Replacing Fossil Fuel based thermal generation with Renewable Fuel in textile and garments sector in Bangladesh – Prefeasibility Study

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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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
RLNG	Regasified Liquefied Natural Gas
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].

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 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 can be significantly reduced by a conversion to biomass sources to fuel boilers. Although this is uncommon in Bangladesh, it is prevalent at a significant scale in H&M's other production markets such as India and Cambodia.

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 the largest apparels buyer in Bangladesh. As a responsible retail H&M is leading many sustainability efforts along with different stakeholders in Bangladesh.

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. The goals of the study are to identify potentials to reduce the GHG emissions with the focus on renewable energy resources. This includes three separates, sequenced but linked phases:

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[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

1. 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 Bangladesh’s textile and garments sector
2. Phase-2: To conduct a detail study on the most relevant and suitable renewable fuel source to use in boiler operation in the industry
3. Phase-3: To support H&M to initiate a pilot in 8 - 10 factories and demonstrate the viability of renewable fuel boiler that will help to develop a business case for a much broader cross section of suppliers

This document presents the Phase-1 of the study which shall be followed by the Phase-2; however, the execution of Phase-3 is yet to be formalized between H&M and GIZ.

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, 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 biomass 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 assesses the suitability and technical viability of using (i) Biomass for generation of steam replacing natural gas, and (ii) solar water heaters to heat up process water instead of using steam.

Various types of biomasses 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 biomass is not available.

Various technology options are assessed in the report and their suitability for different kinds of bio-mass fuels are suggested. The selection of biomass fired boiler depends on the biomass to be used as fuel and the variety of biomass as well. Generally, for rice husk and other small particle sized biomass, 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 biomass 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 biomass 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, biomass 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 biomass 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.

A detailed study is proposed at the end of this document with following options (refer to Way forward for further details).

Option-1: Develop pilot for adopting biomass for one selected supplier; ideally selecting a supplier where bio-mass boilers are already installed or are located near the Agri-based bio-mass source.

Option-2: Develop pilot for adopting solar energy (thermal or PV) for one selected supplier.

4. LIMITATIONS

Major part of the study included evaluation of using biomass in the boilers. However, very limited data and facts were available on supply chain of biomass 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 biomass for domestic cooking either by direct burning or through bio-gasification. No specific study on usage of biomass 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 biomass 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 biomass.

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 biomass. 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 biomass in Bangladesh were reviewed to evaluate the supply chain of biomass. 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 biomass 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 biomass, its types and its nation-wide uses was conducted. This also included evaluating global warming potential and calorific values of various available biomass 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.

6. AREAS OF THERMAL ENERGY DEMAND IN TEXTILE AND 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

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- Biomass for steam generation (Combustion and Gasification)
2- Solar Water Heating

7.1. Biomass 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. 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.

Managing the supply chain for biomass 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 from various sources in Bangladesh[2]

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.

[2] 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

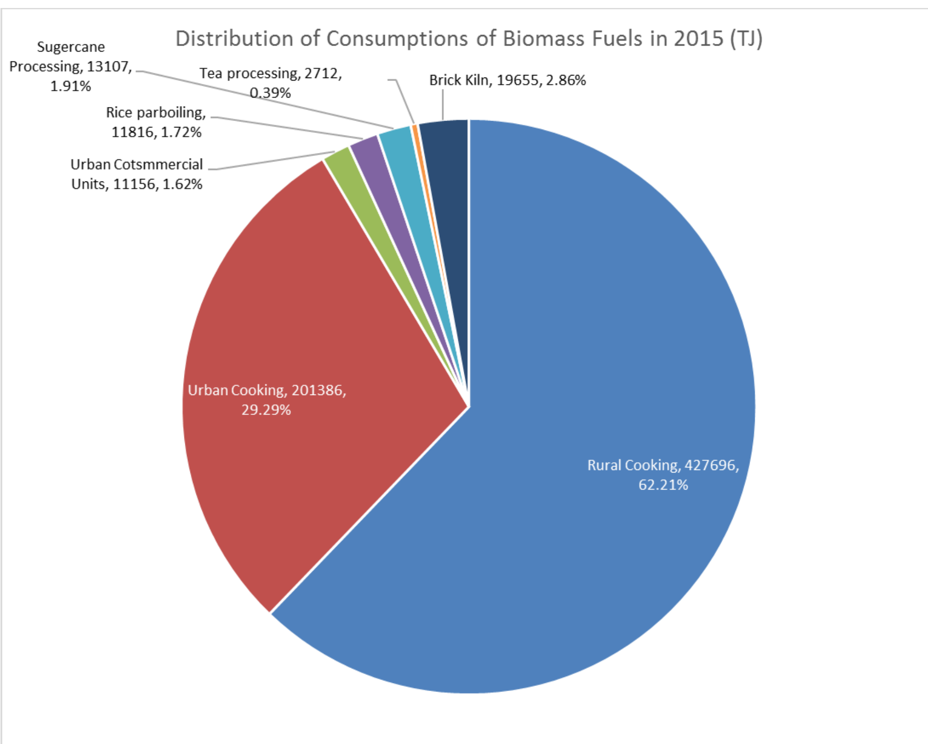
Crop residues (e.g., bran, oil cake etc.) are generally used as cattle and poultry feed. Rice husk also has multiple uses like poultry bedding materials and as a fuel in paddy parboiling. There is hierarchical gradation of plant and crop residues depending on their economic value. Fodder, feed and building 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.

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 biomass 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) [3]



[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

As per Bangladesh Auto Major and Husking Mill Owners Association[4], there are three seasons for rice cultivation: (i) January – May, (ii) July – December, and (iii) June – September. Estimated paddy production is 52 million tonnes out of which 30% are kept by farmers for their own consumption mostly for cooking as fuel including the related agricultural waste and rice husk. Rest 70% (36.4 million tonne) are processed in rice mills. 7kg rice husk (17.5%) is produced from 40 kg rice paddy. 50% of husk is used by traditional mills to run their boilers and rest 50% are sold to poultry farms and wood stick manufacturers who produce these sticks from husk which are ultimately used for domestic cooking. 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 biomass for industrial consumption as fuel.

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 biomass to natural gas as soon as a gas connection is awarded. This is mainly due to almost double steam generation price using biomass (especially rice husk) compared to natural gas as well as consistency in supply of natural gas (see 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 biomass boilers, but steam cost still poses a challenge.

Case study of a textile company in Bangladesh

The "Textile Company"[5] 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.

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[4] Interview with General Secretary, Bangladesh Auto Major and Husking Mill Owners Association, March 04, 2021

[5] Company name not mentioned to keep confidentiality

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.

On average, 70% of steam demand at the Textile Company is met by natural gas fired sources while 30% though the biomass 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 to 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 biomass especially fluctuation of supply and prices, and storage requirements due to high moisture in biomass.

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

Prices of biomass in Bangladesh

As explained above, the prices of biomass are variable in Bangladesh. Following table provides prevailing prices of prominent biomass being used in Bangladesh.

Table 2: Biomass prices in Bangladesh[6]

Biomass	**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 biomass	No reliable price data available

Current practices in Pakistan textile and garment industry[7]

Due to unreliable supply of natural gas in the country, textile and other industries in Pakistan started shifting to biomass for steam generation around 2009-2010. Rice Husk, Corn Cob, and Wood logs were major bio-mass sources for textile industry. Sudden shift to biomass at mass scale resulted in price rise of biomass and also disrupted the supply throughout the country. Currently, majority of textile companies have abandoned using biomass 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 biomass are provided below.

- Gas fired boilers were converted by adding poorly designed refractory furnaces for biomass burning. Boiler capacity would reduce due to inefficient area available for burning in the furnaces.

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

[7] Interviews with four textile factories in Pakistan, February 15, 2021

- Maintenance cost increased as tube leakages were often experienced in furnaces due to poor design.
- Particulate matter is major challenge in flue gases of biomass 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.

Selection of boiler for biomass

The selection of biomass fired boiler depends on the biomass to be used as fuel and the variety of biomass 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 reciprocating grate biomass boiler (feeding corn cob)

Bio-mass briquetting

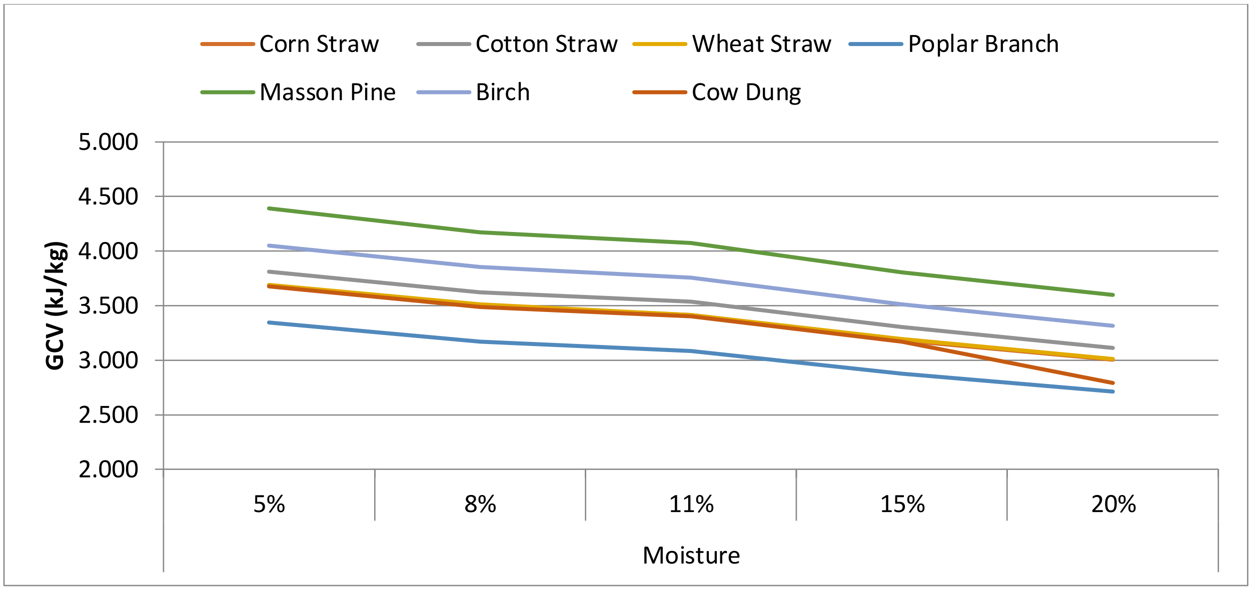
The biomass briquettes are mainly produced from the agricultural waste material, livestock, industrial/urban waste, or a mixture thereof. The process includes (i) crushing the biomass to required size, (ii) drying the crushed biomass depending on moisture content (materials with less moisture content need no drying), (iii) compacting the biomass to form briquettes of various shapes depending on method. Binders are sometimes required to be added to the biomass to ensure the briquette stays firm; in Pakistan cow dung or saw dust are usually mixed with biomass 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 biomass 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[8]. 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 biomass; 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 biomass, weather conditions, storage conditions, transportation methods, and if the biomass comes from a recent harvest or from a

[8] https://briquettesolution.com/biomass-briquette-machine-guideline/

longer storage. For example, the moisture in cow dung and cotton straw is generally above 70%[9,10] 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) [11]



Briquetting process adds to the cost of biomass 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 per kg of biomass is added to the cost. However, the compact biomass 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 biomass. So even if this seems more efficient, briquetting can only be used if supply of biomass 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 biomass which can be compensated by reduced energy required for briquetting in the factory and reduced human resource requirements.

[9] 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

[10] https://fertilizerproductionlines.com/manure-dewatering-machine/#:~:text=As%20you%20know%2C%20the%20moisture%20in%20cow%20dung,and%20has%20higher%20capacity.%20Cow%20dung%20drying%20machine

[11] https://briquettesolution.com/bio-and-fuel-briquette-calorific-value-biomass-sawdust-coal-charcoal/

Using biomass 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 m3/hour water from 25^{o}C to 75^{o}C through water heater would require 210-230 kg/hour biomass. 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 (see Current practices in Pakistan textile and garment industry), 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 biomass (especially forest-sourced biomass) carries double global warming potential (GWP) compared to that of natural gas. However, GWP of biomass 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[12]. A study[13] 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[14] suggest not recording the CO_2 emissions of biomass, 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 biomass and 0.00000011 for biogas), 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.

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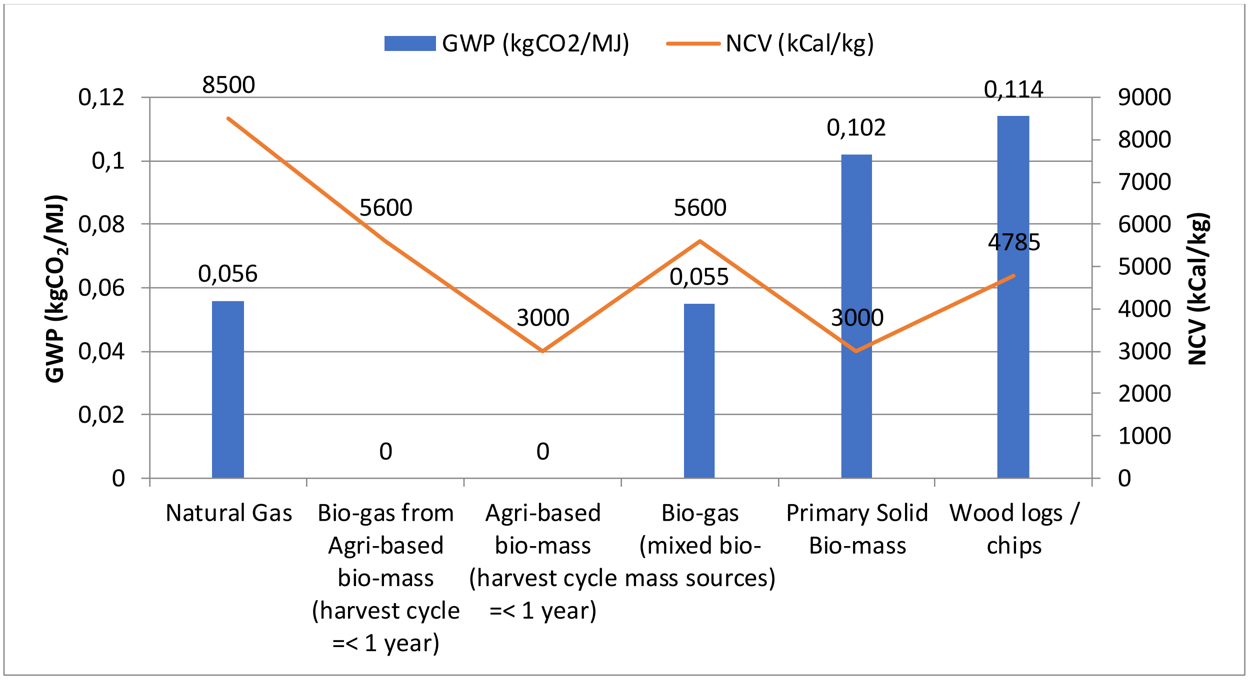
[12] Demystifying the carbon neutrality of biomass, Anil Baral, Posted in The International Council of Clean Transportation, https://theicct.org/blogs/staff/demystifying-carbon-neutrality-biomass#:~:text=A%20GWP%20bio%20factor%20represents%20the%20relative%20global,in%20turn%20corresponds%20to%20harvesting%20cycles%20(rotation%20periods).. (June 13, 2014)

[13] Accounting Framework for Biogenic CO_2 Emissions From Stationary Sources https://yosemite.epa.gov/sab/sabproduct.nsf/0/2F9B572C712AC52E8525783100704886/$File/Biogenic_CO2_Accounting_Framework_Report_LATEST.pdf (US EPA, September 2011)

[14] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, CHAPTER 1 (iges.or.jp)

Figure 5: Comparison of Global warming potential and Net Calorific Values of fuels[15]



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.

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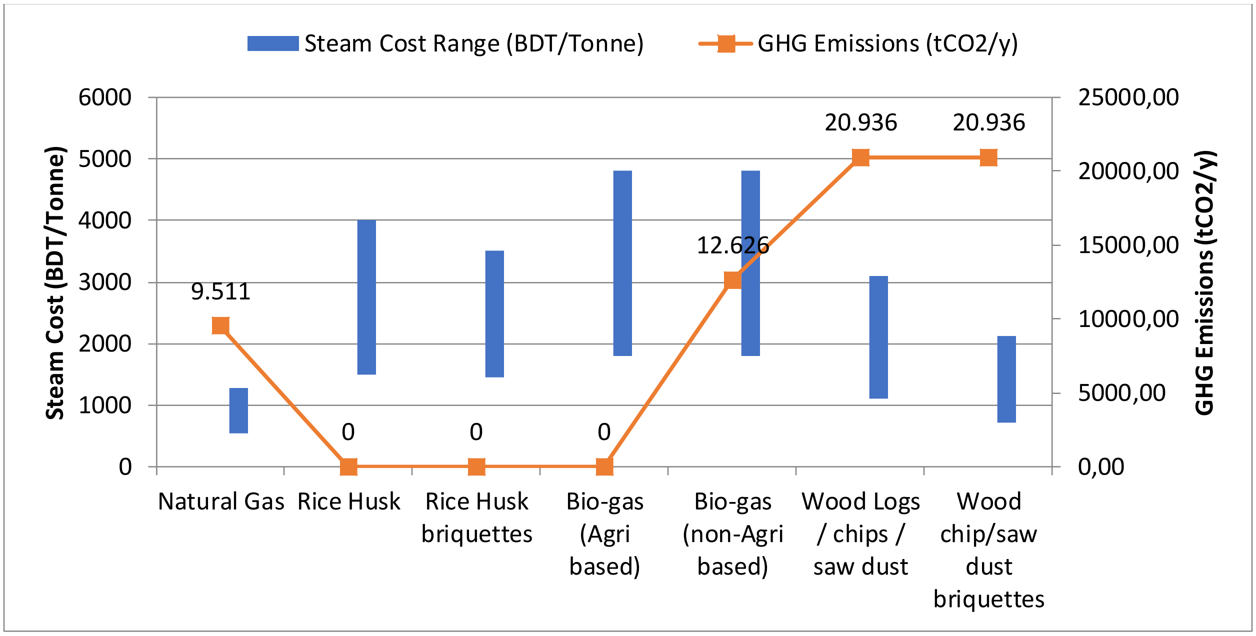
[15] Values calculated using Stationery Combustion Tool Version 4-1 by Greenhouse Gas Protocol

Table 3: 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	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
Biogas (Agri-based or sewage waste biomass)	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



Rationale for switching to Agri-based biomass

It is evident that 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. 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 biomass.

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 Re-gasified 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, biomass may provide a competitive edge due to being locally produced.

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 biomass 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 biomass.
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 biomass varies across the year which significantly effects boiler combustion efficiency. The variation in moisture depends upon source of biomass, weather conditions, storage conditions, transportation methods, and if the biomass comes from a recent harvest or from a longer storage. Large storage space is required to stock enough biomass 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 biomass behind natural gas in the race.
e. Managing the supply chain for biomass 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.

7.2. 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 subcategories 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[16]:

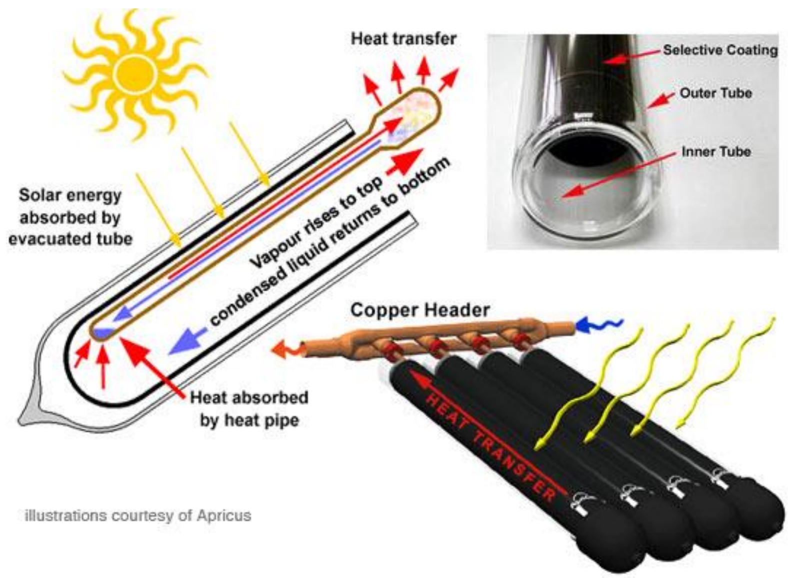
a. Lower heat loss due to radiation & hence higher efficiency for higher temperature delivery
b. Easy to install
c. Capability to endure environmental conditions (rain, dust etc.)
d. Capable of enduring large variations in temperature
e. Resistance to leakage from any part of the system
f. Stable and durable

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%

[16] 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

Figure 7: 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[17].

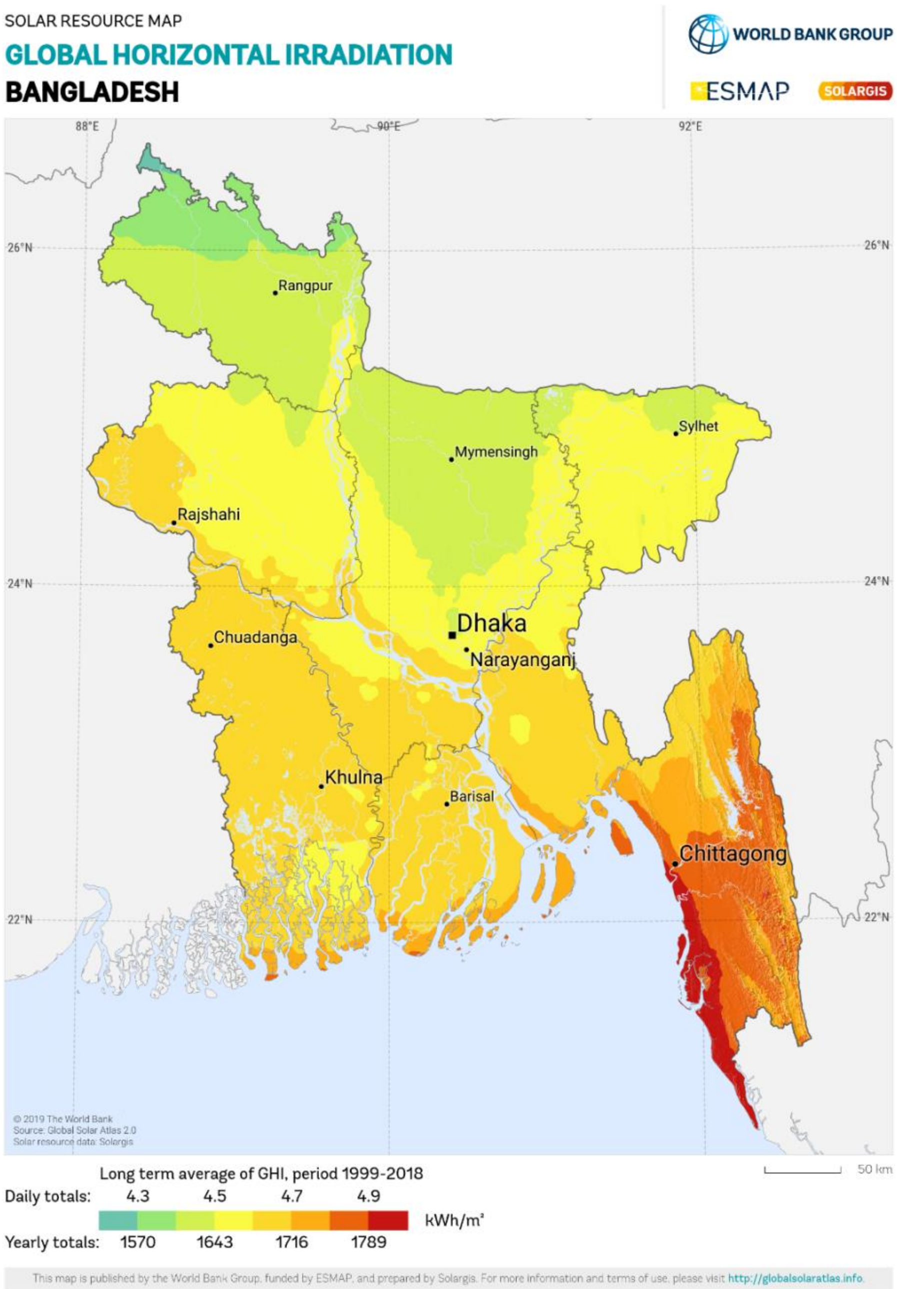
Figure 8: Solar water heater installed at a roof-top in Pakistan

[17] 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[18]

Average potential Global Horizontal Irradiation (GHI) in Bangladesh is 4.596 kWh/m^2 which varies across the country. This presents great potential for solar water heaters as usually solar water heaters are designed at 2.53 kWh/m^2. Following map provides the GHI potential across Bangladesh.

Figure 9: Global Horizontal irradiation in Bangladesh



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

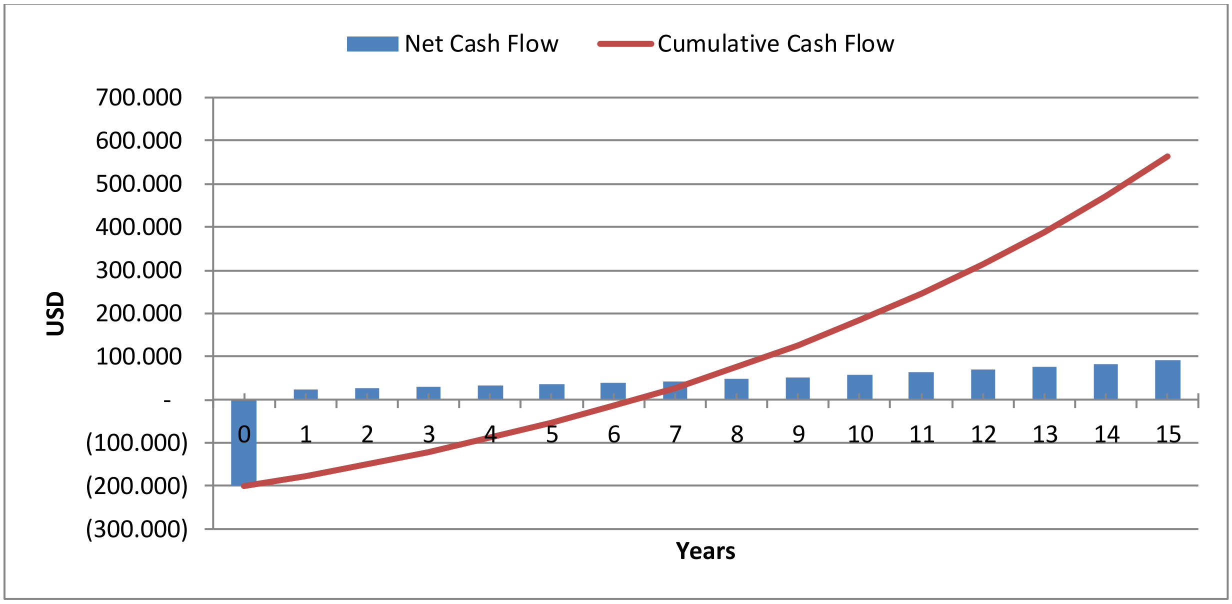
Economic feasibility of solar water heating

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 18% internal rate of return (IRR) and a significant positive net present value (NPV).

Table 4: 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 m2
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
Pumping energy cost	4,041 USD/year
Natural Gas saving	711 m^3/d
GHG emission reduction	434 tCO_2/year
Natural Gas cost saving (1st year)	28,085 USD/year
Investment	200,237 USD
Dynamic payback period	6 years
Lifecycle	15 years
IRR	18 %
NPV	116,028 USD

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



Limitations of Solar Water Heating System

Main implementation constraints to be considered from a technical perspective for implementation of solar water heating are[19];

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[20]. 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.

[19] 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

[20] 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[21]; 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 5: 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
Annual energy generation capacity	209,538		kWh/Year
Energy gain	2,066		MJ/d
GHG emission reduction	126.5	118.9	tCO2/year
Hours of operation (average)	3.2-3.9		hrs
Specific weight of the system	25		kg/m^2
Gross weight of the system on rooftop	37,175		kg
Investment	144,142		USD
Electricity cost saving (1st year)	22,268	13,639	USD/year
Dynamic payback period	6	9	years
Lifecycle	20		years
IRR	20	12	%
NPV	163,137	20,501	USD

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

Figure 11: Return on investment for 203 kWp (DC) solar PV system (replacing grid power)

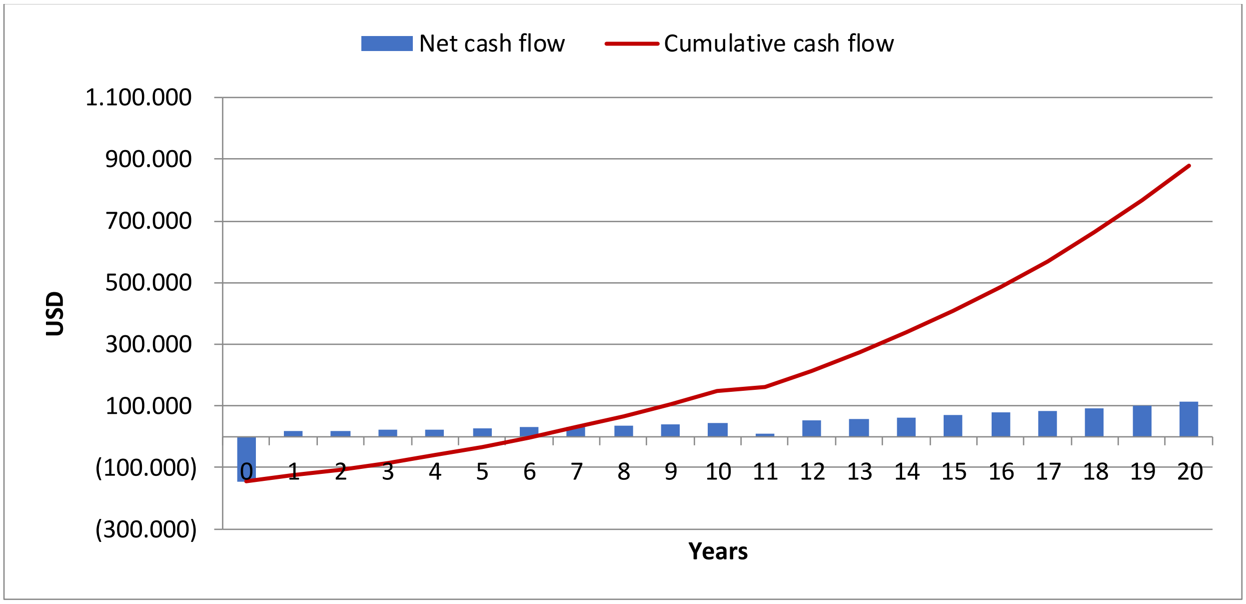
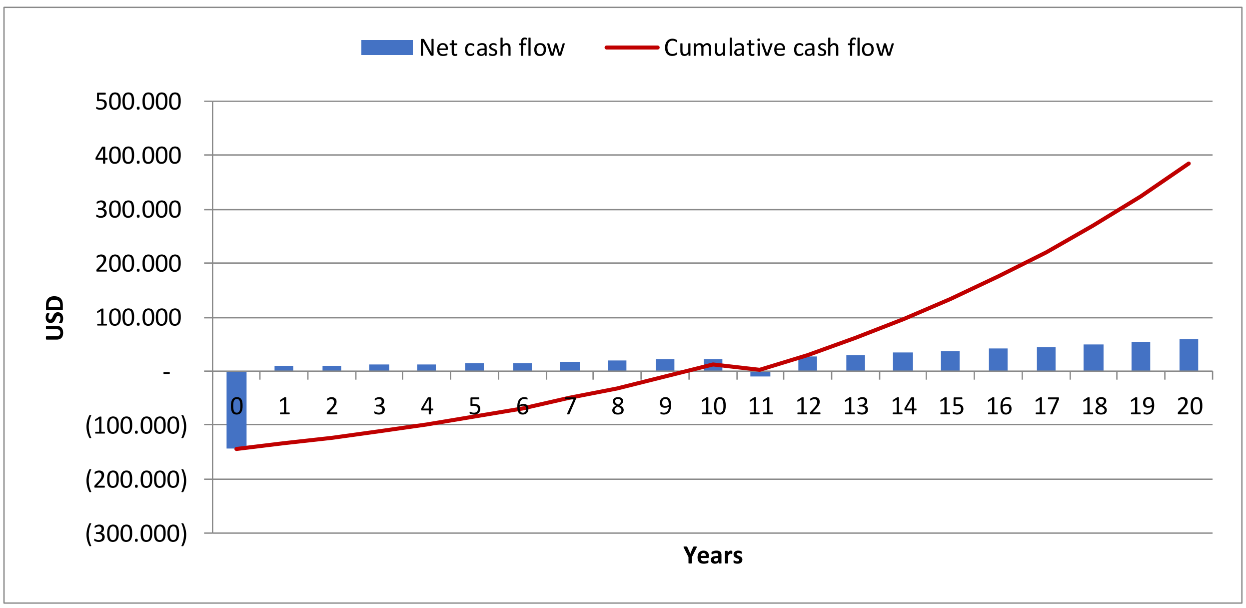


Figure 12: Return on investment for 203 kWp (DC) solar PV system (replacing natural gas engines)



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.

Comparison between Solar Water Heater and Solar PV systems

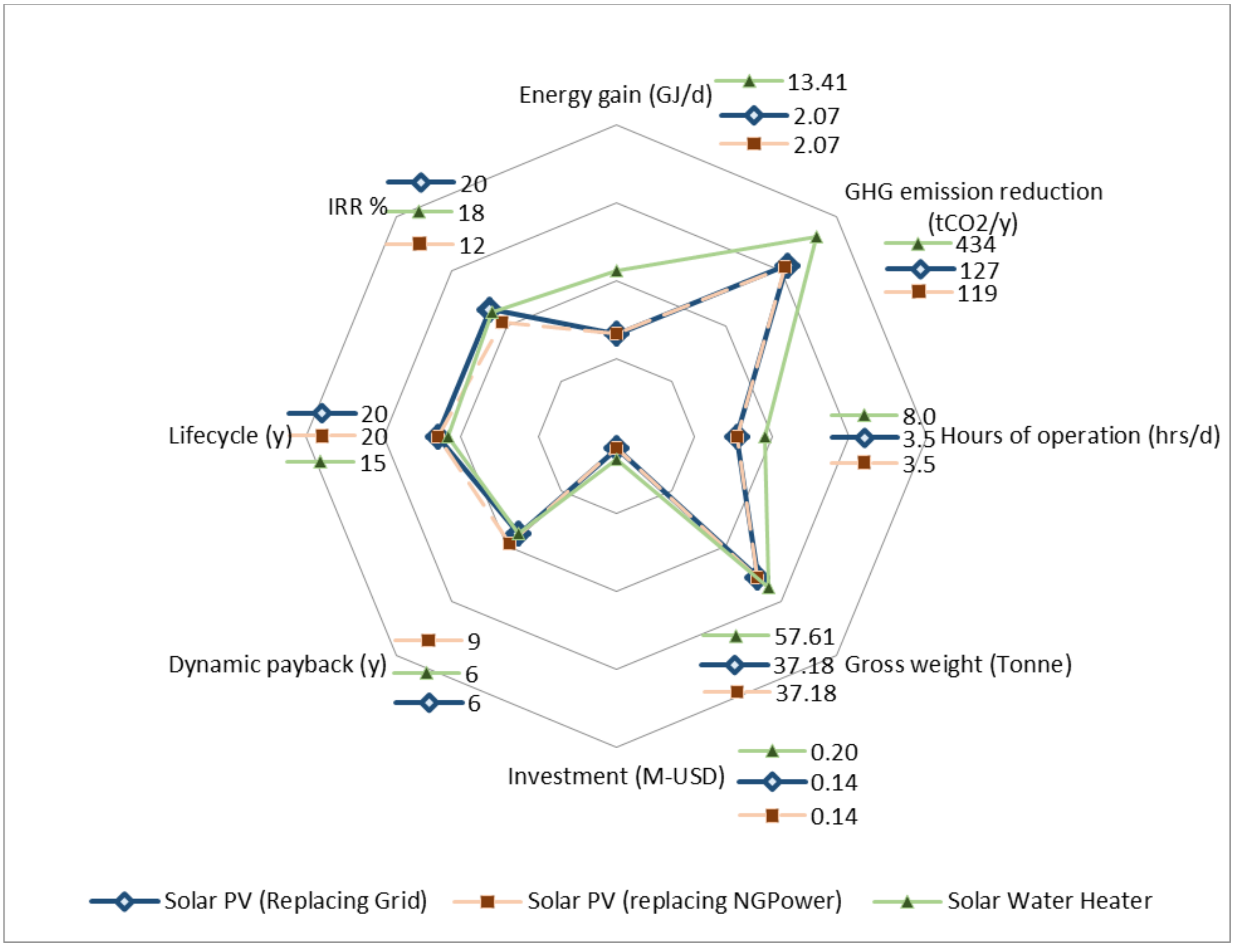
Following are the outcomes of comparison between Solar Water Heater and Solar PV systems based on the above feasibility assessments. The comparison is presented graphically in following figure.

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 13: Comparison between Solar Water Heater and Solar PV systems



8. CONCLUSION

Conclusions are presented here summarizing the results of the study:

1- **Biomass is cost-intensive but can reduce GHG emissions:** 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, biomass 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.

2- **Major challenge to adopt biomass:** 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 biomass fired boilers as back-up option; in which case the critical indicators would be supply, steam cost and GHG emissions.

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 biomass, solar water heaters, and solar PV systems.

Table 6: Mapping biomass /biofuel /alternate resource (Solar) potential assessment

Renewable energy options	**Energy cost**	**GHG emission**	**Nature and direction of regulation**	**Geography**	**Seasonality**	**Key vendors**	**Pricing considerations**	**Current Uses**
Biomass	Increased steam cost compared to natural gas	No GHG emission accounted for agri-based biomass with harvest cycle equal or less than 1 year	No restriction	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
Solar Thermal	Financially feasible even when compared with Natural gas fired steam boilers	Significant reduction	Supportive[22]	Geographically 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	Financially feasible compared to grid; longer payback against natural gas-based power	Significant reduction	Supportive[23]	Geographically variable irradiation potential	Seasonally variable irradiation potential	Bangladesh Solar and Renewable Energy Association; Bangladesh Solar Energy Society	Generally established prices but variable based on currency exchange rate	No mapping available for industrial sector

[22] Sustainable Finance Policy for Banks and Financial Institutions, 2020

[23] Sustainable Finance Policy for Banks and Financial Institutions, 2020

Way forward

Keeping in view the findings of this prefeasibility study, a detailed study may be conducted with following options:

Option-1: Develop pilot for adopting biomass for one selected supplier; ideally selecting a supplier where bio-mass boilers are already installed or are located near the Agri-based bio-mass source. Support may be provided to the supplier in:

1- Improving efficiency of the bio-mass steam generation system. This may also include introducing briquetting machines, improving combustion efficiency, training of boiler operators, evaluating potential for heat recovery etc.
2- Adopting new bio-mass boiler using biomass from nearby reliable sources of Agri-based biomass.
3- Selecting right steam source mix to achieve GHG reduction while maintaining steam cost in acceptable range.

Option-2: Develop pilot for adopting solar energy (thermal or PV) for one selected supplier.

1- Assessing solar energy potential at site
2- Selecting suitable solar energy option (thermal, PV or both)
3- Conducting pre-feasibility for selected option along with financial analysis and suitable financing options