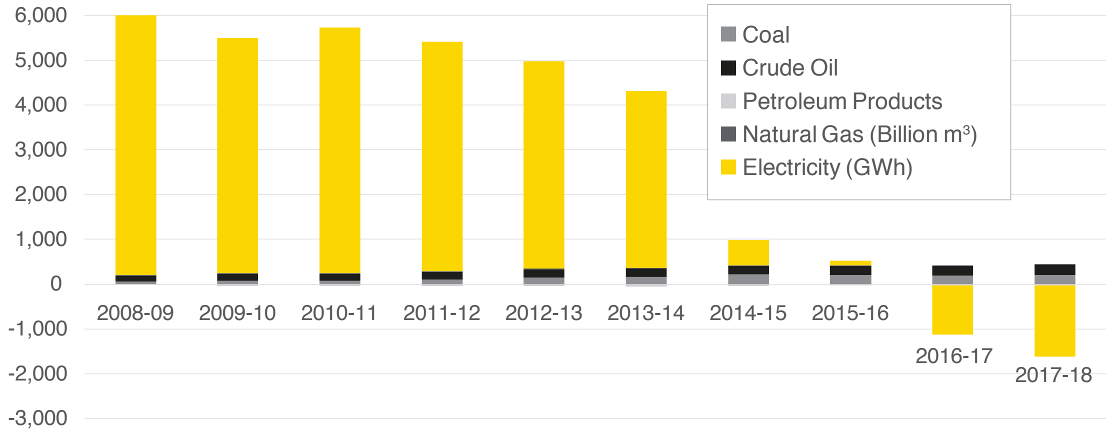

FIGURE 4: NET OIL AND COAL IMPORTS FROM 2008 TO 2018

Source 6: Ministry of Statistics, 2019[10]

2.2.2 Sectoral Energy Demand and Growth

According to the concentrating solar thermal (CST) Roadmap by GEF-UNIDO, 57% of India's final energy consumption was in the industry segment in 2017.[11] The Draft National Energy Policy[12] by NITI Aayog projects energy consumption between 2012 and 2040 under alternative scenarios, with respect to efforts towards achieving greater energy efficiency and conservation. Table 3 shows these estimates under a range of two sets of assumptions: a baseline effort and a significantly more ambitious effort. The baseline scenario (BAU) generates the higher demand bound and the ambitious scenario is represented by the lower bound. Industrial energy will range between 48% and 55% of all energy demand between 2012 and 2040. In the ambitious scenario, industrial energy consumption ends up being 17% below one of the baseline cases, illustrating the influence of energy conservation and efficiency.

TABLE 3: Projections of Different Sectors and Industries

Annual Energy Consumption					
Sectors	**2012 (TWh)**	**2022 (TWh)**		**2040 (TWh)**	
		BAU	**Ambitious**	**BAU**	**Ambitious**
Buildings	238	568	525	1,769	1,460
Industry	2,367	4,010	3,600	8,764	7,266
Transport	929	1,736	1,628	3,828	3,243
Pumps and Tractors	237	423	388	728	592
Telecom	83	131	124	207	164
Cooking	1,072	829	684	524	467
Total	4,926	7,697	6,949	15,820	13,192

Source 7: Draft National Energy Policy, NITI Aayog[13]

In the following section fossil fuel resources will be looked at separately for a more detailed overview.

10 http://www.mospi.gov.in/sites/default/files/publication_reports/Energy%20Statistics%202019-finall.pdf, Table 4.1

11 https://mnre.gov.in/sites/default/files/India.pdf

12 https://niti.gov.in/writereaddata/files/new_initiatives/NEP-ID_27.06.2017.pdf

13 https://niti.gov.in/writereaddata/files/new_initiatives/NEP-ID_27.06.2017.pdf

2.2.2.1 Oil/Petroleum Products

India is heavily dependent on crude oil imports, with crude petroleum accounting for about 34% of the total inward shipments. It is anticipated that by 2025, India will overtake Japan to become the world's third largest oil consumer after the US and China.[14] India is expected to be one of the largest contributors to non-OECD petroleum consumption growth globally. Nevertheless, many oil products used in the industry have seen a rapid decline from 2008, while Liquefied petroleum gas (LPG) has seen a massive increase in the compound average growth rate (CAGR) as shown in Table 4.

TABLE 4: Use of Selected Petroleum Products in the Industry in India

	Unit in 1,000 tonnes		
	2008-09	2017-18	Change CAGR 2008-09 to 2017-18
High Speed Diesel Oil	1,310	1,120	-1.55%
Light Diesel Oil	171	145	-1.67%
Furnace Oil	2,843	2,299	-2.10%
Low Sulphur Heavy Stock	1,294	54	-27.24%
Liquefied Petroleum Gas	825	2,290	10.74%

Source 8: Ministry of Statistics, 2018

2.2.2.2. Natural Gas

India's production of natural gas was 40.91 billion cubic meters (BCM) in 2018. The country's gas production is expected to more than double by 2040 to 90 BCM. Industry-wise off-take of natural gas shows that natural gas has been used both for energy (56%) and non-energy (44%) purposes. The gross import of natural gas has increased to 19.87 billion m^3 in 2017-18 from 8.06 billion m^3 in 2008-09, a CAGR of 9.44%.

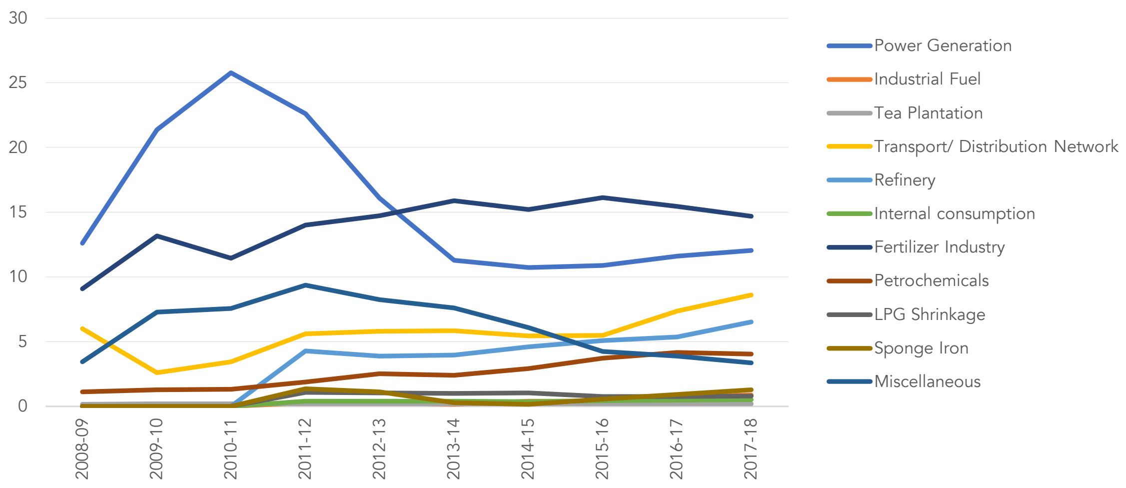

FIGURE 5: INDUSTRY-WISE OFF-TAKE OF NATURAL GAS IN INDIA FOR ENERGY AND NON-ENERGY PURPOSES (IN BILLION M³)
Source 9: Ministry of Statistics, 2019[15]

14 http://petroleum.nic.in/sites/default/files/pngstat_1.pdf

15 http://www.mospi.gov.in/sites/default/files/publication_reports/Energy%20Statistics%202019-finall.pdf

India is the fourth-largest Liquefied Natural Gas (LNG) importer after Japan, South Korea and China, and accounts for 5.8% of the total global trade. Domestic LNG demand CAGR is seen at 16.9% to 306.54 Million Metric Standard Cubic Meter per Day (MMSCMD) by 2021 from 73 MMSCMD in 2018. A small part of this will be used to fuel industrial production.

2.2.2.3 Coal and Lignite

India is one of the biggest lignite and coal producers worldwide. Coal deposits are mainly confined to eastern and south-central parts of the country. The states of Jharkhand, Odisha, Chhattisgarh, West Bengal, Madhya Pradesh, Telangana and Maharashtra account for 98.58% of the total coal reserves in the country.[16] The estimated amount of coal resources in the country is 315.149 billion tonnes as per "The inventory of Geological Resources of Indian Coal" prepared by the Geological Survey of India. The total coal extracted from the coalfields of India during 2017-2018 was 675.40 million tonnes.[17] Every year about 3-5 billion tonnes of resources are added to India's coal inventory through fresh exploration. Though coal and lignite are mostly used in electricity production, they are also important to the steel and cement industries, as well as to sponge iron and others.[18]

The average quality of Indian coal is not too high, which necessitates the import of high-quality coal to meet the requirements of steel plants. In fact, the imports of coal have seen a rising trend, steadily increasing to 208.27 MTs in 2017-18 from 59.00 MTs in 2008-09. In the same time frame, the quantum of coal exported decreased to1.50 MTs from 1.66 MTs.

Coal (62%) and lignite (90%) contribute mainly to electricity production and the cement industry, but relatively little to other industrial use, as is visible in Figure 6.

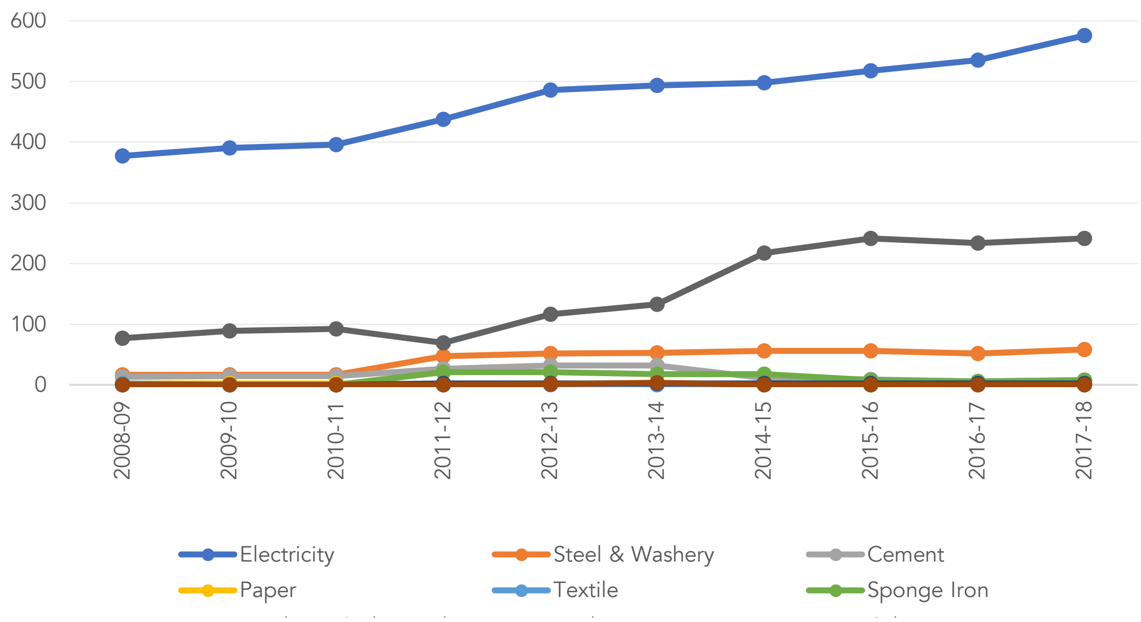

FIGURE 6: TRENDS IN INDUSTRY-WISE CONSUMPTION OF RAW COAL IN INDIA

Source 10: Based on Ministry of Statistics 2019[19]

16 http://www.mospi.nic.in/sites/default/files/publication_reports/Energy_Statistics_2017r.pdf.pdf . 1 April 2017 http://www.mospi.gov.in/sites/default/files/publication_reports/Energy%20Statistics%202019-finall.pdf

17 https://www.gsi.gov.in/

18 Trends in Consumption of Lignite in India * Includes sponge iron, colliery consumption, jute, bricks, coal for soft coke, chemicals, fertilisers and other industries' consumption

19 http://www.mospi.gov.in/sites/default/files/publication_reports/Energy%20Statistics%202019-finall.pdf Table 6.4

Figure 7 shows that lignite has also seen an overall increase in use, though not as much as raw coal. Nevertheless, only a small portion is used for non-electricity energy.

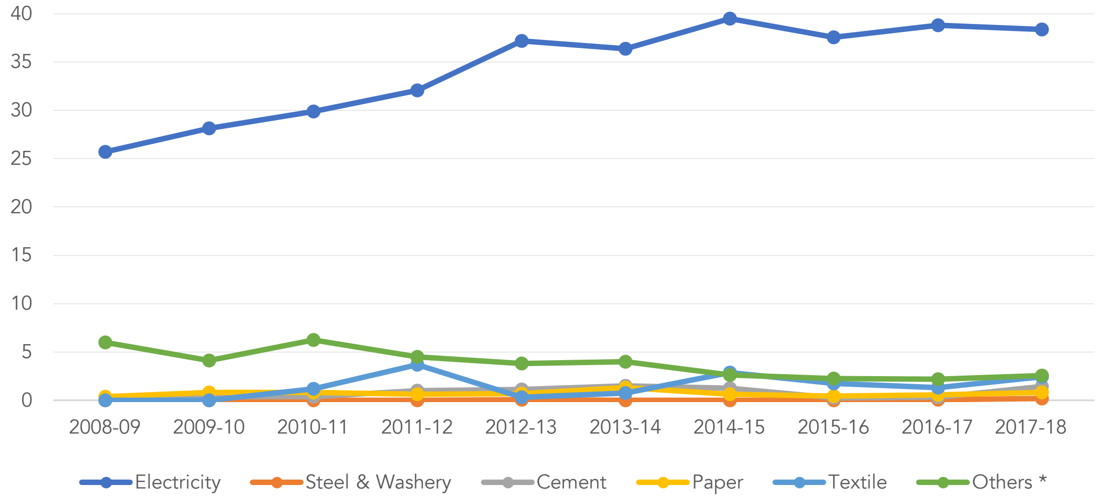

FIGURE 7: TRENDS IN INDUSTRY-WISE CONSUMPTION OF LIGNITE IN INDIA

Source 11: Ministry of Statistics 2019[20]

2.2.2.4 Highlights of the Energy Sector 2017-18

Production and consumption

- Production CAGRs of coal and lignite from 2008-09 to 2017-18 were 3.20% and 3.62% respectively, while their consumption CAGRs were 5.01% and 3.70%.
- Crude oil and natural gas, production CAGRs were +0.63% and (-) 0.06% while consumption CAGRs were +4.59% and +4.82%.
- CAGR in generation of electricity was 5.71% and consumption of electricity was 7.39%.

Imports and exports

- CAGR in imports of coal from 2008-09 to 2017-18 was 13.44% while the exports CAGR was -0.96%.
- CAGRs of imports of natural gas and crude oil were 9.44% and 5.20%.
- CAGR in imports of petroleum products was 6.67%, while CAGR in exports was 5.55%.
- For electricity, the net imports saw a significant change in the last two years i.e., 2016-18. Exports have shown a robust CAGR of 61.83% in 2008-09 to 2017-18 whereas imports saw a CAGR of -0.50%.

Usage of energy

- The most energy intensive sector was the industrial sector, accounting for about 56% of the total energy consumption.
- CAGR in per-capita consumption of energy was 2.54% for 2011-12 to 2017-18.

20 http://www.mospi.gov.in/sites/default/files/publication_reports/Energy%20Statistics%202019-finall.pdf. Table 6.5

2.2.3 Energy Infrastructure

Supply of fuel oil is decentralised, distributed, and largely controlled by PSU oil marketing companies (OMCs) that have done a commendable job in maintaining petroleum supplies through a strong dealer network. This is possible through an efficient road transportation and rail infrastructure. Transportation of fuel nearly accounts for 5% of the total retail fuel price. India consumes close to 4 million barrels per day, which translates to 73 million barrels per year of oil wasted in transportation until it reaches beneficiaries.

To curb emissions, substitution of liquid fuel by natural gas is the key, and will have to be prioritised. To increase penetration of natural gas, a national gas grid is planned to be rolled out throughout the country. Ensuring sufficient supply will require funding support to provide storage infrastructure. Gas pipeline infrastructure in the country stood at 16,470 km in September 2017.

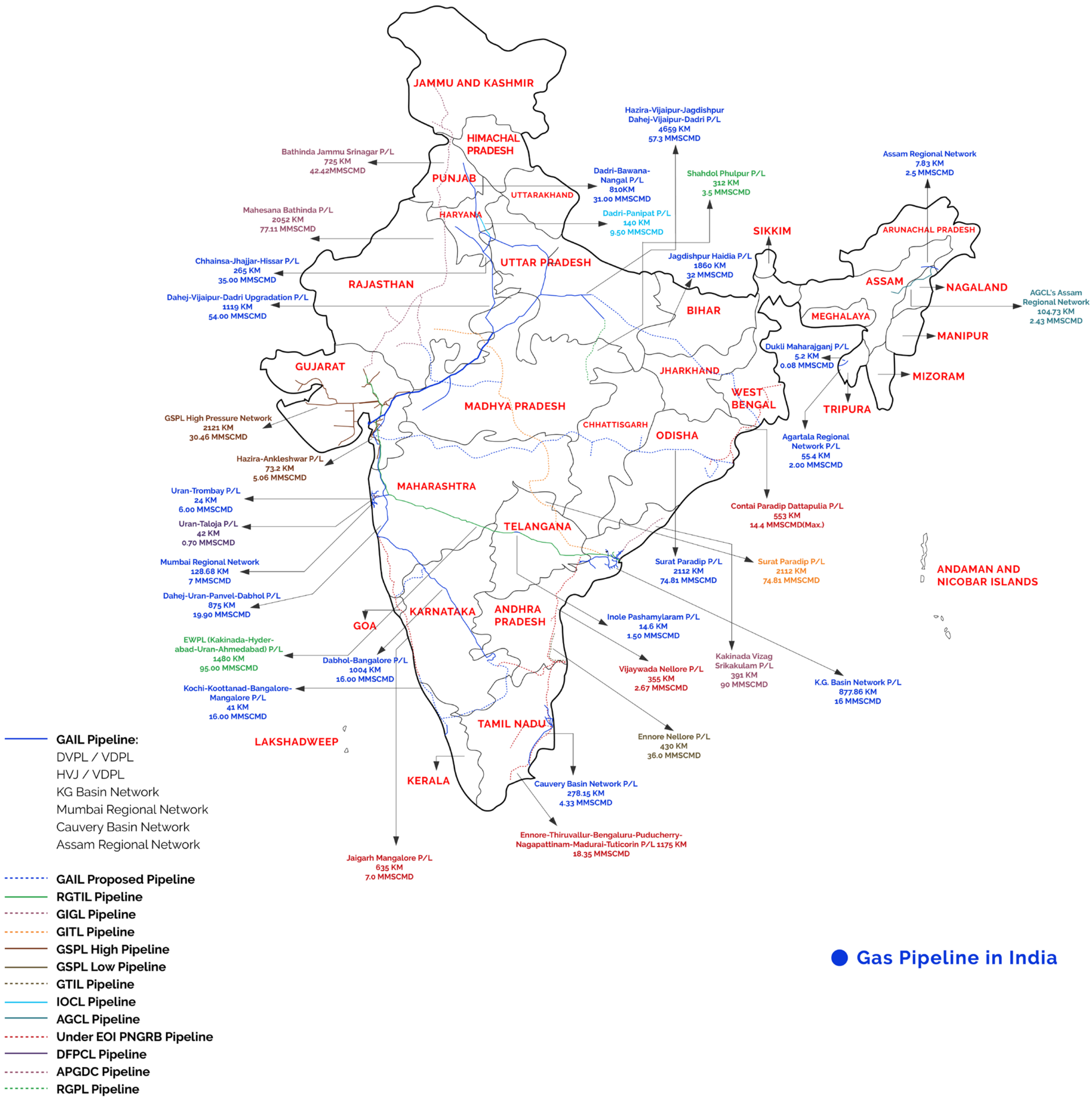

FIGURE 8: GAS PIPELINES AS OF 2018

Source 12: Petroleum and Natural Gas Regulatory Board

Infrastructure will play an important role in delivering energy to distant locations in the country. It is obvious that with an over three times expansion in energy supply, there would be a naturally accompanying growth in infrastructure. As the energy mix evolves, the type of infrastructure would also change, with an ensuing impact on investment, revenue model and technology. By nature, infrastructure must precede energy supply, but will not be created unless the latter is assured. Therefore, there is an interdependent relationship between energy and infrastructure. The **NITI Aayog**[21] report states that the government will ensure that the policy framework for energy supply and related infrastructure will be harmonious.

2.3 Renewable Energy in the Institutional Setting

The potential for renewable energy in India is huge. The MNRE estimates that in the electricity sector, there exists around 900 GW from commercially exploitable sources, of which the largest share consists of 750 MW of solar electricity (MNRE 2017).[22]

The MNRE is a nodal Ministry of the Government of India for all matters pertaining to new and renewable energy. It has evolved from the previous commission and departments since 1981, and has its current name and form since 2006.

The broad aim of this Ministry is to develop and deploy new and renewable energy for supplementing the energy requirements of the country. It is responsible for formulating and implementing policies and programmes for development of new and renewable energy, apart from coordinating and intensifying research and development (R&D) in the sector. Its most important task since 2010 has been the implementation of the National Solar Mission (NSM).

The Solar Potential

In India, and area of 3,287,240 km^2 receives solar radiation worth 4,300 quadrillion kcal (5,000 trillion kWh) every year. The daily average solar energy incident over India varies from 3,500 to 6,000 kcal/m^2 with about 2,300-3,200 sunshine hours per year, depending on the location. Even if a fraction of this natural and inexhaustible energy is captured, it would be enough to meet all heat and electricity needs for India's industries.

Figure 9 shows the Direct Normal Irradiance (DNI) map of India.

21 http://niti.gov.in/writereaddata/files/new_initiatives/NEP-ID_27.06.2017.pdf

22 https://mnre.gov.in/file-manager/annual-report/2016-2017/EN/pdf/1.pdf

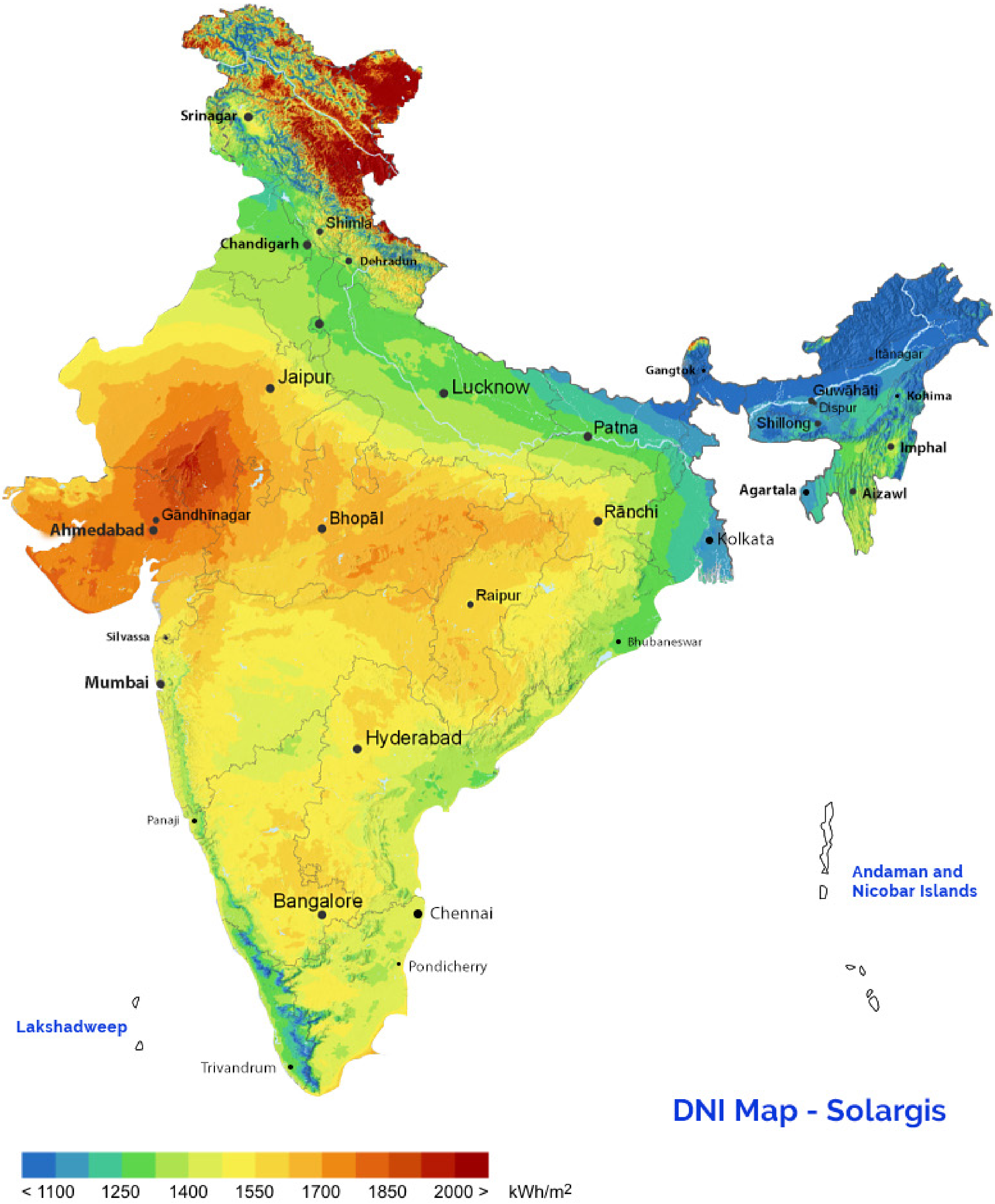

FIGURE 9: DIRECT NORMAL IRRADIATION IN INDIA

Source 13: solargis s.r.o., Slovakia

2.3.2 Energy Efficiency Programmes and Incentives

The Energy Resources Institute (TERI)[23] indicated in a study in 2015 that the industrial sector accounts for about 45% of total commercial energy consumption in India.

Newly established large plants in industries such as cement and paper mostly adopt energy efficient, state-of-the-art technological options on their own, in line with global standards. However, as already established plants tend to use outdated technologies and unskilled manpower, these often present opportunities for energy efficiency improvements.

The Bureau of Energy Efficiency (BEE) is the apex body certifying energy auditors in India through an academic programme.[24] It implements the Perform Achieve and Trade (PAT) scheme that awards and trades in energy efficiency certificates to the country's most energy-intensive industries with an aim to improve and reduce energy consumption.[25] It is a market-based mechanism to enhance the cost effectiveness in improving energy efficiency in energy-intensive industries (called Designated Consumers DCs) through certification of energy saving, which can be traded in form of ECerts (Energy Certificates).

2.4 The Economic and Political Situation on Energy Use in India

- India will see fast growth in energy demand and will become the third biggest energy consumer of the world by 2025.
- The high import dependency on fuel sources (such as petroleum based fuels, especially LPG and natural gas) create a great opportunity for the country to benefit from its abundant solar resources in the form of high solar irradiation.
- Coal and lignite only play a minor role in the industry for heating, while LPG, natural gas and to a lesser extend diesel-based fuels play an important role, but need the relevant infrastructure (such as pipelines) that might not be available everywhere.
- India's industry has a growing demand for energy sources to produce heat.
- Government programmes, especially the NSM, have been promoting the use of solar thermal systems for the industry.
- Solar heat rivals other technologies in terms of energy cost savings. Therefore, investments in energy efficiency will often be the first approach before investing in solar heat.

23 http://www.teriin.org/projects/green/pdf/National-Industry.pdf

24 http://www.beeindia.gov.in/

25 https://beeindia.gov.in/content/pat-read-more

CHAPTER 3

SOLAR THERMAL FOR INDUSTRIAL PROCESSES

3.1 Solar Thermal Technologies for Industrial Processes

For many years now, solar thermal technologies have been used for domestic hot water, and in colder climates, for space heating. However, production of heat for direct use in industrial processes is rather new. At the end of 2018, there were around 741 SHIP plants in operation worldwide.[26]

Solar thermal collectors convert solar radiation into usable heat. SHIP describes systems that provide solar heat in a factory.

Figure 10 shows a SHIP plant where a solar collector field heats up a thermal transfer fluid in a heat exchanger. This transfers the generated heat to supply a system or production process in the factory with hot water, air flow, or steam. Storage units also make it possible to use the generated heat at night-time. Usually, solar thermal energy only supports an existing heating process and is optimized according to the demand at times of maximum irradiation, especially during the summer.

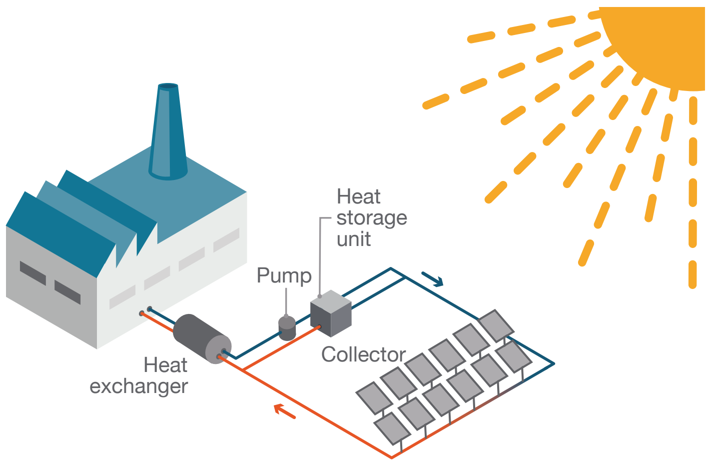

FIGURE 10: SCHEME OF A SHIP PLANT

Source 14: Solar Payback 2017

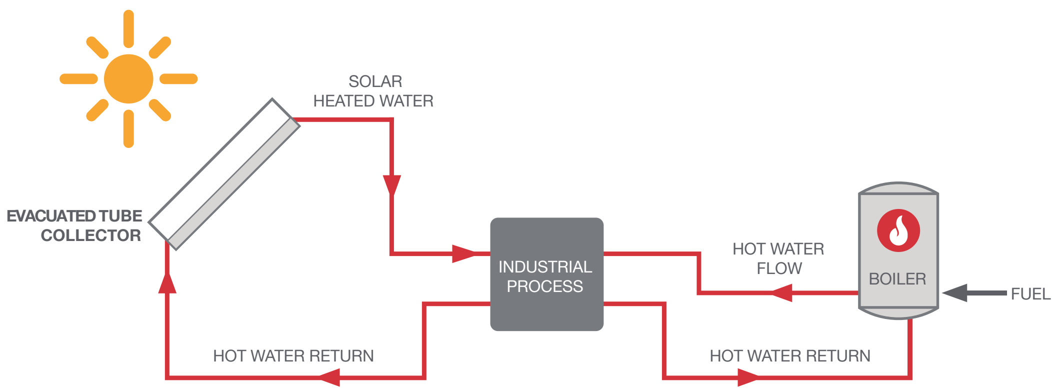

FIGURE 11: SIMPLIFIED ILLUSTRATION OF THE PROCESS-HEAT-CIRCLE CYCLE

Source 15: Solar Payback 2017, IRENA

26 https://www.iea-shc.org/solar-heat-worldwide

When exposed to the sun, the 'collector' heats up a thermal transfer fluid (either water with or without glycol for frost protection or thermo-oil). Collectors are connected to the production process or to a storage tank, either directly or via a heat exchanger. Electric pumps move the heat transfer liquid within the solar circle. Figure 11 shows a simplified illustration of the process heat cycle.

Various collector technologies available in the market supply heat at different temperature levels and can be used for different processes:

- Stationary collectors: Are orientated towards the sun on fixed racks. They can be unglazed, air, flat plate, and evacuated tube collectors and can yield temperatures of up to 150°C, but are mostly used for applications below 100°C.
- Concentrating collectors: Work on the principle of reflecting and concentrating direct solar radiation at its focus (a point or line), thereby using the concentrated solar radiation as a high temperature thermal energy source to produce process heat. The mirror elements that reflect and concentrate solar radiation vary in geometry and size. To facilitate concentration of direct normal irradiation (DNI), the mirrors need to be continuously tracked following the path of the sun in single or two-axes. Fresnel and parabolic trough collectors are 1-axis tracking systems. Concentrating dish collectors are mostly 2-axes tracking solutions. Thus, they make sense in areas with a lot of direct solar irradiation. They can generate heat with temperatures of up to 400°C and even higher for electricity production, and can be operated by pressurized water or thermal oil.

TABLE 5: Overview of collector types for solar process heat generation

Air collector

Air collectors use air to transport heat. Various types of air collectors use either glazed, unglazed or vacuum tubes to collect usable heat. They rely on either natural convection, or use fans to transport air via a well-insulated tube system. In industrial processes, air collectors are well suited for drying processes providing hot air between 20°C to 70°C.

Photo: Grammer Solar

Flat-plate collector

Flat-plate collectors use water to transport heat to the heat exchanger, the storage tank, or the production process. They consist of an insulated case containing a metallic absorber, which has an absorber sheet and a piping system below to transport the heat. The casing is covered with a single or double-glass plate, as anti-reflective coating reduces transmission losses. They achieve operating temperatures of between 30°C and 90°C and are produced in many countries. For solar process heat applications, usually large-scale collectors are used. Evacuated flat plate collectors can supply even significantly higher temperatures due to reduced convection losses.

Photo: E3 Energy group

Evacuated tube collector

Evacuated tube collectors use vacuum as an insulation to protect the absorber from the environment. Double-glass evacuated tube collectors consist of two tubes that are evacuated between them while single-glass evacuated tube collectors consist of one evacuated tube. With direct flow types, the heat transfer liquid flows through the tube. With so-called heat pipe or U-pipe collectors, a separated circuit inside the tube transports the collected heat to the top of the tube. Inside the header, the energy is transferred to the heating circuit.

To improve efficiency, some types of evacuated tube collectors are equipped with a reflective metal sheet behind the tubes, called compound parabolic concentrators (CPC). Evacuated tube collectors can deliver temperatures of 50–150°C.

Photo: Himin

Parabolic trough collectors

In parabolic trough collectors, bent mirrors reflect sunlight on to the receiver tubes. The mirrors or troughs are mostly aligned on a north-south axis, and rotate from east to west to track the sun along its daily path. Temperatures of up to 400°C can be produced and direct steam generation is possible. The temperature levels depend on the size of the parabolic trough and the evacuation of the receiver tube.

Photo: Amul Fed Dairy

Linear Fresnel collectors

Fresnel collectors concentrate the sun with several flat mirrors that track sunlight on one axis onto a central receiver tube. The single mirrors are easy to replace and the exposure to wind is only minimal. There are Fresnel collectors that have a secondary mirror placed above the receiver tube to reflect light back down to the absorber. Temperatures of up to 400°C can be produced and direct steam generation is possible.

Photo: Industrial Solar

Concentrating dish collector

Parabolic dishes concentrate solar irradiation on one spot and produce high temperatures of up to 400°C depending on the size of the mirror field and the evacuation of the receiver tube. Examples include Scheffler dishes used for cooking in India and some process applications. Tracking via two axes requires a high level of precision.

Photo: ARS Glasstech

Source 16: Overview by Solar Payback

3.2 Temperature Ranges of SHIP

Industrial process temperatures typically vary according to the production process involved. They are classified into three ranges (see Figure 12): first below 150°C (called low temperature), a second range of 150-400°C (medium temperature), and above 400°C (high temperature). Many industrial processes in the chemicals, food and beverage, machinery, mining, textiles and wood industries use temperatures that can be easily generated with solar thermal technologies – as hot water or steam. Since fixed costs dominate the overall cost structure of solar thermal energy, processes that have a summer peak load as well as those that can be applied all-year-long are of special interest for the use of solar thermal applications. As the economics of SHIP improve, the costs for competing energy sources become higher, and the savings that can be realised by the use of SHIP increase.

The type of solar thermal collector used depends greatly on the temperature level required. In some applications, such as for washing or drying processes, only a low temperature of about 50°C is needed, for which mainly flat-plate collectors or air collectors are used. Numerous industrial processes require temperatures of up to 95°C. Both evacuated tube collectors and improved flat-plate collectors are able to provide this temperature with very good efficiency. Higher temperature levels can be reached if a vacuum is used for insulation.

Above approximately 140°C solar radiation must be concentrated. Higher concentration factors of parabolic trough, linear Fresnel collectors, or concentrating dish systems provide operating temperatures up to 400°C. For most applications, more than one collector type could be used. The criteria are – available space, economics, and location among others.

INDUSTRY	LOW Below 150 °C	MEDIUM 150 to 400 °C	HIGH > 400 °C
Chemical	• Boiling	• Distilling	
Food and beverage	• Drying • Boiling • Pasteurising • Sterilising		
Machinery	• Cleaning • Drying		
Mining	• Copper electrolytic refining • Mineral drying processes	• Nitrate melting	
Textile	• Washing • Bleaching	• Dyeing	
Wood	• Steaming • Pickling • Cooking	• Compression • Drying	

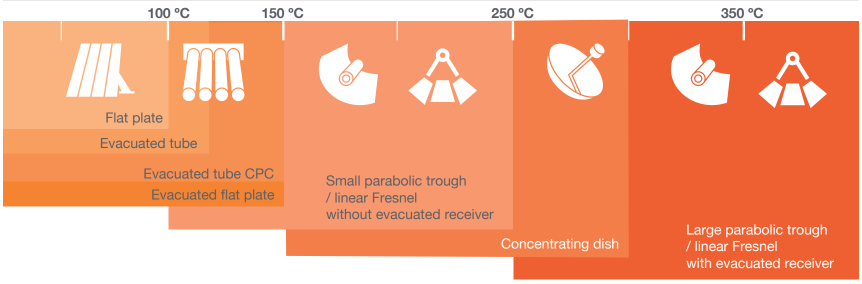

FIGURE 12: COLLECTOR TEMPERATURE RANGES, APPLICATIONS, AND TECHNOLOGIES

Source 17: IEA TASK 49

3.3 Solar Thermal Industry in India

As per a survey undertaken by Global Environment Facility – United Nations Development Programme (GEF-UNDP) annually over 15 million tonnes of fuel oil in industries requiring heat up to 250°C, and 500 trillion units of electricity in various sectors is consumed for heating water and air. Main thermal applications – process heat, residential cooking, and water heating – account for more than 90% of the thermal energy requirement. Presently, this demand is primarily met through coal, biomass and petroleum fuels. However, several areas in India receive good Direct Normal Irradiance (DNI) and solar thermal energy has the potential to convert this radiant energy to meet heating needs of up to 250°C. Even if only 1% of this heating energy requirement is met by using concentrated solar thermal, the potential for SHIP is estimated to be over 2.5 million m^2.[27]

SHIP largely achieves this through concentrating technologies on opportunities for increasing yield per unit. Only on rare occasions are flat-plate collectors used, when low temperatures are needed and area availability is not a problem.

In India, the main drivers for SHIP are the GEF-UNDP programme for concentrating solar thermal (CST) market development, and the GEF-UNIDO programme for solar thermal industrial process heat. While GEF-UNDP achieved 44,949 m^2 of CST market, GEF-UNIDO is progressing with an additional 45,000 m^2 installed area of CST systems. As an incentive, the Indian Renewable Energy Development Agency (IREDA)[28] offers a 5%-interest loan. This scheme is also extended to manufacturing now, which makes this the first instance of any incentive for the solar thermal manufacturing industry ever announced.

The country has achieved a little over 50% of the target set under the National Solar Mission until December 2018, largely from solar water heating systems. Almost 80% of India's present solar thermal operative capacity was installed since 2010.

The federal subsidy scheme on solar thermal collectors has been removed, but concentrating solar thermal systems continue to receive a subsidy of 30% (60% in special category states) or a fixed benchmark cost per square metre[29] until the fiscal year 2018-19. It has been reduced to 20% (40% in special category states) for the next fiscal period.

TABLE 6: Benchmark Cost for Different Types of Concentrating Collectors

Sl.	Solar collector type	Benchmark cost (INR/m^2)
1.	Solar collector systems for direct heating	12,000
2.	Concentrator with manual tracking	7,000
3.	Compound Parabolic Collector, direct heating and drying	12,000
4.	Single Axis tracking and Scheffler dishes	15,000
5.	Single Axis tracking using solar grade mirrors	18,000
6.	Double axis tracking	20,000

Source 18: MNRE, Government of India, 2019

27 Solar Thermal Federation of India (STFI)

28 http://www.ireda.in/writereaddata/Approved%20UNIDo%20Loan%20scheme..pdf

29 http://mnre.gov.in/file-manager/UserFiles/subsidies_solar_thermal_systems_devices.pdf

3.4 The Indian Solar Thermal Market

India has profound experience in the solar thermal sector with the last decade seeing an upsurge of medium high temperature solar thermal systems such as parabolic troughs, Scheffler dishes, Fresnel lens, parabolic dish, and compound parabolic collectors, stimulated by the solar thermal programme initiated by MNRE and its predecessors. Table 6 and Table 7 provide the cumulative installed solar thermal area that is operative until December 2018.

TABLE 7: Cumulated Collector Area in Operation by the end of 2018

Water Collectors (m²)			Air Collectors [m²]		Concentrators [m²]	Total [m²]
Unglazed	Glazed	Evacuated	Unglazed	Glazed	PTC, Fresnel, etc.	
0.0	40,56,399	74,25,876	0	12,150	77,473	**11,566,648**

Source 19: Renewables 2019 Global Status Report[30]

MNRE has estimated the potential of solar thermal collectors to be about 140 million m^2. The Government of India wants to install 175 GW of renewable energy for power generation and an estimated 20.13 million m^2 installed area of solar thermal collectors by the year 2022.[31] According to the information available from MNRE, until March 2019, India had an installed capacity of about 78.316 MW of grid-connected renewable energy, largely from solar photovoltaics, wind energy, small hydro, and biomass waste in the electricity sector.

According to information available from International Energy Agency (IEA), India's installed cumulative capacity of solar water heaters stands close to 1.16 million m^2 and little over 72,000 m^2 through concentrated solar thermal technologies.

The National Solar Mission (NSM), which was announced in January 2010, was a turning point for the solar thermal market development. The mission, which will last until March 2022, targets a cumulative solar thermal area of 20 million m^2 and is spread over three phases:

- Phase 1 (2010 – 2013) - 7 million m^2
- Phase 2 (2013 – 2017) - 15 million m^2
- Phase 3 (2017 – 2022) - 20 million m^2

The MNRE has a separate programme for CSH[32] used for community cooking, process heating, and air drying and cooling. It will continue its policy to support concentrated solar thermal systems and has set a target (as part of its continuation of policy for community cooking, process heating and cooling) with a budget of INR 70 million. The support will be in force until fiscal 2019-2020 and targets 90,000 m^2 area during this period. Year-wise targets are given in Table 8.

TABLE 8: MNRE Programme on CSH with Targets

Fiscal Year	Target area (m²)
2017-18	20,000
2018-19	30,000
2019-20	40,000
TOTAL	90,000

Source 20: MNRE, Government of India

30 https://www.ren21.net/gsr-2019/

31 https://mnre.gov.in/sites/default/files/uploads/potential_electricitysSavings_swhs.pdf

32 https://mnre.gov.in/file-manager/dec-solar-thermal-systems/CST-Scheme-2017-2020.pdf

As per the Renewables Global Status Report 2018 (REN21 2018),[33] India continues to maintain its position among the top-five markets for solar thermal globally.[34] SHIP is an upcoming market in India and placed fourth in the world. The Indian solar thermal capacity saw a 25% y-o-y growth in 2018, the highest globally. With a capacity of 2.8 MW thermal, India was among the top-10 markets for concentrated heat technologies in 2018, along with Oman, China, Italy and Mexico. When it comes to solar water heating collector capacity in operation, India was in sixth position, behind China, the US, Turkey, Germany, and Brazil.

Solar water collectors dominate the market with 90% share and the rest is for process heat. Figure 13 shows the year-wise solar water collector market in India until 2018. Within process heat, the market share of industrial process heat is around 55% and the rest is for cooking.

The Indian solar thermal market is on the growth path as the year 2018 showed an impressive performance in comparison to the previous year. Overall, the glazed collector market grew by 20% to 1.79 million m^2 (1,248 MWth). Another 4,500 m^2 were installed for use in concentrating collector systems.[35]

Imports of solar thermal components and systems with no checks on quality can be a problem for the sustainability of the market. Unless the government intervenes by establishing stringent and mandatory Indian standards, more and more sub-standard imports will enter the country from China. For local manufacturers, this competition is a serious threat, since it could even drive them out of the manufacturing business.

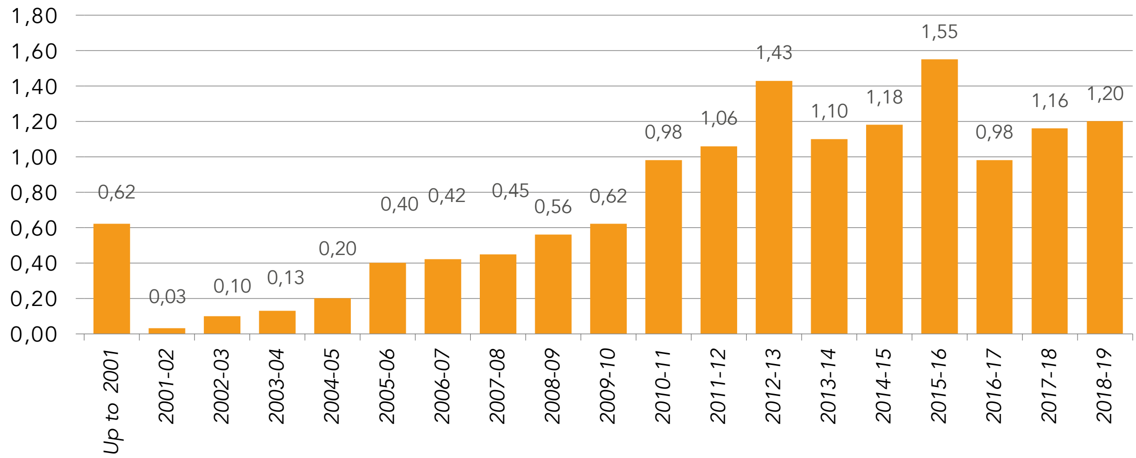

FIGURE 13: SOLAR COLLECTOR INSTALLATIONS IN INDIA YEAR-WISE

Source 21: Solar Thermal Federation of India

3.4.1 Solar Thermal Energy Research and Development (R&D) at MNRE

The MNRE plans activities on research, design, and development that lead to deployment. It also proposes the commercialization of various solar thermal technologies for power generation, industrial process heat systems, and solar cooling.[36] In addition to this, it aims at continuing efforts to develop technologies for improving various low-temperature applications, namely solar water heating and solar cooking. The major thrust areas of the plan include solar thermal

33 http://www.ren21.net/status-of-renewables/global-status-report/

34 https://www.ren21.net/wp-content/uploads/2019/08/Full-Report-2018.pdf

35 This analysis is based on the import statistics of vacuum tubes and a survey among the few flat plate collector manufacturers still in business in the country today.

36 https://mnre.gov.in/concentrating-solar-system-solar-cookers-steam-generating-systems

power generation, parabolic trough technology, central receiver technology, dish, engine, turbine technology and solar heat (up to 250°C) for industrial processes and cooking systems. Other areas include solar distillation/water purification systems, solar air heating, drying and food processing systems, solar cooling, solar architecture, solar detoxification of wastes, development of low-cost materials, and development of performance standards.

R&D on Solar Heat (up to 250°C) for Industrial Processes

Efforts will be made to develop advanced solar collectors with optical efficiency greater than 75% and with overall heat loss coefficient reduced to 4.0 W/m^2K (or lower) for flat plate collectors. For industrial process heat applications, the development of high performance solar concentrating collectors and systems will be initiated. It is proposed to undertake up to 20 R&D installations, each of about 50 kWth capacity based on the developed technology in different industries with a view to fine-tune the technology and technology validation.

The Indian solar thermal industry is still largely dominated by the solar collector business. As per IS 12933 of the Bureau of Indian Standards (BIS) there are 58 approved manufacturers.[37] However, for evacuated tube manufacturing, no BIS standard is mandatory, hence the list is not published.

There are 29 manufacturers empanelled by MNRE for sale and distribution of concentrating solar cooking devices and can be accessed at a website.[38]

For process heating and cooling, there are 34 manufacturers and an additional 16 new entrepreneurs empanelled by MNRE for sale and distribution and can be accessed at the overview of channel partners of MNRE.[39] All the listed manufacturers have their manufacturing bases in India.

3.4.2 Testing Agencies

For testing of solar thermal process heating systems using concentrated solar thermal, the National Institute of Solar Energy, Gurugram, and Savitribai Phule University of Pune, School of Energy Studies, are approved by MNRE.[40]

3.4.3 Promoting Agencies

Solar Thermal Federation of India (STFI)

STFI works towards the larger interest of the industry. It constitutes members with over 80% share of the solar thermal market.[41]

National Institute of Solar Energy (NISE)

The Government of India converted a 25-year-old Solar Energy Centre (SEC) under MNRE to an autonomous institution in September 2013, to assist the MNRE in implementing the National Solar Mission and to coordinate research, technology, skill development, training, consultancy, incubation, and other related works.

37 https://mnre.gov.in/sites/default/files/uploads/list_ahs.pdf

38 https://mnre.gov.in/file-manager/UserFiles/list_manufacturers_dsc.pdf

39 https://mnre.gov.in/file-manager/UserFiles/OM-list_channelpartners_st_cst_jnnsm.pdf

40 https://mnre.gov.in/file-manager/UserFiles/Advising-manufacturers-CSTs.pdf

41 STFI is a pan-India body Registered under Societies Registration Act XXI of 1860 Regd. No. S/69506/2010 working

Indian Renewable Energy Development Agency (IREDA)

IREDA is a Government of India Enterprise under the administrative control of MNRE. It is a public limited government company, established as a non-banking financial institution in 1987, engaged in promoting, developing, and extending financial assistance for setting up projects relating to new and renewable sources of energy and energy efficiency/conservation.

Solar Energy Corporation of India (SECI)

The SECI is a central public sector undertaking under the administrative control of MNRE to facilitate the implementation of the NSM, which has set an ambitious target for encouraging solar thermal applications in domestic and industrial segment. The key strategies are:

- To make solar heaters mandatory through building by-laws and incorporation in the national building codes.
- To ensure effective mechanisms for certification/rating of manufacturers.
- To promote such thermal applications through local agencies/power utilities.
- To support the upgrading of technologies and manufacturing capacities through concessional funding.

3.4.4 Quality Standards, Certification and Norms

The Bureau of Indian Standards (BIS)[42] is the national standards body of India working under the aegis of the Ministry of consumer affairs, food and public distribution, Government of India. It is established by the Bureau of Indian Standards Act. BIS has put in place standards for flat plate collectors as IS 12933-1 (2003), which is mandatory for all installations in India.

Similarly, it has also set draft standards for Evacuated Tube Collectors as IS 16544: 2016, which will soon be made mandatory.

For concentrating solar technologies, BIS standards are available for the following:

1. Solar Flat Plate Collectors

IS 12933(Part1):2003	Solar Flat Plate Collector – Specification Part 1 Requirements (Second Revision)
IS 12933(Part 2):2003	Solar Flat Plate Collector – Specification Part 2 Components (Second Revision)
IS 12933(Part 3):2003	Solar Flat Plate Collector - Specification Part 3 Measuring Instruments (First Revision)
IS 12933(Part 5):2003	Solar Flat Plate Collector – Specification Part 5 Test Methods (Second Revision)
IS 16368: 2015	Test Procedure for Thermosyphone Type Domestic Solar Hot Water Heating System

2. All Glass Evacuated Tubes Solar Collectors

IS 16542 : 2016	Direct Insertion Type Storage Water Tank for All Glass Evacuated Tubes Solar Collector — Specification
IS 16543 : 2016	All Glass Evacuated Solar Collector Tubes — Specification
IS 16544 : 2016	All Glass Evacuated Tubes Solar Water Heating System

3. Concentrated Solar Thermal

IS 16648 (Part 1):2017	Concentrated Solar Thermal – Specification Part 3 Parabolic Through Concentrator
IS 16648 (Part 2):2017	Concentrated Solar Thermal – Specification Part 2 Scheffler Concentrator
IS16648(Part 3):2017	Concentrated Solar Thermal – Specification Part 3 Parabolic Trough Concentrator
IS16648 (Part 4):2017	Concentrated Solar Thermal Specification Part 4 Non-Imaging Concentrator
IS16648(Part 5):2017	Concentrated Solar Thermal - Specification Part 5 Test Methods

42 https://bis.gov.in/

3.5 Limits in the Spread of Solar Thermal Usage in India

The barriers for industrial process heat systems using concentrator solar-heating technologies can be summarised as:

- A mandatory Bureau of Indian Standards has not been implemented, which encourages substandard systems.
- Lack of volume demand creation to achieve economies of scale.
- There is no policy that makes it mandatory for industries to meet a certain percentage of heat through sustainable energy.
- Lack of technical knowledge with certified energy auditors/ managers.
- Lack of awareness amongst bankers and financial institutions about the performance of SHIP, which impairs their ability to finance projects and provide working capital.
- No policy for performance-based incentive. Area-based subsidy encourages sub-standard components or underperforming technologies with larger areas used to deliver the same quantity of heat.
- Cheap imports of low-quality vacuum tube collectors, especially from China.
- The bureau of energy efficiency in its Perform Achieve Trade (PAT) scheme has not made it compulsory for specific sectors to achieve energy conservation.
- Not enough thrust to encourage the Energy Service Companies (ESCo) model for better life-cycle operation.
- Lack of initiatives for domestic manufacturing of glass used in mirrors.
- No helpline to guide potential beneficiaries.

Based on some of the successful projects in operation, if conducive policies and an enabling environment are created, Indian manufacturers have the potential to export their technologies. The government has also provided a platform via the International Solar Alliance (ISA)[43] to enable trade among the members of 121 countries lying within the tropics with good solar radiation.

Manufacturing has the potential to emerge as one of the high growth sectors in India. The 'Make in India' programme focuses on placing India on the world map as a manufacturing hub and gaining global recognition for the Indian economy. India is expected to become the fifth-largest manufacturing country in the world by the end of 2020, and the government has set an ambitious target of increasing the contribution of manufacturing output to 25% of gross domestic product (GDP) by 2025 — this would be a 9% increase from the current level of 16%.

3.6 Conclusions

- Different collector technologies exist for providing diverse temperature levels up to 400°C, which can be used for many industrial processes. The complexity of installation and the integration increases with temperature demand.
- India's solar industry has a lot of experience with large-scale projects; around 78.000 m^2 of concentrating projects have been realised until 2018.
- The National Solar Mission has supported further growth of the solar thermal market with ambitious goals in terms of installation targets.
- Prices for solar collectors for concentration systems are benchmarked by several institutions.
- Standards for solar thermal collector systems are in place.
- Cheap imports and lacking standards can be a barrier for market growth in a price-sensitive market environment.

43 http://isolaralliance.org/

CHAPTER 4

SOLAR THERMAL ENERGY FOR INDUSTRIES IN INDIA

4.1 Relevant Industrial Sectors

India is highly dependent on energy imports – thus, import prices for coal, oil, and natural gas have a strong influence on production costs, especially oil, gas, and coal.

The heat requirement of many industrial processes ranges from 50˚C to 400˚C. These processes account for a significant share of energy consumption, indicating a potential for the application of solar thermal technologies at medium and medium-to-high temperature ranges.

However, there are very few studies that quantify this parameter across various industrial sectors. Only secondary research has been carried out to identify and estimate heating/cooling loads in different industrial sectors. Due to a lack of existing secondary research on the percentage of heating/cooling loads in these 15 short-listed industries, the average percentage of heating/cooling loads in these sectors has been established by consultations with sector experts and energy auditors in relevant organizations (that have extensive experience of studying the energy profiles of various manufacturing processes), along with studies of various energy audit reports..

TABLE 9: Heat Requirement by Various Industries at Different Processes

Industrial sector	Cleaning	Drying	Evaporation	Distillation	Pasteurisation	Sterilisation	Cooking	Process Heating	Boiler Feed Water Heating	Cooling
Automotive and other Transport	■						■	■	■	■
Breweries	■	■	■	■	■	■	■	■	■	■
Cement								■	■	■
Ceramics	■	■						■	■	■
Chemical	■	■	■	■		■		■	■	■
Dairy	■	■	■	■	■	■	■	■	■	■
Electronics and Electrical Equipment										■
Food Processing	■	■	■	■	■	■	■	■	■	■
Glass	■							■	■	■
Iron and Steel								■	■	■
Leather and Footwear		■	■				■	■	■	■
Machinery	■									■
Non-ferrous metals	■							■	■	■
Non-Metallic	■	■							■	■
Petroleum refineries	■	■	■	■		■	■	■	■	■
Pharmaceutical	■	■	■	■		■	■	■	■	■
Plastics and Polymers	■	■	■	■				■	■	■
Pulp and Paper		■						■	■	■
Rubber		■	■					■	■	■
Textile	■	■						■	■	■
Tobacco	■	■		■				■	■	■
Waste Treatment	■	■	■	■				■	■	■
Wood and Furniture	■	■								■
Other Manufacturing	■	■				■				■
Others	■	■	■	■	■	■	■	■	■	■

Source 22: Based on MNRE-UNIDO report on India's CST sector Vision 2022

Industrial energy consumption is responsible for 32% of India's total energy consumption. The energy demands of the industrial sector accounted for 42% of the imported crude oil in 2018 at 217 million tonnes, out of which around 35 million tonnes provided thermal energy at temperatures of below 250°C, a large amount of which was met by coal, biomass, oil products, gas, and electricity.

Almost 42% of all energy consumed in India is by industrial processes heat alone that includes temperatures of below 250°C. This entails about 15 million tonnes of fuel oil annually. The working fluid required for industrial heat process applications is pressurized hot water, steam or hot air in temperature ranges of 60-250 °C. The energy for heating constitutes 10-30% of total fuel requirements, and is met mainly through fuel oil and solar thermal heating. SHIP can be explored to supplement heating demands of the Indian industries, for example the dairy industry, which need low and medium temperatures.

4.1.1 The Dairy Industry

India ranks first among the world's milk producing nations since 1998, and has the largest bovine population in the world. Milk production in India during financial year 2017-2018 was 176.3 million tonnes.[44] Figure 14 shows the top-ten milk producing states with an annual capacity.

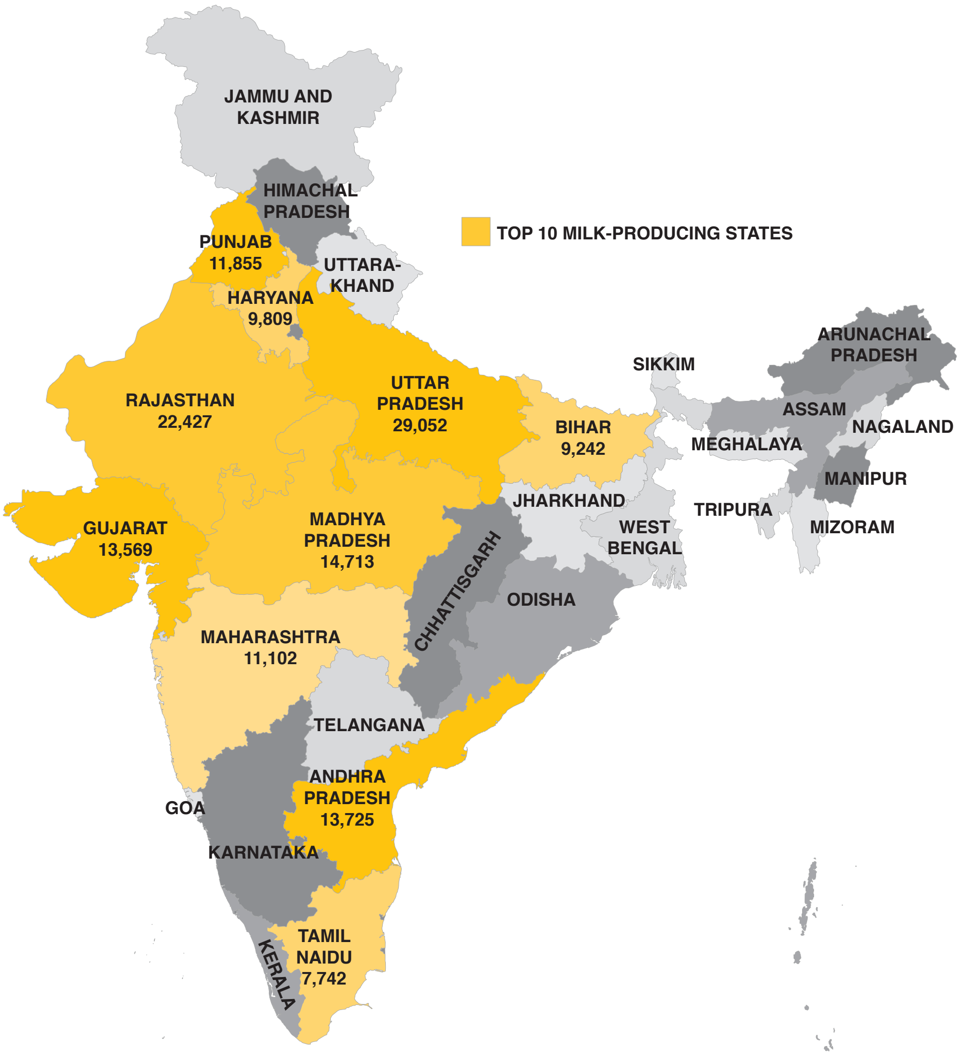

FIGURE 14: TOP 10 MILK-PRODUCING STATES IN INDIA, WITH CAPACITY IN '000 TONNES

Source 23: National Dairy Development Board 2017

44 https://www.nddb.coop/information/stats/milkprodindia

A 2011 United States Department of Agriculture (USDA) report on the Indian dairy industry says that the sector has private, cooperative, and governmental owned companies.

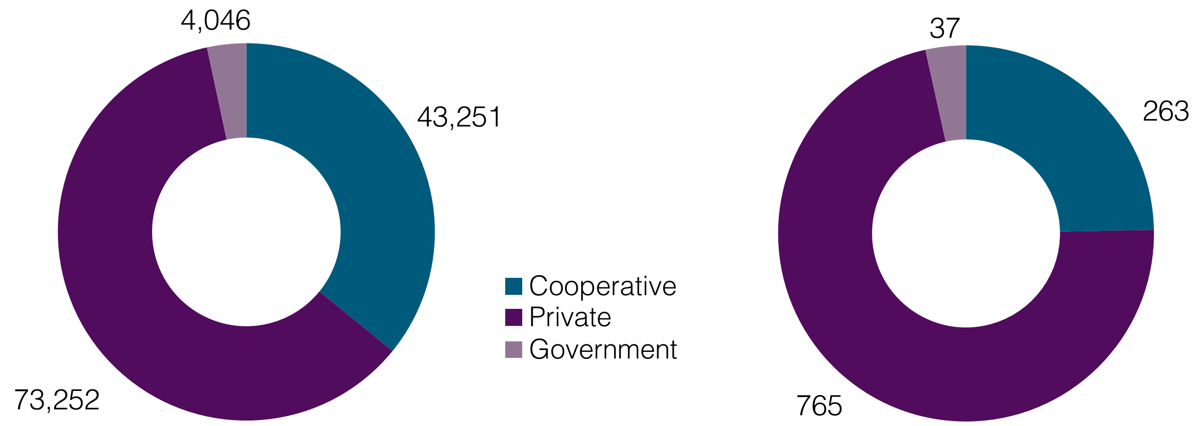

FIGURE 15: CAPACITIES AND NUMBER OF DAIRY COMPANIES, 2011

Source 24: (Landes et al 2017)[45]

4.1.1.1. Energy Requirement of India's Dairy Industry[46]

The dairy sector is highly interesting for technologies that provide low temperature heat such as SHIP since:

- Almost 30% of overall production costs for dairy products in India are comprised of energy costs.
- Thermal energy accounts for 70% of energy needs in the value chain.
- Heat is used for cleaning, powdering, chilling and storage units, sterilization processes, spray drying, evaporation, pasteurisation, and other processes.
- Heat is often produced on-site at processing plants, powered by conventional fuels such as oil and gas or biomass (e.g. rice husk).

The information for India roughly corresponds to the findings of a United Nations Industrial Development Organisation (UNIDO) working paper, which says that 90% of the energy required in the dairy industry is for heat.[47,48]

45 https://www.ers.usda.gov/webdocs/publications/82639/ldpm-272-01.pdf?v=0

46 https://energypedia.info/wiki/Greening_the_Indian_Dairy_Value_Chain

47 http://apki.net/wp-content/uploads/2012/07/Global-Industrial-Energy-Efficiency-Benchmarking-An-Energy-Policy-Tool.pdf

48 See also the study: Energy consumption during manufacturing of different dairy products in a commercial dairy plant: A case study - https://www.arccjournals.com/uploads/articles/3DR917.pdf

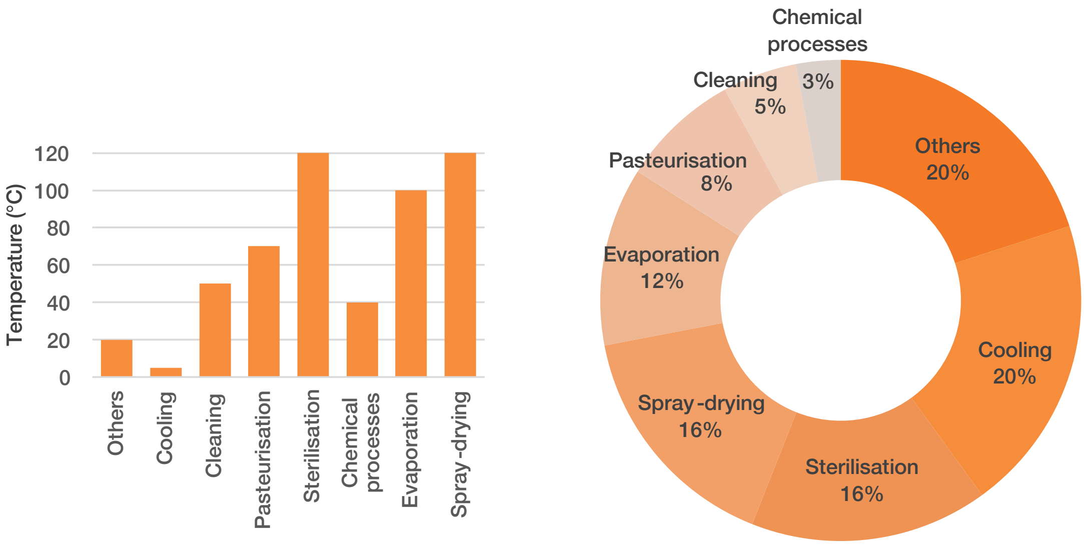

FIGURE 16: PROCESS-WISE HEAT DEMAND (LEFT) AND SHARE OF ENERGY CONSUMPTION (RIGHT) IN THE DAIRY INDUSTRY, MILK PROCESSING

Source 27a: STFI, 2018

Solar thermal systems can contribute enormously to driving various thermal processes in the dairy industry, which demand water temperatures at <120°C. Apart from this, solar PV systems as well as solar thermal systems can contribute to saving electrical energy consumed for refrigeration.

TABLE 10: Solar Technology Mapping in the Dairy Sector

Process	Energy/Fuel being used	Application media	Temperature required °C
Washing and cleaning	Electricity and boiler fuels like furnace oil, rice husk	Hot water	40-60
Chilling/Cold storage	Electricity and diesel	-	< 5
Pasteurisation	Boiler fuels like furnace oil, rice husk	Process heat	70
Sterilization/ Evaporation	Boiler fuels like furnace oil, rice husk	Process heat	100-120
Spray drying	Boiler fuels like furnace oil, rice husk	Hot air	120

Source 25: National Dairy Development Board

TABLE 11: Source-wise Distribution of Energy Consumption in the Dairy Sector

Industrial sector	Subsector	Coal (kilo tonne)	Electricity (GWh)	Petroleum products	Other fuels
Dairy	Milk and derived products	969	2009	N.A.	N.A.

Source 26: Annual Survey of Industries 2015-16

In order to derive the cost-wise share of different fuels employed in the dairy sector, the quantity of different fuels was monetised and its corresponding monetary share is depicted in Table 12 and also plotted in Figure 17.

TABLE 12: Cost-wise Share of Fuel in the Food Processing and Beverages Industry

Industrial sector	Subsector	Coal (INR)	Electricity (INR)	Petroleum products (INR)	Other fuels (INR)
Dairy	Milk and derived products	1,137,206	15,459,613	7,186,487	3,877,329

Source 27: *Annual Survey of Industries 2015- 2016*

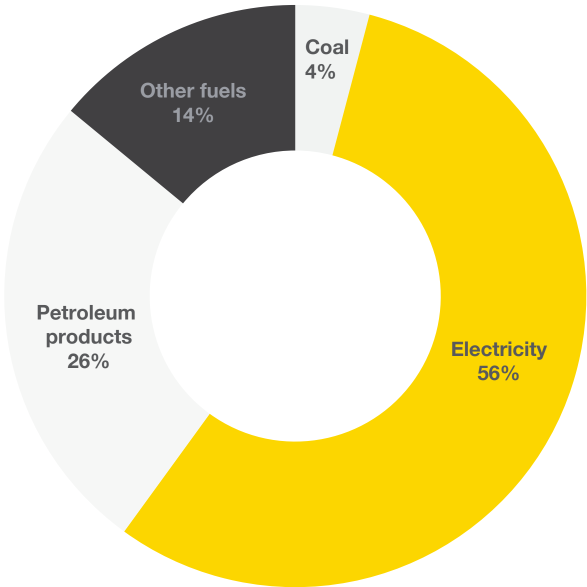

FIGURE 17: COST-WISE BREAKUP OF FUEL BEING USED IN THE DAIRY INDUSTRY

Source 28: Annual Survey of Industries, 2015-2016

Figure 17 indicates that coal, petroleum products, and other fuels account for 44% for various processes. Production cycles in the dairy industry can be broadly classified into two major segments:

- The primary production and processing of liquid milk.
- The production of milk-derived products

The industry consumes a substantial amount of thermal (heat) energy for milk processing (pasteurization, sterilization, spray drying, evaporation, etc.) and electrical energy for refrigeration during milk pre-chilling, chilling of milk after pasteurization, cold storage of packed milk, compressed air requirement for pneumatic milk packaging machines, milk homogenization, and clarification operations.

4.1.2 Food Processing

The food processing sector is a highly fragmented industry. It comprises of the sub-segments such as fruits and vegetables, milk and milk products, beer and alcoholic beverages, meat and poultry, marine products, grain processing, packaged or convenience food, and packaged drinks. India is the world's top producer of milk, ghee (clarified butter), ginger, bananas, guavas, papayas, and mangoes. It is the second largest producer of rice, wheat, and several other vegetables and fruits. The country's food processing market was valued at USD 65 billion in 2018 and has seen an 11% CAGR in the past five years. As per the annual survey of industries 2015-2016, the total number of factories in the registered food processing sector in the country, excluding milk processing, was 35,501. The government has sanctioned 42 Mega Food Parks (MFPs) to be set up in the country under the MFP scheme. Currently, 17 MFPs have become functional.

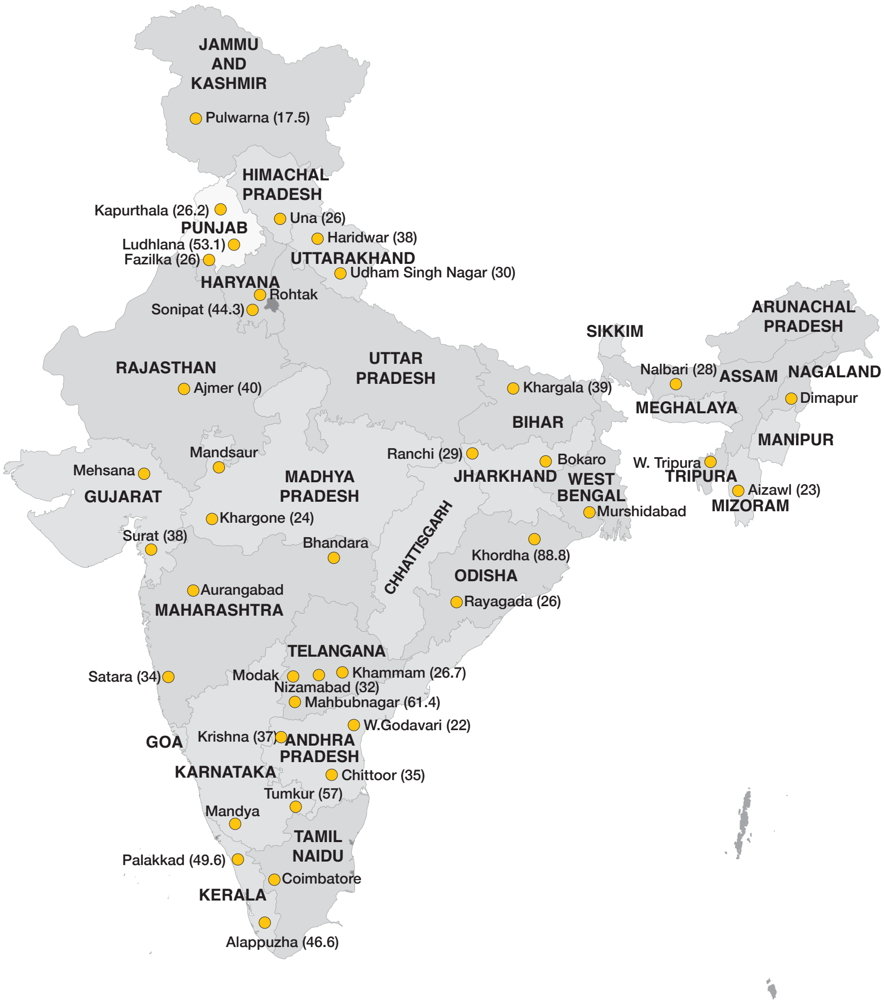

FIGURE 18: FOOD PROCESSING AND BEVERAGE INDUSTRY CLUSTERS IN INDIA

Source 29: Maps of India[49]

Many processes such as pasteurisation, sterilisation, and food preservation and techniques such as drying, freezing/chilling, packaging, and canning need heat-treatment processes. Most of the energy required by these industries goes towards these processes.

TABLE 13: Source-wise Distribution of Energy Consumption in Food Processing and Beverage Industries

Industrial Sector	Sub-sector	Coal (kilo tonne)	Electricity (GWh)	Petroleum products	Other fuels
Food processing and beverage	Vegetable and animal oil and fats	33,630	2,023	N.A.	N.A.
	Manufacture of grain mill products, starches and starch products	1,147	5,591	N.A.	N.A.
	Manufacture of other food products	6,450	5,179	N.A.	N.A.
	Manufacture of prepared animal feeds	3,059	735	N.A.	N.A.
	Manufacture of beverages	9,651	2,124	N.A.	N.A.
	TOTAL	**53,937**	**15,651**	**N.A.**	**N.A.**

Source 31: Annual Survey of Industries 2015-2016

In order to derive the cost-wise share of different fuels employed in the food processing and brewery industry, the quantity of different fuels was monetized and its corresponding monetary share is depicted in Table 14 and also drawn in Figure 19.

49 https://www.mapsofindia.com/ and https://mofpi.nic.in/

TABLE 14: Cost-wise Share of Fuel in Food Processing and Beverage Industries					
Industrial sector	**Subsector**	**Coal (INR)**	**Electricity (INR)**	**Petroleum products (INR)**	**Other fuels (INR)**
Food processing and beverage	Vegetable and animal oil and fats	2,953,171	15,401,346	2,790,841	6,463,681
	Manufacture of grain mill products, starches and starch products	1,423,982	41,311,581	6,760,931	3,001,270
	Manufacture of other food products	9,348,643	40,084,737	16,689,541	20,027,976
	Manufacture of prepared animal feeds	308,146	5,330,284	1,427,006	84,6203
	Manufacture of beverages	2,781,734	16,256,922	4,712,376	4,723,857
	TOTAL	**16,815,676**	**118,384,80**	**32,380,695**	**35,062,987**

Source 32: Annual Survey of Industries 2015- 2016

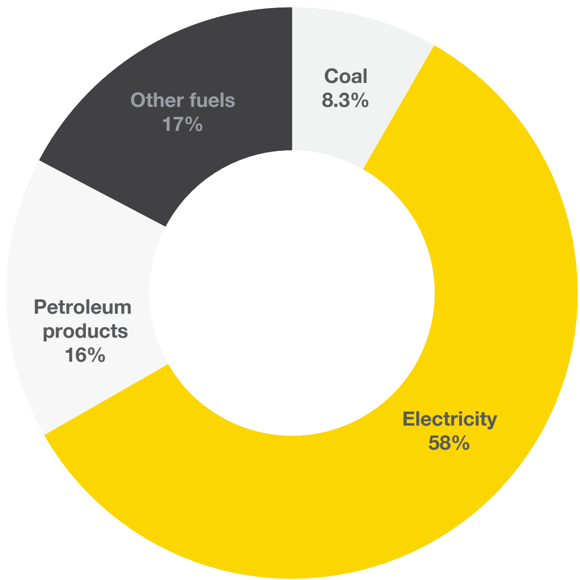

FIGURE 19: COST-WISE BREAKUP OF FUEL BEING USED IN FOOD PROCESSING AND BEVERAGE INDUSTRIES

Source 33: Annual Survey of Industries 2015-2016

Figure 19 shows that coal, petroleum products, and other fuels account for 41% of various processes of the food and beverage industry.

4.1.3 Textiles Industry

The textiles sector is one of the largest and oldest sectors in the country and amongst the most important in the economy in terms of output, investment, and employment. It plays a major role in the Indian economy. The size of India's textile market as of July 2017 was around USD 150 billion and is expected to touch USD 250 billion by 2019, a CAGR of 14% between 2009 and 2019. It contributes 14% to India's industrial production and 4% to the GDP, 18% of employment in the industrial sector and 16% to the country's total exports earnings. This sector employs nearly 45 million people and after agriculture, it is the second largest employer in the country. India is becoming the largest exporter of cotton yarn and an important player in readymade garments.[50, 51]

The textiles finishing industry involves many operations that convert inputs into a final product.

50 https://www.ibef.org/industry/textiles.aspx

51 http://texmin.nic.in/textile-data

All products do not necessarily follow the same process sequence, but broadly these do not vary by a very large extent. Major operations involved are de-sizing, scouring, bleaching, mercerizing, dyeing and finishing. Many plants recover heat from waste streams with heat exchangers in order to preheat the process water. Large quantities of steam are also used for heating drying cans and to a lesser degree for humidifying space conditioning air.

Mapping Solar Technology Applications

Any textile finishing requires hot water at temperatures ranging from 40°C to 110°C at different stages of the process. Hot water of this temperature range can easily be generated through the use of solar energy. Various solar technologies were identified that can be used to meet these hot water requirements. Table 15 details these technologies.

TABLE 15: Solar Mapping in Textile Finishing

Process	Energy being Used	Temperature Required °C	Recommended Solar Technology
De-sizing	Thermal	60-90	Solar Thermal
Scouring	Thermal	90-110	Solar Thermal
Bleaching	Electrical	----	Solar PV
	Thermal	90-93	Solar Thermal
Mercerizing	Electrical	----	Solar PV
	Thermal	60-70	Solar Thermal
Dyeing	Thermal	70-90	Solar Thermal
Finishing	Thermal	40-100	Solar Thermal
Sizing	Electrical	----	Solar PV
	Thermal	80-85	Solar Thermal

Source 34: Indian Institute of Technology, Delhi

As can be seen in Figure 20, textile manufacturing is spread all over the country.

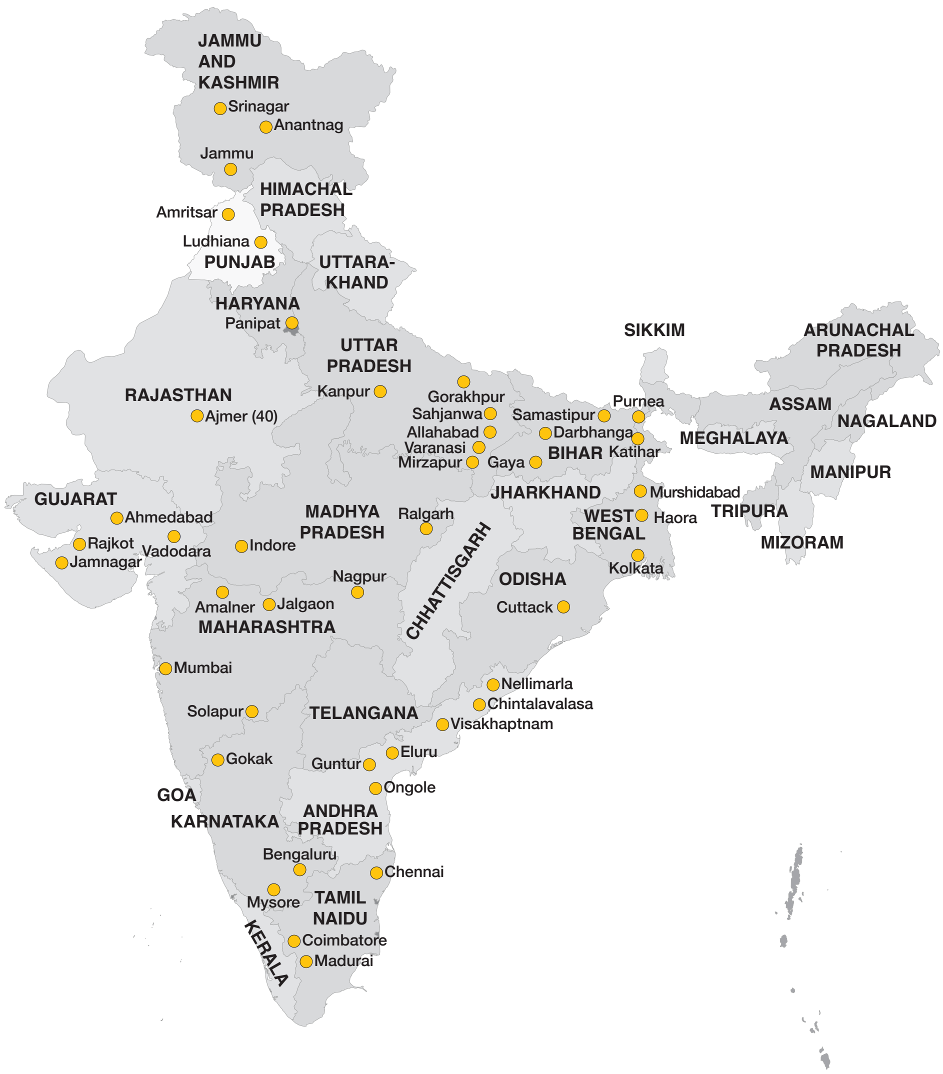

FIGURE 20: LEADING TEXTILE PROCESSING CITIES OF INDIA

Source 35: Maps of India, IBEF[52] and Silk Board

TABLE 16: Source-wise Distribution of Energy Consumption in Textiles Finishing

Industrial Sector	Coal (kilo tonne)	Electricity (GWh)	Petroleum products	Other fuels
Textile finishing	280,179	3,881	N.A.	N.A.

Source 36: Annual Survey of Industries 2015-2016

In order to derive the cost-wise share of different fuels employed in textile finishing, the quantity of different fuel was monetized and its corresponding monetary share is depicted in Table 17 and also plotted in Figure 21.

TABLE 17: Cost-wise Share of Fuel in Textiles Finishing

Industrial Sector	Coal (kilo tonne)	Electricity (GWh)	Petroleum products	Other fuels
Textile finishing	23,534,510	29,954,471	4,362,700	8,544,055

Source 37: Annual Survey of Industries 2015-2016

52 https://www.slideshare.net/IBEFIndia/textiles-and-apparel-sector-report-june-2017 slide 35

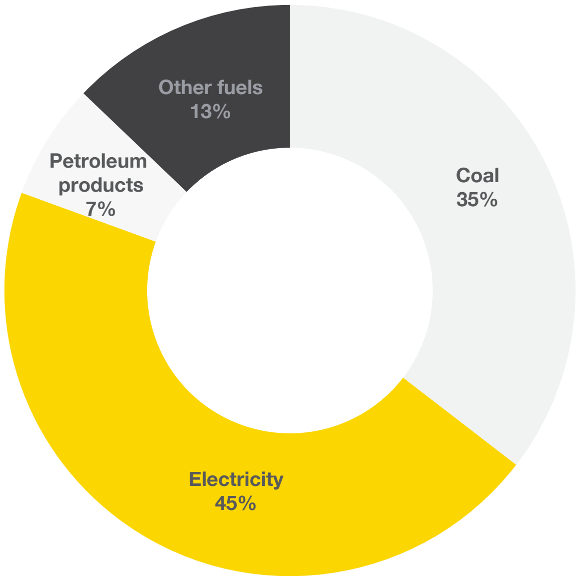

FIGURE 21: COST-WISE BREAKUP OF FUEL BEING USED IN TEXTILES FINISHING

Source 38: Annual Survey of Industries 2015-16

Figure 21 indicates that coal, petroleum products and other fuels account for 55% of the energy needed for various processes.

4.1.4 Pharmaceuticals Industry

The pharmaceuticals industry in India ranks third in the world in terms of volume and 14th in terms of value.[53] According to the department of pharmaceuticals, the Ministry of Chemicals and Fertilizers, the total turnover of India's pharmaceuticals industry was USD 19.25 billion in 2018. The industry is expected to reach USD 100 billion by the year 2025. Figure 22 shows the locations of the major clusters of this industry in India.

By 2018, it was estimated that India had more than 24,000 registered units and about 3,300 large and 10,000 small-scale units – which form the core of the pharmaceutical industry.[54]

53 https://en.wikipedia.org/wiki/Pharmaceutical_industry_in_India#cite_note-et-1

54 https://www.equitymaster.com/research-it/sector-info/pharma/Pharmaceuticals-Sector-Analysis-Report.asp

FIGURE 22: PHARMACEUTICAL INDUSTRY CLUSTERS IN INDIA

Source 38: Maps of India and India Drug Manufacturers Association

4.1.4.1 Mapping Solar Technology Applications in the Chemicals and Pharmaceuticals Industries

The sectors consume both electrical and thermal forms of energy at different stages of processes. Hence, the possibility of replacing conventional energy by solar energy for these sectors is high. An added advantage is that solar energy can replace thermal energy more economically and viably than electrical energy. Most of the thermal energy applications in pharmaceutical units require low-range temperatures, which are easily achievable by using solar systems. Solar energy may also replace electricity if sufficient free space is available within the plant. The process-wise solar mapping is shown in Table 18.

TABLE 18: Solar Thermal Processes in the Chemical Industry

Industrial Process	Application Media	Temp required °C	Recommended solar technology
Distillation	Hot water	55-80	Solar thermal
Evaporation	Steam	>120	Solar thermal
Drying	Steam/Hot air	>120	Solar thermal

Source 39: Annual Survey of Industries 2015-2016

TABLE 19: Source-wise Distribution of Energy Consumption in Pharmaceutical, Medicinal Chemical and Botanical Products Manufacturing				
Industrial Sector	Coal (kilo tonne)	Electricity (GWh)	Petroleum products	Other fuels
Manufacture of pharmaceuticals, medicinal chemical and botanical products	11,983	7,253	N.A.	N.A.

Source 40: Annual Survey of Industries 2015-2016

In order to derive the cost-wise share of different fuels employed in pharmaceutical, medicinal chemical, and botanical products manufacturing, the quantity of different fuels was monetized and its corresponding monetary share is depicted in Table 20 and also plotted in Figure 23.

TABLE 20: Cost-wise Share of Fuel in Pharmaceutical, Medicinal Chemical and Botanical Products Manufacturing				
Industrial Sector	Coal	Electricity	Petroleum Products	Other Fuels
Manufacture of pharmaceuticals, medicinal chemical and botanical products	4,409,331	53,248,143	13,443,524	7,678,819

Source 41: Annual Survey of Industries 2015-2016

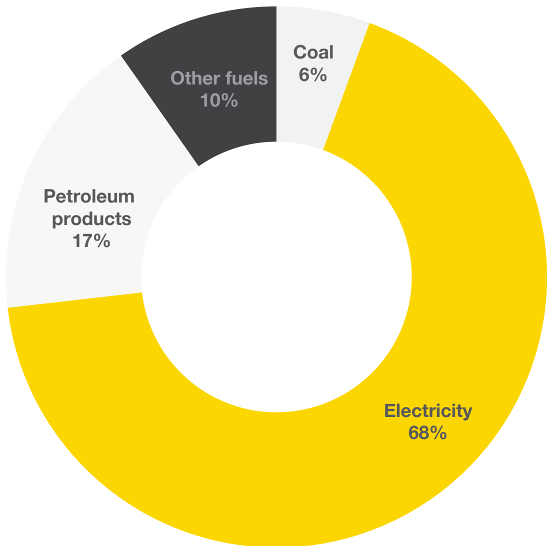

FIGURE 23: COST-WISE BREAKUP OF FUELS BEING USED IN PHARMACEUTICAL, MEDICINAL-CHEMICALS AND BOTANICAL-PRODUCTS MANUFACTURING

Source 42: Annual Survey of Industries 2015-2016

Figure 23 indicates that coal, petroleum products and other fuels account for 33% for various processes.

4.1.5 Automobile Component and Metals Casting Industries

India's automobiles sector is one of the largest in the world and accounts for over 7.1% of India's GDP. It also contributes to nearly 22% of the country's manufacturing GDP. The sector was first opened to foreign direct investment (FDI) in 1991 during the liberalisation of the Indian economy, and has come a long way since. The country is also currently the sixth-largest market in the world for automobiles, and is expected to become the world's third-biggest car market by the year 2020. India produced a total 29,075,605 vehicles including passenger vehicles, commercial vehicles, three-wheelers, two-wheelers and quadrocycles in the financial year 2017-2018, registering a growth of 15% y-o-y.[55] As per the Automotive Components Manufacturers Association of India (ACMA), the ranking of the Indian automobile sector in the world is as follows:

- Largest tractor manufacturer
- 2nd largest two-wheeler manufacturer
- 2nd largest bus manufacturer
- 5th largest heavy truck manufacturer
- 6th largest car manufacturer
- 8th largest commercial vehicles manufacturer

With the emergence of five large automotive clusters in the country – Delhi-Gurgaon-Faridabad in the north, Sanand-Halol and Mumbai-Pune-Nasik-Aurangabad in the west, Chennai-Bengaluru-Hosur in the south, and Jamshedpur-Kolkata in the east – India is on its way to become a primary global automobiles manufacturer. The map in Figure 24 depicts prominent places of automobile manufacturing and metal casting industries in the country.

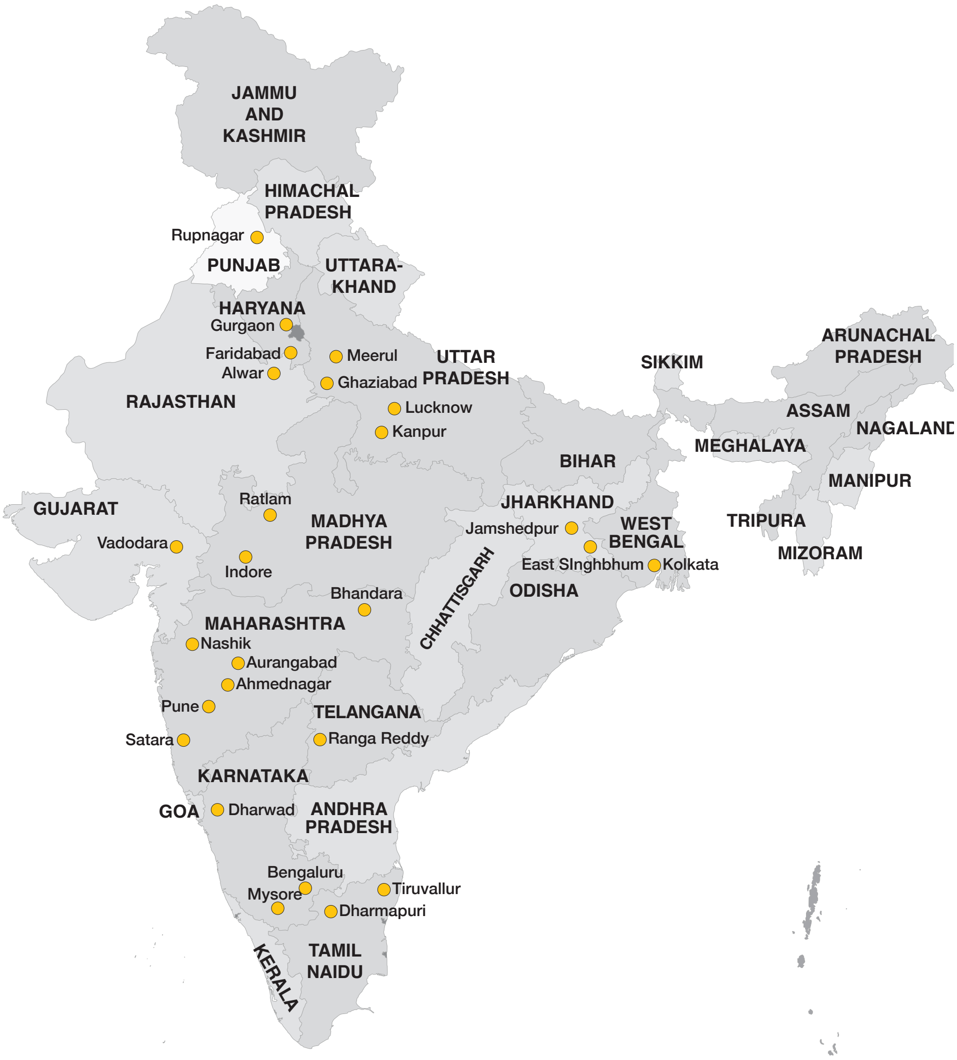

FIGURE 24: AUTOMOBILE MANUFACTURING SITES IN INDIA

Source 43: Automotive Component Manufacturers Association of India (ACMA)

55 http://www.siamindia.com/statistics.aspx?mpgid=8&pgidtrail=9

Metals casting components are used practically in the entire automobile industry and are therefore included in this section. Most of the processes in the auto industry are mechanical and driven by electricity. Only a few operations, such as machine shop and paint shop, use certain conventional fuels for producing thermal energy for metal casting, steel forging, de-greasing, pre-treatment before painting, drying, air-conditioning, etc. Figure 25 shows the entire process flow in detail.

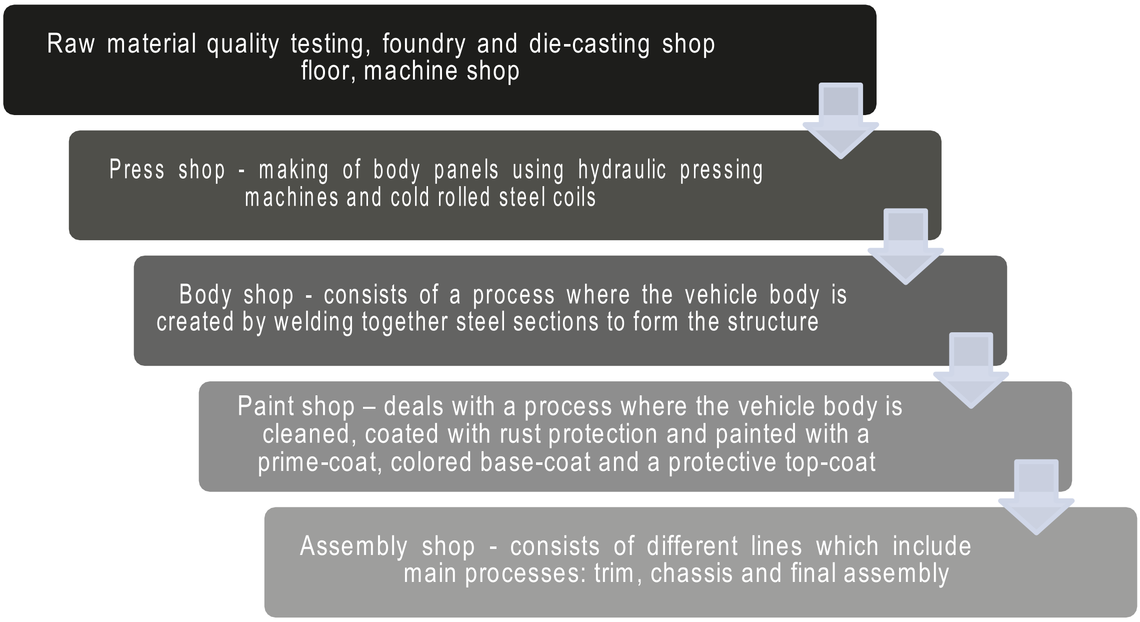

FIGURE 25: PROCESSES IN THE AUTOMOTIVE INDUSTRY

Source 44: Solar Thermal Federation of India, 2017

Mapping of Solar Technology Applications in the Automotive Industry

The process described above shows that only a few operations, such as machine and paint shops, use a significant amount of thermal energy. The temperature requirement in machine shops is well beyond 300˚C, but in paint shops it is <150˚C. Therefore, solar thermal energy applications are more appropriate for use in paint shops for pre-treatment, drying, and air-conditioning. Hot water at 30-45˚C is generally required for rinsing the body during pre-treatment. Table 21 shows the mapping of applications relevant to processes in a paint shop.

TABLE 21: Solar Technology Mapping in Automotive Processes

Process	Energy/fuel being used	Application media	Temperature required ˚C	Recommended solar technology
Press shop – electric and pneumatic machines	Electricity	-	-	Solar PV system
Body shop – electric and pneumatic machines	Electricity	-	-	Solar PV system
Paint shop – pre-treatment	Electricity and boiler fuels	Hot water	40	Solar Thermal
Paint shop – air-conditioning	Electricity and boiler fuels	Hot/cold air supply	5 – 50	Solar thermal
Paint shop – evaporation and drying	Boiler fuels	Hot air supply	80-100	Solar air heating systems
Assembly shop – automated robots and machines	Electricity	-		Solar PV system

Source 45: Annual Survey of Industries 2015-2016

TABLE 22: Source-wise Distribution of Energy Consumption in Automobile Components Manufacturing				
Industrial Sector	**Coal (kilo tonne)**	**Electricity (GWh)**	**Petroleum products**	**Other fuels**
Manufacture of automobile components	1	21,987.96	N.A.	N.A.
Casting of metals	8,893	7,410.59	N.A.	N.A.
TOTAL	**8,894**	**29,398.55**	**N.A.**	**N.A.**

Source 46: Annual Survey of Industries 2015-2016

In order to derive the cost-wise share of different fuels employed in automobile components manufacturing and casting of metals, the quantity of different fuel was monetized and its corresponding monetary share is depicted in Table 23 and also plotted in Figure 26.

TABLE 23: Cost-wise Share of Fuel in Automobile Components Manufacturing and Casting of Metals				
Industrial Sector	**Coal (kilo tonne)**	**Electricity (GWh)**	**Petroleum products**	**Other fuels**
Manufacture of automobile components	9,675	15,467,438	5,086,244	1,896,965
Casting of metals	2,850,021	55,470,160	7,136,636	2,963,395
TOTAL	**2,859,696**	**70,937,598**	**12,222,880**	**4,860,360**

Source 47: Annual Survey of Industries 2015-2016

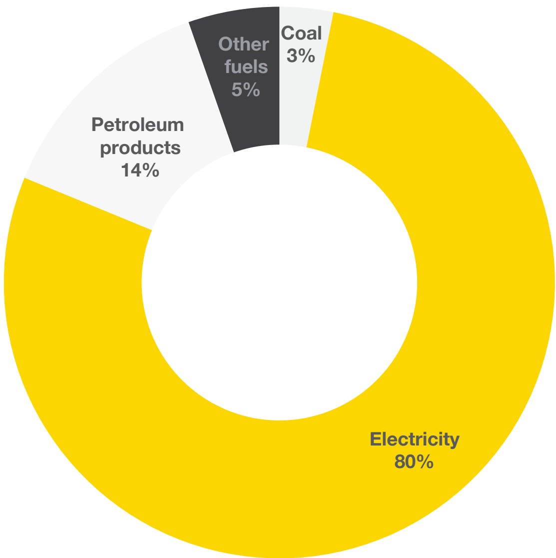

FIGURE 26: COST-WISE BREAKUP OF FUEL BEING USED IN AUTOMOBILE COMPONENTS MANUFACTURING AND CASTING OF METALS

Source 48: Annual Survey of Industries 2015-16

Summary of Industries with High Potential for the Use of Solar Thermal Systems

TABLE 24: CONVENTIONAL ENERGY REPLACEMENT POTENTIAL THROUGH SOLAR APPLICATIONS

TABLE 24: Conventional Energy Replacement Potential through Solar Applications				
Industry	Market Size	Geographical Distribution	Output per annum (2015/16)	Employment
Dairy	USD 122 billion in FY17	Punjab, Uttar Pradesh, Rajasthan, Gujarat, Maharashtra, Telangana and Andhra Pradesh	15% CAGR	Employs about 150 million people directly and indirectly
Food processing and Brewery	USD 65 billion in 2018	Punjab, Haryana, Bihar, Madhya Pradesh, Gujarat, Maharashtra, Odisha, Telangana, Andhra Pradesh, Tamil Nadu and Kerala	11% CAGR	Employs about 12 million people directly and about 35 million people indirectly
Textile	Around USD 150 billion in 2018, which is expected to touch USD 250 billion by 2019	Bengaluru, Delhi, Ludhiana, Mumbai, Ahmedabad, Surat, Tirupur, Coimbatore and Kashmir	8.5% CAGR	Employs about 40 million people directly and 20 million indirectly
Pharmaceutical	USD 40 billion in 2018	Maharashtra, Gujarat, Madhya Pradesh, Telangana, Punjab and Himachal Pradesh	10% CAGR	Employs about 1.8 million people directly and indirectly
Automobile component	USD 75 billion in 2018	Mumbai-Pune-Nashik-Aurangabad, Ahmedabad-Rajkot, Chennai-Bengaluru-Hosur, Indore, Kolkata-Jamshedpur and Delhi-Gurugram-Faridabad	3% CAGR	Employs about 29 million people directly and indirectly

Source: STFI Research 2018

4.1.6.1 Industrial Potential of SHIP in India

A MNRE GEF UNIDO study of 25 industries from 2018 assessed the technical and economic market potential of concentrating solar thermal (CST). It is assumed that almost 53% of the temperatures below 100°C can be covered with non-concentrating technologies, while more than 47% can only be covered with CST technologies (operating up to 400°C).[56] The technical potential for CST is 13.18 GWth. However, with restrictions undertaken such as the available space, integration potential and economics, the study comes to a conclusion about an economic potential of 6.45 GWth for the use of CST technologies operating with up to 400°C.[57] When non-concentrating technologies are included, the potential would be 27.8 GWth (technical) and 13.6 GWth (economic potential) for those 25 industries.

The MNRE GEF UNIDO study estimates the CST potential of different sectors:

TABLE 25: Technical and economic potentials of CST in different industries			
Sector	**Technical potential for CST**	**Economic potential for CST**	**Economic potential for CST of total energy demand of industries**
Dairy	60 %	39 %	23%
Food processing / brewery	60 %	41%	25%
Textile	60 %	43%	26%
Pharmaceuticals	30 %	38%	11%
Automotive and Transport	20 %	44%	9%

56 https://open.unido.org/api/documents/12714793/download/india_cst%20_roadmap_2022.pdf

4.2 Conclusions about the Industry Analysis for India

- India has many conventional industries that use low to medium temperatures – particularly dairy and other food and beverage industries, automotive, textile, chemicals, and pharmaceutical industries.
- All of these industries have seen growth in the past years and it can be expected that they will gain importance in the future. Many process steps include very low and low temperature processes – the use of stationary and tracking technologies might thus be a suitable option to produce the needed temperatures.
- Many of these industries use a mix of energy sources including electricity, petroleum products, as well as coal.
- SHIP will be particularly competitive with expensive fuel sources – such as electricity and petroleum products, especially in states with high irradiation such as the north western and central states of India
- There are significant industry agglomerations in parts of the country with good or very good irradiation. Depending on the conventional heater's efficiency and the cost of the conventional fuel, it can be evaluated if any of the solar thermal technologies might be an economically viable option for replacing the existing fuel.
- Considering the assumptions of a recent study by MNRE GEF UNIDO, 13.6 GWth of solar thermal economic potential should exist for 25 relevant industries, of which the five industries analysed in this study form an important share.

CHAPTER 5

PROJECT DEVELOPMENT OF A SHIP PLANT

This chapter briefly explains the most important steps in the planning of a SHIP plant and points out some particularities for India.

5.1 General Process of the SHIP Plant Design

The design of a SHIP plant is a process that goes from a preliminary analysis to estimate the feasibility of the project, and ends with the commissioning of the system. The key steps of the design and planning of a SHIP plant are listed below:[58]

- **Preliminary analysis:** To identify the potential for a SHIP application, based on basic information about the end-users' energy consumption, location, and heat requirements, and current energy costs.
- **Detailed analysis of heat supply and the heat-consuming processes:** This would include information on site conditions – such as available space on the ground or on the facilities' roof, access to general infrastructure including water and electricity networks, and proximity to the integration point or to operation and maintenance activities.
- **System-yield simulation and economic modelling:** Based on the results of simulation, economics of solar systems can be calculated according to full costs of the investment and prices of conventional fuels.
- **Technical and economic viability study:** This identifies the design and integration options of the solar system and defines the technical and economic conditions for the investment to be viable.
- **System engineering:** Including the definition of technical requirements to be considered in the tendering and commissioning stages.
- **Tendering and commissioning:** In this, three aspects should be guaranteed:
    - An objective comparison between different supply offers.
    - The suitability of the equipment and services to be supplied.
    - The quality of the installation and functionality of the system according to the planned operation.
- **Operation and maintenance procedures:** To be carried out either by an external service provider, or internally by a servicing unit for the facilities.

Key aspects of the design and planning process of a SHIP plant are – a comprehensive analysis of the current heat-supply system, the calculation of the effective heat demand, and solar integration. These are explained further below.

5.1.1 Current Heat-Supply System

Heat supply and distribution is usually based on steam boilers, or on other heat-transfer fluids such as hot water, thermal oil, air, and steam. It could also rely on combined heat and power systems or heat pumps.

- **Steam boilers** are the most common heat supply systems in the industry. They feed different processes directly or indirectly through heat exchangers with steam. Steam-driven systems are often used even in processes that occur at low temperatures (T<100°C). They have a higher complexity due to make-up water treatment, condensate recovery, degasification (see Figure 27), and operational requirements. Steam-driven systems have a high energy density that enables smaller diameters and lower heat losses in the heat distribution network, and high heat transfer rates driven by condensation, which results in heat delivery at a constant temperature.

58 Source in bibliography IEA/SHC Task 49 "Solar Heat Integration in Industrial Processes".

- **(Pressurized) hot water** is suitable for low temperatures (T< 100-120°C). It relies on less demanding hot water boilers, but needs higher piping diameters. It also potentially presents higher heat losses in view of higher mass flows and lower energy density.
- **Thermal oil** is suitable for temperature levels of up to 350°C. It relies on thermal oil boilers. Its advantages are a higher operating temperature than usually used in steam-driven systems, as well as lower pressure. Its drawbacks relate to higher cost of heat-transfer media and lower heat capacity compared to water, thus requiring higher mass flows, larger piping diameters and higher heat losses. Thermal oil-driven systems also present specific hydraulic circuit requirements related to safety (for example, prevention of leakage, inflammation/explosion, and toxicity) and operation (gas protection preventing thermal oil oxidation, pre-drying of hydraulic loop before filling).
- **Air** has the lowest heat capacity compared to water or thermal oil. Air-driven systems are used only in direct supply to specific processes – drying or thermal curing chambers. Heat supply relies on hot-air burners rather than on boilers.
- **Combined heat and power (CHP)** or co-generation systems – which simultaneously produce electricity and heat.
- **Heat pumps** can upgrade low temperature waste heat to higher, process-suitable temperatures by way of vapour compression (electricity driven) or absorption (thermally driven) cycles. Electrical resistances may also be used, but are normally used only in smaller systems.

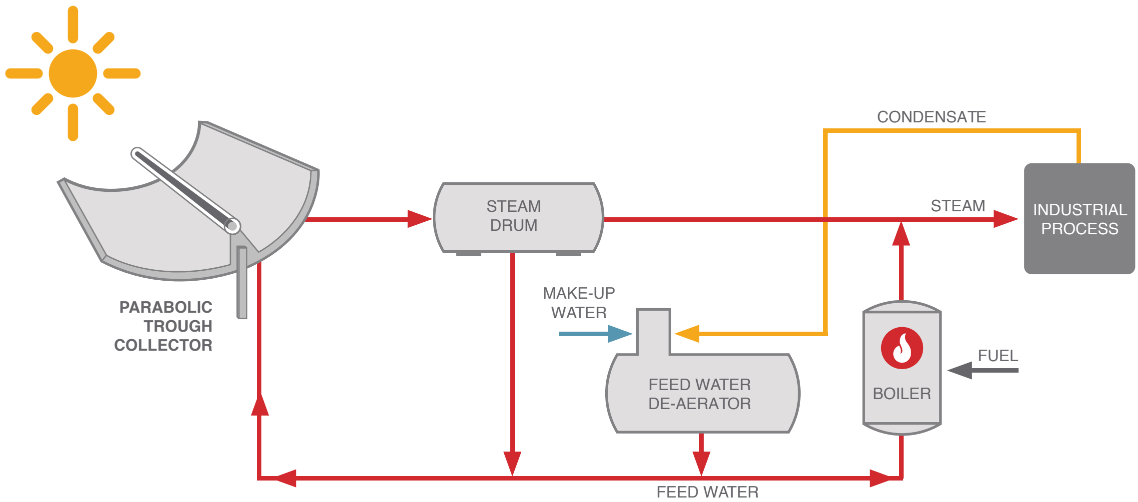

FIGURE 27: SCHEME OF SOLAR HEAT INTEGRATION TO GENERATE STEAM

Source 49: IEA Task 49

In direct solar steam generation, the water is partly evaporated in the concentrating collector and then separated from the remaining water in the steam drum. In indirect solar steam generation, the collector field heats water or thermal oil in a closed circuit to generate steam via a heat exchanger.

In terms of energy sources, heat-supply systems might rely on the use of gaseous, liquid, or solid fuels, besides electricity. The difference in start times required by gaseous/liquid fuel or solid fuel-driven boilers must be mentioned, with the latter requiring longer periods and thus impacting the duration of stand-by periods. A summary of common heat-conversion technologies, heat-transfer fluids and energy sources is presented in Table 26.

TABLE 26: Heat Conversion Technologies vs. Heat Transfer Fluid and Energy				
	Gaseous (gas, biogas)	**Liquid (LPG, oil)**	**Solid (coal, biomass)**	**Electricity**
Steam	Boiler, Combined Heat and Power (CHP) Heat pump			Electrical resistance
Hot water				Heat pump
Thermal oil				
Hot air	Burner			

Source 50: Source: Fraunhofer ISE[59]

5.1.1.1 Effective Heat Demand

The cornerstone of any optimized solar system design is an updated view of the energy-efficiency potential and an estimation of the effective heating demand after possible adoption of energy efficiency measures, including load profiles and heat-supply temperatures.

The dimensioning of the solar thermal system should be based on effective heat requirements, i.e., considering first waste-heat recovery potential – both at heat-supply and process levels. Often, it is possible to identify heat recovery possibilities in most of the industrial sites, either through equipment inefficiencies (such as surface thermal losses, steam leakage) or through the identification of waste streams carrying heat, which can be used directly in the process or in a neighbour processes (exhaust gases, cleaning in place, naturally cooled material streams).

5.1.1.2 Solar Integration

Once effective heating requirements have been analysed, it is possible to identify both the required demands and the temperature at which they occur. The latter is a vital design parameter, as it influences the suitable solar thermal technologies heavily.

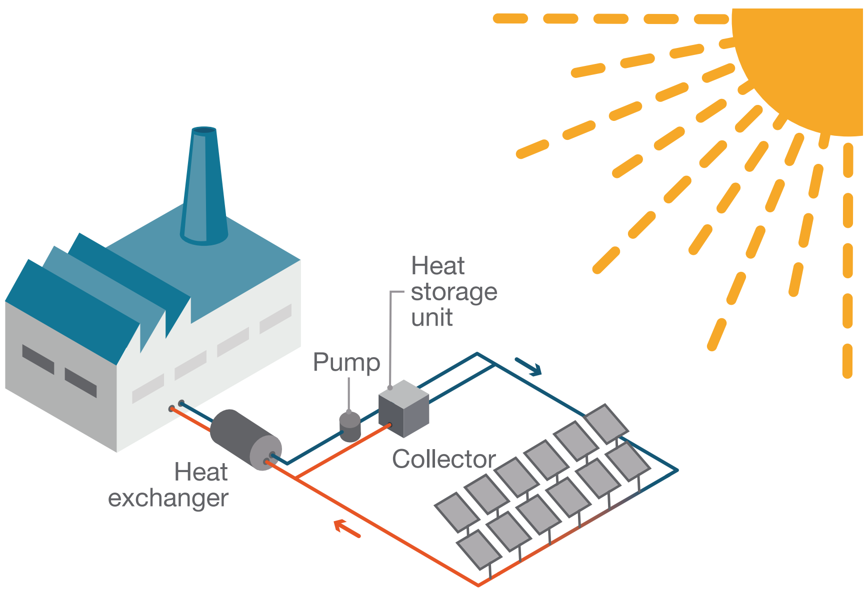

FIGURE 28: SCHEME OF A SHIP PLANT

Source 50: Solar Payback 2017

59 Ben-Hassine, I. et al. 2015. Guideline for solar planners, energy consultants and process engineers giving a general procedure to integrate solar heat into industrial processes by identifying and ranking suitable integration points and solar thermal system concepts. IEA/SHC Task 49/IV, Subtask B, Deliverable B2

The integration of solar heat might occur at two different levels:

Supply level: Solar heat is integrated directly or indirectly at some point of the heat-supply circuit. Integration might occur after a pre-heating approach, before the boiler (pre-heating make-up water, condensate of feed-water), or after a direct or indirect steam generation concept, with integration at the steam line. A supply-level approach usually stands for higher integration temperatures. Integration at the supply level presents the potential for higher solar fractions, but at the expense of higher operating temperatures and lower efficiency on the solar field side, potentially calling for the use of tracking solar collectors.

Process level: Solar heat is integrated in the process, either directly or indirectly via heat exchangers. Heat is supplied at the process temperature, often lower than a conventional heat-supply temperature. Whereas process-level integration presents the potential for lower operating temperatures at the solar field, it faces resistance from end-users, who are often reluctant on direct interactions with their processes. Integration at the process-level requires deep knowledge about process temperature and load profile.

TABLE 27: Comparing Process and Supply-Level Integration Methods

	Process Level	Supply Level
Accuracy of process data (data needed for system design)	High	Medium
Flexibility (in case of process changes)	Low	High
Collector efficiency (efficiency decreases with temperature)	High (for lower temperature processes)	Low (except for heating of boiler makeup-water)
Solar share (solar yield/total heat demand)	Low (restricted to supplied processes)	High
Required storage size (storage increases investment costs)	Large	Small

Source 51: Martin Haagen 2017[60]

60 http://www.pharmtech.com/using-solar-energy-process-heating?pageID=1

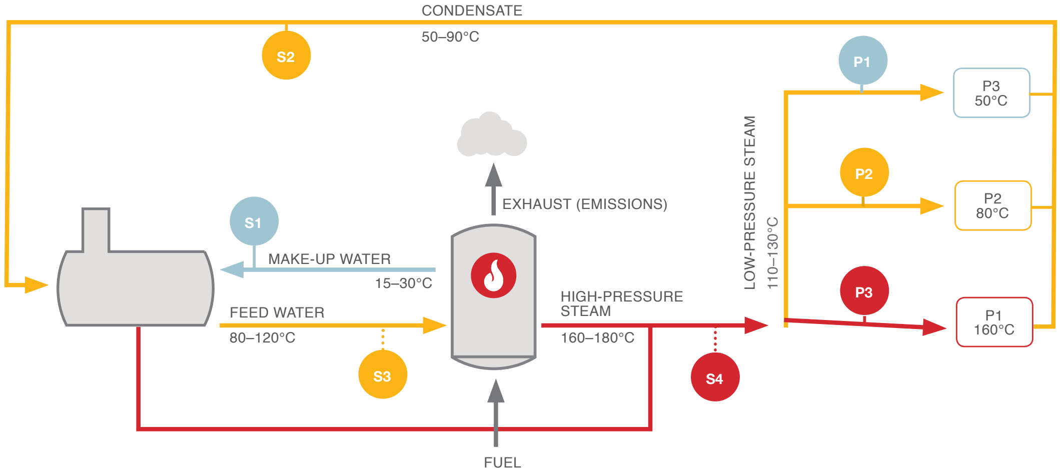

FIGURE 29: POSSIBLE SOLAR INTEGRATION POINTS ON A CONVENTIONAL HEAT-SUPPLY SYSTEM*

Source 52: Fraunhofer ISE

S1, S2, S3 mark three possible integration points for different processes: P1 presenting a process temperature T_P=160°C, P2 with T_P = 80°C, and P3 with T_P = 50°C.

5.2 Structure of a SHIP Project in India

The following list shows different stakeholders in a typical SHIP project:

Beneficiary (heat consumer): The customer, who intends to set up a SHIP project to offset presently high fuel/electricity costs.

Supplier: Manufactures the complete system and maintains it under a stipulated warranty.

EPC contractor: A registered engineering company that installs the complete system. In most cases, the supplier.

Developer: Identifies an industry that can use SHIP systems, obtains the system from the supplier, and gets commissioned from an EPC contractor. Also arranges for finance. Prepares a detailed project report.

O&M service provider: Supplier or EPC contractor who maintains the system for a stipulated period.

Dealer: Network of the supplier and developer in different parts of the country.

Bank / Financial institution: Provides a loan for the project after due diligence. Some also opt for equity participation.

Central/State government agency: Provides grant in aid, if any, as per the available policy.

Development aid agency: Unilateral or multilateral agency that has a country-specific programme to promote and accelerate SHIP technology by providing grant-in-aid or easy financing.

1. Industry suitable for a SHIP project is identified by a developer/supplier/dealer, unless it is in tender-mode – where the end-users are defined

2. Analyse process-heat requirement on daily/weekly/monthly/yearly basis

3. Point of integration including temperature, load profile and access planning. Studying the criticality of storage if desired.

4. Analysis any Energy Audit conducted for energy efficiency – measures suggested. If heat recovery is in place, arrive at the net heat loss suitable for considering a SHIP project

5. Site survey for available space, shading analysis, load bearing, availability of water, appropriateness for installation and maintenance. Planning of collector type based on area and storage.

6. Perform environment, health & safety analysis. Study suitability of Indian Boiler Regulations, if applicable

7. Developer/supplier submits a Detailed Project Report as a Technical and Financial Feasibility. Incentive schemes from central/state government and fiscal benefits from Development Aid Agencies and Banks are included. If any standards are applicable, suitably is included. Simulation of yield in terms of heat + value.

8. Follow-up for negotiation, if any, and order finalisation with advance money. Loan to be arranged by the heat consumer

9. Make an application to the central/state government agency for capital subsidy and Development Aid Agency. Apply for an interest subvention loan from IREDA, if desired.

10. Give delivery period and commissioning schedule.

11. Execute the project and train manpower for maintenance. EPC contractor to maintain the system, as stipulated by guarantees / loan agencies.

FIGURE 30: PLANNING PROCESS OF A SHIP SYSTEM IN INDIA

Source 53: Solar Thermal Federation of India

5.2.1 Operation and Maintenance

The project operation and maintenance is usually bound to be provided for a period of five years by the developer/supplier, unless otherwise specified. In a few cases, developers enter into an annual maintenance contract (AMC). All projects commissioned under the MNRE capital scheme have to be monitored and maintained for five years from the date of commissioning. Banks and financial institutions will mandatorily build in a clause of operation and maintenance until the loan is repaid, to ensure that the project is not a non-performing asset (NPA).

5.3 Process Heat System Integration for India

- Standardised processes for planning, structuring, as well as running SHIP projects exist internationally, and could be applied to Indian industrial companies.
- The development of a SHIP plant requires a thorough analysis of the existing processes, required temperature levels as well as the economic potentials for energy efficiency and waste-heat recovery.
- Integration points for SHIP can be at a supply level, which provides an additional source of heat, usually steam or hot water, for running industrial processes. At the process level, integration of SHIP offers a very accurate provision of heat directly into already existing processes.
- The stakeholders that have to be involved are the Project Owner, the EPC and the O&M contractors, the technology providers as well as the financing bodies.
- In India, the MNRE monitors projects that have been supported with public funds.

CHAPTER 6

ECONOMIC PROFITABILITY OF SHIP SYSTEMS

Within the Solar Payback project, a calculation tool for simple pre-assessment of the technical and financial viability of SHIP systems has been developed. The goal is to facilitate decision makers in industrial companies to make a quick financial analysis of a SHIP plant for their processes. The tool gives information on solar irradiation and solar yield, and can be used before local measurements or simulations.

Once the site, conditions of operations, quantity and type of conventional fuel as well as the project lifetime have been selected, this tool offers a comprehensive range of technical input parameters that enable users with a preliminary evaluation. The tool offers default values that can be adapted. For complexity reasons, five destinations were chosen for the solar yield simulations in each of the four project countries. Users are advised to choose the destination closest to the place where a solar thermal process plant might be considered.

The principal financial indicators of the tool include the **static and dynamic payback time**, **internal rate of return (IRR)**, and the **net present value (NPV**) as well as the **levelized costs of heat (LCOH)**. The results are presented in a list of input parameters as well as in the form of a graph. The tool is accessible on the website **www.solar-payback.com/calculator.**

The Return on investment (ROI) is a performance measure to assess the effectiveness of an investment. A project should be considered for investment if the ROI is higher than another available investment opportunity.

In the context of the study, the tool was used to calculate some individual SHIP plants (fictional) that might be suitable for India. Section 6.1 explains the methodology and the applied parameters, while section 6.2 presents results for the cases given.

6.1 Methodological Considerations

In order to make an appropriate selection, the selection of case studies to be used for the calculations in section 6.2 has to be done thoroughly. The upfront investment costs have a high impact on the economic feasibility of a SHIP project, since interest rates are high in India. Therefore, locally produced components like collectors and tanks should be used. This will also help to avoid the taxes on imported goods. Flat-plate collectors as well as parabolic-trough collectors are the dominating solar collector types in India for larger solar thermal systems. In addition, concentrating dish systems have been used, but are no longer considered state of the art.

Operating temperatures between 30°C and 90°C for flat-plate technologies and slightly higher ones for vacuum-tube collectors are common. For temperatures of up to 400 °C parabolic trough collectors are appropriate. Nevertheless, economics increase with lower temperatures, since cheaper and simpler technology can be used.. As described in Chapters 3 and 4, many industrial production processes can be covered with these temperatures – such as washing and bleaching in the textile industry, retaining in leather factories, pasteurising milk in dairies, cleaning surfaces in machinery production, also, distilling and dyeing in the higher temperature range. This is why sample case studies with vacuum tube collectors and operating temperatures of 75°C are used in Chapter 6.2 as well as an variation example with higher temperatures with a parabolic trough collector with steam at 200°C. The later could be used for drying or dyeing in the textile industry for analysing the impact of different frame conditions on the profitability of SHIP plants for the sample calculations. The explanation serves to outline the usability and understanding of the tool developed in the project.

A limiting factor of many SHIP plants is the available space on the factory site for mounting the collector field. Since Indian companies in SHIP-relevant sectors (food and beverages) are usually small to medium sized, these might prove to be good sample cases for future market exploration. In addition, they usually use oil, gas or biomass, which will increase the competitiveness of solar thermal solutions, since costs are high for these energy sources; however, in biomass, logistics might make its use more complicated.

The available area for the collector field can be mounted on an area of 900 m^2 to avoid shading between the rows. This reflects in an active area of the collector field and is set at 500 m^2 for flat-plate collectors or vacuum-tube collectors and 360 m^2 for parabolic-trough collector fields (which use more space) in the case study calculations.

In the fictional case, the total heat demand in the factory was set at 800 MWhth annually, so that an applied collector field reaches around 50% solar fraction. This is, however, a rather arbitrary value, and other solar fractions are certainly also possible.

At this point it seems good to add a short introduction into the methodology used in the tool. The German Fraunhofer Institute for Solar Energy (Fraunhofer ISE), one of the Solar Payback partners, has calculated the annual solar yield reached with SHIP plants for 4,800 Indian cases, differing in the following parameters:

Five irradiation sites (GHI-values):	Delhi (2.0 MWh/m^2a), Jodhpur (2.0 MWh/m^2a), Ahmedabad (1.9 MWh/m^2a), Nagpur (1.9 MWh/m^2a) and Mumbai (1.8 MWh/m^2a)[61,62]
Conventional Heat Supply Source	Coal, LPG, Electricity, Diesel[63] as INR/tonne steam, INR/tonne, INR/l, INR/Nm^3, INR/MWh
Thermal conversion efficiencies	Between 100% and 50%
Daily production operation modes	Three in the factory: daytime, night time, continuous
Production operation modes	Two weekly in the factory: Five days per week and seven days per week
Annual production operation mode	12 months continuously or 1 month stoppage (for holiday etc.)
Four collector technologies	Flat plate, evacuated tube, parabolic trough, Linear Fresnel [64]
Average collector operation temperatures	50, 75, 100, 150 or 200 °C
Storage volume per m^2 collector area	25 to 100 l

Users of this tool can carry out economic and financial pre-assessments based on these default yield values, without running a technical simulation of the planned SHIP system. All the several thousand solar yields were calculated with a solar fraction of 50%, to make them comparable with one another. That is why, even for the economic feasibility calculations in chapter 6.2, a solar fraction of 50% is assumed.[65] For all parameters, users can either choose one among the given values (e.g., factory site or collector) or insert their own values.[66]

61 GHI-Values for non-concentrating technologies. DNI-values are Delhi (1.9 MWh/m^2a), Jodhpur (1.9 MWh/m^2a), Ahmedabad (1.8 MWh/m^2a), Nagpur (GHI - 1.9 MWh/m^2a / DNI 1.6 MWh/m^2a) and Mumbai (1.4 MWh/m^2a)

62 Due to complexity, only 5 major regions could be used per Solar Payback country. Users from other areas can either try to employ the most similar irradiation zone, or use their own values.

63 Eventually, the default prices are given (researched in 2017), and can be replaced by other values per unit if another heat source at different costs is being used.

64 Dish systems are common in India, but currently most new concentrator systems are installed with parabolic-trough technologies. Thus, these systems were not included in the calculator.

65 For complexity reduction reasons, a number of restrictions had to be introduced.

66 If the users know irradiation values and collector yield for the site that they wants to analyse, they can insert those values in the tool.

TABLE 28: Description of the Case Study Parameters Cases 1+2[67]		
Parameters	**Case 1**	**Case 2**
Factory site	Nagpur	Nagpur
Used collector type	Vacuum tube	Parabolic trough
Average operation temperature	75°C	200°C
Supplied processes	Washing, bleaching, re-tanning, pasteurising, and cleaning	Steam production / distilling
Estimated solar resource (in Nagpur) (MWh m^2 / year)	1.86 (GHI)	1.64 (DNI)
Estimated annual energy consumption	800 MWhth/year	800 Mhth/year
Estimated annual final energy consumption at 80 % efficiency (MWth/year)	640 MWth/year	640 MWth/year
Necessary space for mounting the collector field	900 m^2	900 m^2
Active collector area	500 m^2	360 m^2
Specific solar collector yield in the area given (MWth/m^2)	0.73	0.75
Specific thermal storage volume	25 litre / m^2 collector area	25 litre / m^2 collector area
Thermal storage volume (according to l/collector area) in m^3	12.5	9
Production profile in the factory	Daytime, 7 days a week, continuous over the year	Daytime, 7 days a week, continuous over the year
Moderate thermal conversion efficiency of existing heat supply system	80%	80%
Estimated annual final energy consumption at 80 % efficiency (MWth/year)	640 MWth/year	640 MWth/year
Estimated annual solar yield of the system	363 MWhth/year	268.9 MWhth/year
Estimated solar fraction (for energy demand)	76%	42%
Complexity correction factor of the system (0.8 to 1.5)	Somewhat complex = 1	Somewhat complex = 1

Source: Financial Tool in Solar Payback 2018

Net end-consumer price per m^2 collector area including hydraulics and installation	INR 14,923/m^2 *[68]	INR 39,800/m^2
Net end-consumer prices for water storage tank (above 3 m^3)*[69]	INR 101,400 /m^3	INR 101,400 /m^3

Based on technical parameters (summarised in Table 28) the tool calculates the total investment costs of the SHIP installation. These are based on specific net collector field and storage tank prices, including installation, which were researched by questioning Indian solar thermal manufacturers in 2017.

67 All values (such as costs) can be adapted, with the exception of solar yield values for different sites. Results that are automatically given are marked in blue.

68 *The specific collector price was identified by a survey among Indian solar thermal manufacturers. The final price depends on the complexity of the system. It ranges from simple, with certain deductions, to highly complex, which makes overall installations more expensive. The default value is “somewhat complex” = 1

69 **The specific storage tank price is set at 1300 EUR/m^3 for a tank above 3 m^3, which was converted with 1 EUR = INR 78 in the tool.

6.2 Economic Calculations of Case Studies under Certain Frame Conditions

6.2.1 Application of the Tool on the Example[70]

In this chapter, the tool is used to assess the economic feasibility of the case study defined in Chapter 6.1, CASE 1, which is 900 m² available roof space, onto which a 500 m² flat plate collector system supplying hot water of 75 °C that could be used in a dairy, leather factory or metal processing plant can be installed. The alternative CASE 2 is a parabolic trough collector at 200°C, which, on the same roof area, will add up to 360 m² of aperture area. Table 29 summarises additional parameters set for this reference case. Diesel is used in the "fictive" factory with an estimated energy price of INR 5,635/MWh.[71]

TABLE 29: Technical Parameters for the Basic Case Study Calculation

Technology	Case 1: Vacuum Tube Collector	Case 2: Parabolic Trough Collector
Annual medium irradiation potential as in Nagpur	1.9 MWh/m² / GHI	1.6 MWh/m² / DHI
Energy source for current heat supply system	Diesel	Diesel
Average price for current energy source	INR 5,635 /MWh	INR 5,635 /MWh
Daily production profile in the factory	Daytime	Daytime
Weekly production profile in the factory	Seven days a week, continuously over the year	Seven days a week, continuously over the year
Average collector operation temperature	75 °C	200 °C
Storage size per m²collector area	25l	25l
Energy inflation rate per year, over 20 years	10.5 %	10.5 %
Investment / technology lifetime	20 years	20 years
Annual O&M costs	1% of CAPEX	1% of CAPEX
Subsidy	None	20%
Corporate tax rate	30%	30%

Source: Assumptions Solar Payback 2018

TABLE 30: Technical Summary

Parameter	Case 1: Vacuum Tube Collector	Case 2: Parabolic Trough Collector	Unit
Estimated solar source	1.86	1.64	MWh/(m² year)
Estimated annual final energy consumption	640	640	MWhth/year
Solar collector type	Evacuated Tube	Parabolic Trough	
Specific solar collector yield	0.98	0.75	MWhth/(m² year)
Average collector operation temperature	75	200	°C
Specific thermal storage volume	25	25	l/m²collector
Collector aperture area	500	360	m²
Thermal storage volume	12.5	9	m³
Estimated annual solar yield	488.5	268.9	MWhth/year
Estimated solar fraction	76	42	%
Estimated avoided emissions	155.1	85.4	tonne $CO_{2,eq}$/year

Users employing the online tool would have to fill in these values to make an estimation of the costs of SHIP. Based on simulations and default values, users will either have to choose a default value or insert their own values. Once all technical and financial values have been filled in, users will receive an overview of all the parameters they inserted, or the ones that have been calculated according to the settings.

70 All values such as costs etc. can be adapted, with the exception of solar yield values for different sites.

71 Costs may vary; the values used for the sample calculations were taken from an analysis made in 2017. For more current figures, please consult https://www.mypetrolprice.com/diesel-price-in-india.aspx. In the tool, these values serve as default ones, but can be replaced by more accurate values.

The financial data for the investment is then displayed in an overview of financial parameters. Here, default values have been taken, but users can always insert their own values (for example, values such as energy or system costs).

TABLE 31: Financial Parameters CASES 1+2 Nagpur (simplified overview)

Parameter	Case 1: Vacuum Tube Collector	Case 2: Parabolic Trough Collector	Unit
Total investment costs*	8,889,125	12,192,660	INR
Total investment costs including margin*	28,439,093	16,003,860	INR
Heat production costs (current or target, current prices)**	7,044	7,044	INR/MWhth
Residual value	0	0	INR
Total annual O&M costs*	88,891	121,927	INR/year
Non-refundable investment subsidy	0	2,438,532 (20 % for CST)	INR
Non-refundable operative subsidy*	0	0	INR/year
Avoided emissions revenues*	0	0	INR/year
Investment lifetime**	15	15	years
Debt 0**	0	0	INR
Equity (100 %)**	28,439,093	16,003,860	INR
Effective cost of capital (COC)	14.7	14.7	%
General inflation rate per year over the investment life time*	5.2	5.2	%
Energy inflation rate per year over the investment life time *	10.5	10.5	%
Corporate Tax Rate*	30	30	%

Source 54: Solar Payback Investment Tool
*Based on default values; ** Chosen values

TABLE 32: Investment Assessment results: CASES 1+2 Nagpur (simplified overview)

Parameter	Case 1: Vacuum Tube Collector	Case 2: Parabolic Trough Collector	Unit
Project IRR	43.2	24.2	%
Equity IRR (given input: 14.7%)	14.7	14.7	%
Simple payback	1.6	4.7	years
Discounted payback	2.4	9.2	years
Current LCOH	13,412	13,412	INR/MWhth
Solar LCOH	6,666	11,023	INR/MWhth

Source 55: Solar Payback Investment Tool

In Table 32, users find an overview of financial results per case. Here, key data for the economic assessment of the investment are displayed, of course taking into account the above parameters. Results can then be displayed in graphics of cash flows.

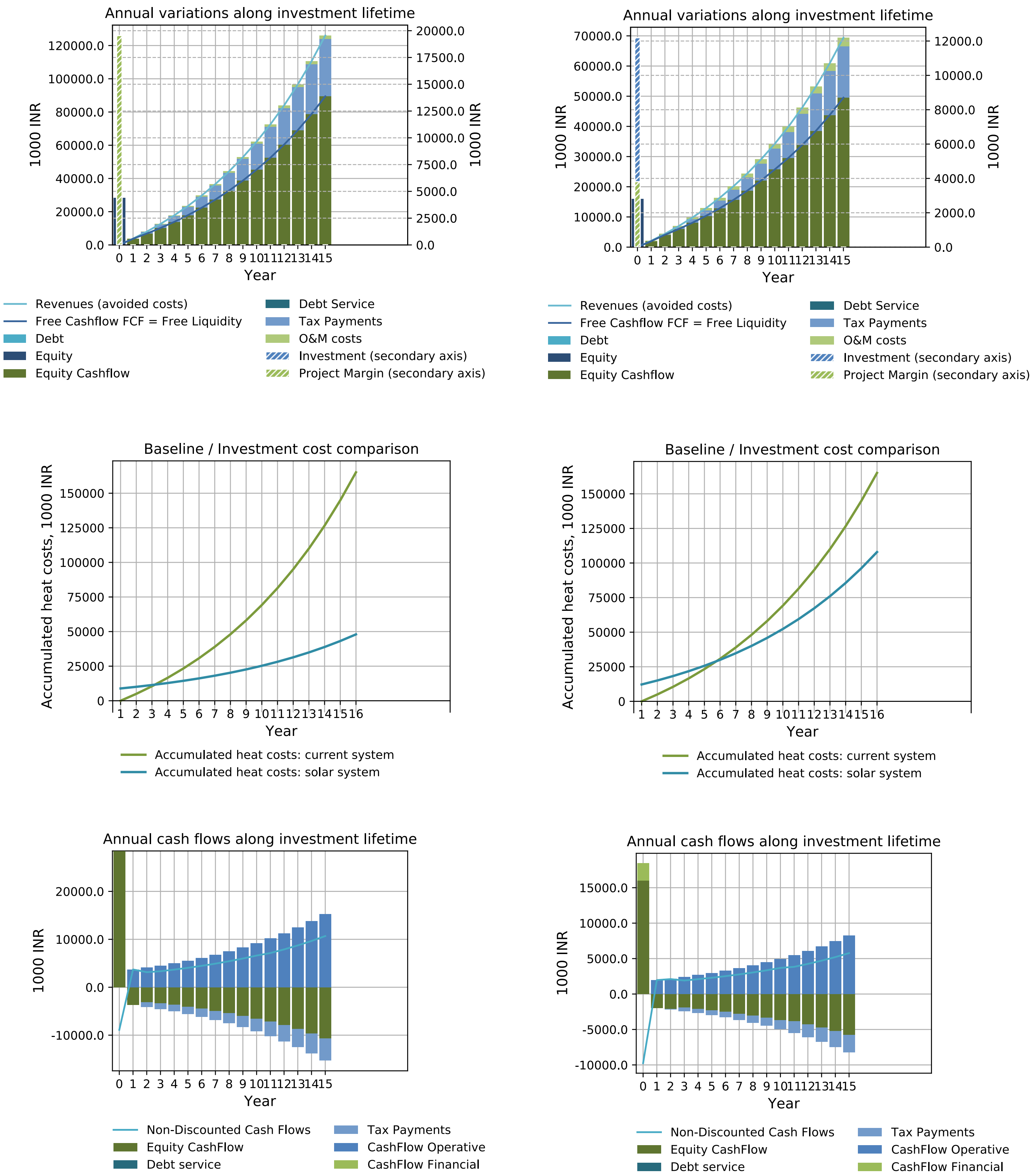

FIGURE 31: TABLE OF CUMULATED CASH FLOWS FOR THE ASSUMED CASE 1 / CASE 2 NAGPUR

Source 57: Solar Payback online tool

6.2.2 Discussion of results

Under the given circumstances, both systems are profitable, though there are striking differences, both in simple as well as discounted payback periods; these periods are between 1.4 and 4.7 years for simple, and 2.9 to 9.4 years for discounted. Among the five selected cities in the tool, Nagpur has the second-weakest direct irradiation. This affects the profitability of the parabolic-trough collectors that need direct irradiation to produce high temperatures. Despite a 20% upfront subsidy, costs of parabolic troughs are considerably higher per m^2 installed capacity and they require more space than flat-plate collectors, thus less aperture area can be set up. In addition, the lower direct irradiation leads to only little more heat production per m^2 than with vacuum tube collectors, though at a different temperature level. Nevertheless, other frame criteria would make the case attractive, especially an unrealistic assumption of 365 days of daytime production, which would not require storage or consider maintenance processes or vacations. In addition, it can be said that the assumed energy inflation level over 15 years of 10.5% per year is a relatively high value over such a long period, and should be cross-checked with assumptions and the experience of the investor.

Variation a) of irradiation

The same fictional factory case is transferred to the Delhi region; it has considerably higher direct irradiation than Nagpur, but all other frame conditions remain equal. As assumed, the higher direct irradiation increases the profitability of the parabolic-trough system especially, while the economics of the vacuum-tube collector system improves only slightly – as shown in Table 33.

TABLE 33: Financial Results CASES 1a+2a – Variation on Irradiation – Delhi Region

Parameter	CASE 1a VTC	CASE 2a Parab. T.	Unit
NPV project margin	21,072,387	6,228,807	INR
Project IRR	45.9	27.4	%
Equity IRR (given input: 14.7%)	14.7	14.7	%
Simple payback	1.4	4.1	years
Discounted payback	2.2	7.5	years
Current LCOH	13.412	13.412	INR/MWhth
Solar LCOH	6475	10.048	INR/MWhth

Source 58: Assumptions Solar Payback 2019

Variation b) of cases 1a+2a – Lower energy inflation rate

Provided that the energy inflation over 15 years is much lower than assumed, for example if it is not 10.5% per year as assumed in the default value, but 5.21% (in line with general inflation), then, with all other parameters being equal, in the case of Delhi (a), the financial results will be less favourable. The variation indicates that although the project is profitable in general terms, many companies might not invest since the acceptable pay-back time of the investment is very close to five years or higher for parabolic trough technology (2b). Thus, investors might look for other investment opportunities. Investors that just rely on low temperatures would still find it attractive to invest, as indicated in Table 33.

TABLE 34: Variation b) of Cases 1a+2a – Lower Energy Inflation			
Parameter	CASE 1ab VTC	CASE 2ab Parab. T.	Unit
NPV project margin	12.871.430	1.229.426	INR
Project IRR	39.1	21.5	%
Equity IRR (given input: 14.7%)	14.7	14.7	%
Simple payback	1.7	4.9	years
Discounted payback	2.6	11.1	years
Current LCOH	9.558	9.558	INR/MWhth
Solar LCOH	5.326	8.894	INR/MWhth

Source 59: Assumptions Solar Payback 2019

Fuel Price Variations

It is obvious that the comparison with the conventional fuel diesel in the given case leads to favourable results. If the conventional fuel is a more expensive source of heat, such as industrial electricity, it should be a lot easier to reach high net-present values and short pay back times. On the other hand, comparison with a very cheap fuel source such as coal or LPG will make it difficult to reach profitability at all, or at least acceptable NPVs or payback times.

Other Variations

It becomes obvious that all parameters should be considered while making an investment decision. Nevertheless, those parameters that tend to multiply over the years due to compound growth rate are particularly relevant for the assessment of a project over 10 to 20 years. As such, the assumed energy inflation rate is particularly very important.

Positive effects for profitability of the SHIP system are related to:

Technical aspects:

- High irradiation.
- Low process temperatures, which allow the use of cheaper and less sophisticated effective and simple collector solutions.
- High coincidence of heat demand and solar heat production, small storage needs, as well as short stoppage times; for example, day-time production at 7 days a week.
- Inefficient conventional boiler processes, which waste a lot of energy.
- Low complexity of integration.
- A lot of available unshaded space or roof area.

Financial aspects:

- High conventional energy costs (for e.g., electricity or diesel)
- High energy inflation rate
- Low system and maintenance costs
- Low costs of capital and/or low interest rates, below or much below the cost of equity.
- Financial support for the installation and operation; or funds/payments for the reduction of greenhouse gases.

Awareness of these factors can lead to a pre-assessment of the overall economics of a SHIP-project, which would then facilitate the application of a pre-feasibility tool for further evaluation.

6.3 Conclusions

- The Solar Payback Tool for economic analysis allows the calculation of Key Performance Indicators (KPIs) based on thousands of solar yield calculations for different Indian SHIP case study sites and pre-defined default values.
- Simple Payback Period (SPP) and a project's Net Present Value (NPV) are used to compare the economic profitability of different technologies and operational variants.
- The reference case is a 500 m^2 vacuum-tube collector system that supplies hot water at 75°C to a dairy, leather factory, or metal-processing plant for bleaching, washing, re-tanning, pasteurising and cleaning, which is a rather favourable economic application. The alternative case of a parabolic-trough collector field of 360 m^2 that provides steam at 200°C is economically a lot more challenging. For the choice of technology, it is very important to evaluate temperature demand and the irradiation level at the site of the installation.
- Higher the utilisation rate of the SHIP system, better the economic results.
- Substituting the conventional diesel fuel with the SHIP reference plant is economically profitable under many frame conditions, though it reveals that lower temperatures imply considerably lower SHIP costs, which makes its usage much more attractive. Substitution of electricity by SHIP, which has even higher MWh costs, will also be economically attractive in many cases. Substituting LPG needs higher solar irradiation, but might lead to acceptable pay back times as well. It is very difficult to substitute coal, which has a very low cost.
- It is very important to define assumption about energy costs development very well, in order to have a realistic assumption of future expenses for conventional fuels, which are the benchmark for a levelized heat cost.
- A paradigm-shift away from investment decisions mainly on short SPP (below five years) towards considering the cumulated savings over a 15- to 20-year technology period – the lifetime of the SHIP plant – will increase the number of SHIP variants that will be economically profitable. Nevertheless, SHIP will compete with other investment opportunities in the core business of the enterprise, which also could have attractive economic benchmarks.

CHAPTER 7
CONCLUSIONS

The industrial sector's energy consumption is responsible for close to 57% of India's total energy consumption.[72] Coal, fuel oil, and natural gases largely account for energy sources; seldom, it is electricity. Industrial heat is characterised by a wide mixture of temperature levels, pressures, and production processes to meet process demands.

According to the Ministry of Statistics and Information, Government of India, the country imported 219.4 million metric tonnes of crude oil during the fiscal 2017-18, and this is projected to rise by about 20% in 2018-2019. Energy demand of the industrial sector accounted for almost 40% of the imported crude oil, out of which around 40 million metric tonnes provided thermal energy at temperatures below 150°C.[73]

Different types of solar thermal technologies can produce a range of temperatures between 50°C and 400°C, which can be used to offset heat demand in a variety of thermal applications. Offsetting electricity, furnace oil, diesel, and other petroleum products such as LPG and natural gas results in a payback period of 2-4 years, while for coal, biomass, or wood, the payback period is higher and might reach 5-7 years. A first estimation for five exemplary Indian regions with comparable climates could be calculated with the Solar Payback tool, which can give an indication for the economics of different use cases of SHIP.

As per STFI estimations, if right policies are in place, and capital subsidy applications are processed speedily, then an annual target of even 100,000 m^2 collector area is achievable. Metal processing in automobile industries and dairy processing have already established as feasible markets. Pharmaceutical, food processing, brewery and textiles are the other promising sectors.

The GEF-UNIDO CST road map study reveals the market potential in India as 6.45 GWth, as against the net energy input of 200 GWth by all industries from fuel oil. This market is worth tackling.

7.1 Recommendations for investors and the solar industry

Following are some recommendations based on the existing policy framework and cost assumptions – for development of and investment in SHIP:

7.1.1 Market drivers of SHIP in India

Capital subsidy, easy financing, social commitments and the need to offset the use of fuel oil are drivers for SHIP projects in India. Presently, the following two incentives are available for any SHIP project:

Capital subsidy

MNRE will continue its policy to support concentrated solar thermal systems of 90,000 m^2 for community cooking, process heating, and cooling, until fiscal 2019-20, with capital subsidy of 30% of benchmark cost or actual cost, whichever is less (60% in special-category states).

Interest subvention

The ongoing GEF-UNIDO offers interest subvention of 5% for loans taken for SHIP projects. Nevertheless, tedious paperwork, stricter bank guarantees, and a minimum loan amount of INR 10 million limits project sizes. While a subsidy is helpful, the bureaucracy is exhausting.

72 http://mospi.nic.in/sites/default/files/publication_reports/Energy_Statistics_2018.pdf

73 http://mospi.nic.in/sites/default/files/publication_reports/Energy_Statistics_2018.pdf

Desirous end users prefer existing banks for obtaining such loans, as it is easier for them to receive loans based on their banking relationships.

7.1.2 Policy Recommendations

Renewable Energy Service Companies (RESCOs)

RESCOs offer great potential for market development as end users are assured of reliable performance and relieved of high capital investments. For popularising RESCO, awareness is key, and sharing successful case studies and evidence of working concepts with bankers/financial institutions is important.

Renewable Heat Obligation

An obligatory policy measure in process industries with high heating needs, which will act as a driver, could drive the market hard. Historically, mandatory targets were major drivers for solar PV commercialisation. Likewise, a framework for *renewable heating certificates* based on kWth generated and converted to equivalent kWh should be constituted. MNRE must formulate a policy to develop solar heating obligation, much like renewable purchase obligations, and allow trading of solar heating energy through certificates.

Performance-Based Incentive

Lack of standardisation is providing liberty to developers to build their own technologies. Since the present subsidy scheme is linked to installed area, its relative performance has negligible significance. It is highly recommended that MNRE makes standards mandatory and lists indigenous testing labs. If this happens, only select technologies that perform as per standards will receive unit-based incentives, instead of upfront capital subsidy. Those systems that give better performance will receive higher incentives. Industries using fossil fuels for heating should be subject to a green cess. Each unit of fuel oil saved could be incentivised.

7.1.3 Other Recommendations

Capacity Building with Certified Energy Auditors/Managers

Energy Auditors/Managers are the backbone of promoting energy efficiency. There are now over 1,000 Certified Energy Auditors/Managers, but very few are aware of SHIP technologies and their advantages. They can be bound with targets, and the best-performing ones can be rewarded.

Making Use of Social Media and Creating a Helpline

Digital social media (such as Facebook) and messaging and print media has emerged as very strong in India; it is the driving force for business development. Various marketing agencies have identified digital video marketing as a relevant tool for creating awareness. Due to the vastness of the country, this mode is economical and can reach the very last customer. As an extension to this media, an industrial helpline should be operated to educate SHIP consumers. A one-to-one interaction vastly helps to promote an understanding of the real problem and for recommending a solution.

Integrating SHIP in BEE and PCRA activities

BEE and Petroleum Conservation Research Association (PCRA) are the premier Indian institutions promoting energy efficiency. BEE operates a mandatory energy efficiency improvement scheme of PAT for large, energy-intensive industrial sectors (designated consumers) and incentivizing them suitably through tradable certificates. Additionally, PCRA conducts a series of awareness workshops in industries on energy saving through its network of professionals and certified energy auditors and managers. They can be the best ambassadors to generate awareness on SHIP and support rapid scaling up.

7.1.4 Summary of Recommendations

- Create demand worth 100,000 m^2 annually through tenders from large scale PSUs and identified potential industries.
- Encourage the RESCO model as it ensures proper life-cycle operation.
- Renewable Heat Obligation (RHO) policy should be framed.
- Mandatory standards should be implemented on PRIORITY.
- Subsidy should be linked to the performance equivalent of MWth (or MTOE averted). Claimed output can be correlated to the DNI of the region. Underperforming system owners/ installers can be reprimanded or penalized.
- Special mention about solar thermal heating in PAT curriculum of BEE and involve PCRA in generating mass awareness through their industrial activities. Conduct capacity building workshops for certified energy auditors.

ABBREVIATIONS

ACMA	Automotive Components Manufacturers Association of India
AMC	Annual Maintenance Contract
ASI	Annual Survey of Industries
BCM	Cubic Meters
BCM	billion Cubic Meters
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
CAGR	Compound Annual Growth Rate
CASE	Commission for Additional Sources of Energy
CBM	Coal Bed Methane
CHP	Combined Heat and Power
CPC	compound parabolic concentrators
CSH	Concentrating Solar Heat
CST	Concentrating Solar Thermal
DCs	Designated Consumers
DNES	Department of Non-Conventional Energy Sources
DNI	direct normal irradiation
DNI	Direct Normal Irradiance
ESCerts	Energy Saving Certificates
FDI	foreign direct investment
GDP	gross domestic product
GEF-UNDP	Global Environment Facility
GHGs	greenhouse gas emissions
GHI	global horizontal irradiation
GNI, PPP	(current international $)
HFO	Heavy Fuel Oil
HTST	high temperature short time
IEA	International Energy Agency
IREDA	Indian Renewable Energy Development Agency
IRR	Internal Rate of Return
JVs	joint ventures
KPIs	key performance indicators
LCOH	Levelized Costs of Heat
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
m^2	square metres
MMSCMD	Million Metric Standard Cubic Meter per Day
MNES	Ministry of Non-Conventional Energy Sources
MNRE	Ministry of New and Renewable Energy
NISE	National Institute of Solar Energy
NPA	non-performing asset
NPV	Net Present Value
NSM	National Solar Mission
OMC	Oil Marketing Companies
PAT	Perform Achieve and Trade
P-IRR	Project Internal Rate of Return
PSUs	Government-owned public sector undertakings
PV	photovoltaic
PwC	PricewaterhouseCoopers
ROI	Return on Investment
SECI	Solar Energy Corporation of India
SHIP	Solar heat for industrial processes
SPP	Simple Payback Period
STFI	Solar Thermal Federation of India
TCF	Trillion cubic feet
TERI	The Energy Resources Institute
UNIDO	United Nations Industrial Development Organisation
USD	United States Dollar
WACC	Weighted Average Cost of Capital

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