EVALUATING RENEWABLE THERMAL ENERGY OPTIONS FOR TEXTILE AND GARMENTS SECTORS IN BANGLADESH AND PAKISTAN

PREFEASIBILITY STUDY

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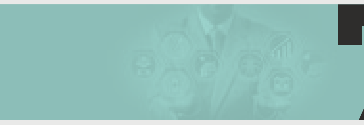
CONTENTS



List of Tables

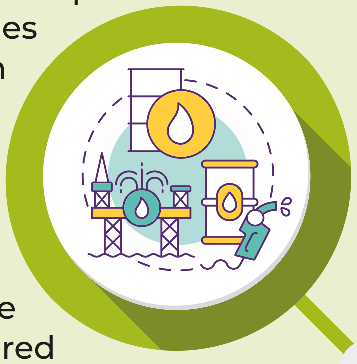
List of Figures

List of Abbreviations

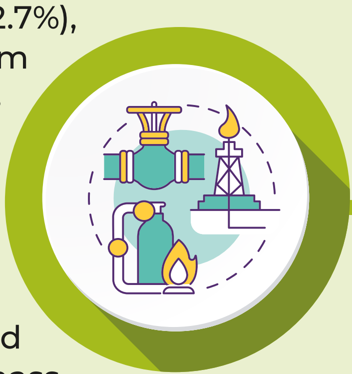
BAF	Biogenic Accounting Factor
BDT	Bangladesh Taka
BMZ	Federal Ministry of Economic Development and Cooperation
CFBC	Circulating Fluidized Bed Combustion
FABRIC	Fostering and Advancing Sustainable Business and Responsible Industrial Practices in the Clothing Industry in Asia
FBC	Fluidized Bed Combustion
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GHG	Green House Gas
GHI	Global Horizontal Irradiation
GWP	Global Warming Potential
IRR	Internal Rate of Return
LNG	Liquefied Natural Gas
NG	Natural Gas
NPV	Net Present Value
MJ	Mega Joule
MWh	Mega Watt Hour
RCR	Residue to Crop Ratio
RLNG	Regasified Liquefied Natural Gas
PKR	Pakistani Rupee
TPH	Tonne per hour
USD	United States Dollars

1 BACKGROUND

Bangladesh's energy production is primarily dependent on fossil fuels. Conventional fuel energy generation contributes to greenhouse gas (GHG) emission. Alternatively, renewable fuel - biomass fuel-based energy generation is considered to low the emission of carbon dioxide by substituting the use of fossil fuel. In the country, biomass fuels (such as rice straw, rice husk, leaves, bark, roots, branches, wood processing residues and dung cake) are predominantly used for cooking and small-scale agriculture in rural areas. Some crop residues are also used as a source of energy in agro-industries such as rice and sugar mills. However, biomass is missing in industries such as textile and garments. The Bangladesh textile and garments supply chain depends mainly on the natural gas-based onsite generation which is 90% to 97% of total energy consumption; followed by 1%-7% from the national grid, 1%-2% from on-site diesel generation and 0.1% from solar energy. Bangladesh is also importing LNG since 2018 to convert diesel-based power generation to gas fired power generation.[1]



Pakistan's energy production also primarily depends on fossil fuels; mainly Natural Gas (34.6%), Oil (31.2%), Coal (12.7%), LNG (8.7%), Hydro (7.7%), and remaining from Nuclear and other renewables[2] . Bio-mass is predominantly used in uses other than energy except for Bagasse which is used by sugar mills internally for combined cycle power plants or low-pressure steam generation. Private sector is showing healthy interest in Solar PV and many textile factories have initiated the projects of Solar PV installation. Bio-mass, however, is rarely being used for energy generation in textile and garment sector due to limited supply, price fluctuations and operational challenges.



Within the fashion industry and its consumers, there is a heightened awareness about the environmental impact of garment production. Major fashion brands are embracing their consumer's concerns relating to the climate agenda. H&M has been at the forefront of setting ambitious climate related goals and strives to be climate neutral by 2030 and climate positive by 2040. Existing efforts to drive down GHG emissions in Bangladesh and Pakistan relate to energy efficiency and solar power. In addition to these, renewable fuelled boilers have been identified as a new area of work that could have a significant impact on overall GHG reductions in the supply chain. At present, on average, boilers consume 51% of the total energy in H&M supply chain. The environmental impact of this may be significantly reduced by a conversion to biomass sources to fuel boilers. Although this is uncommon in Bangladesh and Pakistan, it is prevalent at a significant scale in H&M's other production markets such as India and Cambodia.

1.https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/012221-bangladesh-aiming-to-boost-lng-imports-by-a-third-in-2021-via-spot-purchases-official
2. Chapter14-Energy.pdf (finance.gov.pk)

This is aligned with the objectives of the GIZ and its regional project Fostering and Advancing Sustainable Business and Responsible Industrial Practices in the Clothing Industry in Asia (Called FABRIC in short). GIZ is an enterprise owned by the Government of the Federal Republic of Germany and provides services worldwide in the field of international cooperation for sustainable development and international education. GIZ is mainly commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ). GIZ's regional project FABRIC is being implemented in Bangladesh, Cambodia, China, Myanmar, Pakistan and Vietnam by German Development Cooperation (GIZ). FABRIC is addressing sustainability in the textile and garment industry in its social, economic and environmental dimensions, supporting knowledge exchange and sharing of good practices in the textile and garment industry in Asia. Through its project activities, FABRIC supports the textile and garment industry in Asia to reduce GHG emissions, thereby contributing to the global climate agenda.

The partner is H&M Puls Trading Far East Ltd. Bangladesh Liaison Office. H&M as Swedish fashion Apparel Buyer is one of the significant apparels buyers in Bangladesh and Pakistan. As a responsible retail H&M is leading many sustainability efforts along with different stakeholders in Bangladesh and Pakistan.

GIZ FABRIC is supporting H&M in conducting the study on replacing fossil fuel based thermal generation with renewable fuel (biomass, biofuel) in textile and garments sector in Bangladesh and Pakistan. The goals of the study are to identify potentials to reduce the GHG emissions with the focus on renewable energy resources. This includes two separates, sequenced but linked phases:

Phase-1:

To conduct a pre-feasibility study on renewable fuel market and identify alternative renewable sources for boilers or thermal application replacing fossil fuel in textile and garments sectors of Bangladesh and Pakistan.

Phase-2:

To conduct a detail study on the most relevant and suitable renewable fuel source to use in boiler operation in the industry.

A consortium of consulting companies; adelphi consult of Germany taking the lead, and one consulting company from each of the three partner countries (Espire Consult in Pakistan, RCB in Bangladesh and TUV Rheinland in Vietnam); support GIZ for implementation of the environment component of the project; and also, to conduct this study.

2
ACKNOWLEDGEMENT

The teams of GIZ, adelphi consult, RCB and Espire Consult in Bangladesh and Pakistan supported the expert in collecting primary and secondary data and information and also contributed to the report with their expert opinion. GIZ FABRIC and REEEP team in Bangladesh have been instrumental in gathering data and information from Bangladesh market. Many reports and studies provided by GIZ REEEP were consulted in this study, which have provided significant insights to expert on the subject.

H&M team have provided extensive support in gathering market studies as well as information from the suppliers in Bangladesh and Pakistan.

Bangladesh Auto Major and Husking Mill Owners Association supported in assessing the rice husk supply and demand as well as in understanding the market dynamics.

Highly useful data and technology updates were provided by **Thermax Bangladesh** and **SK Industrial Concern Pakistan** without which the report would be incomplete.

The expert and team are extremely thankful to ten factories in Pakistan and Bangladesh for sharing the data and experience on using bio-mass boilers and solar water heaters.

Special thanks to **Dr. Shoeb Ahmed** from Department of Chemical Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh for sharing the research paper on “Systematic assessment of the availability and utilization potential of biomass in Bangladesh”; which provided important insights in the supply and demand of the bio-mass in Bangladesh.

3 EXECUTIVE SUMMARY

This prefeasibility study on replacing fossil fuel based thermal generation with renewable fuel in textile and garments sector of Bangladesh and Pakistan assesses the suitability and technical viability of using (i) Bio-mass for generation of steam replacing natural gas, and (ii) solar water heaters to heat up process water instead of using steam.

Various types of bio-mass are available in Bangladesh and are being used in industrial sector for steam generation purposes; however, domestic cooking has major share in the consumption. Analysis of supply and demand of bio-mas is provided in the report but is based on the data from 2015. Latest data on supply chain of bio-mass is not available. Bio-mass in Pakistan is mainly used for purposes other than energy generation except for Bagasse which is used by the sugar mills themselves for energy generation. Due to limited willingness of farmers and industry to sell bio-mass for energy generation, the amount of bio-mass residue is not very significant and thus industry is generally driving away from using bio-mass. In summary, there is not enough surplus bio-mass available in both countries to drive a major shift towards replacing fossil fuels with Bio-mass.

Various technology options are assessed in the report and their suitability for different kinds of bio-mass fuels are suggested. The selection of bio-mass fired boiler depends on the bio-mass to be used as fuel and the variety of bio-mass as well. Generally, for rice husk and other small particle sized bio-mass, fluidised bed combustion (FBC) or circulating fluidized bed combustion (CFBC) are preferred due to high system efficiency and better emission control. Reciprocating Grate (Chain or Step Grate) may also be used in such cases when lower investment is planned, however; later provides much lower efficiency compared to FBC or CFBC boilers. FBC and CFBC require small bio-mass particle size (0-10mm) and hence require a crushing machine and a grading machine to be installed at site. Small sized briquettes can also be fed to these boilers. Stationery grate (manual fuel feeding), or Reciprocating Grate (automatic fuel feeding) boilers are preferred bio-mass having larger particle sizes and variable moisture content e.g., wood chips, wood logs, and biomass briquettes.

Briquetting is a high utility process that compresses the bio-mass and reduces the moisture content. Calorific value of the bio-mass briquette is higher than the base bio-mass due to lower moisture content and higher density; thus, providing better control of combustion process and higher combustion efficiency. Depending on briquetting machine design, it is also possible to make briquettes small enough to match the feeding requirements of FBC and CFBC boilers. Additional space is needed at site for the briquetting machine, its allied utilities and storage of briquettes; the benefits though, surpass the drawback of additional space requirement.

Having high calorific value and low fuel price, Natural gas is by far the cheapest fuel in terms of steam generation cost, and also has the lowest variation in steam cost due to less frequent fuel price fluctuations compared to other fuels having more variable steam cost due to frequent price fluctuations. However, there are no GHG emissions associated with agri-based bio-mass fuels, hence establishing these as more suitable in terms of climate improvement targets. Moreover, bio-mass may become economically viable if natural gas prices increase in future due to introduction of RLNG in the national supply line. The trade-off needs to be made between the steam cost and GHG emissions and a suitable fuel mix may be selected by factories keeping the steam cost suitable as well as minimizing the environmental impact.

An important element to consider for switching to bio-mass fuels is additional space and human resource requirement which may become a challenge for smaller companies having low steam demand; however, medium and large-scale companies usually have sufficient resource available. Investment required for switching to bio-mass fuels may become a relevant indicator as well for companies who do not have a bio-mass boiler available at site. It is observed that larger companies keep bio-mass fired boilers as back-up option; in which case the only critical indicators would be steam cost and GHG emissions.

Solar water heaters are found to be a feasible option to heat up process water and reduce steam demand; while GHG emission reduction potential is also considerable. This may come with some limitations e.g., rooftop space availability, structural strength to bear the load, and careful planning for companies with intermittent warm water requirements.

Solar PV proves to be quite feasible when replacing grid electricity and complimented with net metering system. Comparing with Solar water heaters, the Solar PV systems provide much less energy gain for same amount of footprint area; however, the specific weight of PV system is significantly lesser than that of solar water heaters hence requiring lesser structural reinforcements. GHG emission reduction for solar PV is considerable when replacing grid power, however, potential significantly reduces when replacing natural gas power.

4 LIMITATIONS

Major part of the study included evaluation of using bio-mass in the boilers. However, very limited data and facts were available on supply chain of bio-mass in general and Rice Husk and Saw Dust in specific. Available data was mostly outdated as latest data on bio-mass availability and consumption was from year 2015. Most of the available studies were limited to usage of bio-mass for domestic cooking either by direct burning or through bio-gasification. No specific study on usage of bio-mass in industrial enterprises was available in Bangladesh. One study on bio-mass usage in Pakistan was based on corn cob only.

Availability of local cases of using bio-mass were also limited in Bangladesh as majority companies tend to shift towards natural gas once the gas connection is granted. Cases were explored in Pakistan as well to learn from the experience but majority textile companies have shifted to using coal in boilers due to unreliable supply of bio-mass.

Evaluation of potential for solar water heating in Bangladesh was available to a limited extent. However, solar irradiation data was available in detail. Estimated average irradiation values were used to calculate the sizing of the system.

Time for this study was limited which necessitated that expert and teams mainly rely on secondary data in various studies and some primary data from factories that use bio-mass. Detailed primary research on bio-mass supply chain could not be conducted in such short time.

5 METHODOLOGY

Various studies conducted by GIZ and other organizations, and some research papers on availability and use of bio-mass in Bangladesh were reviewed to evaluate the supply chain of bio-mass. Technology suppliers in Bangladesh and Pakistan were interviewed to evaluate (i) availability of technology, (ii) suitability of usage in textile and garment industry, and (iii) cost of steam production.

Interviews of textile and garment factories in Bangladesh were conducted and data was collected to understand the existing scenario of bio-mass usage and its viability.

Interviews of textile and garment factories in Pakistan were conducted to understand their experiences of using bio-mass and reasons for shifting to coal.

Data and quotations for technology options were collected from boiler contractors in Bangladesh, Pakistan and China.

Based on available secondary data and collected primary data, an analysis of availability of bio-mass, its types and its nation-wide uses was conducted. This also included evaluating global warming potential and calorific values of various available bip-mass fuels and their comparison with natural gas to explore replacing natural gas with suitable bio-mass fuels. A comparison of various steam generation technologies was conducted taking a common boiler size (10 Tonne per hour), reviewing the investments for boiler and allied accessories, space required for storage of fuels, and cost of steam production for these technologies and various bio-mass fuel options. Annual emissions for various fuels and technologies were calculated and caparison was provided.

Potential for Solar Water Heating was explored (mainly using evacuated tubes technology) and its financial pre-feasibility was analysed. Further, solar water heater system was compared with Solar Photo Voltaic system and results were elaborated.

Analysis was compiled in form of the prefeasibility study along with recommendations and presented to GIZ and H&M for review and finalization.

5.1. Assumptions:

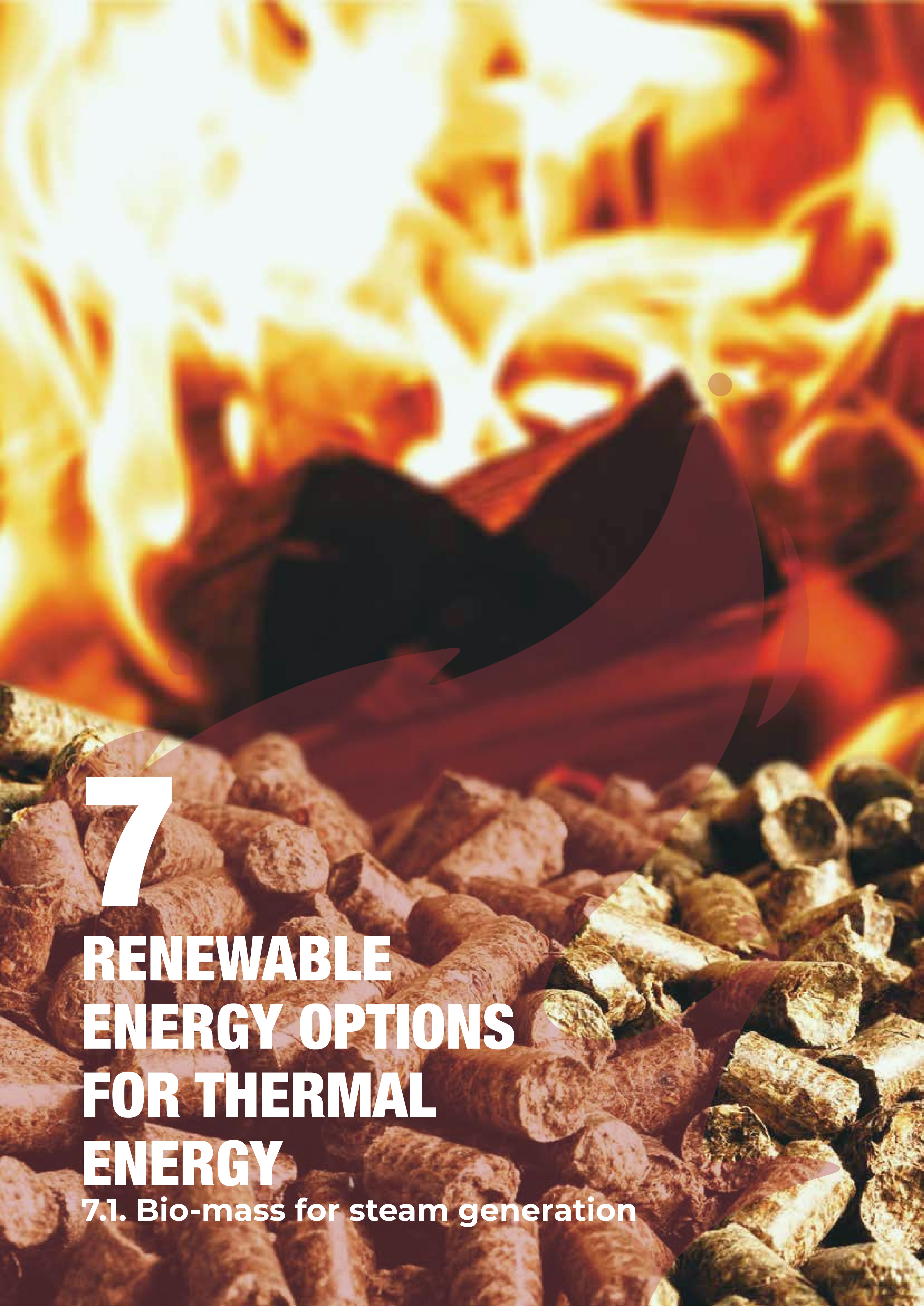
USD to BGD exchange rate	84.5 BDT/USD
Natural Gas Price BGD	10.7 BDT/m^3
Grid Electricity Price BGD	8.98 BDT/kWh
USD to PKR exchange rate	164 PKR/USD
Natural Gas Price PAK	37 PKR/m^3
Grid Electricity Price PAK	14 PKR/kWh
Coal price PAK	29 PKR/kg
Coal Emission Factor	0.0989 kgCO_2/MJ
Natural Gas Emission Factor	0.056 kgCO_2/MJ
National Grid Emission Factor BGD	0.603521296 kgCO_2/kWh
National Grid Emission Factor PAK	0.437505864 kgCO_2/kWh

6 AREAS OF THERMALENERGY DEMAND IN TEXTILE & GARMENT FACTORIES

Following tables present steam and water usage in textile processes;

Table 1: Water and Steam usage in Textile and Garment processes

Woven & Knitted Fabric Processing (Non-denim)	Water	Steam
Fabric Bleaching	✓	✓
Fabric Washing	✓	✓
Fabric Dyeing and Printing (Reactive)	✓	✓
Fabric Finishing	✓	✓
Denim Fabric Processing		
Denim Rope Dyeing	✓	✓
Denim Fabric Processing	✓	✓
Denim Fabric Finishing (Sizing, Mercerizing etc.)	✓	✓
Denim Garment Process		
Denim Garment Dyeing	✓	✓
Garment Washing	✓	✓
Laundry Drying		✓
Garment finishing	✓	✓
Knitted Garment Process		
Garment finishing (pressing)		✓



7

RENEWABLE ENERGY OPTIONS FOR THERMAL ENERGY

7.1. Bio-mass for steam generation

The focus of this study is mainly to substitute fossil fuel used in boilers to generate steam. Considering this, following renewable energy options are identified and assessed in this section which either suggest changing the boiler fuel, or substituting hot water demand through renewable energy;

1- Bio-mass for steam generation (Combustion and Gasification)

2- Solar Water Heating

7.1. Bio-mass for steam generation

Biomass resources meet a large percentage of the energy demand, particularly in resource rich countries in the Asian and African region. The resources of biomass include various natural and derived materials as agricultural crops and residues, forest wood and leave residues, municipal solid wastes (MSW), forest and mill residues, animal residues and sewage. Forest and agriculture constitute the major source of biomasses.

Managing the supply chain for bio-mass is a formidable challenge because of the distributed nature of the resources, availability over a short period of harvesting time and its physical characteristics.

Unlike other energy resources, the sources of major constituents of biomass resources are farmers and agriculture. A systematic approach is therefore required for understanding the issues involved in managing biomass resources.

The critical components of a biomass resource management system include:

A	Estimation of overall production of biomass residues
B	Estimation of actual availability taking into account harvesting efficiency & competitive usages
C	Biomass supply chain
D	Biomass characterization and energy technologies

Bio-mass availability and use in Bangladesh[3]

Somewhat formal markets have developed in Bangladesh for the domestic consumption of biomass resources, but a formal system for industrial and commercial consumption does not exist.

Total supply of biomass residues from different sources has been estimated as 138 million tonnes in 2015 including: tree residues (16.18 million tons), agricultural residues (111 million tons), animal dung (dry) (10.9 million tons).

Extraction of trees from Government Forest has been banned since 2015. Whereas there is no such restriction on the extraction of tree residues obtained from Village Forests by tree felling and pruning. It has been projected that in future, extraction and consumption of wood fuel will decline while the extraction of round wood or timber wood may increase.

Agricultural residues have two major components: plant residues and crop residues. There are multiple uses of plant residues (e.g., straw, stalks and sticks etc.) such as fodder, building materials and fuels. Crop residues (e.g., bran, oil cake etc.) are generally used as cattle and poultry feed. Rice husk also has multiple uses like poultry bedding materials and as a fuel in paddy parboiling. There is hierarchical gradation of plant and crop residues depending on their economic value. Fodder, feed and building materials are higher value usages than fuel. It means to an individual owner if there is opportunity to use available residues for higher value product, they will not be used for lower valued usage (fuel). Only 43 million tonnes out of agricultural residues may be used as fuel.

3. A comprehensive assessment of the availability and use of biomass fuels for various end-uses with special attention to power generation, SREPGen Project, UNDP Bangladesh, June 2019

Out of **23.64 million** cattle, **97.3%** are found in households. Under traditional practice animal dung is used either as fuel or as manure. Use of animal dung and poultry litters in Biogas technology is now being recognized as an efficient method of use of dung, because it can provide both fuel and manure. However, most of the dung is consumed by the producers for stated purposes. Also keeping in mind that majority cattle are found in households, it is very challenging to create a formal supply chain to consume dung as bio-mass for industrial or commercial purposes.

Industrial waste is not significant in Bangladesh while municipal solid waste available in huge quantities and estimated to grow drastically **(65% from 2015-2040)**. Sewage sludge is also estimated to grow manifolds **(21 time from 2015-2040)**. It may need further exploring if any regulatory structure exists allowing to collect this waste and distribute to industrial sector for fuel usage.

Total biomass fuel consumption in **2015** was estimated as **51.3 million** tonne which is almost equal to the amount of bio-mass available as fuel. Majority of biomass in Bangladesh is consumed for rural cooking, while rest is consumed by urban cooking, brick kiln, sugar processing, rice parboiling, urban commercial units, and tea processing. Following figure presents the consumption of bio-mass fuels in Bangladesh.

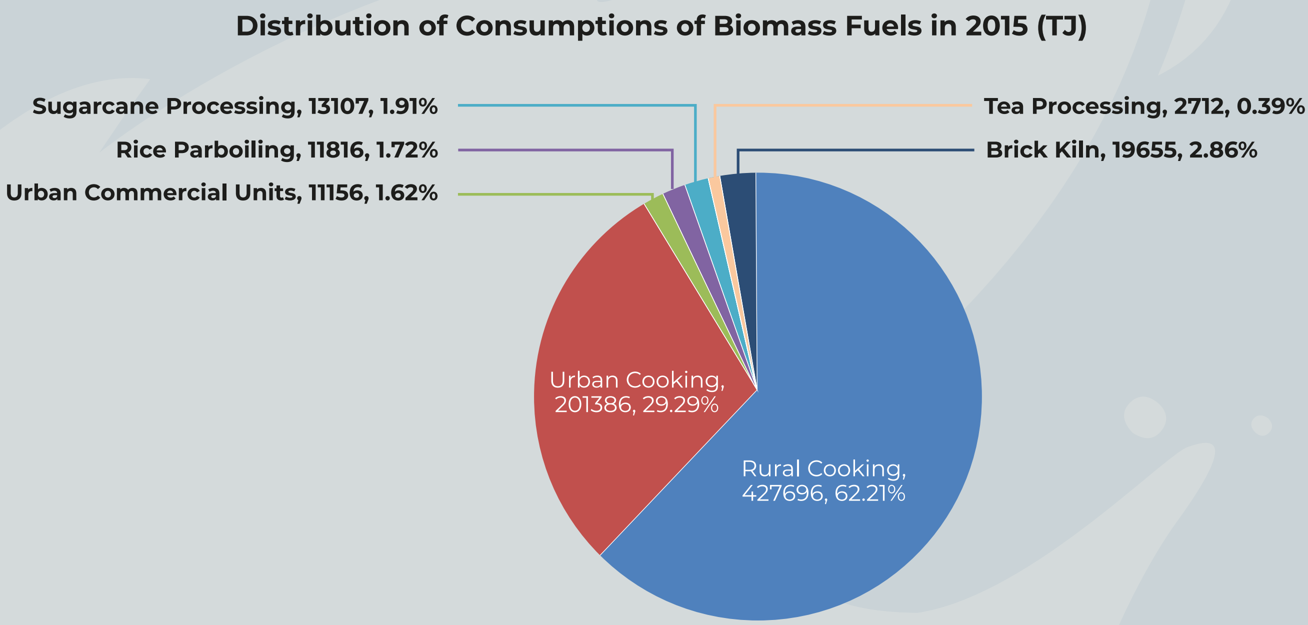
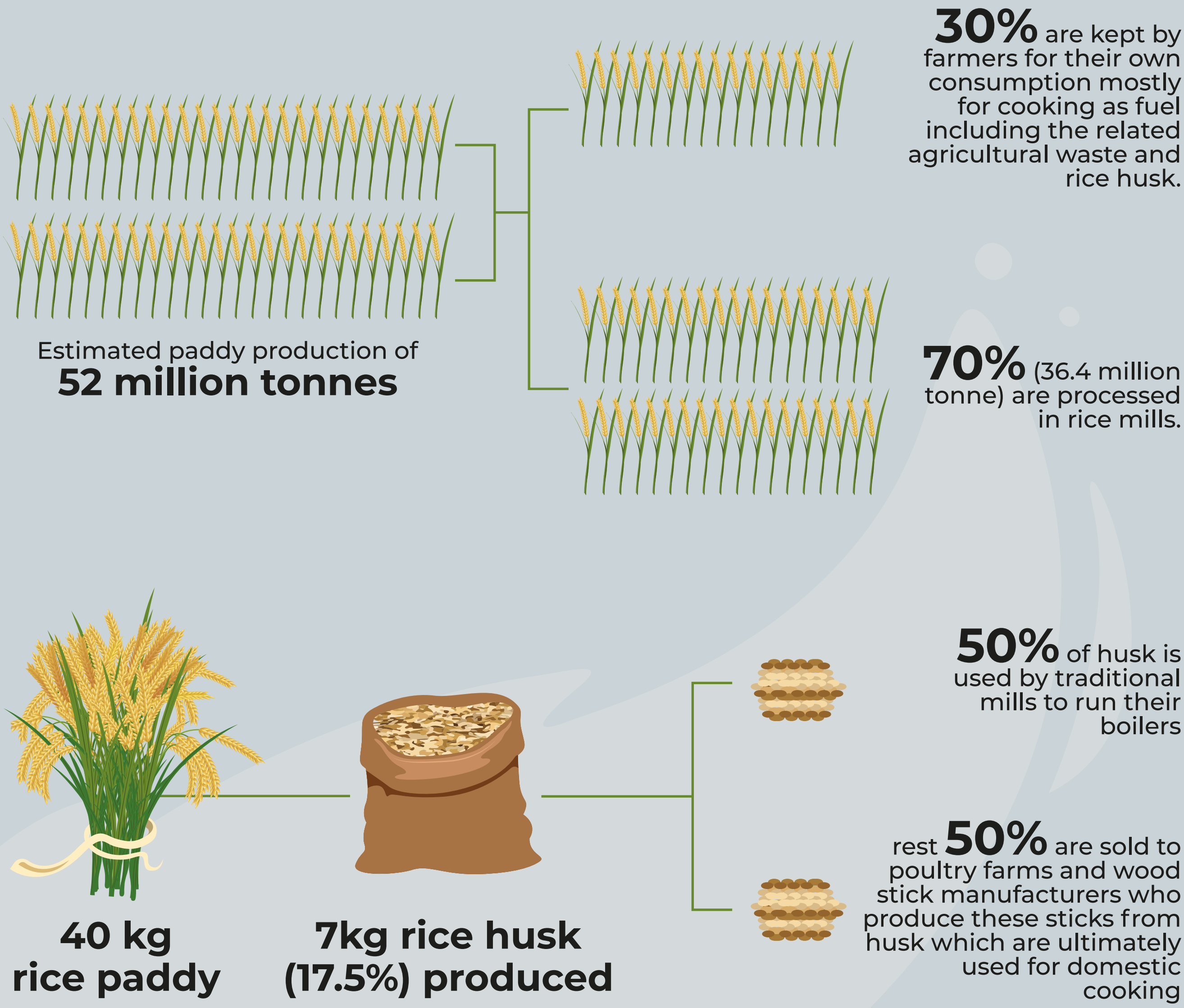


Figure 1: Distribution of biomass fuel consumption in Bangladesh (2015)[4]

4. A comprehensive assessment of the availability and use of biomass fuels for various end-uses with special attention to power generation, SREPGen Project, UNDP Bangladesh, June 2019

As per Bangladesh Auto Major and Husking Mill Owners Association[5] , there are three seasons for rice cultivation: (i) January – May, (ii) July – December, and (iii) June – September.



Rice Husk supply from rice mills is not uniform in quantity throughout the year. Sometimes the husk supply is surplus so that the husk is leftover after consumption and sometimes the husk supply is deficit than needed. Rice husk is also sold to industrial units for use as fuel in steam boilers but instability of supply and fluctuation of price result in higher cost of steam production compared to most commonly available fuel i.e. Natural gas.

Keeping above in mind, there seems to be insufficient availability of bio-mass for industrial consumption as fuel.

5. Interview with General Secretary, Bangladesh Auto Major and Husking Mill Owners Association, March 04, 2021

Current trend in Bangladesh textile and garment industry

Based on information gathered from the textile and garment factories in Bangladesh, general tendency of industry is to shift from bio-mass to natural gas as soon as a gas connection is awarded. This is mainly due to almost double steam generation price using bio-mass (especially rice husk) compared to natural gas as well as consistency in supply of natural gas (see page 34: "Comparison of bio-mass fuel with natural gas for steam generation (10 TPH Boiler) in textile and garment industry"). Larger textile manufacturing companies might have the capacity to maintain and ensure biomass supply chain for the bio-mass boilers but steam cost still poses a challenge.

Case study of a textile company in Bangladesh

The "Textile Company"[6] is a vertically integrated mill consisting of Spinning, Weaving, Yarn Dyeing, Fabric Dyeing and Fabric Finishing processes; having production capacity of 20 tonne per day. The company is located in Manikganj district (Dhaka division) and is part of a big group of companies having multiple businesses including wood mills and wooden products as well. Steam demand for the processes is met through multiple sources;

1- One 4 TPH boiler operated on wood logs which costs about 2,000 BDT/Tonne-steam

2- One 10 TPH locally customised multi-fuel boiler, operated on a mixture of fuels including saw dust, cotton waste, wood chips, and wood barks. Company also has a briquetting machine (100 kg/hr capacity) which forms briquettes from process waste in briquettes. This is a SCADA controlled boiler which mixes fed fuels keeping the GCV at 4,000-4,500 kcal/kg. Steam from this boiler costs 1,000-1,100 BDT/Tonne-steam. The reason for low steam cost is that the company procures wood chips and wood barks at very low prices from the sister companies (wood mills); transportation cost is negligible as the source companies are located nearby. Company does not use rice husk due to depleting supplies in the vicinity; the price of husk is also very high in the area due to high transportation cost.

3- One 6 TPH natural gas fired boiler which costs 700-1,000 BDT/Tonne-steam. However, as the natural gas pressure varies quite often, the company has to operate above mentioned boilers to fulfil the steam demand.

4- 9 MW capacity natural gas fired co-generation system which produces 12 TPH steam

5- An old fluidized bed combustion (FBC) boiler is also installed at site but could not provide required performance due to high moisture in saw dust and rice husk; and is not used anymore.

6. Company name not mentioned to keep confidentiality

On average, 70% of steam demand at the Textile Company is met by natural gas fired sources while 30% though the bio-mass fired boilers. The company has also applied for an additional natural gas connection for 3MW co-generation power plant in which case whole steam demand would be met by natural gas fired sources. According the company manager, natural gas would be preferred due to (i) being the lowest cost option for steam generation, (ii) ensure capacity utilization of co-generation system, and (iii) difficulties associated with bio-mass especially fluctuation of supply and prices, and storage requirements due to high moisture in bio-mass.

However, the company would continue using bio-mass boilers as back-up option in case of low natural gas pressure.

Prices of bio-mass in Bangladesh

As explained above, the prices of bio-mass are variable in Bangladesh. Following table provides prevailing prices of prominent bio-mass being used in Bangladesh;

Table 2: Bio-mass prices in Bangladesh[7]

Bio-mass	Price
Rice Husk	8-12 USD-cents/kg (7-10 BDT/kg)
Saw Dust	2.3-14 USD-cents/kg (2-12 BDT/kg; Average 5 BDT/kg)
Wood logs / chips	4.5-5.7 USD-cents/kg (4-5 BDT/kg)
Other bio-mass	No reliable price data available

Bio-mass availability and use in Pakistan

Five major crops in Pakistan are Sugarcane, Rice, Wheat, Cotton and Maize and are main sources of bio-mass in the country. All these crops produce crop harvesting residue and crop processing residue. Usual uses of crop harvesting residues are: animal fodder, domestic burning (cooking), selling to biomass supplier, selling to industry (e.g. paper making[8]), organic fertilizer or open field burning. To estimate the amount of residue from both stages (i.e. harvesting and processing), it is important to estimate the Residue to Crop Ratio (RCR) for both stages as well. Following paragraphs explain generation and availability of the bio-mass from each of these crops.

7. As per information from two textile factories (bio-mass users), one conventional rice mill and Bangladesh Auto Major and Husking Mill Owners Association

8. Pulp and Paper INDUSTRY IN PAKISTAN (mre.gov.br)

Major Agri-based Bio-mass sources

Bagasse and Sugar Cane Trash

As per World Bank estimates in 2015[9] , a total of 17.1 million tonnes/year of bagasse was generated in 84 existing sugar mills in Pakistan. Around 90% of this amount of bagasse are used as fuel in cogeneration plants to produce electricity and low pressure steam for covering the energy demand of the sugar mills while remaining 10% is sold to various consumers. In addition, the mills procured huge amount of feedstock for energy generation in 2015-16; the quantity of which is not known. As per the annual report by Pakistan Sugar Mills Association[10] , total 48.7 Million Tonne sugar cane was crushed in 90 mills in Pakistan in year 2019-20. Considering the average Residue to Crop Ratio (RCR) of 0.3 (for sugar cane crushing) suggested by the World Bank report, the Bagasse production from the mills is estimated to be 14.6 Million Tonne in year 2019-20; which does not leave enough quantity for use in energy production by users other than the sugar mills themselves.

The crop harvesting Residue to Crop Ratio (RCR) as per World Bank report is 0.12 which means in 2019-20, the sugar cane crop residue would be 7.96 Million Tonne against a crop of 66.38 Million Tonne[11] . Out of the 7.96 Million Tonne sugar cane trash; as per the World Bank report; only about 25% (~2 Million Tonne) are available after considering all uses and farmers' willingness to sell. These are usually the residues which are burnt by farmers at site.

The difference of 17.68 Million Tonne between sugar cane production and sugar crushing in mills is used by local farmers and producers to produce Gur. There is no data of the residue quantity. Considering same RCR (0.3) as for Sugar, the bagasse amount from Gur making is estimated to be 5.3 Million Tonne. Uses and availability of this bio-mass are not well known; and since the production is scattered, collection of this not formalised, hence this is ignored for this study.

9. Biomass Resource Mapping in Pakistan, Final Report on Biomass Atlas, June 2016, ESMAP, The World Bank
10. Annual Report 2020, Pakistan Sugar Mills Assocation
11. Table-1 Area and Production of Important Crops, Agriculture Statistics Tables, Pakistan Bureau of Statistics (pbs.gov.pk)

Rice Husk and Straw

Rice Straw is left as harvesting residues while Rice Husk is generated as processing residue; both having RCR of 1.0 and 0.2 respectively[12] . Using same methodology as that for Bagasse, the rice production of 7.41 Million Tonne would produce 7.41 Million Tonne[13] Rice Straw and 1.48 Million Tonne Rice Husk. About 30% of both bio-masses are available for energy production; i.e. 2.23 Million Tonne Rice Straw and 0.44 million Tonne Rice Husk.

Wheat Straw

Wheat Straw is the harvesting residue of wheat crop. With an RCR of 1.0 for the crop weighing 1.4 Million Tonne, the Wheat Straw amounting 1.4 Million Tonne is estimate to be produced. The wheat straw is used by the livestock and dairy industry as an essential component of fodder for cattle and is also being increasingly used as an alternative source of fuel for power generation. As per estimates, 50% of wheat straw is used for animal consumption and 40% is used by other sectors which include exports. Of this 40%, nearly 5% is used by the pulp and paper industry. The Competition Commission of Pakistan (CCP) has recommended that provincial governments should ban the burning of wheat straw in fields and as a fuel as this is the main raw material in the production of pulp and paper and constitutes approximately 85% of the total cost of low-quality paper[14,15] . Keeping this in mind, the availability of wheat straw for energy generation is not considered in this study.

12. Biomass Resource Mapping in Pakistan, Final Report on Biomass Atlas, June 2016, ESMAP, The World Bank
13. Table-1 Area and Production of Important Crops, Agriculture Statistics Tables, Pakistan Bureau of Statistics (pbs.gov.pk), 2021
14. CCP seeks ban on use of wheat straw as fuel (tribune.com.pk), 2019
15. Pulp and Paper INDUSTRY IN PAKISTAN (mre.gov.br), 2012

Cotton Stalks

Cotton stalks are left as harvesting residue of cotton crop. With an RCR of 3.4 for the crop weighting 9.15 Million Tonne, generation of cotton stalk is estimated to be 31.11 Million Tonne out of which only ~8.6% or 2.67 Million Tonne is available for energy generation.

Maize

Maize cob and Maize husk are generated as processing residue while Maize stalks are generated as harvesting residue; having RCR of 0.33, 0.22, and 1.25 respectively. Against the crop of 7.88 Million Tonne in 2019-20, the bio mass generation is estimated as 2.6 Million Tonne Maize Cob, 1.73 Million Tonne Maize Husk, and 9.85 Million Tonne Maize Stalk. Only 10% availability of all these bio-masses is estimated for energy generation; i.e., as 0.26 Million Tonne Maize Cob, 0.173 Million Tonne Maize Husk, and 0.985 Million Tonne Maize Stalk.

Summary of available bio-mass for energy generation

Following table summarises the availability of bio-mass for energy generation in Pakistan based on above discussion;

Table 3: Availability of bio-mass for energy generation in Pakistan

Bio-mass	Bio-mass available for energy generation (Million Tonne/year)	NCV[16] (MJ/kg)	Energy generation potential (GWhth/year)
Bagasse	Negligible	7.5	0.00
Sugar Cane Trash	2.0	12.6	555.55
Rice Straw	2.23	12.5	619.44
Rice Husk	0.44	13.5	122.22
Wheat Straw	Not Considered	14.4	0.00
Cotton Stalk	2.67	15.0	741.66
Maize Cob	0.26	14.0	72.22
Maize Husk	0.173	11.6	48.05
Maize Stalk	0.985	13.0	273.61
Sub-total	**8.758**		**2,432.77**

This 2,432.77 GWh_{th} is equivalent to approximately 277 MW_{th} or 73 MW power generation output capacity (22.5% efficiency and 0.85 plant capacity factor). Considering if all the bio-mass is used for saturated steam generation at 8 bar, 2,432.77 GWh_{th} would be equivalent to steam generation capacity of 361.2 Tonne per hour. These are not very significant figures considering the collection and supply chain challenges of bio-mass, and demand of textile and garment industry.

16. Biomass Resource Mapping in Pakistan, Final Report on Biomass Atlas, June 2016, ESMAP, The World Bank

Current trend in Pakistan textile and garment industry[17]

Due to unreliable supply of natural gas in the country, textile and other industries in Pakistan started shifting to bio-mass for steam generation around 2009-2010. Rice Husk, Corn Cob, and Wood logs were major bio-mass sources for textile industry. Sudden shift to bio-mass at mass scale resulted in price rise of bio-mass and also disrupted the supply throughout the country. Currently, majority of textile companies have abandoned using bio-mass in boilers and shifted to imported coal using chain grate boilers mostly and circulating fluidized bed boilers in few cases. Major reasons for the shift from bio-mass are provided below;

- Gas fired boilers were converted by adding poorly designed refractory furnaces for bio mass burning. Boiler capacity would reduce due to inefficient area available for burning in the furnaces
- Maintenance cost increased as tube leakages were often experienced in furnaces due to poor design
- Particulate matter is major challenge in flue gases of bio-mass fired boilers. Heavy investments were needed for installing multi-cyclone separators, and wet-scrubbers. In rare cases electrostatic precipitators may be installed where particulate matter is not controlled, but it increases operations cost as well.
- Rapid conversion to Rice husk was not supported by supply chain so price fluctuations were unprecedented
- Low availability of bio-mass due to seasonal affects
- Cost of transportation was too high for distant consumers
- Very low calorific value and high moisture content compared to coal and other fuels
- Post combustion issues: Ash equivalent to ~30% of fuel is generated. This ash was welcomed by farmers initially but then farmers slowly declined as it suited less to their needs.

Prices of bio-mass in Pakistan

Like in Bangladesh, prices of bio-mass in Pakistan are also variable. Following table provides prevailing prices of prominent bio-mass being used in Pakistan;

Table 4: Bio-mass prices in Pakistan[18]

Bio-mass	Price
Rice Husk	5.5-8.0 USD-cents/kg (9-13 PKR/kg)
Maize Cob	5.5-8.0 USD-cents/kg (9-13 PKR/kg)
Other bio-mass	No reliable price data available

17. Interviews with four textile factories in Pakistan, February 15, 2021
18. As per purchase data of three textile companies in Punjab using Bio-Mass

Selection of boiler for bio-mass

The selection of bio-mass fired boiler depends on the bio-mass to be used as fuel and the variety of bio-mass as well. Generally, for rice husk, fluidised bed combustion (FBC) or circulating fluidized bed combustion (CFBC) are preferred due to high system efficiency. Reciprocating Grate (Chain or Step Grate) is also used when lower investment is planned. However, later provides lower efficiency as well compared to FBC or CFBC boilers. FBC and CFBC require small bio-mass particle size (0-10mm) and hence require a crushing machine and a grading machine to be installed at site. Small size briquettes can also be fed to these boilers. Stationery grate (manual fuel feeding), or Reciprocating Grate (automatic fuel feeding) boilers are preferred for wood chips, wood logs, and biomass briquettes.

Figure 2: Combustion chamber of fluidized bed boiler

Figure 3: Feeding mechanism of a travelling grate bio-mass boiler (feeding corn cob)

Bio-mass briquetting

The biomass briquettes are mainly produced from the agricultural waste material, livestock, industrial/urban waste or a mixture thereof. The process includes **(i)** crushing the bio-mass to required size, **(ii)** drying the crushed bio-mass depending on moisture content (materials with less moisture content need no drying), **(iii)** compacting the bio-mass to form briquettes of various shapes depending on method. Binders are sometimes required to be added to the bio-mass to ensure the briquette stays firm; in Pakistan cow dung or saw dust are usually mixed with bio-mass as binders. In some cases, if preheating of biomass is done, it causes sweating of the biomass which results in release of gluing agents from the biomass itself. That is why preheating is an integral part of screw extruder for rice husk. Such machines usually also the preheating system at compression stage.

Biomass briquette has high specific density (600-1200 kg/m^3) and bulk density (400-800 kg/m^3) compares to lose biomass (60-180 kg/m^3). Briquetting process does not increase calorific value of the base bio-mass itself. However, calorific value of the bio-mass briquette is higher than the base bio-mass due to lower moisture content and higher density; thus give much higher efficiency[19]. This effect on the calorific values is presented in the following figure. Objective of this chart is to clarify the reason why briquettes carry more calorific value compared to source bio-mass; data in this table does not represent the moisture in bio-mass available in Bangladesh. No reliable data was available for moisture in fuels in Bangladesh. Naturally the moisture varies across the year depending on source of bio-mass, weather conditions, storage conditions, transportation methods, and if the bio-mass comes from a recent harvest or from a longer storage. For example, the moisture in cow dung and cotton straw is generally above 70%[20 21], but in this table conditions for much lower moisture values have been compared.

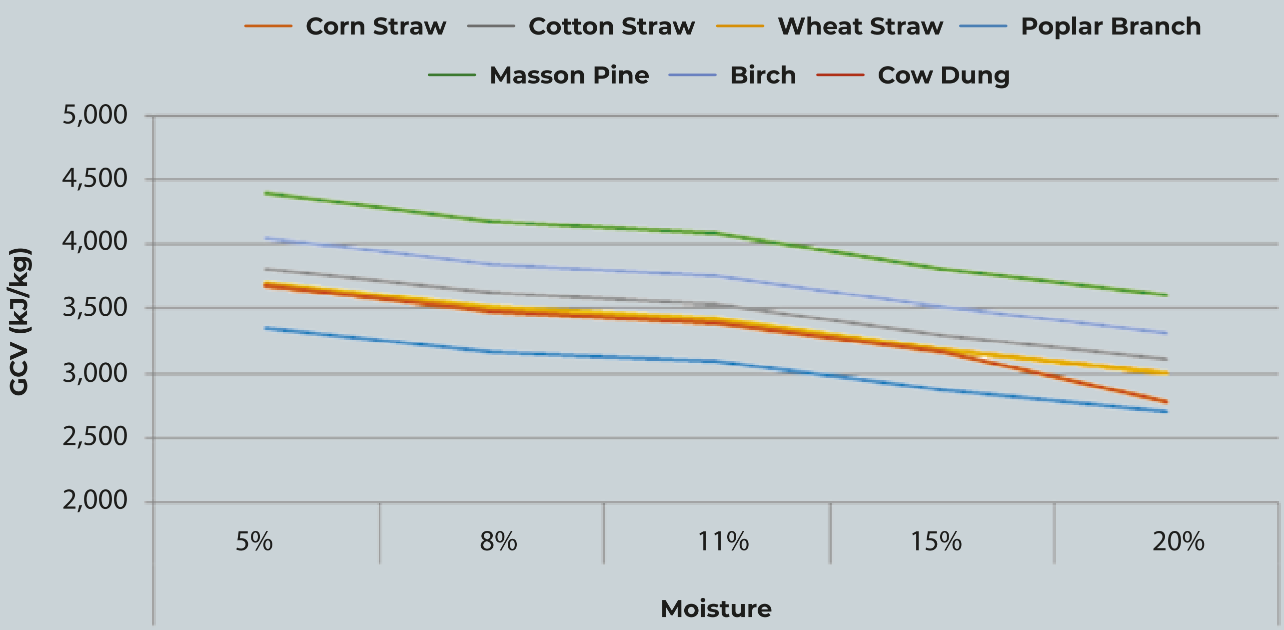


Figure 4: Effect of moisture on bio-mass calorific value (kJ/kg) [22]

19. https://briquettesolution.com/biomass-briquette-machine-guideline/
20.https://www.sciencedirect.com/science/article/pii/0144456586901149#:~:text=The%20comparatively%20high%20moisture%20content%20%2870-40%25%29%20necessitates%20drying,of%20the%20most%20economical%20ways%20to%20conserve%20CS
21.https://fertilizerproductionlines.com/manure-dewatering-machine/#:~:text=As%20you%20know%2C%20the%20moisture%20in%20cow%20dung,and%20has%20higher%20capacity.%20Cow%20dung%20drying%20machine
22.https://briquettesolution.com/bio-and-fuel-briquette-calorific-value-biomass-sawdust-coal-charcoal/

Briquetting process adds to the cost of bio-mass as the process requires energy for crushing, drying and compacting processes. For a briquetting machine of 2-2.5 tonne/hour production, an approximate 0.3 BDT or 0.6 PKR per kg of bio-mass is added to the cost. However, the compact bio-mass now requires 6-7 times lesser storage space than the raw bio-mass and higher calorific value. Investment for the bio-mass machine of this capacity is around 5,000 USD from Chinese sources; however, if produced locally, the machine may cost much lower than stated.

Following may be considered before moving into briquetting at textile factories;

1. The machine and briquettes would require space in addition to the existing bio-mass storage. Additional human resource would also be required to operate the machine, transport the material and briquettes, and technical supervision.

2. Briquetting also has same issues of supply chain as of the base bio-mass. So even if this seems more efficient, briquetting can only be used if supply of bio-mass is ensured and reliable.

3. Managing the briquetting process at source of bio-mas may result in reduced cost and environmental footprint of transportation, reduced bio-mass storage area requirement at the boiler house, and improved housekeeping. However, this may result in slight increase in the price of bio-mass which can be compensated by reduced energy required for briquetting in the factory and reduced human resource requirements.

Using bio-mass for water heating

Biomass may also be used to preheat water instead of generating steam. Steam boilers are pressure vessels and high investment is associated with them. Using biomass fired water heaters may require less cost with simpler design. Such water heaters are usually used in Hotel Industry and are mostly natural gas or fuel oil fired. Heating 10 m^3/hour water from 25°C to 75°C through water heater would require 210-230 kg/hour bio-mass. Old oil heaters or boilers could be retrofit to convert into water heaters; for this purpose, bio-mass combustion furnace could be added to existing gas fired water heaters. The investment of a typical system (as per experience in Pakistan) would be around 10,000 USD with additional 3,000 USD for emission control equipment. However, as stated earlier, such systems are generally not very efficient and safe to operate, therefore due diligence must be done while designing and installing such an equipment.

Global Warming Potential (GWP) of various fuels

Primary solid bio-mass (especially forest-sourced bio-mass) carries double global warming potential (GWP) compared to that of natural gas. However, GWP of bio-mass with rotation cycles of 1 year or less carry zero GWP; i.e., are carbon neutral. The basic concept of carbon neutrality is that biogenic CO_2 emitted during biomass harvest and use is eventually sequestered during plant growth, resulting in zero net emissions[23] . A study[24] by United States Environment Protection Agency suggests that "biologically based feedstocks fall into three major categories that are functionally similar: (1) forest-derived woody biomass, (2) agricultural biomass, and (3) waste materials. The agricultural feedstocks may have a Biogenic Accounting Factor (BAF) of 0 due to the annual growth/harvest cycle. Therefore, depending on the program, it may be appropriate to treat those feedstocks differently from other types of feedstocks used at stationary sources". IPCC guidelines[25] suggest not recording the CO_2 emissions of bio-mass, however, IPCC suggest so account for CH_4 and N_2O emission due to the combustion in this case. As the values of CH_4 and N_2O emission are very small (0.000024 for bio-mass and 0.00000011 for bio-gas), these are neglected in this report.

Following figure compares the global warming potential (GWP) of Natural gas and bio-mass fuels using Stationery Combustion Tool by Greenhouse Gas Protocol.

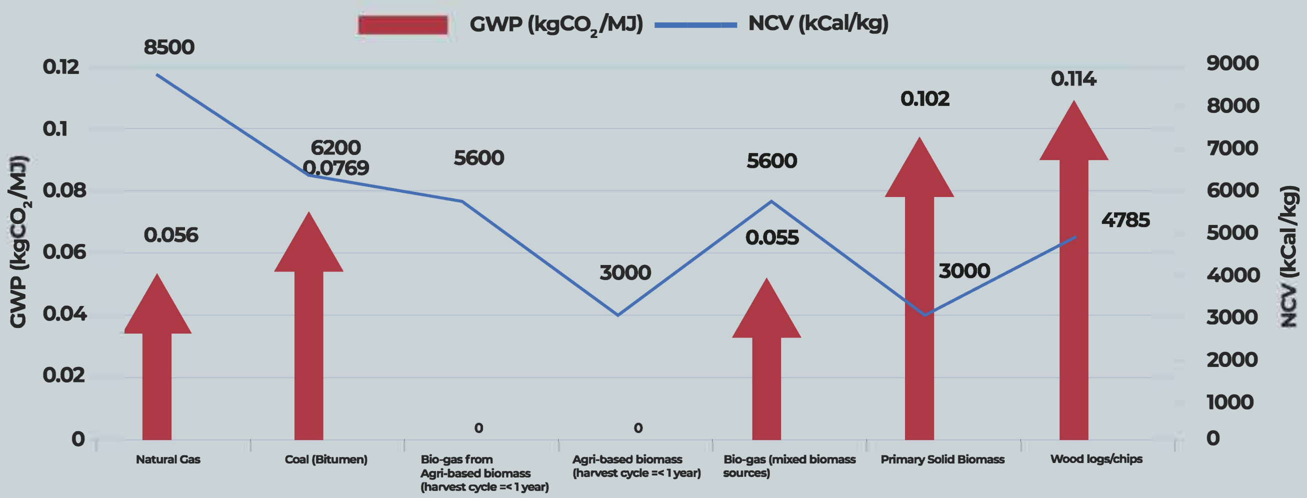


FIGURE 5: COMPARISON OF GLOBAL WARMING POTENTIAL AND NET CALORIFIC VALUES OF FUELS [26]

23. Demystifying the carbon neutrality of biomass, Anil Baral, Posted in The International Council of Clean Transportation, https://theicct.org/blogs/staff/demystifying-carbon-neutrality-biomass#:~:text=A%20GWP%20bio%20factor%20represents%20the%20relative%20global,in%20turn%20corresponds%20to%20harvesting%20cycles%20(rotation%20periods).. (June 13, 2014)
24. Accounting Framework for Biogenic CO2 Emissions From Stationary Sources https://www.epa.gov/sites/default/files/2016-08/documents/biogenic-co2-accounting-framework-report-sept-2011.pdf (US EPA, September 2011)
25. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, CHAPTER 1 (iges.or.jp)
26. Values calculated using Stationery Combustion Tool Version 4-1 by Greenhouse Gas Protocol

Comparison of bio-mass fuel with natural gas for steam generation (10 TPH Boiler) in textile and garment industry

Comparison of technology options, required investments and additional space requirement for various bio-mass fuels with natural gas for steam generation is provided in the following table. For calculation purposes, average to Tonne per hour (TPH) capacity boiler producing steam at 10 bar pressure is considered. The table shows that bio-mass systems require additional space compared to natural gas fired boilers and also additional investment for emission control equipment.

Table 5: Comparison of technology options for steam generation (10 TPH Boiler)

Fuel	Boiler Technology	Investment (USD)	Investment for emission control equipment (USD)	Additional Space required
Natural Gas	Fire tube	220,000	-	-
Rice Husk	Water tube Travelling Grate, Circulating Fluidized Bed	320,000 – 400,000	18,000 – 40,000	7,700 m^3
Rice Husk briquettes	Water tube Travelling Grate	Boiler 320,000 – 400,000 Briquetting machine ~5,000	18,000 – 40,000	9,000 m^3
Wood Logs / chips / saw dust / Maize Cob	Water tube Travelling Grate	320,000 – 400,000	18,000 – 40,000	7,700 m^3
Wood chip/saw dust briquettes	Water tube Travelling Grate	Boiler 320,000 – 400,000 Briquetting machine ~5,000	18,000 – 40,000	9,000 m^3 for storage
Bio-gas (Agri-based or sewage waste bio-mass)	Bio-gasification + fire tube boiler	860,000 – 1,100,000	–	7,700 m^3 for storage 1,676 m^3 for gasifier

Calculation of steam generation cost and annual GHG emission for 10 TPH boiler on various fuels is provided in the following figure.

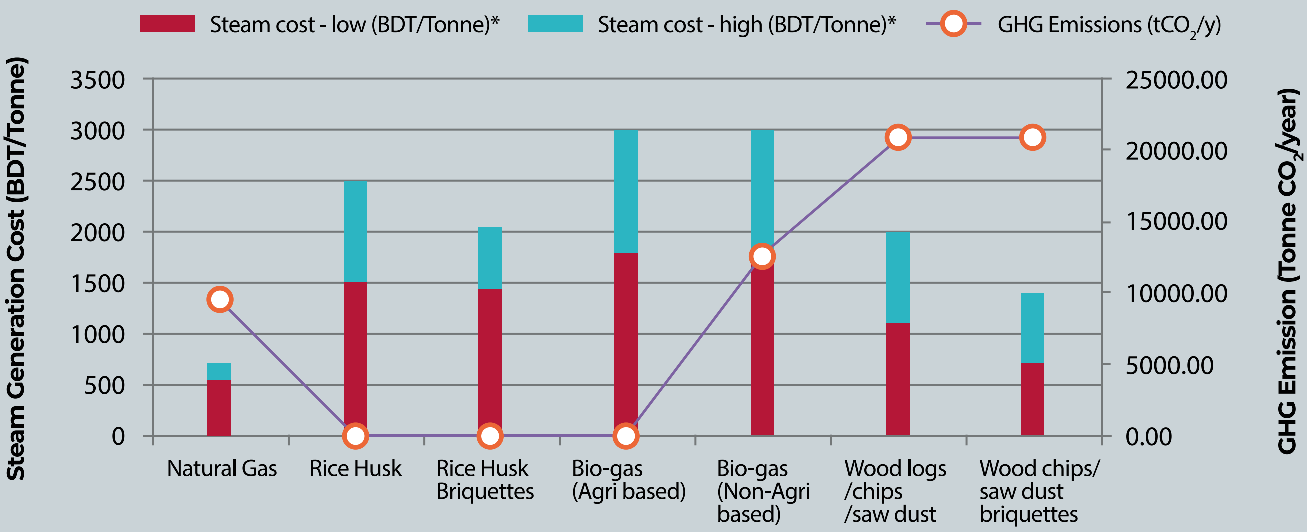


Figure 6: Steam cost and Annual GHG emissions for 10TPH Boiler on various fuels in Bangladesh

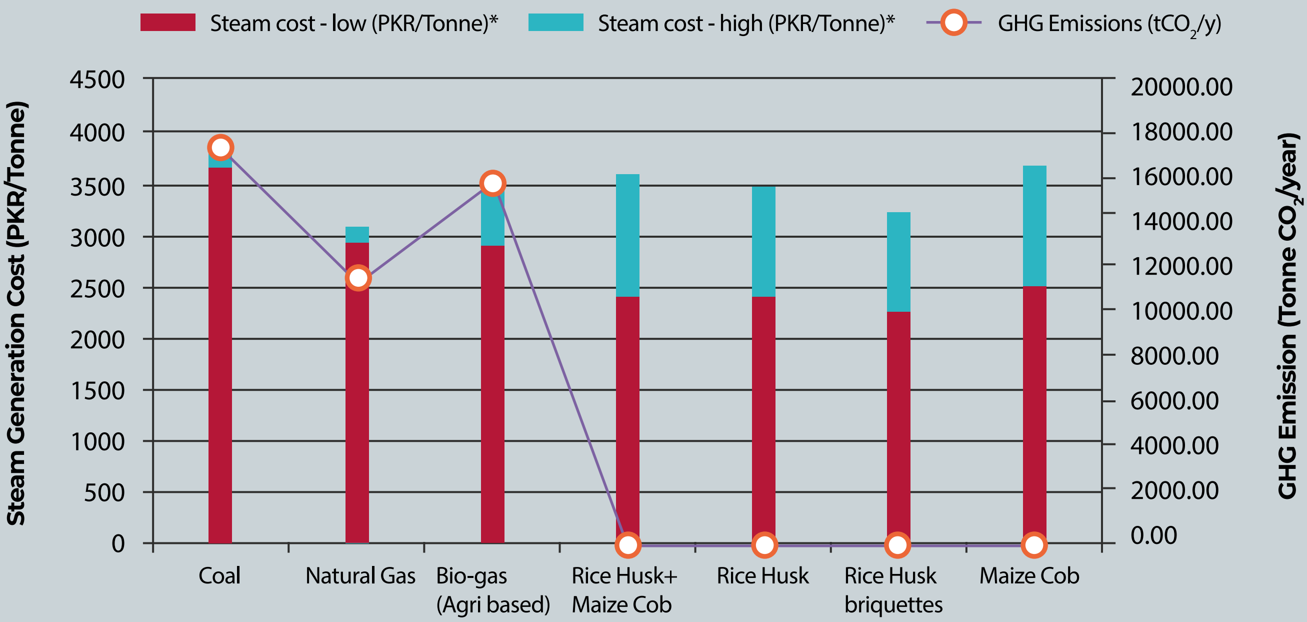


Figure 7: Steam cost and Annual GHG emissions for 10TPH Boiler on various fuels in Pakistan

Rationale for switching to Agri-based bio-mass

It is evident that natural gas is by far the cheapest fuel in terms of steam generation cost in Bangladesh, and also has the lowest variation in steam cost due to less frequent fuel price fluctuations. Other fuels are subject to higher and more variable steam cost due to more frequent price fluctuations. Moreover, the steam cost does not include labour and maintenance cost for any of the presented options; which would actually result in much higher cost of steam production than what is mentioned in the comparison. Briquetting reduces the steam generation cost significantly as it has better calorific value due to reduced and controlled moisture in the bio-mass.

However, there are no GHG emissions associated with Agri-based bio-mass fuels as established earlier in this document hence establishing these as more suitable in terms of climate improvement targets. The trade-off needs to be made between the steam cost and GHG emissions and a suitable fuel mix may be selected to keep the steam cost suitable as well as minimize the environmental impact.

Another important factor to account for is that Bangladesh has started importing Regasified Liquefied Natural Gas (RLNG) which may result in increased tariffs in future as has been the case in Pakistan and other countries that opted for this option. In such a scenario, bio-mass may provide a competitive edge due to being locally produced.

In Pakistan, the Natural Gas pricing are increasing significantly each year due to procurement of RLNG. Coal prices have recently increase bringing it near the Natural Gas in terms of steam generation cost, however, before the recent global price hike[27] [28] of about 30%, Coal was the cheapest fuel for steam generation in Pakistan. Bio-mass seems to be a good option in terms of steam cost; however, the limitations laid out earlier need to be considered.

27. Coal | 2008-2021 Data | 2022-2023 Forecast | Price | Quote | Chart | Historical | News (tradingeconomics.com); accessed on August 19, 2021
28. Purchase data from textile companies in Pakistan

Limitations of Bio-mass based Steam System

Main implementation constraints to be considered from a technical perspective for using bio-mass based steam systems are;

a. Natural gas combustion efficiency is easier to control compared to solid fuels like bio-mass which required extensive monitoring and manual control by operators. So, for the operators experienced in firing natural gas it becomes a challenge to gain same efficiency of steam generation with solid bio-mass

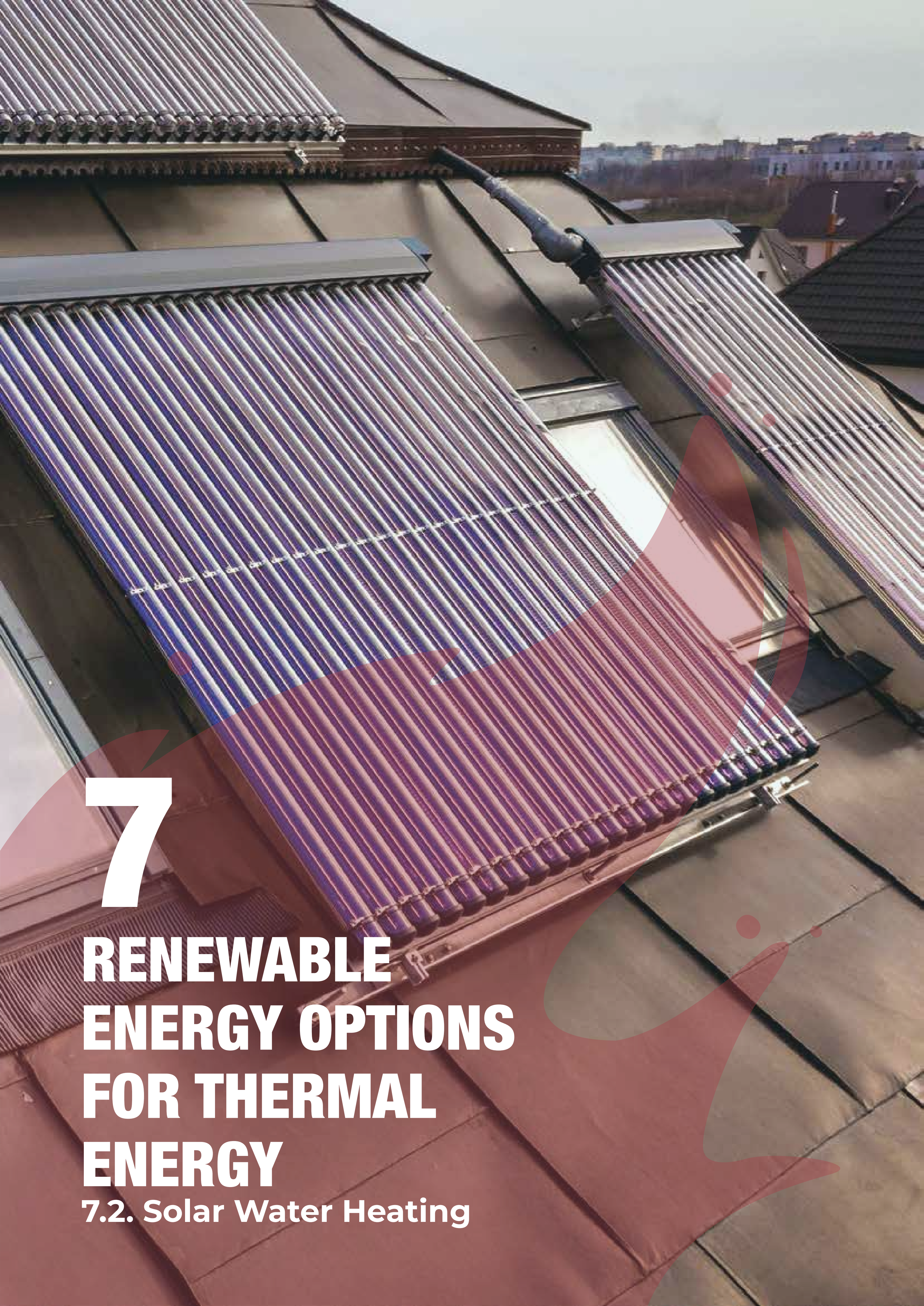
b. Not all boilers are capable of firing all types of bio-mass materials. Some designs allow for variable and larger particle size or even wood logs, whereas some designs particularly require graded and small sized particles of feed stock (e.g., fluidised bed combustion)

c. Naturally the moisture in bio-mass varies across the year which significantly effects boiler combustion efficiency. The variation in moisture depends upon source of bio-mass, weather conditions, storage conditions, transportation methods, and if the bio-mass comes from a recent harvest or from a longer storage. Large storage space is required to stock enough bio-mass to allow natural moisture reduction as well as to reduce transportation cost

d. Bio-mass price fluctuations result in significant variation in steam generation cost which puts the bio-mass behind natural gas in the race.

e. Managing the supply chain for bio-mass is a formidable challenge because of the distributed nature of the resources, availability over a short period of harvesting time and its physical characteristics.

f. Bio-mass combustion generates significant amount of ash and particulate matter for which special arrangements are required for (i) filtering out the ash from air and water, (ii) drying, handling and storing the ash, and (iii) safe disposal. All these arrangements result in additional operational cost.



7

RENEWABLE ENERGY OPTIONS FOR THERMAL ENERGY

7.2. Solar Water Heating

7.2. Solar Water Heating

Solar energy is the cleanest and most inexhaustible energy source. Solar energy is being used around the globe for electrical as well as thermal energy generation. In scope of this study solar water heating is considered for prefeasibility purpose. There are two types of solar water heating systems **(i)** Flat plate collector, and **(ii)** evacuated tube collector. Evacuated tubes systems are more suitable for high temperature requirements and are thus preferred for industrial use; and hence are focused in this study. The efficiency of flat plate collector reduces as ambient temperature increases. Similarly, the efficiency of evacuated tube collector is superior to the flat plat collectors even at low temperature and irradiation. Moreover, due to cylindrical nature of collectors the incident sun's rays on the tubes are at 90 degrees throughout the day.

Evacuated tube collector uses solar energy to heat the fluid inside the tube through absorption of radiation, but reduce the loss of heat to atmosphere due to vacuum inside the tube. Evacuated tube has different sub categories based on material used and application requirement. Life of the evacuated tube collectors is around 15 years.

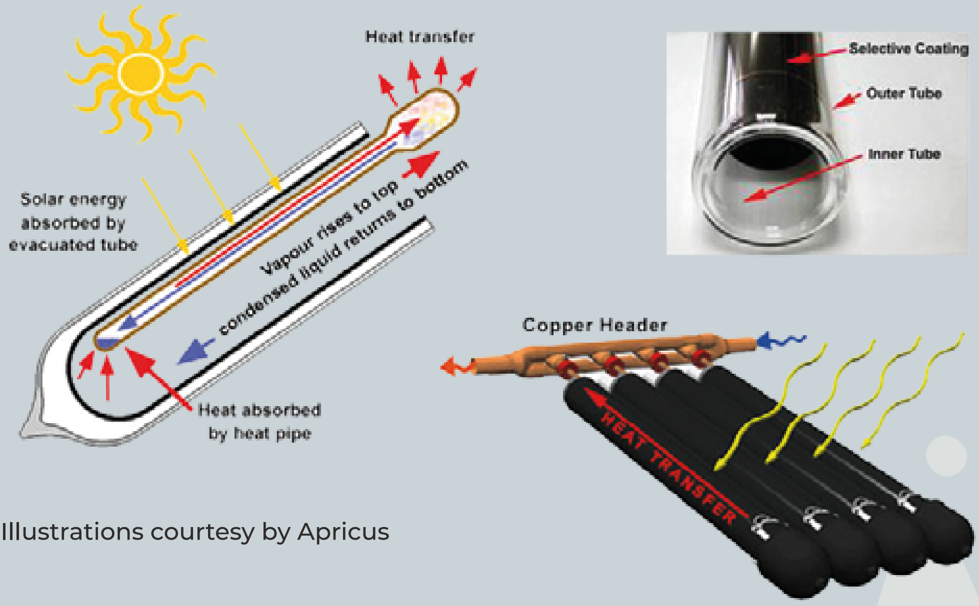
Main characteristics of the evacuated tube collector are[29] :

A	Lower heat loss due to radiation & hence higher efficiency for higher temperature delivery
B	Easy to install
C	Capability to endure environmental conditions (rain, dust etc.)
D	Capable of enduring large variations in temperature
E	Resistance to leakage from any part of the system
F	Stable and durable

29.Training Manual on Solar Water Heaters for Industrial Applications, UNDP/GEF Project on Global Solar Water Heating, Ministry of New & Renewable Energy, Government of India, March 2012

The main components of an evacuated tube collector are as listed below and depicted in the following figure:

1	**Glass tube**: The glass tube shall be formed by fusing two co-axial glass tubes at both the ends. Air between the two glass tubes is evacuated to create vacuum which works as insulation. Outer surface of inner tube in the evacuated tube collector forms the collector area.
2	**Tubular metal absorber (Heat Pipe)**: The absorber is tubular in shape and is made up of highly conducting material like copper. It is placed in between the co-axial glass tubes.
3	**Absorber coating**: Absorber coating is applied on the collector tube to selectively absorb the solar radiation to collect energy and to convert light energy into heat energy. The selective absorption coating is currently the most widely used coating. This coating is capable of absorbing 93% solar energy and reflects back 6%



Illustrations courtesy by Apricus

Figure 8: Components of Evacuated Solar Tube

The pipes must be angled at a specific degree above horizontal so that the process of vaporizing and condensing functions. There are two types of collector connection to the solar circulation system. Either the heat exchanger extends directly into the manifold ("wet connection") or it is connected to the manifold by a heat-conducting material ("dry connection"). A "dry connection" allows exchanging individual tubes without emptying the entire system of its fluid. Evacuated tubes offer the advantage that they work efficiently with high absorber temperatures and with low irradiation[30] .

Figure 9: Solar water heater installed at a roof-top in Pakistan

30. GreenSpec: Solar power: Solar panel hot water collectors, https://www.greenspec.co.uk/building-design/solar-collectors/, as on March 10, 2021

Solar irradiation potential in Bangladesh[31]

Average potential Global Horizontal Irradiation (GHI) in Bangladesh varies between 4.3-4.6 kWh/m² which varies across the country. This presents great potential for solar water heaters as usually solar water heaters are designed at 2.53 kWh/m². Following map provides the GHI potential across Bangladesh.

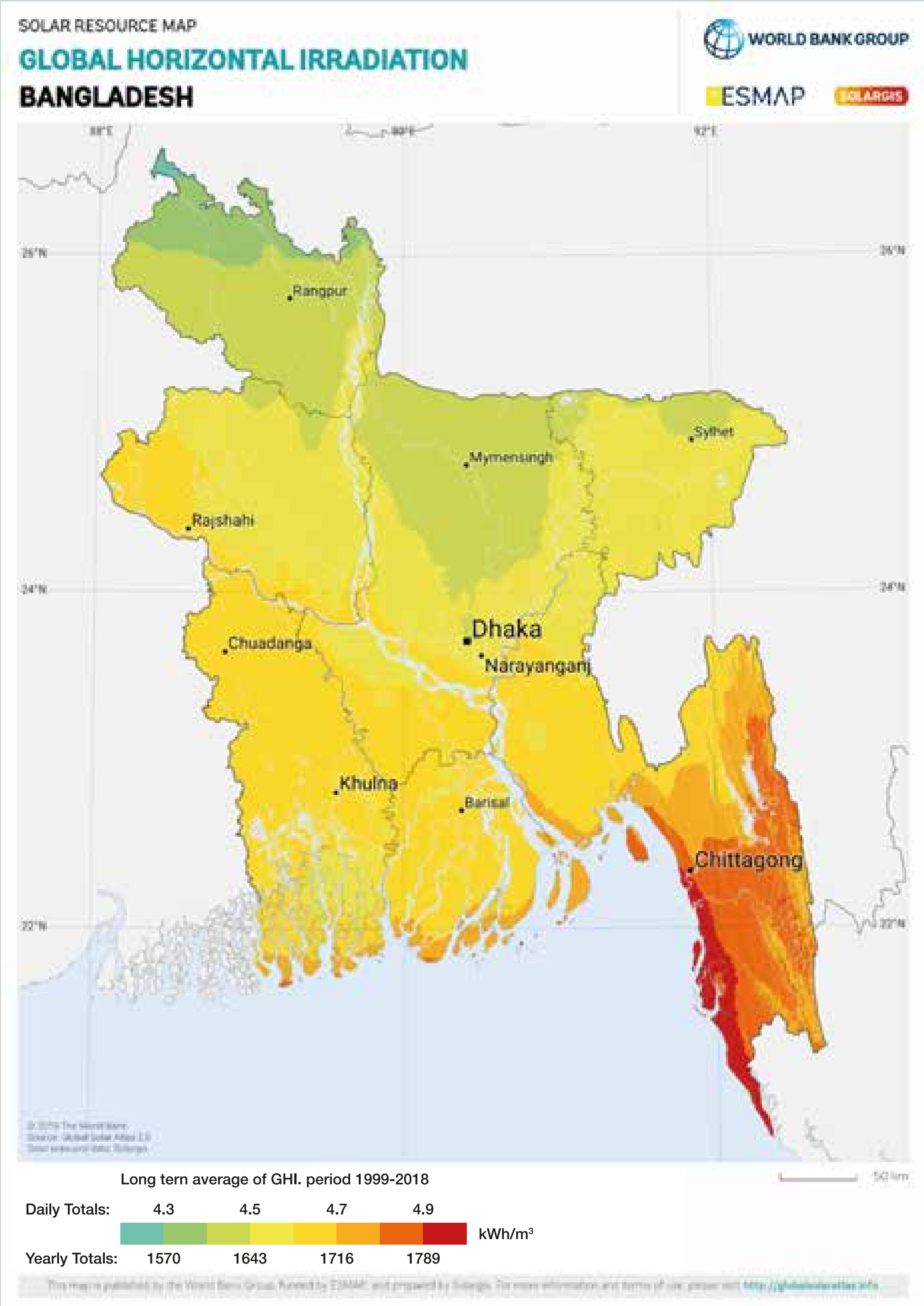


Figure 10: Global Horizontal irradiation in Bangladesh

31. Bangladesh - Solar irradiation and PV power potential map | Data Catalog (worldbank.org)

Solar irradiation potential in Pakistan[32]

Average potential Global Horizontal Irradiation (GHI) in Pakistan varied between 3.6-6.4 kWh/m^2 which varies across the country. This presents great potential for solar water heaters. Following map provides the GHI potential across Pakistan.

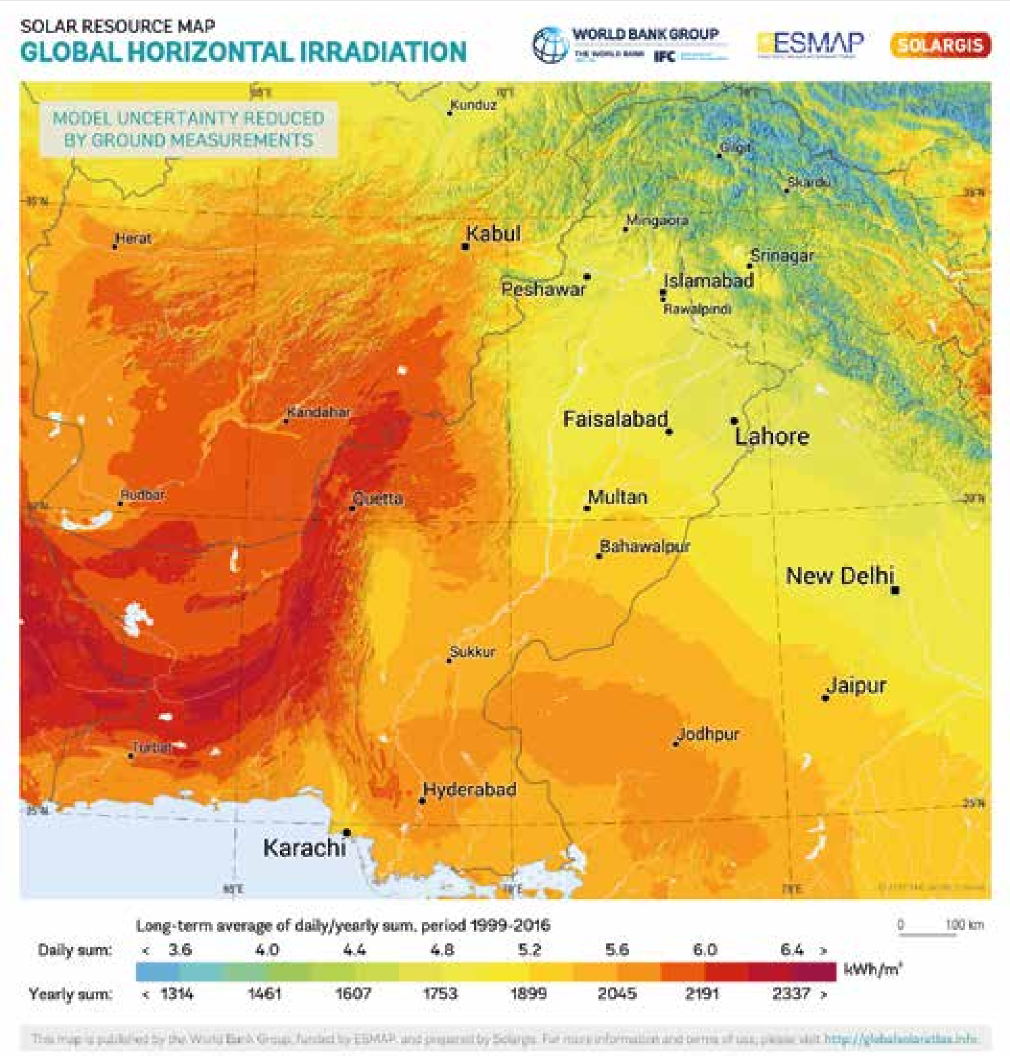


Figure 11: Global Horizontal irradiation in Pakistan

Economic feasibility of solar water heating

Following analysis is conducted considering hot water demand of 10,000 litres per hour, heating water from 25°C to 65°C on average (may go up to 90°C in summer) for 8 hours a day. A system of approximately 9,000 evacuated tubes would be needed for this thermal load. Following table provides financial analysis for such a system, while proceeding chart presents cash flow for the system with dynamic payback period calculation. Analysis shows that the return on investment is very lucrative with a significant positive net present value (NPV).

32. https://datacatalog.worldbank.org/dataset/pakistan-solar-irradiation-and-pv-power-potential-maps

Table 6: Feasibility for 10,000 Litres/hour solar water heating system

Water flow	80 m^3/d
Collectors (50 tubes each)	180
Average Temperature gain (ΔT)	40°C
Energy gain	13,408 MJ/d
Hours of operation (average)	8 hrs
Footprint area	1,487 m^2
Specific weight of the system	38.75 kg/m^2
Gross weight of the system on rooftop	57,606 kg
Storage tank	20 m^3
Pumping energy	16 kWh/h
Investment	200,237 USD
Lifecycle	15 years
Feasibility for Bangladesh	
Natural Gas saving	711 m^3/d
GHG emission reduction	434 tCO_2/year
Energy cost reduction	28,084 USD/year
Dynamic payback period	6 years
IRR	18 %
NPV	116,028 USD

Feasibility for Pakistan when Natural Gas is main heating source	
Natural Gas saving	711 m^3/d
GHG emission reduction	434 tCO_2/year
Energy cost reduction	50,038 USD/year
Dynamic payback period	4 years
IRR	32 %
NPV	396,005 USD
Feasibility for Pakistan when coal is main heating source	
Coal saving	1.1 Tonne/d
GHG emission reduction	862 tCO_2/year
Energy cost reduction	59,182 USD/year
Dynamic payback period	3 years
IRR	37 %
NPV	509,370 USD

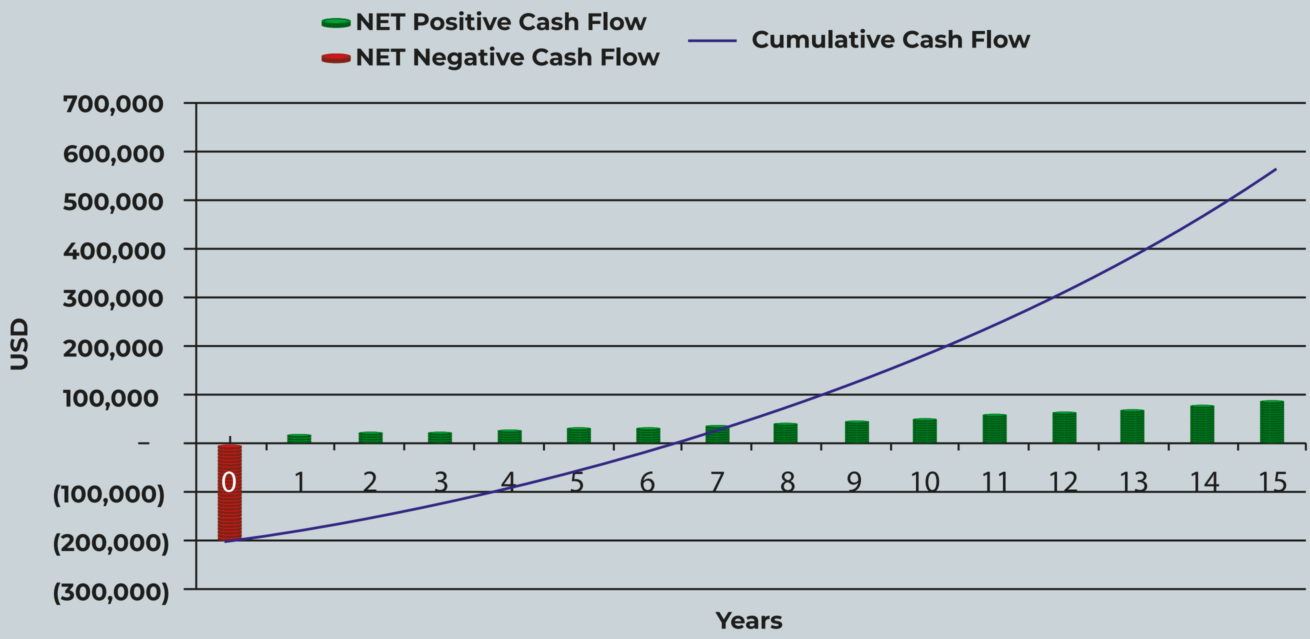


Figure 12: Return on investment for 10,000 liters/hour solar water heating system Bangladesh

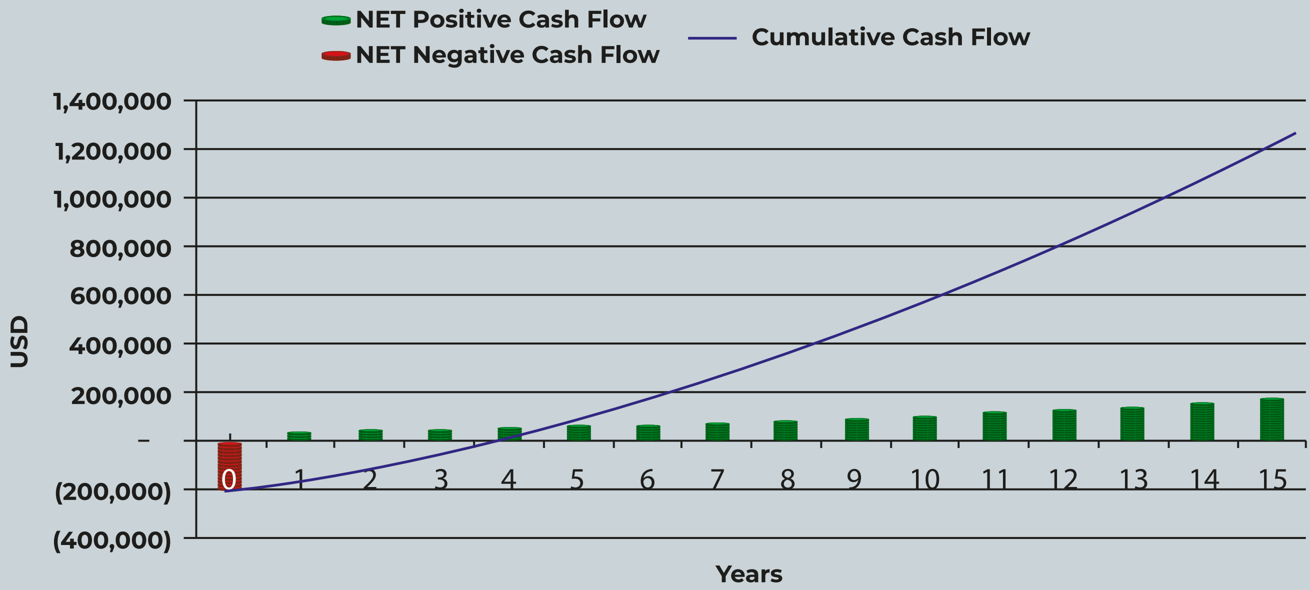


Figure 13: Return on investment for 10,000 liters/hour solar water heating system Pakistan (replacing natural gas heat)

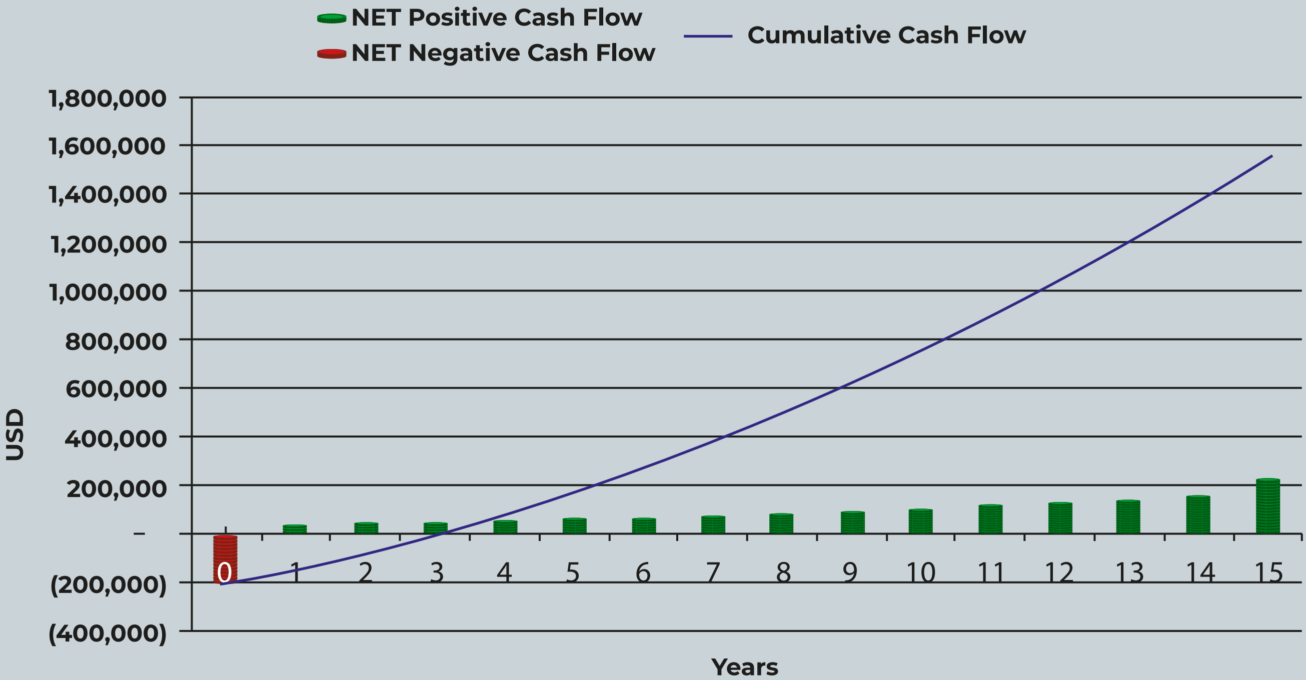


Figure 14: Return on investment for 10,000 liters/hour solar water heating system Pakistan (replacing coal heat)

Limitations of Solar Water Heating System

Main implementation constraints to be considered from a technical perspective for implementation of solar water heating are[33] ;

A	Availability of roof space and load bearing capacity of the structure; which varies from case to case. The weight of these collectors is much more than that of Solar PV panels so careful consideration is require (see above table).
B	The system must be fed with soft water from water softening plant or reverse osmosis to avoid scaling in the evacuated tubes.
C	The system requires proper "safe start" procedure as the tubes are hot even if there is no water inside, and feeding cold water directly at start-up often results in bursting the tubes.
D	Availability of alternative waste heat streams: The fuel mix used in an industry can result in generation of waste heat streams which are a more inexpensive alternative to provide low grade heating. Especially if a factory uses natural gas fired prime engines, a considerable demand of hot water and steam can be met through waste heat recovery.
E	Requirement of hot water in garment washing process is usually intermittent. Approximately 30% of total water demand is hot water which is also not required continuously. Storage tanks in this case are required where significant temperature loss is usually experienced[34]. However, this loss can be minimized by carefully scheduling the production process and water network. Solar water heaters become even more suitable for factories having more stable hot water demand, such as fabric processing mills.

33. Report on Market Assessment, Solar Water Heaters for Industrial Applications, UNDP/GEF Project on Global Solar Water Heating, Ministry of New & Renewable Energy, Government of India, March 2012
34. Based on discussions with garment factories in Pakistan

Economic Feasibility of Solar Photo Voltaic (PV) system

Economic Feasibility for solar PV systems has been conducted taking help from case study by SREDA[35] ; considering that same roof-top size is utilised for solar PV as suggested earlier for solar water heater; the 1,487 m^2 area would provide following solar PV potential;

Table 7: Feasibility for Solar PV (1,487 m^2 area)

	Solar PV replacing Grid Power	Solar PV replacing Natural Gas Power	Units
Footprint area	1,487		m^2
Typical potential (monocrystalline)	7.3		m^2/kW
Total potential capacity	203 174		kW DC kWp
Specific weight of the system	25		kg/m^2
Gross weight of the system on rooftop	37,175		kg
Investment	144,142		USD
Lifecycle	20		years
Bangladesh			
Hours of operation (average)	3.2-3.9		hrs
Annual energy generation capacity	209,538		kWh/ Year
Energy gain	2,066		MJ/d
GHG emission reduction	126.5	118.9	tCO_2/ year
Electricity cost saving (1st year)	22,268	13,639	USD/ year
Dynamic payback period	6	9	years
IRR	20	12	%
NPV	163,137	20,501	USD

35. Case study on Net Metering Rooftop Solar PV – Industrial and Commercial Electricity Consumer Class, Sustainable and Renewable Energy Development Authority (SREDA)

Continuation of

Table 7: Feasibility for Solar PV (1,487 m^2 area)

	Solar PV replacing Grid Power	Solar PV replacing Natural Gas Power	Units
Pakistan			
Hours of operation (average)	3.8-4.5		hrs
Annual energy generation capacity	242,190		kWh/ Year
Energy gain	2,389		MJ/d
GHG emission reduction	106	137.4	tCO_2/ year
Electricity cost saving (1st year)	22,152	16,245	USD/ year
Dynamic payback period	7	9	years
IRR	20.3	14.5	%
NPV	161,212	63,574	USD

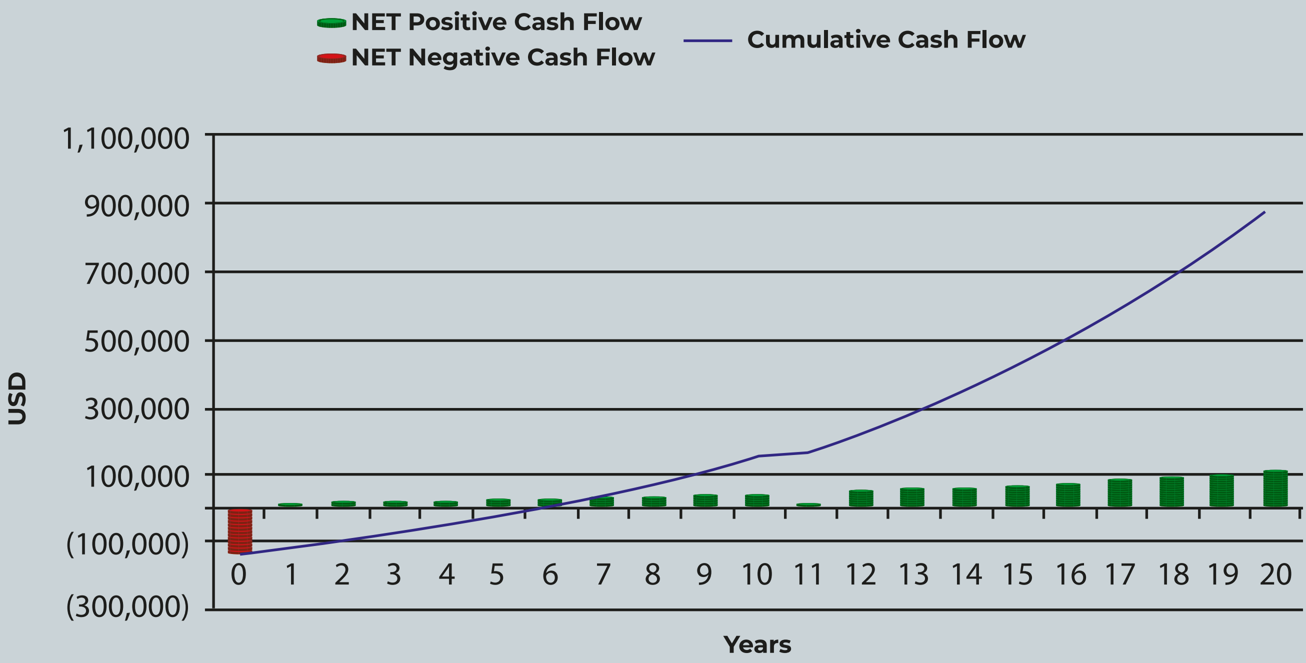


Figure 15: Return on investment for 203 kWp (DC) solar PV system (replacing grid power) Bangladesh

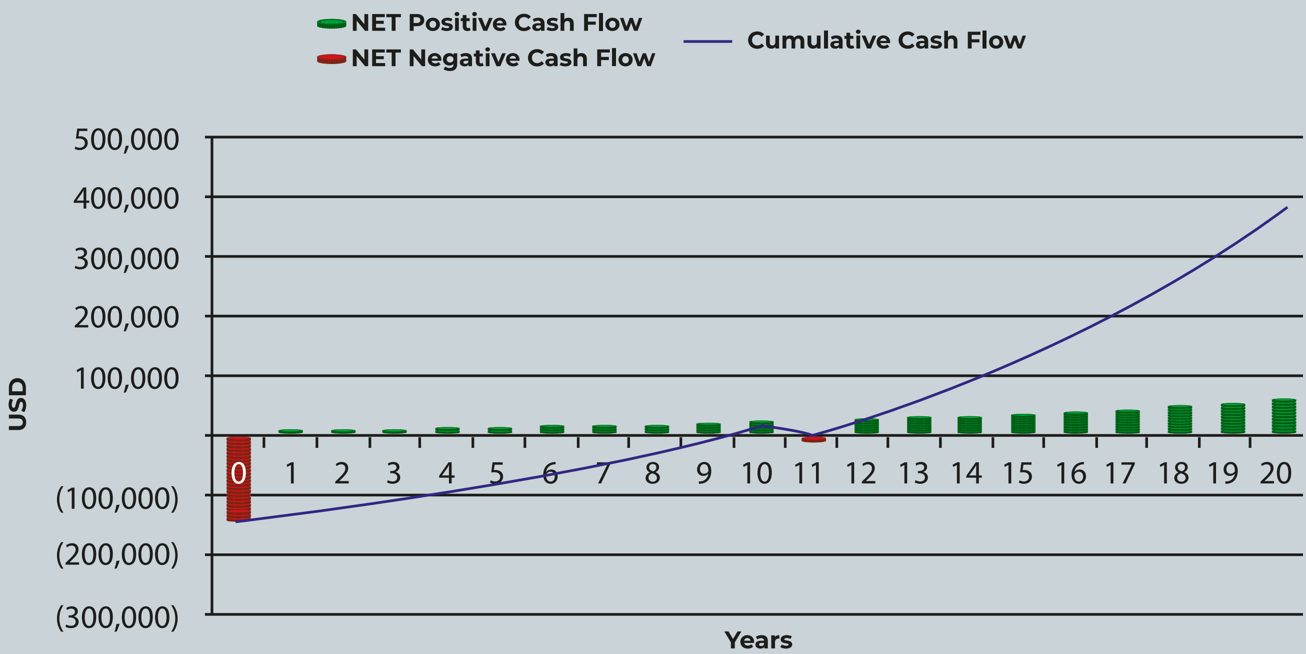


Figure 16: Return on investment for 203 kWp (DC) solar PV system (replacing natural gas engines) Bangladesh

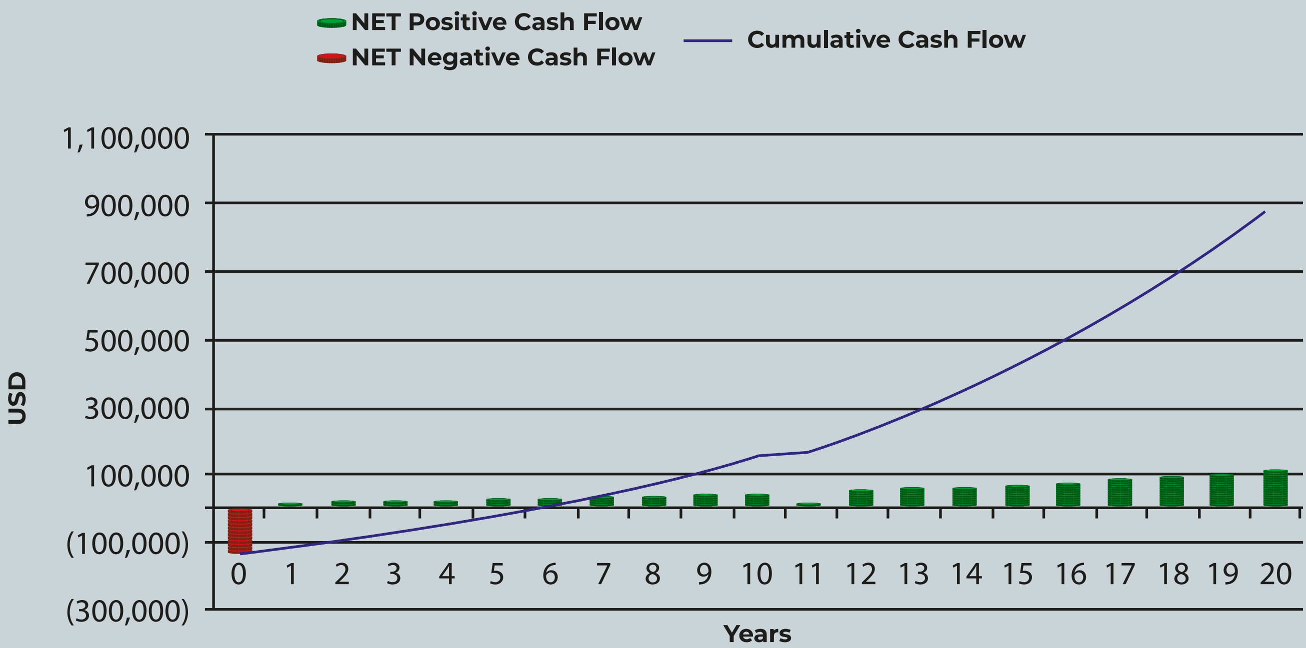


Figure 17: Return on investment for 203 kWp (DC) solar PV system (replacing grid power) Pakistan

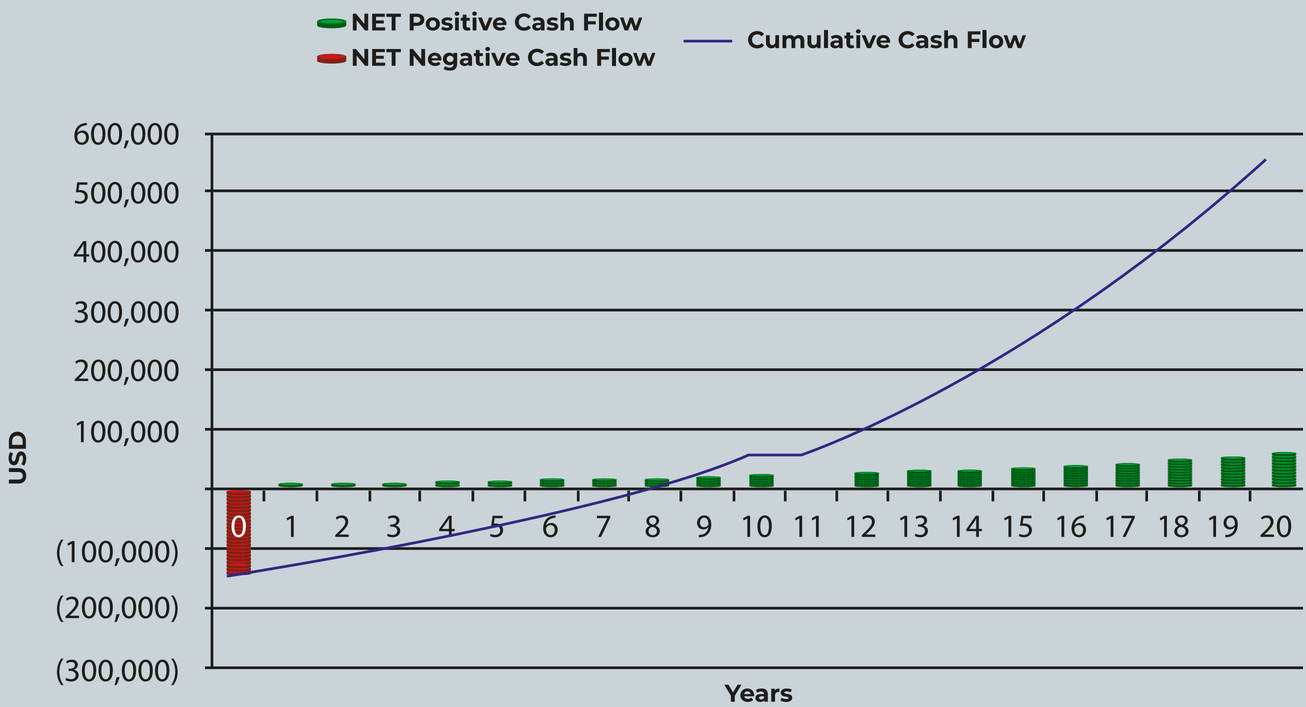


Figure 18: Return on investment for 203 kWp (DC) solar PV system (replacing natural gas engines) Pakistan

The savings and IRR for Solar PV system significantly reduce if main power source is natural gas-based power plants instead of grid power. This is because the electricity cost for natural gas power plants is much lower than that of grid supply in both countries.

Comparison between Solar Water Heater and Solar PV systems

Following are the outcomes of comparison between Solar Water Heater and Solar PV systems based on the above feasibility assessments. The comparison is presented graphically in following figure.

A	In terms of financial performance, Solar PV systems require much more investment for same amount of energy compared to solar water heater; hence the quicker pay-back period. This is because the solar water heaters gain energy for longer daily average duration compared to Solar PV. Payback period for Solar PV replacing Natural Gas based power is even longer; hence the low IRR.
B	It is much easier to install and operate solar PV system as they do not require allied utilities like pumps, heat exchangers and storage tanks.
C	Specific weight of the Solar PV system is much lesser than that of solar water heaters reducing requirements for structural reinforcement.
D	Potential to reduce GHG emissions is much higher for Solar Water Heater compared to Solar PV.
E	Solar water heaters have shorter lifecycle compared to Solar PV and also have higher operations and maintenance costs.

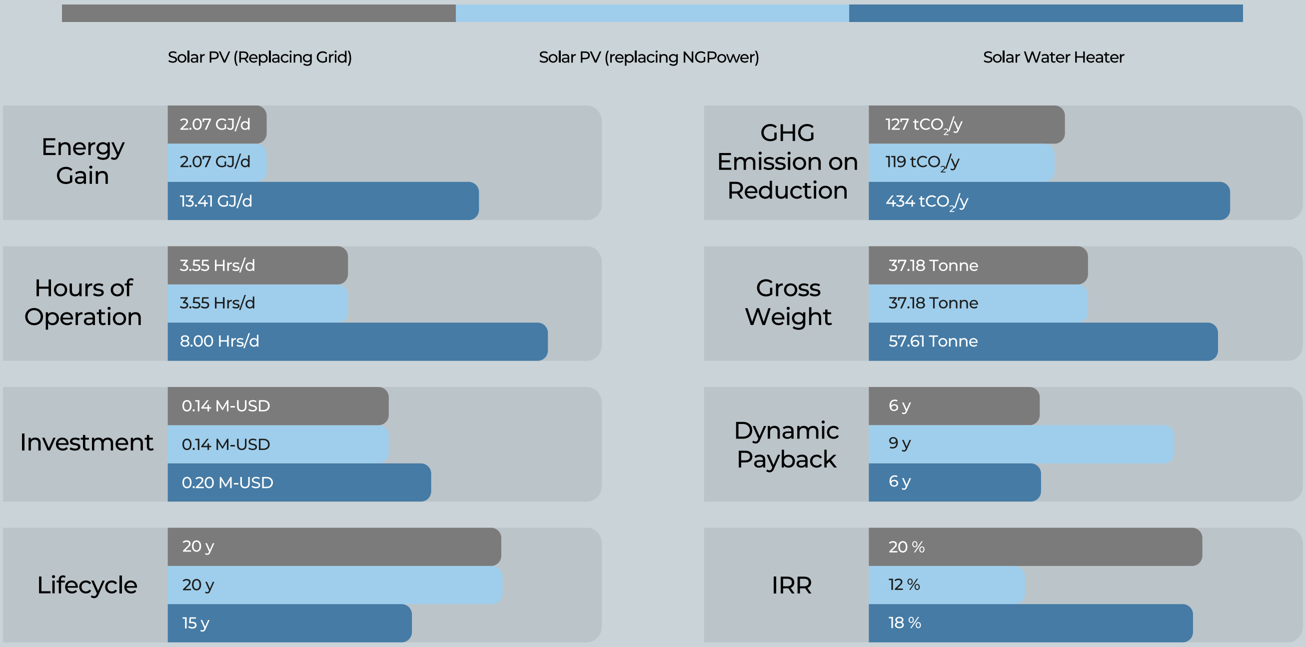


Figure 19: Comparison between Solar Water Heater and Solar PV systems for Bangladesh

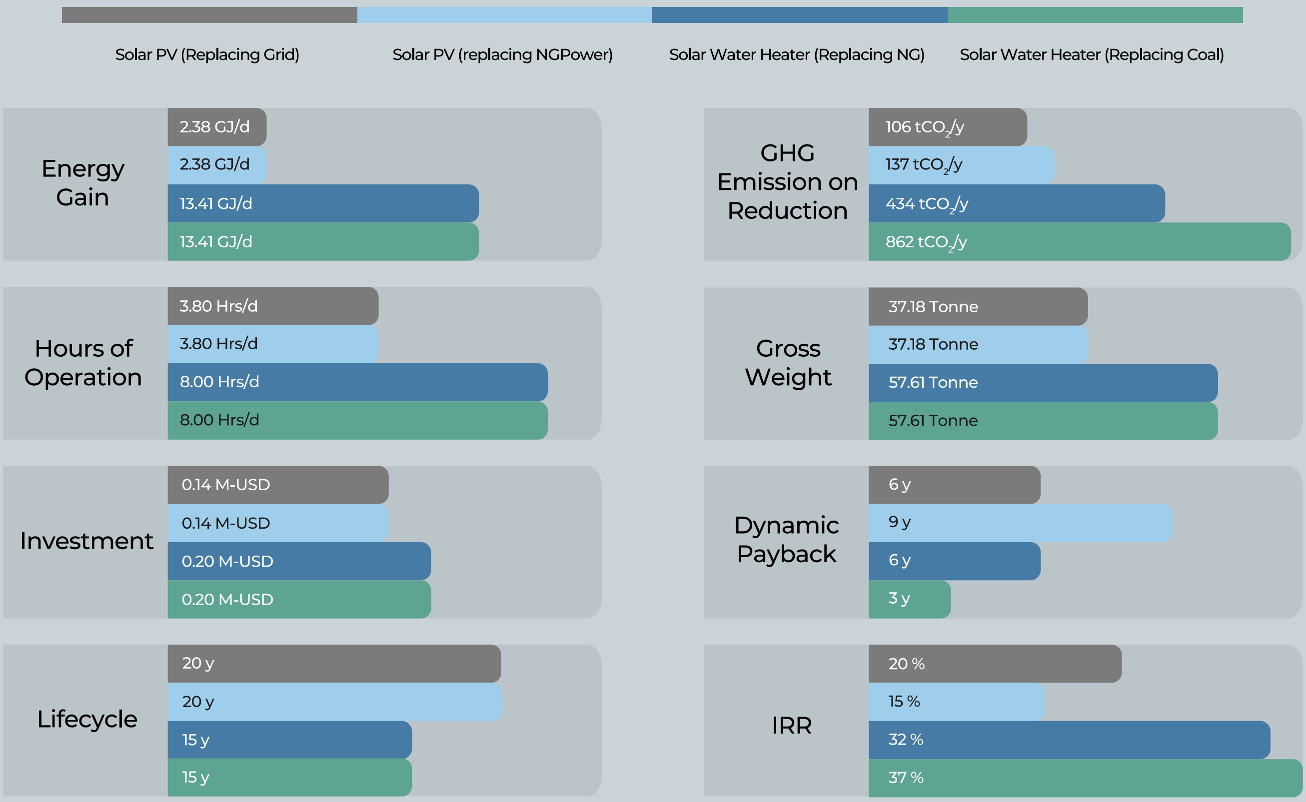


Figure 20: Comparison between Solar Water Heater and Solar PV systems for Pakistan

8
CONCLUSION

Conclusions are presented here summarizing the results of the study;

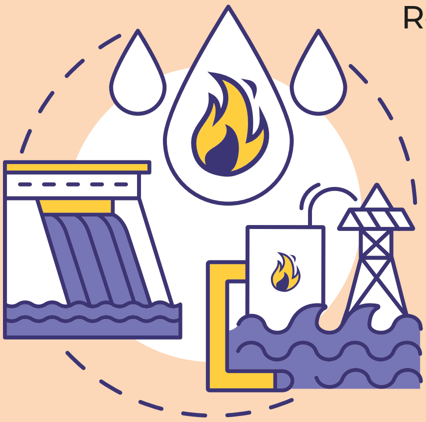
1- Bio-mass is cost-intensive but can reduce GHG emissions:

Natural gas is by far the cheapest fuel in Bangladesh in terms of steam generation cost, and also has the lowest variation in steam cost due to less frequent fuel price fluctuations compared to other fuels having more variable steam cost due to frequent price fluctuations. In Pakistan, Bio-mass competes well in this aspect with coal and natural gas. However, there are no GHG emissions associated with Agri-based bio-mass fuels, hence establishing these as more suitable in terms of climate improvement targets. Moreover, bio-mass may become economically viable in Bangladesh as well if natural gas prices increase in future due to introduction of RLNG in the national supply line. The trade-off needs to be made between the steam cost and GHG emissions and a suitable fuel mix may be selected by factories keeping the steam cost suitable as well as minimizing the environmental impact.

2- Major challenge to adopt bio-mass:

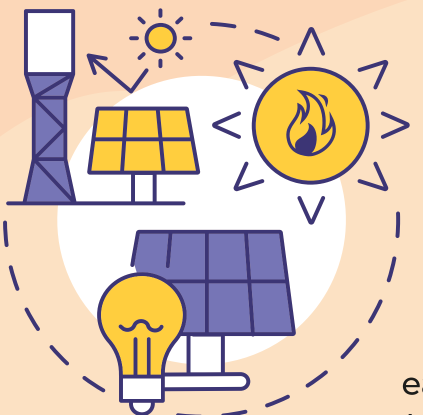
Bio-mass fuel supply chain management is a major concern which results in multiple challenges, especially, price fluctuation and sufficient availability. Another important element to consider for switching to bio-mass fuels is additional space and human resource requirement which may become a challenge for smaller companies having low steam demand; however, medium and large-scale companies usually have sufficient resource available. Investment required for switching to bio-mass fuels may become a relevant indicator as well for companies who do not have a bio-mass boiler available at site. It is observed that larger companies keep bio-mass fired boilers as back-up option; in which case the critical indicators would be supply, steam cost and GHG emissions. Although bio-mass availability data in Bangladesh needs updating; but from the analysis it is evident that there might not be enough bio-mass available to drive a major shift from fossil fuels to bio-mass for energy generation both in Bangladesh and Pakistan.

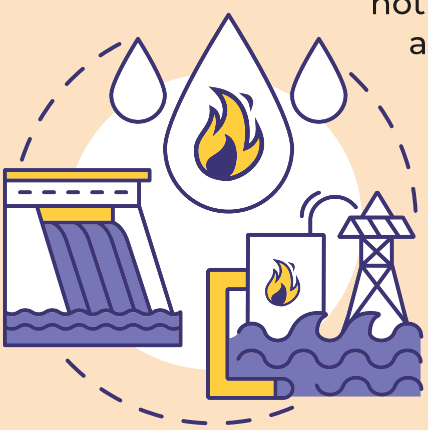
3- Solar Water heaters carry significant potential for thermal energy generation and GHG emission reduction:



Requirement of hot water in garment washing process is usually intermittent. Storage tanks in this case are required where considerable temperature loss is usually experienced. However, careful planning and proper designing and insulation of water circuit may resolve this issue to some extent. Industrial scale Solar Water Heaters may not be feasible for factories using steam only for garment pressing. Solar water heaters are highly suitable for factories having more stable hot water demand, such as fabric processing mills and large garment washing units. Detailed feasibility study may be conducted on Solar Water Heaters for a specific case so that detailed analysis of hot water demand and generation potential could be conducted.

4- Solar PV is feasible, but not as much as Solar Water Heater:





Solar Photo Voltaic may also be considered for reducing dependence on national grid or fossil fuel (natural gas) fired engines. Solar PV systems require much more investment for same amount of energy compared to solar water heaters. However, it is much easier to install and operate solar PV system as they do not require allied utilities like pumps, heat exchangers and storage tanks. Specific weight of the system is much lesser than that of solar water heaters reducing requirements for structural reinforcement. GHG emission reduction for solar PV is considerable when replacing grid power, however, potential significantly reduces when replacing natural gas power.

Following table summarises the key aspects of the study for opting bio-mass, solar water heaters, and solar PV systems.

Table 8: Mapping biomass /biofuel /alternate resource (Solar) potential assessment

Renewable energy options	Energy cost	GHG emission	Nature and direction of regulation
Bio-mass	Increased steam cost compared to natural gas	No GHG emission accounted for agri-based bio-mass with harvest cycle equal or less than 1 year	No restriction
Solar Thermal	Financially feasible even when compared with Natural gas fired steam boilers	Significant reduction	Supportive
Solar PV	Financially feasible compared to grid; longer payback against natural gas-based power	Significant reduction	Supportive[36] [37]

36. Sustainable Finance Policy for Banks and Financial Institutions, 2020
37. State Bank of Pakistan Financing Scheme for Renewable Energy 2016

Continuation of

Table 8: Mapping biomass /biofuel /alternate resource (Solar) potential assessment

Renewable energy options	Geography	Seasonality	Key vendors	Pricing considerations	Current Uses
Bio-mass	Geographical variation in supply; Supply chain data only up-till 2015	Fluctuating based on crop harvesting cycle	No formal data of bio-mass suppliers; technology suppliers available but not formally organized	Basic price data available; concrete fluctuation data not available	Data only up-till 2015 for BGD. Estimates made for 2019-20 for PAK based on data of 2015.
Solar Thermal	Geographical ly variable irradiation potential	Seasonally variable irradiation potential	Limited suppliers for industrial solutions, not formally organized	Generally established prices but variable based on currency exchange rate	No mapping available for industrial sector
Solar PV	Geographical ly variable irradiation potential	Seasonally variable irradiation potential	Bangladesh Solar and Renewable Energy Association; Bangladesh Solar Energy Society. Multiple vendors in Pakistan.	Generally established prices but variable based on currency exchange rate	No mapping available for industrial sector

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