Low-Carbon Thermal Energy Roadmap for the Textile Industry

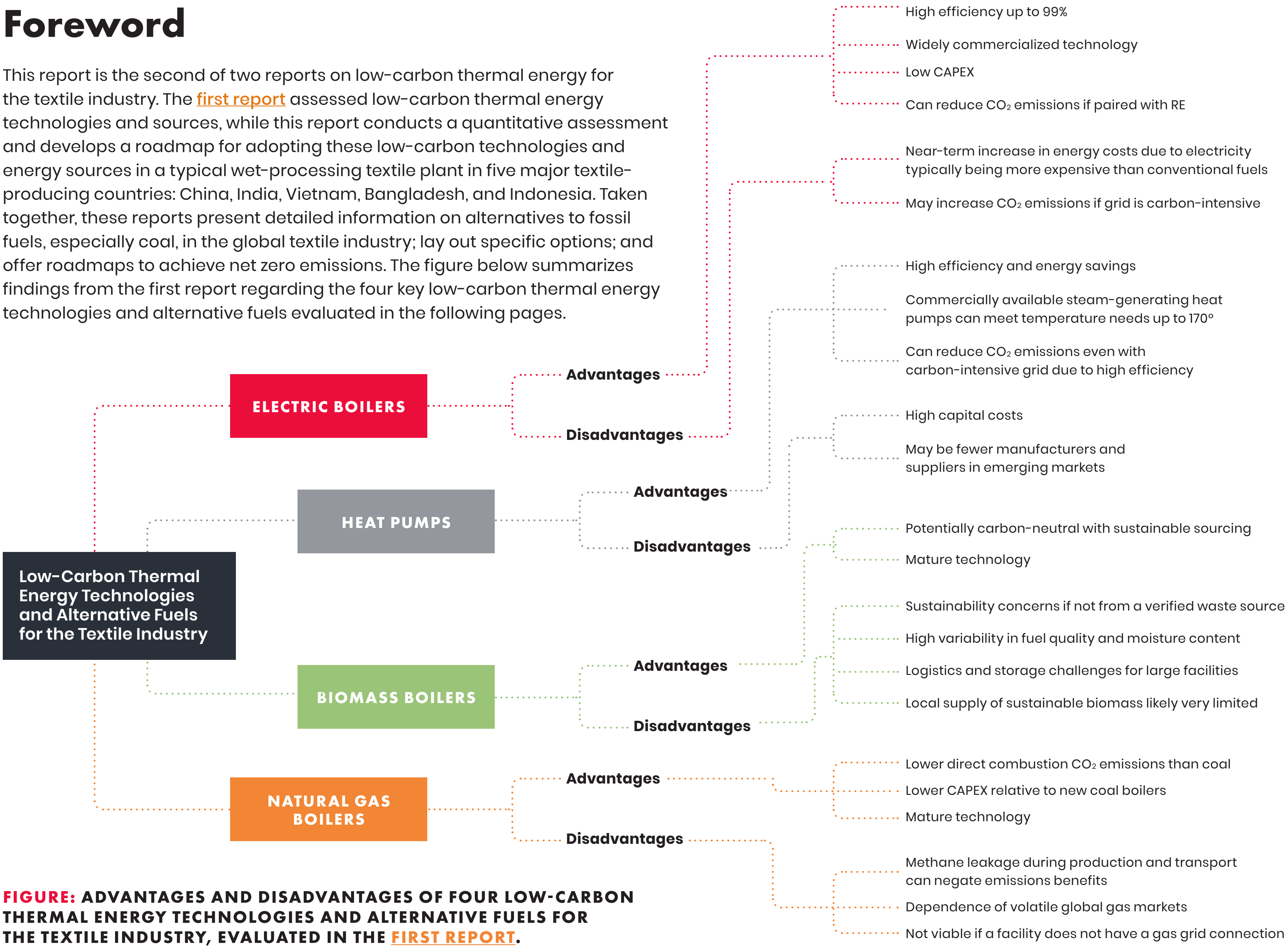
apparel impact institute

ALI HASANBEIGI, CECILIA SPRINGER, AND DENNIS WEI

MARCH 2025

Foreword

This report is the second of two reports on low-carbon thermal energy for the textile industry. The first report assessed low-carbon thermal energy technologies and sources, while this report conducts a quantitative assessment and develops a roadmap for adopting these low-carbon technologies and energy sources in a typical wet-processing textile plant in five major textile-producing countries: China, India, Vietnam, Bangladesh, and Indonesia. Taken together, these reports present detailed information on alternatives to fossil fuels, especially coal, in the global textile industry; lay out specific options; and offer roadmaps to achieve net zero emissions. The figure below summarizes findings from the first report regarding the four key low-carbon thermal energy technologies and alternative fuels evaluated in the following pages.



- **Low-Carbon Thermal Energy Technologies and Alternative Fuels for the Textile Industry**
  - **ELECTRIC BOILERS**
    - **Advantages**
      - High efficiency up to 99%
      - Widely commercialized technology
      - Low CAPEX
      - Can reduce CO_2 emissions if paired with RE
    - **Disadvantages**
      - Near-term increase in energy costs due to electricity typically being more expensive than conventional fuels
      - May increase CO_2 emissions if grid is carbon-intensive
  - **HEAT PUMPS**
    - **Advantages**
      - High efficiency and energy savings
      - Commercially available steam-generating heat pumps can meet temperature needs up to 170°
      - Can reduce CO_2 emissions even with carbon-intensive grid due to high efficiency
    - **Disadvantages**
      - High capital costs
      - May be fewer manufacturers and suppliers in emerging markets
  - **BIOMASS BOILERS**
    - **Advantages**
      - Potentially carbon-neutral with sustainable sourcing
      - Mature technology
    - **Disadvantages**
      - Sustainability concerns if not from a verified waste source
      - High variability in fuel quality and moisture content
      - Logistics and storage challenges for large facilities
      - Local supply of sustainable biomass likely very limited
  - **NATURAL GAS BOILERS**
    - **Advantages**
      - Lower direct combustion CO_2 emissions than coal
      - Lower CAPEX relative to new coal boilers
      - Mature technology
    - **Disadvantages**
      - Methane leakage during production and transport can negate emissions benefits
      - Dependence of volatile global gas markets
      - Not viable if a facility does not have a gas grid connection

FIGURE: ADVANTAGES AND DISADVANTAGES OF FOUR LOW-CARBON THERMAL ENERGY TECHNOLOGIES AND ALTERNATIVE FUELS FOR THE TEXTILE INDUSTRY, EVALUATED IN THE FIRST REPORT.

Aii awarded a Climate Solutions Portfolio grant, made possible by our lead funders, to support the development of this study and the publication of its findings.

Disclaimer

Global Efficiency Intelligence, LLC has provided the information in this publication for informational purposes only. Although great care has been taken to maintain the accuracy of the information collected and presented, Global Efficiency Intelligence, LLC does not make any express or implied warranty concerning such information. Any estimates contained in the publication reflect Global Efficiency Intelligence, LLC's current analyses and expectations based on available data and information. Any reference to a specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply an endorsement, recommendation, or favoring by Global Efficiency Intelligence, LLC.

Recommended citation: Hasanbeigi, Ali; Springer, Cecilia; Wei, Dennis (2025). Low-Carbon Thermal Energy Roadmap for the Textile Industry. Global Efficiency Intelligence, LLC.

globalefficiencyintel.com
textilesustainability.com
industryelectrification.com

Acknowledgments

This report was made possible with support from Apparel Impact Institute (Aii). The authors would like to offer special thanks to Pauline Op de Beeck of Apparel Impact Institute and Linda Greer of Linda Greer Consulting for their extensive input on this report. The authors would also like to thank Kurt Kipka, An Zhou, and Laxmikant Jawale of Apparel Impact Institute, and other reviewers for their insightful comments on the earlier version of this document.

Executive Summary

The textile and apparel industry significantly contributes to global greenhouse gas emissions, accounting for approximately 2% annually (Perkins, Sadowski 2024). A major challenge is the industry's reliance on fossil fuel-based thermal energy for process heating (e.g., steam production and thermal oil heating) which contributes to substantial carbon dioxide emissions. The industry increasingly recognizes the need to decarbonize, especially as global demand for apparel grows.

This report focuses on strategies to transition textile plants in five key textile-producing countries (China, India, Vietnam, Bangladesh, and Indonesia) to low-carbon thermal energy by shifting to alternative fuels and electrification technologies. The report analyzes electrification with electric boilers and heat pumps, and the effects of switching to the alternative fuels of biomass and natural gas. Results are presented for steam and thermal oil heating, which respectively account for 50-60% and 30-40% of fuel used in a typical textile wet processing plant.

To develop a roadmap for textile plants to transition to low-carbon thermal energy, extensive baseline data was collected on textile wet-processing facilities in each country, including boiler systems, energy consumption, and process-specific heat requirements. The study used detailed techno-economic modeling to compare the performance and costs of alternative fuels and electrification technologies against traditional fossil fuel-based boilers, primarily coal-fired. It's important to note that the analysis was conducted for a single, typical textile wet-processing plant in each country, rather than focusing on transitioning the entire industry in those countries to lower-carbon alternatives in the coming years. Projections were made for energy savings, emissions reductions, and energy costs.

For electrification technologies, we assumed grid electricity would be paired with directly procured renewable electricity (RE) (e.g. Power Purchase Agreements, onsite generation), a growing trend in the textile industry. We analyzed two renewable energy procurement pathways for 2030, 2035, and 2040 in each country, differing by the share of procured RE relative to grid electricity: Baseline RE Procurement and Ambitious RE Procurement. Additionally, for steam-producing technologies, the capital costs and projected annual operating costs were used to estimate an overall levelized cost of heat for steam generation that allows a more direct comparison of lifetime costs for each technology.

The Baseline Grid Plus RE Procurement pathway assumes each country will achieve its Nationally Determined Contributions (NDC's) and, where applicable, its stated net-zero target, and that a typical textile facility will be able to supplement its grid electricity supply with a baseline and increasing share of procured renewable energy. The assumed RE share reflects the state of the corporate RE procurement market in each country, with China, India, and Vietnam having greater RE supply and regulatory mechanisms to enable corporate RE procurement relative to Indonesia and Bangladesh. **The Ambitious Grid Plus RE Procurement pathway assumes a more ambitious integration of renewable energy into the grid and availability of RE for corporate procurement, beyond these country's current transition plans and trajectories.** For China, India, and Vietnam, where RE supply and policy support for direct procurement are expanding, we assume that a typical facility pursuing an ambitious low-carbon thermal energy transition could procure 100% of its electricity from renewable sources by 2030.

TABLE ES1: ASSUMED SHARES OF CORPORATE RE PROCUREMENT BY PATHWAY AND COUNTRY STUDIED

Year	China, India, and Vietnam		Indonesia		Bangladesh	
	Baseline Grid Plus RE Procurement	Ambitious Grid Plus RE Procurement	Baseline Grid Plus RE Procurement	Ambitious Grid Plus RE Procurement	Baseline Grid Plus RE Procurement	Ambitious Grid Plus RE Procurement
2030	50%	100%	25%	50%	0%	30%
2035	75%	100%	50%	75%	30%	50%
2040	100%	100%	75%	100%	50%	100%

While the Baseline Grid Plus RE Procurement Scenario is based on current trends, it is not guaranteed. Policy, infrastructure, and finance pinch points must be addressed to achieve the baseline scenario. However, we are confident that our research demonstrates this scenario is likely to happen.

The countries studied would have to accelerate their energy transition to reach the Ambitious Scenario. **When estimating the feasibility and pace of shifts to electrified technologies, the projected availability of RE (which delivers electricity with zero emissions) and its cost are the key determining factors, and these factors differ significantly across the five countries evaluated.** Carbon pricing influences projected energy prices, which drives the transition by raising the price of coal over time and making electrification technologies more competitive. Important differences also derive from the "starting point" of current fuel costs as well as baseline grid emission factors for each country.

Switching to alternative fuels can result in emissions and cost savings in the near term. Switching from coal to natural gas lowers the direct emissions factor. However, there could be an overall increase in annual GHG emissions relative to coal if upstream leakage of methane, a potent greenhouse gas, is not mitigated[1] (Figure ES1). Additionally, natural gas has logistical challenges that limit adoption, and higher costs and price volatility.

If sustainable biomass can be procured (e.g. agricultural residues), it is possible to significantly reduce net CO_2 emissions and lower energy costs in the near term by switching to sustainable biomass-fired boilers. **In this report, we use the term "sustainable biomass" to mean agricultural waste where there is no deforestation risk and certified wood waste and palm kernel shell sources.** Apparel brands and textile manufacturers should refer to existing industry frameworks for biomass procurement such as the Institute for Sustainable Communities Guidelines for guidance to avoid emissions increases and reputation risk through procuring unsustainable biomass. China has relatively abundant sources of biomass, and countries like India and Vietnam are already leveraging this fuel source. While Indonesia may have an abundance of biomass, the sustainable supply is limited due to the risk of deforestation. Bangladesh has the least biomass available for textile manufacturing. The feasibility of an individual textile facility depends on the local availability of sustainable biomass.

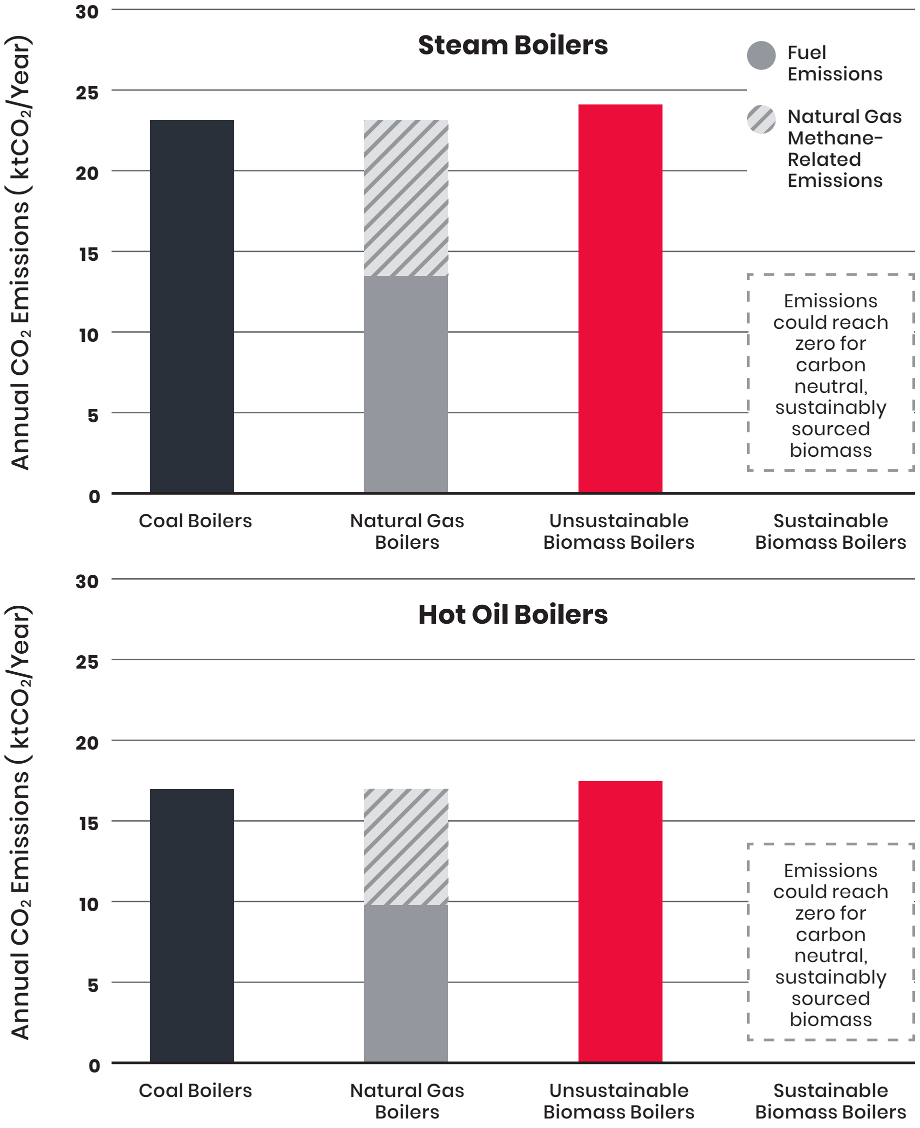


FIGURE ES1: COMPARISON OF ANNUAL CO_2 EMISSIONS FROM DIFFERENT FUEL TYPES FOR STEAM (TOP) AND HOT OIL (BOTTOM) BOILERS FOR A TYPICAL TEXTILE PLANT ANALYZED IN THIS STUDY

Note: Sustainable biomass is assumed to be carbon neutral, while unsustainable biomass uses IPCC emissions factors for direct combustion. **This figure excludes biogenic emissions, which should be accounted for in order to assess the life cycle carbon footprint of biomass.**

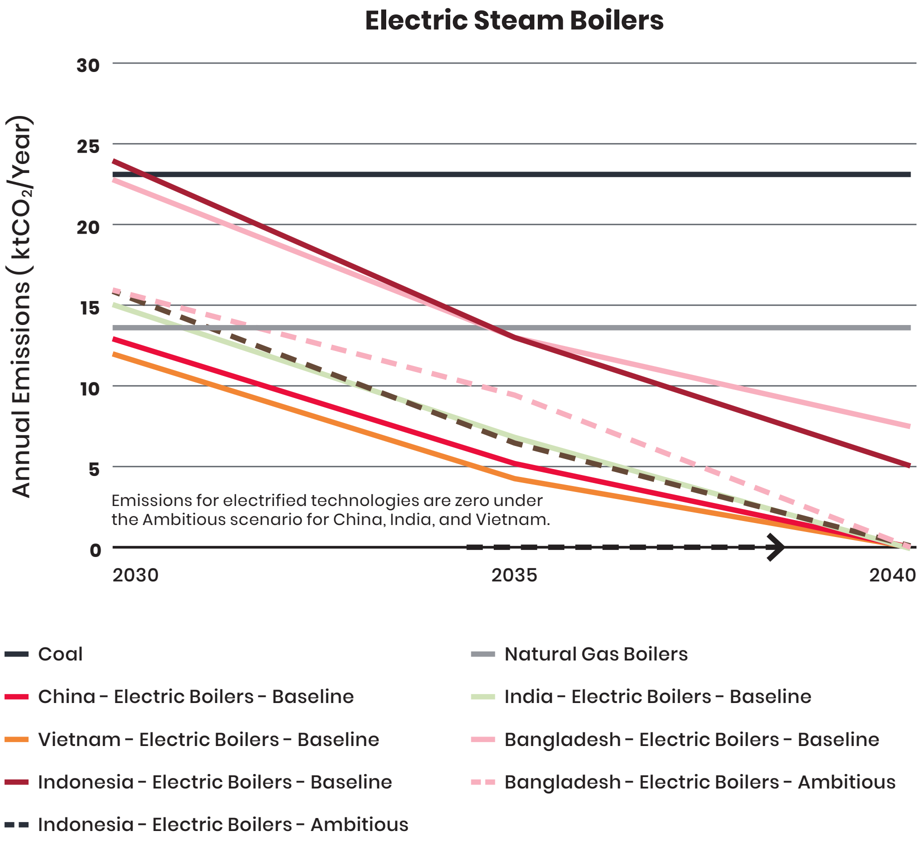
Note: Emissions results for electrification change over time-based on electricity supply decarbonization and are pictured in Figures ES2 and ES3

---

[1] Methane mitigation requires changes in upstream natural gas infrastructure, and will largely be carried out by the oil and gas industry rather than downstream users such as the textile industry.

In the longer term, sustainable biomass supply will be limited and prices will increase, especially if widespread industry adoption raises demand. **Therefore, we conclude that electrification, as discussed below, is the most viable long-term low-carbon solution. Textile manufacturers and apparel brands must monitor biomass supply, transition to electrification, and promote RE as biomass supply becomes more expensive and sustainable biomass becomes limited. Our analysis shows that alternative fuels (biomass and natural gas) can deliver near-term emissions savings under certain conditions; however, they are unlikely to play a role in the long-term decarbonization journey to net zero.**

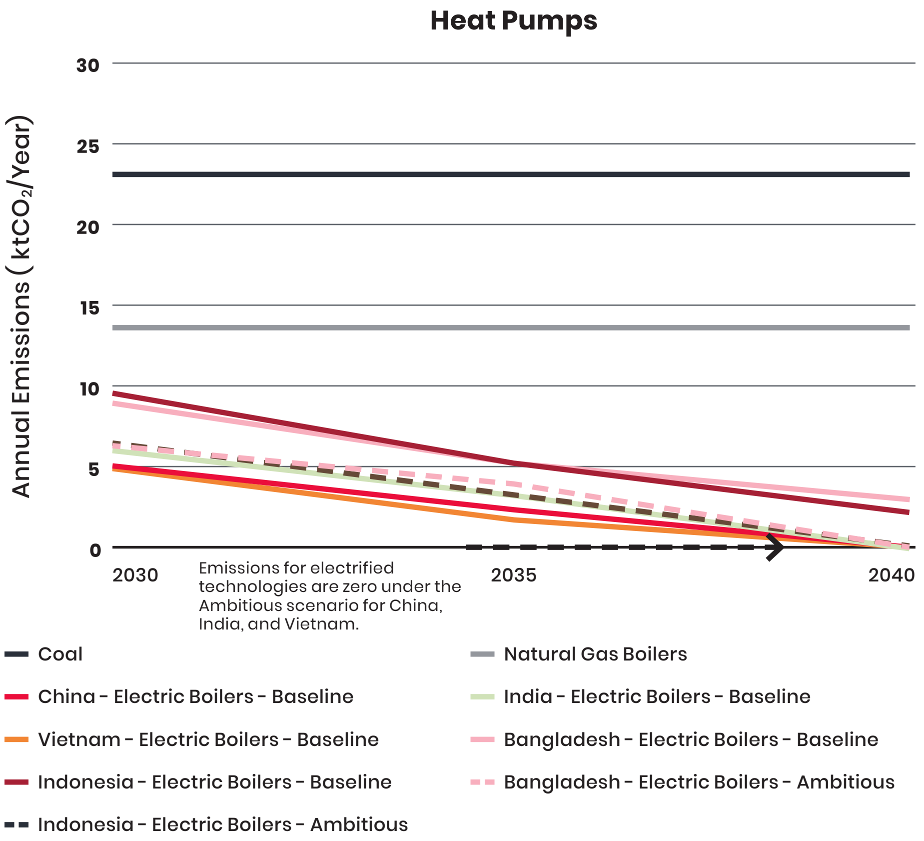
Electrified technologies significantly improve efficiency and reduce overall energy use. When paired with renewable electricity, these are the only long-term, net-zero-compatible solutions. **Our findings show that emissions reductions can be achieved for all electrification technologies,**



Electric Steam Boilers

Emissions for electrified technologies are zero under the Ambitious scenario for China, India, and Vietnam.

FIGURE ES2: COMPARISON OF ELECTRIC STEAM BOILERS FOR A TYPICAL TEXTILE PLANT IN ALL COUNTRIES RELATIVE TO COAL AND NATURAL GAS BOILERS, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Heat Pumps

Emissions for electrified technologies are zero under the Ambitious scenario for China, India, and Vietnam.

FIGURE ES3: COMPARISON OF HEAT PUMPS FOR A TYPICAL TEXTILE PLANT IN ALL COUNTRIES RELATIVE TO COAL AND NATURAL GAS BOILERS, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

pathways, and countries by 2035. In particular, heat pumps, due to their high levels of efficiency, could deliver emissions and cost savings in every geography by 2030, even in the Baseline Grid Plus RE Procurement pathway (Figure ES3). Starting in 2030, electric steam boilers could reduce CO_2 emissions in China, India, and Vietnam relative to coal-fired boilers when grid electricity is paired with an equal share of procured RE. However, without a higher share of directly procured RE, Indonesia's very high grid emissions factor could lead to electric boilers actually increasing CO_2 emissions in 2030. Similarly, in Bangladesh, electrification does not offer near-term emissions benefits because the primary boiler fuel is natural gas, which has a lower direct emissions factor if not procuring RE.

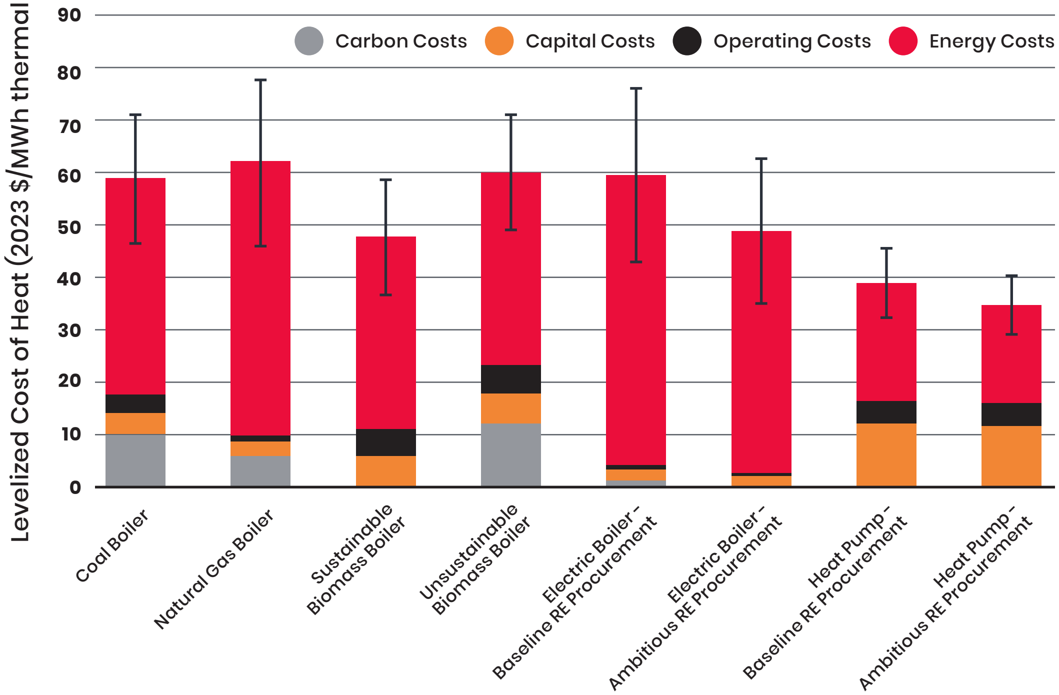
Results for electric hot oil boilers are similar, but slightly lower in magnitude. Since electric boilers have less efficiency gains than heat pumps, they will not deliver cost savings until 2035 in China, India, and Vietnam, and until 2040 in Bangladesh and Indonesia. Across all countries, electrification with steam-generating heat pumps leads to greater efficiency gains and energy savings than converting to electric steam or hot oil boilers. In a typical textile wet-processing facility, we estimate that steam-generating heat pumps can reduce energy by 48 GWh per year relative to conventional steam boilers, while electric steam boilers can offer energy savings of 18 GWh per year.

To compare the lifetime cost of low-carbon thermal energy transition, we estimated the levelized cost of heating (LCOH) for steam production. While electric boilers increase energy costs in 2030 compared to conventional coal-fired boilers in the studied countries, their LCOH — accounting for energy and other costs over the technology's lifetime — is lower than that of coal boilers in China (presented in Figure ES4) and India, due to projected electricity price trends relative to coal. Additionally, carbon pricing, if implemented, could significantly increase costs for fossil fuel-fired boilers.

In all countries, heat pumps have lower LCOH for steam production than coal, natural gas, and electric boilers, driven by their high efficiency — even when accounting for their high capital costs or the potential absence of a carbon price (Figure ES4). Biomass boilers are expected to have lower LCOH compared to fossil fuel-fired and electric boilers; however, if biomass prices rise more than projected and/or facilities with biomass boilers are subject to a carbon price (shown in gray in Figure ES4), biomass boilers may have a higher LCOH than electrified technologies.

A major driver of these results is the electricity pathways developed in this study, which assume increasing shares of corporate RE procurement in the studied countries over time. Corporate RE procurement is a growing global trend, with RE supply increasing as apparel brands and manufacturers in other industries seek to procure low-cost and low-emissions electricity. Corporate RE procurement is also necessary for electrification to achieve decarbonization. **Without it, electrifying industrial processes in countries that rely on fossil fuel-based grid electricity (i.e. all countries in this study) would simply shift emissions to power generation instead of reducing them.**

FIGURE ES4: LEVELIZED COST OF HEATING FOR STEAM PRODUCTION FOR THE TECHNOLOGIES AND ELECTRICITY PATHWAYS IN THIS STUDY — CHINA



Corporate RE procurement mechanisms — like Power Purchase Agreements (PPAs), green electricity tariffs, and onsite generation — can provide companies with stable, lower-cost energy and reduced CO_2 emissions. Each country's unique context shaped the development of the country-specific pathways in this quantitative analysis. China and India, which have greater RE supply and regulatory mechanisms for its growth, and Vietnam, which recently implemented policies supporting RE development and procurement, show promising potential for CO_2 reductions via electrification in the coming decade. Corporate RE procurement is less promising for Bangladesh and Indonesia until 2040. **Thus, while electrified technologies provide the clearest and most likely path to sector decarbonization, this analysis demonstrates the supporting factors needed to make it possible and the role of alternative fuels along the way.**

Given the potential of electrification technologies to lower emissions and energy costs, this report provides step-by-step implementation guidelines for electrification at a textile plant and information on financing mechanisms in each country.[2] We propose four steps for implementing electrification, many of which can be informed by the content in this roadmap:

Step 1: Gathering data on existing electrical systems and fuel-fired equipment, assessing energy use, and determining the facility's potential for electrification.

Step 2: Planning for increased electrical loads by analyzing current infrastructure and determining if upgrades are necessary. Continuously reducing thermal energy needs through best practices.

Step 3: Developing feasibility assessments and evaluating the cost, technical viability, and environmental impacts of electrification technologies.

Step 4: Implementing the selected electrification technologies by securing funds, obtaining permits, conducting procurement, training staff, and installing the new systems.

Financing mechanisms are essential for transitioning textile plants to low-carbon thermal technologies. Key financing options include traditional bank debt, green bonds, sustainability-linked loans, grants, and equity investments (Apparel Impact Institute 2024). Development banks such as the Asian Development Bank (ADB), World Bank and Asian Infrastructure Investment Bank (AIIB), and international climate funds can offer concessional loans and grants in countries like India, Vietnam, Bangladesh, and Indonesia. Apparel brands and coalitions (e.g. the Future Supplier Initiative and the Aii Fashion Climate Fund) play a critical role in guiding suppliers towards electrification as a long-term strategy. Brands can also make longer-term commitments to reduce investment risks and improve the business case.

Our roadmap synthesizes our analysis results to present country-specific recommendations for stakeholders to drive low-carbon thermal energy transition in textile plants over the next 15 years. The roadmap recommends prioritizing electrification paired with RE procurement as a key solution, and using sustainable biomass when sources are traceable and verifiable, and air pollution can be managed. We also provide recommendations to create the enabling environment for our scenarios to be realized. Significant policy and utility-level work must be done to enable the transition to electrification. The summary below presents broad recommendations applicable to textile plants across the studied countries.

Apparel Brands: From 2025 to 2030, apparel brands should actively fund pilot electrification projects and engage suppliers in reducing their thermal load while adopting renewable energy, especially in China and India where RE procurement is currently available. In countries with emerging RE procurement frameworks, brands should advocate for increased RE supply, integration, and corporate procurement mechanisms. Sustainable biomass may be a transition solution in the near term, but brands, alongside their manufacturers, must research the sustainability and viability of the biomass supply or support establishing traceability mechanisms to avoid risks, like deforestation. Ultimately, facilities should prepare for electrification by using this roadmap and other resources to develop electrification plans and promote the potential economic and environmental benefits of electrification. By 2030-2035, brands should work to scale successful pilots across their supply chains, supporting larger adoption of low-carbon technologies and renewable energy and engaging in policy advocacy. By 2040, they should help manufacturers fully transition to electric systems.

---

[2] We did not include implementation guidelines for alternative fuels as they are widely commercialized technologies with already significant levels of adoption in the textile industry.

Textile Manufacturers: Between 2025 and 2030, textile manufacturers should implement pilot electrification projects and initiate workforce training on heat pumps and thermal load-reducing innovations, while also exploring options for RE procurement. During this initial stage, manufacturers should also create long-term investment plans, integrating decarbonization and business strategies. From 2030-2035, manufacturers should expand these efforts across multiple regions, integrating renewable energy sources and refining workforce skills, such as experience managing electrified heating systems. By 2040, the goal is full electrification of heating systems powered by renewable energy, with potential participation in utility programs that optimize energy use (such as demand response).

Based on these findings and recommendations, we developed a simplified decision tree to guide textile facilities in choosing the best low-carbon thermal heating option (Figure ES5). The first step is to assess the feasibility of corporate RE procurement by 2030, as it is necessary for unlocking the decarbonization potential of electrification technologies. If feasible, facilities should evaluate electrification options, considering electricity-to-fuel price ratios, the grid emissions factor, and upfront capital when deciding between electric boilers and heat pumps. If RE procurement is not feasible, heat pumps can still deliver emissions reductions even with highly carbon-intensive grid electricity due to their efficiency. When RE procurement is not available, the grid emissions factor is

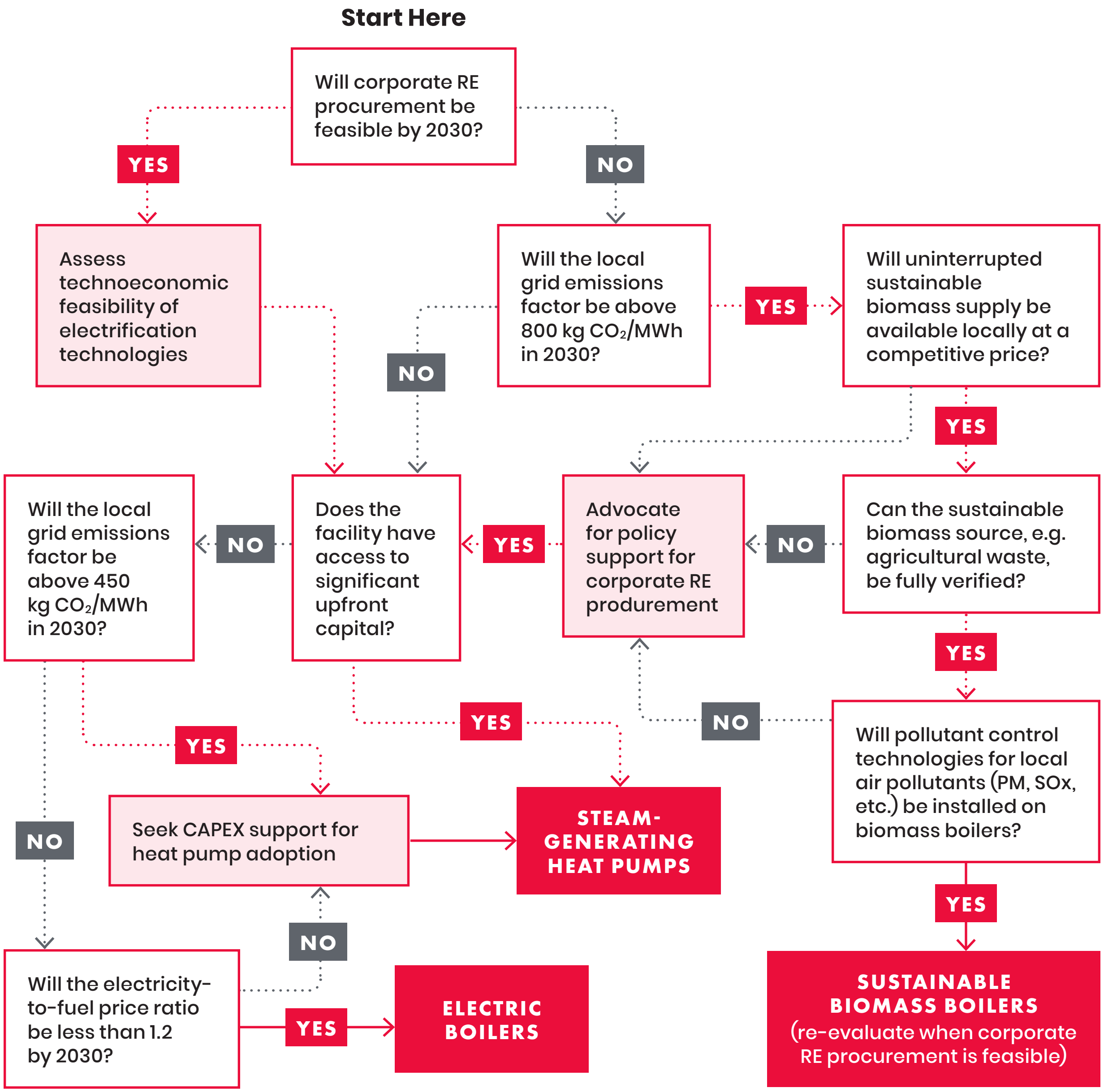


FIGURE ES5: DECISION TREE FOR TEXTILE FACILITIES IN THE STUDIED COUNTRIES SEEKING TO ADOPT LOW-CARBON THERMAL ENERGY TECHNOLOGIES

Note: the specified grid emissions factor thresholds are the emissions intensity level below which the respective electrification technologies deliver emissions reductions extremely high, or there are CAPEX barriers to heat pumps, sustainable biomass may be considered, provided there is a reliable and verifiable supply and pollution control technologies are in place. For facilities unable to meet these criteria, advocating for supportive RE policies may be necessary.

This decision tree is a high-level guide and should be complemented by a facility-specific evaluation that considers factors like boiler age, efficiency, space, and process requirements. In all scenarios, the facility's ability to reduce thermal energy load requirements from production can greatly increase the business case of low-carbon pathways.

Textile plants in China, India, Vietnam, Bangladesh, and Indonesia have significant opportunities for low-carbon thermal energy transition. Electrification technologies and sustainable biomass can reduce emissions and drive cost-effective energy use in the textile industry when coupled with corporate renewable energy procurement. For sustainable biomass, rigorous verification of sustainable sourcing and air pollution controls are essential.

While the roadmap is limited to five studied countries, the same logic and frameworks can be used to evaluate low-carbon thermal energy options in other textile-producing countries. **This report's analysis highlights that electrification can be both environmentally and economically viable in the near term. However, the transition requires textile plants to receive strong support from apparel brands, policymakers, financial institutions, and utilities. By creating favorable policies, offering financial incentives, and modernizing infrastructure, these stakeholders can accelerate the textile industry's low-carbon transformation.**

Table of Contents

1. Introduction

The textile and apparel industry currently accounts for approximately 2% of total global anthropogenic greenhouse gas (GHG) emissions (Sadowski et al. 2021). The textile industry has grown rapidly in recent years due to increasing demand from both developed and emerging economies. Without dramatic changes to production modes, environmental and climate impacts will increase. Many textile and apparel companies are seeking opportunities to reduce their carbon footprints and leading companies in the apparel industry have committed to ambitious GHG reduction goals of 45% by 2030, aligned with commitments under the Paris Agreement on climate change.

A key challenge for the textile industry in lowering its carbon footprint is its heavy reliance on thermal energy primarily to produce steam and hot water for production processes. Heating alone typically represents more than half of the textile industry's total energy demand. Textile plants primarily generate steam for heating by combustion boilers using fossil fuels. Thermal oil boilers (also known as hot oil boilers) are also used in wet processing at some textile plants, typically comprising 30-40% of total thermal energy demand. In most countries, boilers in the textile industry use fossil fuels (coal, natural gas, or fuel oil) as an energy input, which results in substantial carbon dioxide (CO_2) emissions.

Within the context of industrial decarbonization, there are five primary strategies, or pillars, for addressing the GHG emissions from industrial production (U.S. Department of Energy 2022):

- **Material Efficiency**, Aims to reduce material demand through design optimization, reuse, recycling, and the adoption of low-carbon alternatives.
- **Energy Efficiency:** Focuses on enhancing system efficiencies, expanding energy management practices, and recovering energy.
- **Electrification:** Involves transitioning from fossil fuel-based heating to electrified solutions, such as electric boilers and heat pumps, which can be decarbonized when powered by renewable electricity sources.
- **Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES):** Includes switching to lower-carbon fuels and feedstocks for industrial production.
- **Carbon Capture, Utilization, and Storage (CCUS):** Encompasses technologies that capture CO_2 emissions at their source, utilize them in other processes, or store them to prevent atmospheric release. (Note that CCUS is not technically or economically feasible for the textile industry.)

This report focuses on the Electrification and LCFFES pillars for the decarbonization of heating in the textile industry while recognizing other pillars will also be critical for reaching net zero.[3] Electrification in particular is more efficient in generating or transferring heat than traditional combustion-based technologies, leading to significant energy savings that can also translate into cost reductions. While this report does not focus on energy efficiency, it is a core enabler of the benefits of electrification.

This study is the second in a series of reports on low-carbon thermal energy solutions for the textile industry. The first report identified and assessed six low-carbon thermal energy technologies and alternative fuels for decarbonizing industry heating. This report undertakes a quantitative techno-economic assessment of the performance potential of four selected technologies and compares their performance to conventional coal-fired boilers. Then, taking stock of the current status and

---

[3] Please note, however, that energy efficiency is a key first step that is important to take in advance or in conjunction with the two pillars discussed in this report, including steps such as waste heat recovery and waterless dyeing.

growth potential of each technology and alternative fuel, the report analyzes the energy, emissions, and cost savings each can deliver between now and 2040.

The report concludes that there is a significant opportunity to decarbonize the textile and apparel sector by shifting heat production to lower-carbon alternative fuels (sustainable biomass) in the near term and more efficient, clean, electrified processes in the longer term to achieve net zero. However, there are also major challenges inherent in this transition that, if not properly addressed, will not only prevent success but, in the worst case, will lead to increased emissions and costs. The performance potential of each low-carbon thermal energy technology is very much tempered by the success of policies and incentives that will be required to promote their competitive advantage, maturation, and adoption. Textile manufacturers and brands thus need detailed information and feasibility analysis for successfully transitioning to low-carbon thermal energy at the facility level, as well as clear roadmaps for how to achieve this transition. Thus, this report provides a quantitative analysis of the energy, emissions, and cost implications, and identifies the programmatic and policy needs — and key barriers to be addressed — for each low-carbon thermal energy technology to truly drive emissions reductions.

This report focuses on five of the top textile-producing countries: China, India, Vietnam, Bangladesh, and Indonesia. These countries represent a diverse range of policy, economic, and energy landscapes. Moreover, the textile industry's economic significance varies widely in these countries, which affects the sector's ability to influence policies or access limited clean energy resources.

China is the largest textile exporter in the world by an order of magnitude. However, due to the prominence of other major industries in China, textiles contribute only 10% of value added in China's manufacturing sector. Conversely, Bangladesh's textile industry is roughly 10% the size of China's by global export value, but represents 57% of the total value added in manufacturing, demonstrating its significant weight in the country's economy (World Bank 2024). Germany and Italy have higher textile export value than the countries in this study (besides China); however, this is due to a significantly higher price per item compared to textiles manufactured in India, Vietnam, Bangladesh, and Indonesia. China, India, Vietnam, and Bangladesh are likely the top four countries in the world by production volumes, and Indonesia is likely within the top 10.

TABLE 1.1: TEXTILE INDUSTRY ECONOMIC DATA FOR COUNTRIES ANALYZED IN THIS REPORT

Source: Hasanbeigi et al. 2024

Country	Textile Export Value, 2021 (billion USD)	Textile Share of Value Added in Manufacturing
China	478	10%
India	48.1	9%
Vietnam	83.4	15%
Bangladesh	49.1	57%
Indonesia	24.2	11%

This analysis can be replicated for other countries as sourcing trends evolve.

For each of these five countries, we investigate low-carbon thermal energy opportunities in typical textile plants with wet processing. We model replacing steam-based and thermal oil heating processes with electrification technologies. We evaluate electric steam and hot oil boilers, steam-generating heat pumps, biomass steam and hot oil boilers, and natural gas steam and hot oil boilers.

The results of our quantitative analysis, as well as qualitative assessment of key market factors in each country, are used to develop a roadmap for low-carbon thermal energy transition. All assumptions underlying our analysis and projections are clearly documented.

2. Low-Carbon Thermal Energy Technologies for the Textile Industry

2.1. Low-Carbon Thermal Energy Technology Descriptions and Comparison

Many top textile-producing countries and regions use fossil fuels to meet heating needs. Coal is a particularly carbon-intensive fuel, driving the industry's greenhouse gas emissions. It is also associated with harmful onsite air pollution and other environmental problems. Notably, coal is very heavily used in the world's top textile-producing countries, including those analyzed in this study: China, India, Vietnam, and Indonesia. In Bangladesh, natural gas is the primary boiler fuel for the textile industry.

In a typical textile plant, fabric preparation (de-sizing, bleaching, etc.), dyeing and printing, and finishing together consume more than 50% of thermal energy. A significant amount of thermal energy is lost during steam generation and distribution (up to 35%) due to inefficiencies in conventional steam boilers. Electrification technologies offer higher efficiency, potentially reducing fossil fuel use and GHG emissions in the textile industry. Alternative fuels, on the other hand, reduce emissions during combustion in conventional boilers rather than improving the boilers' efficiency.

This study evaluates four alternative fuels and electrification technologies for the textile industry: electric boilers for steam and hot oil heating, heat pumps (steam only), biomass boilers for steam and hot oil heating, and natural gas boilers for steam and hot oil heating. The subsections below summarize each technology, followed by a direct comparison of the opportunities they present and the barriers to their adoption. For more detailed technology descriptions and comparisons, see the first report in this series, "Low-Carbon Thermal Energy Technologies for the Textile Industry" (Hasanbeigi et al. 2024).

Electric Boilers

Unlike conventional combustion boilers that burn fossil fuels like coal or natural gas, electric boilers use electricity to generate steam or hot water for industrial processes. Electric boilers are a mature and readily available technology, with lower capital, installation, and maintenance costs compared to conventional boilers. They can achieve high efficiency levels — up to 99% — and can significantly reduce CO_2 emissions when powered by a grid of a certain emissions factor threshold and/or when coupled with renewable electricity. They also offer non-energy benefits such as reduced onsite air pollution, faster ramp-up times, and quieter operation. However, operation costs can be high due to the typically high costs of electricity.

Electric steam boilers are divided into two main types: electric resistance boilers and electrode boilers.[4] In most textile plants, 1-3 boilers with a capacity of 5 MW or smaller are typically sufficient to meet steam demand. Additionally, thermal oil boilers can be electrified for textile production processes that require medium to high temperatures, such as fabric heat setting.

Currently, electric boiler adoption rates are low due to the higher cost of electricity compared to conventional fuels, not capital costs — electric boilers have lower capital costs than new coal boilers. Despite their efficiency and various operational benefits, their primary adoption challenge is higher energy costs from switching to electricity in some cases, adoption may lead to a near-term CO_2 emissions increase due to the emissions intensity of the grid mix and/or a lack of availability of RE that can be procured in a given country (see Section 3.1.).

Industrial Heat Pumps

Industrial heat pumps present a promising solution for low-carbon process heat in various industrial applications, including textiles — especially when powered by clean electricity. Heat pumps are highly efficient because, instead of generating heat directly like conventional boilers, they transfer and concentrate it from one source (e.g. air, water, or

---

[4] Electric resistance boilers use electrically heated elements to transfer heat to water, while electrode boilers directly pass an electric current through water to generate steam. Electric resistance boilers are more suitable for lower-capacity needs (less than 5 MW); electrode boilers are capable of higher capacity operation (Zuberi et al. 2021).

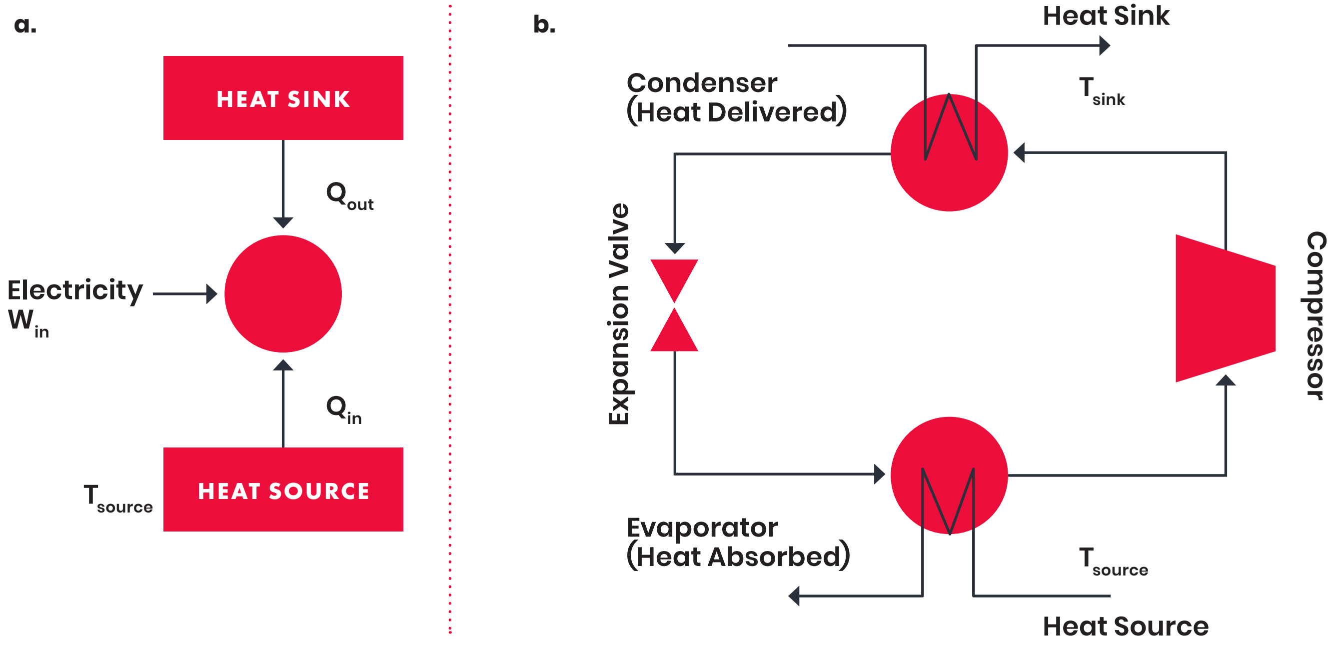
waste heat from industrial processes) to where it is needed. This process uses significantly less energy since the heat is not generated from combustion but rather moved and amplified through a refrigeration cycle (Figure 2.1). For every unit of energy input (electricity), a heat pump can deliver multiple units of useful heat — often achieving efficiencies of 200% to 500% or more, depending on the temperature differentials. This very high efficiency can significantly reduce emissions, even if the electricity grid is highly carbon-intensive.

Industrial heat pumps can generate steam and provide heat up to 170°C, covering the needs of most textile processes such as dyeing and drying.[5] Additionally, heat pumps do not produce on-site air pollution, and their flexibility allows them to adjust temperature outputs for various processes. As heat pump technology continues to improve, it could meet even higher temperature demands.

The deployment of heat pumps in industrial settings remains limited due to economic and technical challenges. They are not a "drop-in solution" as electric boilers are, this presents a barrier to behavior change and deviation from the facility status quo. Additionally, the high initial capital costs make them less attractive from an investment standpoint, and, like other electrification technologies, they face high energy costs and high electricity-to-fuel price ratios in many countries. (However, their higher efficiency means that energy cost savings can be achieved at a higher electricity-to-fuel price ratio than for electric boilers.) Challenges also arise from optimizing refrigerants that they rely upon, with growing regulations on harmful gases like Hydrofluorocarbons (HFCs) and Hydrochlorofluorocarbons (HCFCs). Moreover, integrating heat pumps into existing industrial infrastructure can require significant upgrades to electrical systems.

Currently, there are no known case studies of steam-generating heat pumps in the textile industry in the five studied countries However, the global industrial heat pump market is growing rapidly, with Asia projected to have the greatest growth by 2030 (McKinsey and Company 2024). While heat pumps have yet to be piloted in the textile sector, analysis from our first report gives us confidence that this technology will play a prominent role in decarbonizing heat in the apparel sector.

FIGURE 2.1. THERMODYNAMIC REPRESENTATION OF A HEAT PUMP.
Source: Hasanbeigi et al. 2024



---

[5] Throughout the report, when we refer to heat pumps, we mean industrial heat pumps that can generate steam and operate at relatively high temperatures.

ASSUMPTIONS ON PROJECTED HEAT PUMP ADOPTION IN THIS STUDY

While industrial heat pumps have been adopted in other industries and for lower temperature applications in the textile industry, based on market growth projections, we assume that steam-generating heat pumps will be available for textile facilities by 2030. China and India are expected to have significant domestic manufacturing of industrial heat pump technologies, while Vietnam, Bangladesh, and Indonesia are expected to initially import industrial heat pumps.

Biomass Boilers

Biomass currently accounts for 7.2% of global industrial energy consumption (IEA 2024). The technology behind biomass boilers is mature and widely adopted across industries for power generation and process heating, including in the textile industry. Biomass is burned in either fluidized bed or fixed bed boilers to generate heat for processes like steam and thermal oil boilers.

Biomass-fired boilers have garnered interest in the textile industry due to the potential for low-carbon energy production. Driven by apparel brands' 2025 coal phaseout goals, biomass boilers are already used in the textile industry in various countries, utilizing local agricultural residues like sugarcane bagasse, rice husks, and palm oil mill effluent.

However, the carbon benefits of biomass depend critically on its type and how it is sourced, processed, and transported. The adoption of sustainable biomass for CO_2 emissions reduction depends on addressing key challenges, as the distinction between sustainable and unsustainable biomass is crucial in determining its effectiveness.

Sustainable biomass, often derived from certified wood waste or agricultural residues, is considered CO_2-neutral because the carbon released during combustion is offset by the carbon absorbed during the feedstock's growth. **However, it is not CO_2e-neutral, as emissions of other GHGs from combustion, as well as upstream emissions from land use change, harvesting, and transportation, must also be accounted for.**

Unsustainable biomass, which often involves deforestation or other land use changes, can result in significant emissions increases and reputation risk, undermining its environmental benefits. Comprehensive accounting frameworks, such as those recommended by the GHG Protocol and SBTi, emphasize the need to separately report biogenic emissions, land use change impacts, and upstream emissions to ensure the full climate impact of biomass use is accurately captured.

Aii encourages brands and suppliers to use the Institute for Sustainable Communities' Sustainable Biomass Guidelines and Risk Assessment tool. **Agricultural residues are likely the most sustainable biomass source, as they are byproducts of existing agricultural cultivation.**

Wood and wood-derived sources, the dominant biomass fuel in many places, are a less efficient energy carrier than coal and produce more CO_2 emissions per unit of energy based on IPCC guidelines (Table 2.1). Only wood waste products from certified sources can be considered sustainable biomass. **Even wood waste sources may encourage wood harvesting and are generally very difficult to track.**

Energy crops and woody biomass are not considered sustainable biomass sources as they can contribute to deforestation and increased CO_2 emissions. Moreover, they are not guaranteed to capture as much carbon as they produce upon combustion, negating their carbon benefits (Sterman et al. 2018; Searchinger et al. 2018; Camia et al. 2021). Additionally, the first report in this series further discusses the scientific assessment of woody biomass' carbon impact.

TABLE 2.1: IPCC EMISSIONS FACTORS FOR BIOMASS SOURCES

Source: IPCC 2006

Type of Biomass	Default CO_2 Emissions Factor
Wood/wood waste	112
Black liquor	95.3
Other primary solid biomass	100
Biomass fraction of municipal waste	100

Transportation logistics further complicate the use of biomass, as its low energy density makes it costly to transport over long distances (Searcy et al. 2007). The biomass supply chain varies depending on the type of feedstock and proximity to the final destination. The timeframe to collect biomass is often limited by seasonal weather conditions and can limit the overall amount of biomass generated. Additionally, biomass combustion releases local air pollutants, posing health risks near industrial areas, unless properly managed. There are commercially available technologies to mitigate air pollution from biomass boilers, and these must accompany biomass boiler adoption in the textile industry.

Due to these limitations, large-scale adoption of biomass in the textile industry will be constrained by availability, cost, and environmental concerns. Smaller-scale operations, such as textile facilities with small boilers, are better suited for biomass conversion because they require less biomass fuel and have more manageable storage needs. **However, industry-wide scaling will face major challenges in availability as agricultural residue supply is limited by agricultural production levels in a given location.**

In this report, we use the term sustainable biomass to mean agricultural waste where there is no deforestation risk and certified wood waste and palm kernel shell sources.

Natural Gas Boilers

Natural gas, a fossil fuel composed primarily of methane, is considered an alternative energy source in the textile industry due to cleaner combustion when compared to coal. Natural gas is an established fuel for industrial steam and hot oil boilers in textile manufacturing, and natural gas boilers are a widely commercialized technology. However, despite lower CO_2 emissions during combustion, natural gas remains a fossil fuel, and methane leaks during production and transportation can negate its climate benefits, as methane is a much more potent GHG than CO_2.

The primary strengths of natural gas boilers include reduced direct CO_2 emissions compared to coal, improved air quality with significantly lower nitrogen and sulfur oxide emissions, and fewer safety risks associated with mining and storage. Moreover, natural gas boilers take up less space, offer operational flexibility and ease, and have fewer maintenance issues. However, not all countries have affordable or accessible sources of natural gas. For those that do, transitioning to natural gas involves high upfront capital costs to retrofit or replace existing systems and secure reliable connections to natural gas pipelines — an obstacle for many regions, particularly in countries dependent on imports.

Challenges for adopting natural gas boilers in textile facilities include volatile fuel prices and the reliance on continuous supply — both are vulnerable to geopolitical tensions and natural disasters. Inadequate infrastructure to support natural gas, such as pipelines or LNG regasification facilities, can further complicate adoption, especially in regions without domestic natural gas production. Additionally, addressing methane emissions from the natural gas supply chain is essential to ensure real overall reductions in greenhouse gas emissions. However, tracking methane emissions is still an emerging practice. Technologies are still being developed, and it is not possible at this time to ensure natural gas supply comes from a source that successfully mitigated methane emissions.

BIOGAS AS A POTENTIAL LOW-CARBON THERMAL ENERGY SOURCE

Biogas can be a niche solution in areas where resources are available to generate it. Some of the most currently viable sources of biogas include landfills, animal farms, and agricultural/food processing waste. Rice straw can be burned in biomass boilers or converted to biogas, thereby reducing air pollution. However, there are logistical challenges in producing biogas at the scale needed for a textile facility. In addition, biogas is typically consumed by the facility that produced it, such as a food processing plant. Market availability may be scarce, and we did not specifically analyze biogas in this report.

FIGURE 2.2: **SHARE OF NATURAL GAS CONSUMPTION THAT COMES FROM IMPORTS IN THE FIVE STUDIED COUNTRIES.**

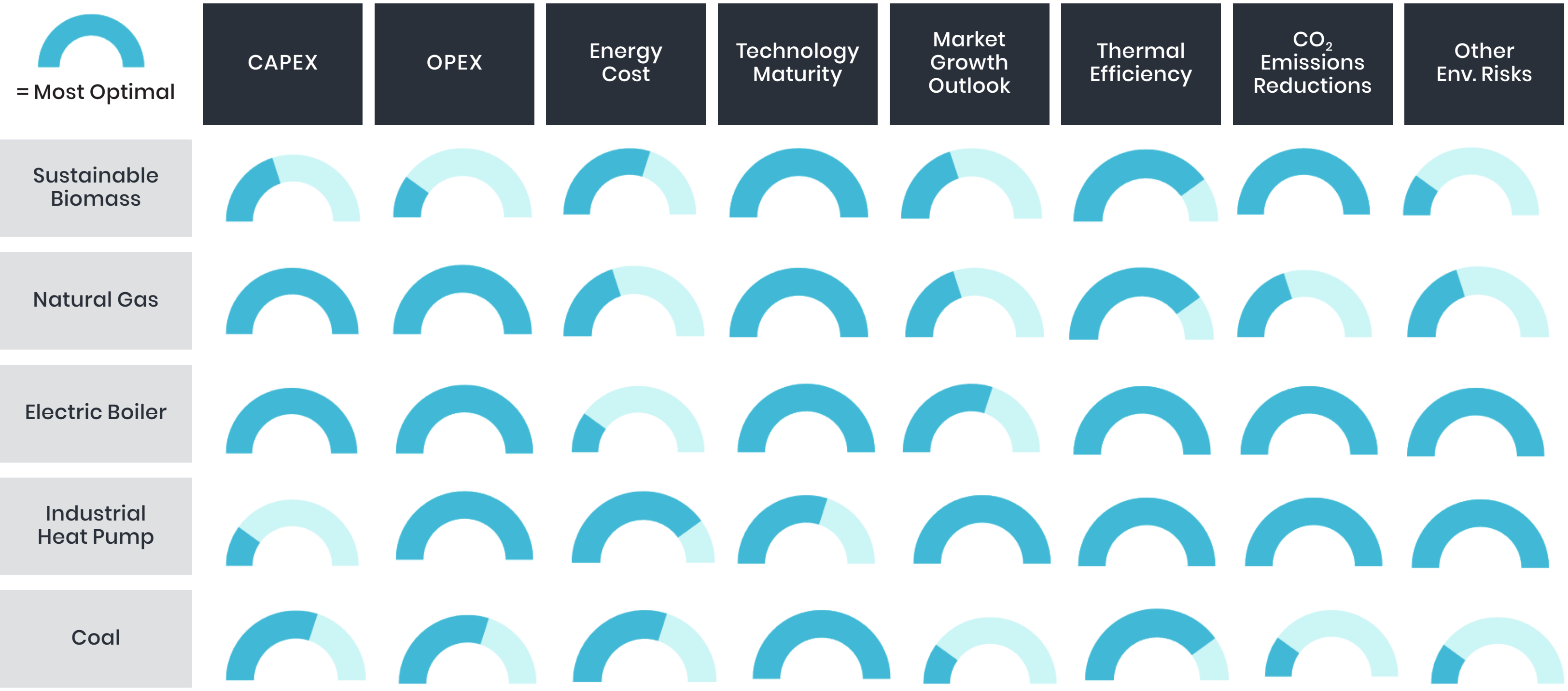
Note: Natural gas consumption in Vietnam is primarily met by domestic production, but overall consumption levels are extremely low. Source: EIA 2024.

The ability of an individual textile facility to switch to natural gas boilers is highly dependent on the local natural gas infrastructure and the feasibility of connecting to the natural gas distribution system. The countries studied in this report largely depend on natural gas imports — or will in the future to meet increased demand, and even though it makes up a minimal part of their total energy supply it will be difficult to source. Bangladesh faces these same challenges, however, unlike the other countries studied it makes up the majority of their energy supply.

The following figure (2.3.) displays a cross-comparison of the studied technologies and the reference, coal boilers, with ratings across a range of indicators based on research from the first report and the findings of this study as discussed below. These ratings consider only the cost and technical performance of the technologies without accounting for the necessary policies to enable their maximum performance potential. A full bar is the most optimal rating for each indicator.

Coal boilers are technologically mature but have the highest emissions and environmental risks of the technologies considered. While they have relatively high capital costs, many facilities have already incurred these as sunk costs. The potential for CO_2 emissions reductions is an advantage for the adoption of sustainable biomass boilers — if carbon-neutral sources are available. However, other environmental risks pose a concern, especially with regard to deforestation and land use change. For natural gas boilers, CAPEX is typically lower than coal boilers, and non-energy OPEX is expected to be low. Energy costs could be a deterrent given the high and volatile gas prices in many countries. Finally, CO_2 emissions and other environmental risks could pose barriers given methane leakage and extensive transport and distribution networks.

FIGURE 2.3: CROSS-TECHNOLOGY COMPARISON MATRIX FOR THE LOW-CARBON THERMAL TECHNOLOGIES AND ALTERNATIVE FUELS ANALYZED IN THIS STUDY. Source: Hasanbeigi et al. 2024



Across the indicators, electric boilers and industrial heat pumps rank highly in the most indicators due to their low non-energy OPEX, high market growth outlook, and high efficiency. Their CO_2 emissions reduction potential is very high; however, decarbonization via electrification depends critically on either a clean electric grid with declining emissions or a readily available and expanding supply of clean RE.

As this cross-comparison shows, the textile industry's transition to low-carbon thermal energy has no easy choices, with barriers ranging from technical and financial constraints to regulatory challenges. Despite these significant barriers, several factors are driving the adoption of low-carbon thermal energy technologies in the textile industry, including technological advancements, policy support, and shifting market demands. Technological progress has increased the readiness and efficiency of electrification technologies, making them more commercially viable. Climate policies, including net-zero targets and emissions reduction commitments, are pushing governments and apparel brands to adopt low-carbon solutions. Additionally, consumer demand for sustainable apparel is creating bottom-up pressure on the industry. There is also increasing awareness that switching to low-carbon technologies lowers operational costs, improves energy efficiency, and reduces dependence on volatile fossil fuel markets, offering both financial and energy security benefits.

2.2. The Importance of Corporate Renewable Electricity Procurement for Electrified Heating Technologies

Corporate renewable energy procurement is a cornerstone to achieving low-carbon heating through electrification in the textile industry. Without a substantial amount of RE generation, the electricity-related CO_2 emissions in manufacturing will remain higher than those from coal-fired boilers. In the studied countries — and in many other textile-producing countries — grid electricity heavily relies on coal and other fossil fuels. Therefore, direct procurement of renewable energy by textile manufacturers is essential for reducing grid-related CO_2 emissions. Since many of these countries have net zero targets set a decade or more after those of apparel brands, RE procurement will be necessary over the long term. Without renewable energy, electrifying industrial processes in these regions could simply shift emissions from on-site coal combustion to upstream coal combustion, resulting in increased emissions. Therefore, **renewable energy procurement by textile manufacturers is a critical prerequisite for realizing meaningful emissions reductions through electrification in the near term.**

Fortunately, corporate renewable energy procurement provides companies benefits beyond reduced emissions, offering increased energy security and cost predictability. As fossil fuel prices become increasingly volatile and carbon pricing mechanisms emerge in more countries, renewable energy offers a stable and potentially lower-cost long-term solution. For textile manufacturers, securing renewable energy will not only align their operations with decarbonization goals but also protect against future regulatory risks such as the EU's CBAM and energy price fluctuations. This can also boost the competitiveness of textile exporters, as global brands increasingly prioritize low-carbon supply chains and products with reduced environmental footprints.

Corporate renewable energy procurement can create a positive feedback loop for broader grid decarbonization. By entering into long-term Power Purchase Agreements, for example, corporations signal a strong demand for renewable energy, incentivizing further investment by independent power producers. This demand-driven market development can accelerate the growth of renewable energy capacity. In countries like Indonesia and Bangladesh, where renewable energy development is still in its early stages, corporate procurement can drive policy changes and investments to scale up renewable energy projects and make low-carbon electrification technologies more viable for industries.

There are several main mechanisms for corporate RE procurement. Power Purchase Agreements (PPAs) allow a company to enter into a contract with an independent power producer, utility, or financier to purchase a specified amount of renewable electricity, or the output from a specific asset, at a set price over a predetermined period. This model provides a more direct linkage between the renewable energy produced and the electricity the company consumes. Companies can also buy renewable electricity directly from their utility through green premium products or through a specifically tailored renewable electricity contract, such as a green tariff program. This arrangement simplifies the procurement process and integrates renewable electricity directly into the company's energy mix. Alternately, companies may choose to invest in their own renewable energy systems by building generation capacity on- or off-site to produce electricity primarily for their own use. This model offers companies control over their energy sources and reduces dependence on external electricity suppliers.

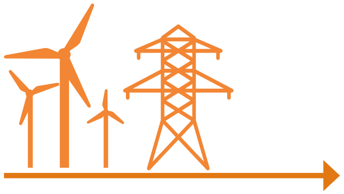
Country-specific mechanisms are discussed in the next chapter.

Apparel brands, while not direct signatories to PPAs and other RE procurement mechanisms, can play an enabling role by supporting textile manufacturers in navigating these mechanisms, providing technical and financial assistance, and advocating for more favorable renewable energy policies. By working together, apparel brands can aggregate demand across multiple suppliers to negotiate better terms, and commit to long-term partnerships with manufacturers, incentivizing investment in renewable energy.

FIGURE 2.4: OVERVIEW OF MECHANISMS FOR CORPORATE RE PROCUREMENT. Source: adapted from Clean Energy Solutions Center 2019

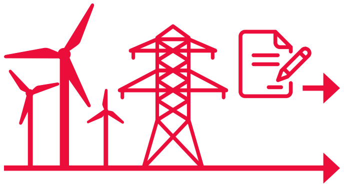
Power Purchase Agreements (PPAs)

A company enters into a contract with an independent power producer, a utility or a financier and commits to purchasing a specific amount of renewable electricity, or the output from a specific asset, at an agreed price and for an agreed period of time.



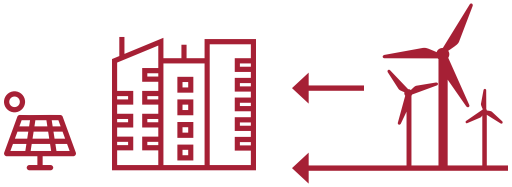
Renewable energy offerings from utilities or electric suppliers

A company purchases renewable electricity from its utility either through green premium products or through a tailored renewable electricity contract, such as a green tariff program.



Production for self-consumption

A company invests in its own renewable energy systems, on-site or off-site, to produce electricity primarily for self-consumption.



2.3. Key Pinch Points To Adoption Of Low-Carbon Thermal Energy Technologies In The Textile Industry

Each country faces unique challenges in adopting low-carbon thermal energy technologies, as discussed in detail in Chapter 3. However, to frame the techno-economic analysis that comes next in this report, we first need to summarize key pinch points identified by country.

The low cost of coal relative to grid electricity is a major issue across countries except Bangladesh, which primarily uses natural gas for heating in its textile industry. Another challenge for electrification is the need for most facilities to upgrade associated electrical equipment in preparation for increased loads (e.g. transformers and cables), increasing overall costs. This would be supported by a reduction in thermal energy use through efficiency and innovation. Regulatory and logistical issues hinder consistent access to biomass in all of these countries as well.

Vietnam and Indonesia have limited mechanisms for corporate renewable procurement, with only early-stage mechanisms that are not yet available at scale for textile facilities. Bangladesh, with its unstable grid and high dependence on imported Liquified Natural Gas (LNG), has particularly limited options for electrification and an underdeveloped framework for renewable procurement and industrial-scale biomass use. However, corporate RE procurement in each country is developing rapidly due to falling RE costs and increased corporate interest.

Given these challenges, successfully implementing any of the technologies modeled in this report requires an understanding of both the techno-economic potential of each technology and the critical policies, regulations, programs, and incentives needed to deliver their success. Thus, to develop a roadmap for the low-carbon thermal energy transition, we must identify the most important policies, regulations, programs, and incentives; assess the current status; and project their growth and maturation over the coming decades. Since their current status and maturity vary from country to country, we must model the transition individually for each assessed country.

The following section analyzes each of the four low-carbon thermal energy options, offering transparent assumptions on techno-economic performance and a qualitative assessment of the policies, regulations, programs, and incentives necessary to achieve the projected results.

Summarizes these varying pinch points, which highlight the need for tailored strategies in each country.

TABLE 2.2: KEY PINCH POINTS BY COUNTRY AND LOW-CARBON THERMAL ENERGY TECHNOLOGY

Country	Natural Gas Boilers	Sustainable Biomass Boilers	Electric Boilers	Heat Pumps
China	• Natural gas supply is largely imported, making scale-up challenging • Competing priorities for the limited supply of natural gas	• Regional variation in biomass availability and costs • Competing demands for sustainable biomass sources from other industries and the electric power sector • Industrial clusters too large to supply sustainable biomass • Ban on biomass boilers in some provinces	• High energy costs in the near term based on the electricity-to-fuel price ratio • High grid emissions factor • Moderate supply of RE for corporate procurement, but not yet ready for scaling across the entire textile industry	• Technology availability in the Chinese market for high-temperature industrial heat pumps is currently limited
India	• Natural gas supply is largely imported and relatively expensive • Natural gas distribution infrastructure limited	• Logistical and storage challenges for biomass for large industrial users in textile-producing regions	• High grid emissions factor • Corporate RE procurement increasingly available, but 24/7 supply is limited	• Capital costs are very high • Technology availability still emerging in the Indian market
Vietnam	• Competing demand for limited natural gas supply • Growing reliance on imported natural gas	• Competing demand for agricultural residues from local communities, exports, and the electric power sector	• High grid emissions factor • Nascent corporate RE procurement mechanisms just established in 2024 face regulatory and scale-up challenges	• Capital costs are very high • Heat pump suppliers have not yet entered the Vietnamese market
Bangladesh	NA – reference fuel	• Limited industrial biomass market due to household and small-scale uses • Limited infrastructure for large-scale biomass adoption	• Grid reliability issues • Lack of corporate RE procurement framework at present • Limited RE supply	• Grid reliability issues • Lack of corporate RE procurement framework at present • Limited RE supply • Limited technology availability
Indonesia	• Natural gas distribution infrastructure is challenging and expensive to scale up across diverse island geographies	• High risk of biomass scale-up contributing to tropical deforestation issues • Competing demand for limited biomass supply	• High grid emissions factor • Limited RE supply • Very limited mechanisms for corporate RE procurement	• Limited RE supply • Very limited mechanisms for corporate RE procurement • Limited technology availability

3. Assessing Low-Carbon Thermal Energy Adoption in Textile Plants

3.1. Methodology and Assumptions

This section explains the methodology used to develop the quantitative analysis that informs this report's roadmap. Our approach involved characterizing the current energy use and emissions profile for steam and thermal oil heating in a typical textile wet-processing facility – representing the majority of overall fuel use at such a facility – and then evaluating changes in energy use, emissions, and costs when switching to each evaluated electrification technologies and alternative fuels individually. We projected these impacts by comparing the performance of the low-carbon technologies to the conventional boiler in 2030, 2035, and 2040. This required detailed assumptions on electricity and fuel price projections, among other factors, which are provided below.

First, we gathered extensive data on typical textile wet-processing facilities, including information from a survey of dozens of textile plants conducted for a previous study (Hasanbeigi and Zuberi 2022). This data includes detailed information on existing boiler systems, annual fuel consumption, energy use, heat requirements, production levels, and process-level specifics. Aii supported us in this process, and where data was unavailable, we supplemented it using existing data from previous projects or online sources.

We also collected region-specific data, such as local fuel and electricity prices and grid emissions factors. We used base year data to project costs in 2030, 2035, and 2040, the timesteps evaluated in this study (see Table 3.3.). We also assumed that fabric production levels and energy intensity would remain constant throughout the study.

Electricity Pathways

Although the studied countries are increasingly integrating renewable energy into grid electricity, direct corporate procurement may accelerate adoption more effectively than waiting for country grid improvements. The status and growth prospects of policies and programs enabling and expanding direct RE procurement is an important factor that varies by country. Thus, for each studied country, we developed two electricity pathways for our typical facility that represent different shares of grid electricity and directly procured RE:

- Baseline Grid Plus RE Procurement Pathway
- Ambitious Grid Plus RE Procurement Pathway

These pathways allow us to assess the sensitivity of results on the electrification technologies that respond to variations in electricity price and emissions factors. We assume that procured RE has an emissions factor of zero and that it can be obtained at a lower price than grid electricity by 2030 (see Table 3.3.). Indeed, renewable electricity can already be directly procured at lower prices than grid electricity in China and India, and this differential is expected to continue in the future.

KEY ASSUMPTIONS FOR ELECTRICITY SUPPLY IN THIS STUDY

In this study, we assume that textile facilities will use a mix of grid electricity and renewable energy (RE) for electrified technologies. We assume that procured RE is lower cost than grid electricity, and that the share of RE in electricity supply for heating grows over time. We also assume electricity costs will decrease over time. The projected cost and emissions factor of grid electricity and RE drive results on costs and emissions. These projections are shown in the assumptions table in this chapter.

The key driver of lower electricity costs is the growing availability of low-cost RE, whether for direct procurement or through integration into the grid. This assumption is based on the observed trend that RE supply has increased significantly over time, while costs have dropped.

The Baseline Grid Plus RE Procurement pathway assumes each country will achieve their stated net zero target, and that a typical textile facility will be able to supplement their grid electricity supply with a baseline and increasing share of procured renewable energy. The studied countries all have net zero target years beyond the scope of this study, which ends in 2040. However, we project grid decarbonization for the analyzed time period based on trajectories towards net zero. We obtained data on base year grid emissions factor from IEA (2022) and projected this linearly to the year of the net zero target. The baseline levels of RE procurement are based on our qualitative assessment of the state of the corporate RE procurement market in each country, with China, India, and Vietnam having greater RE supply and regulatory mechanisms to enable corporate RE procurement relative to Indonesia and Bangladesh. This is discussed further in Section 4.1.2.

The Ambitious Grid Plus RE Procurement pathway assumes greater integration of renewable energy and increased RE for corporate procurement by textile facilities, which are assumed to procure an ambitious and increasing share of RE in addition to grid electricity. For China, India, and Vietnam, which have rapidly expanding RE supply and policy support for direct procurement, we assume that a typical facility pursuing an ambitious low-carbon thermal energy transition could procure 100% of its electricity from renewable sources by 2030.

Figure 3.1.1. Shows the projected electricity emissions factors based on the country-specific grid emissions factor and RE procurement pathway. All countries reach zero carbon electricity by 2040 under the Ambitious pathway, which is meant to be a demonstration of the potential maximum benefits of electrification.

Our price-related assumptions are presented in Table 3.3. We assumed a carbon price of $10 in 2030, $20 in 2035, and $30 by 2040 across the countries due to either domestic policy (e.g. China's national emissions trading system) or a carbon border adjustment mechanism (CBAM) as proposed by the EU, which is likely to include textiles after 2030. **Based on expert consultations and ongoing research, we project electricity prices will generally decrease over time as low marginal cost RE is integrated into grids, and fuel prices will increase.** This electricity-to-fuel price ratio is the key assumption in this analysis and roadmap. Biomass prices are currently lower than conventional fuels in many regions, driving a current adoption trend in the textile industry. However, prices are expected to rise from 2030 onwards if larger scale adoption of limited sustainable biomass resources occurs.[6]

TABLE 3.1: ASSUMED SHARES OF CORPORATE RE PROCUREMENT IN THE BASELINE GRID PLUS RE PROCUREMENT PATHWAY BY YEAR AND COUNTRY

Year	China, India, and Vietnam	Indonesia	Bangladesh
2030	50%	25%	0%
2035	75%	50%	30%
2040	100%	75%	50%

TABLE 3.2: ASSUMED SHARES OF CORPORATE RE PROCUREMENT IN THE AMBITIOUS GRID PLUS RE PROCUREMENT PATHWAY BY YEAR AND COUNTRY

Year	China, India, and Vietnam	Indonesia	Bangladesh
2030	100%	50%	30%
2035	100%	75%	50%
2040	100%	100%	100%

---

[6] For example, GEI has examined a case in which a textile facility adopted biomass sourced from local agricultural residues, but switched back to coal within a year due to prices rising quickly locally

FIGURE 3.1.1: ELECTRICITY EMISSIONS FACTORS BY PATHWAY AND COUNTRY ASSUMED IN THIS STUDY

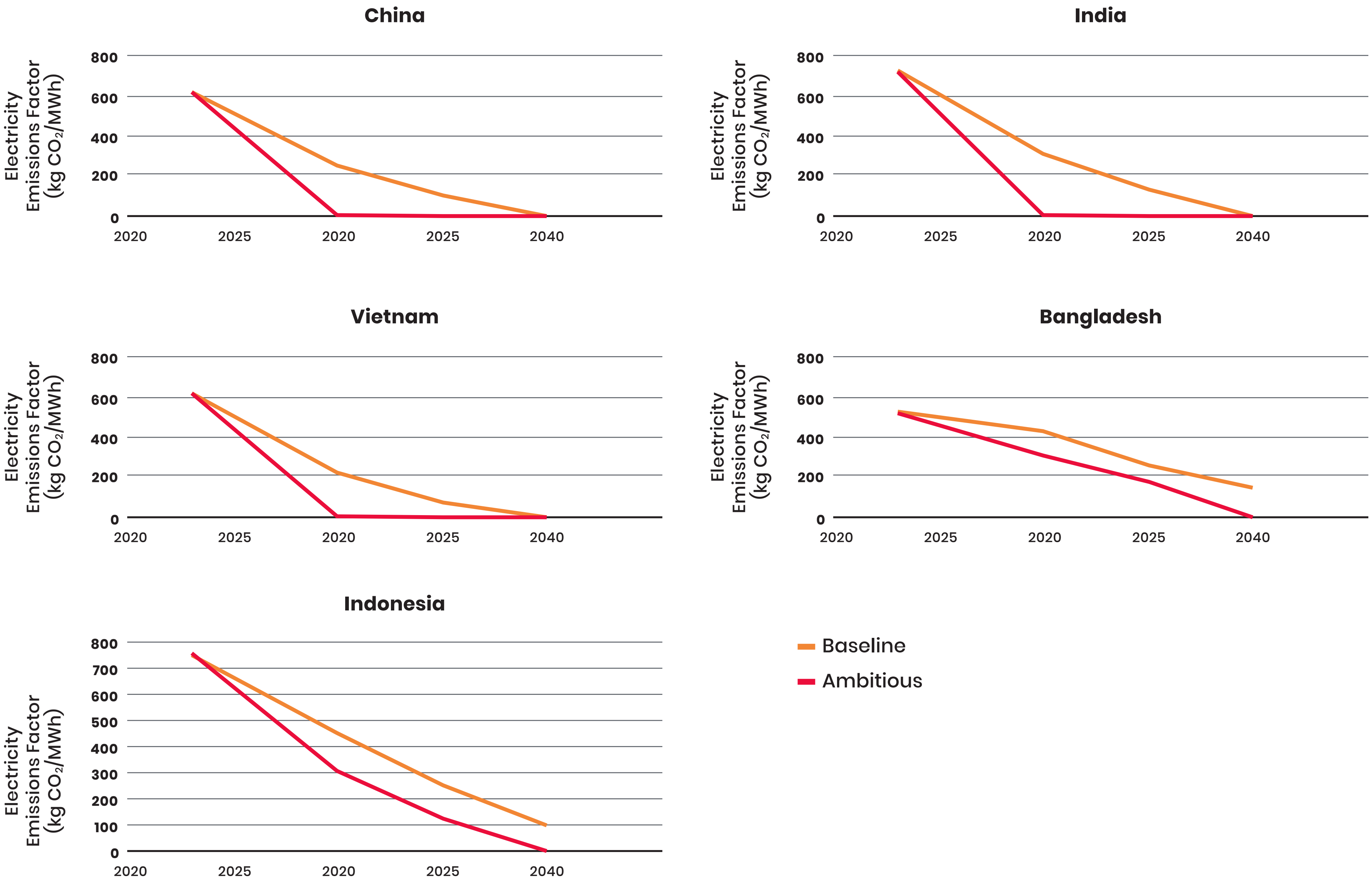


TABLE A1: COUNTRY-SPECIFIC FUEL AND ELECTRICITY PRICE ASSUMPTIONS USED IN THIS STUDY ($/KWH)

	China	India	Vietnam	Bangladesh	Indonesia	Sources and Narrative
Coal 2030	0.023	0.027	0.022	NA	0.017	China: Lu et al. 2024, Hasanbeigi et al. 2024 India and Vietnam: GEI data from local textile manufacturers Indonesia: Based on Indonesia's reported coal price cap for industry Coal prices are expected to rise across Asia (Mitrova et al. 2016), and drivers include environmental regulation and the gradual removal of existing subsidies
Coal 2035	0.030	0.031	0.024	NA	0.022	
Coal 2040	0.036	0.040	0.031	NA	0.024	
Natural Gas 2030	0.026	0.058	0.060	0.038	0.029	China: Lu et al. 2024, Hasanbeigi et al. 2024. Natural gas prices are expected to rise in China through 2050 based on IEA projections (International Energy Agency 2022). India: EIA International Energy Outlook 2023. Vietnam: Based on imported LNG prices (we project imported LNG would meet industry sector natural gas demand) Bangladesh: Based on natural gas tariff for industry (Asifur Rahman 2023) Indonesia: GEI data from local textile manufacturers The EIA projects that natural gas prices will rise across Asia through 2050.
Natural Gas 2035	0.038	0.063	0.065	0.041	0.031	
Natural Gas 2040	0.049	0.068	0.071	0.049	0.034	
Biomass 2030	0.019	0.014	0.016	0.014	0.016	China and Bangladesh: Base year data provided by Aii India and Vietnam: GEI data from local textile manufacturers Indonesia: Based on local palm kernel shell prices
Biomass 2035	0.026	0.021	0.021	0.022	0.020	
Biomass 2040	0.033	0.027	0.027	0.030	0.024	
Grid Electricity 2030	0.090	0.091	0.067	0.063	0.065	China: Qiu et al. 2024, Lu et al. 2024, Hasanbeigi et al. 2024 India, Vietnam, and Indonesia: GEI data from local textile manufacturers Bangladesh: S&P Global, Rahman 2024
Grid Electricity 2035	0.084	0.086	0.063	0.061	0.061	
Grid Electricity 2040	0.079	0.080	0.059	0.059	0.057	
Procured RE 2030	0.05	0.045	0.05	0.07	0.06	China: Base year data from RMI - Lu et al. 2023 India: Multiple expert interviews conducted by GEI Vietnam: CEBI, Allotrope Partners 2024 Bangladesh and Indonesia: GEI estimates based on facility-level models
Procured RE 2035	0.045	0.04	0.045	0.055	0.055	
Procured RE 2040	0.04	0.04	0.04	0.05	0.05	

Note: Bangladesh does not currently use coal for boilers in its textile industry, and we did not evaluate a switch to coal, so coal prices are not provided for Bangladesh
Note: Grid electricity prices are the average electricity price for industrial consumers in each country, and dynamic pricing is not modeled in this study.

Next, we developed a detailed techno-economic model evaluating the four technologies as alternatives to traditional coal-fired boilers (or natural gas-fired boilers for Bangladesh). This analysis focused on wet processing steps such as dyeing, scouring, and bleaching. We estimated the potential efficiency gains of each technology, using 75% for a conventional steam boiler and 85% for a conventional hot oil boiler across fuel sources. Electric steam and hot oil boilers are assumed to have efficiencies of 99% and 98%, respectively.

Hot oil boilers are generally more efficient than steam boilers due to lower energy losses, and they represent a significant amount of total fuel use at a typical wet-processing facility (30-40%). Steam boilers experience significant steam losses during processes like blowdowns, leaks, and condensate return systems, reducing their overall efficiency. In contrast, hot oil boilers use thermal oil, which operates in a closed-loop system, minimizing losses. The absence of phase change (liquid to vapor) in thermal oil systems also prevents energy loss from vaporization.

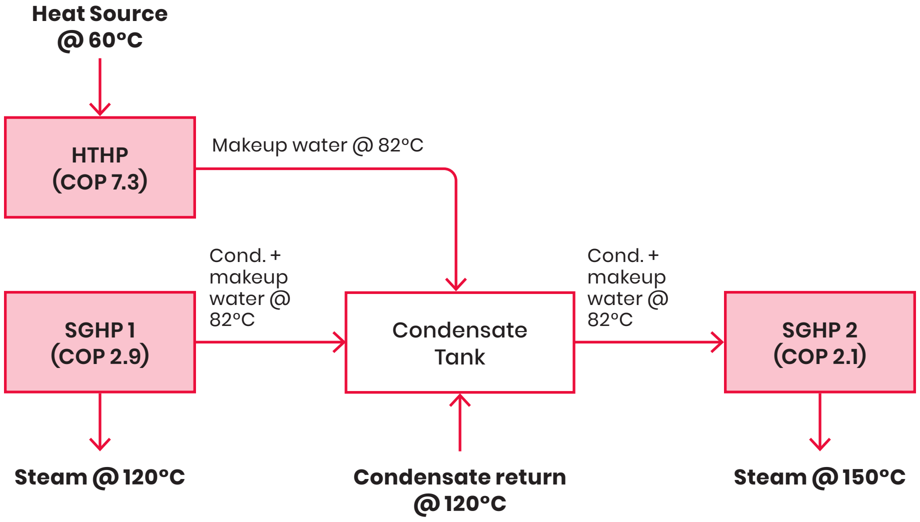
Additionally, thermal oil systems can operate at higher temperatures without the need for high pressure, further improving their efficiency. We estimated potential energy savings from electrification by comparing the current energy use for steam production in conventional boilers with the projected electricity demand of the electrification technologies for the same energy service. The efficiency gains of switching drive the energy, emissions, and cost results compared to conventional boilers.

STEAM VS. HOT OIL

In this study, we assess the replacement of both conventional steam-generating and hot oil boilers.Steam and hot oil are both mediums for delivering heat for processes. A typical textile wet-processing facility uses both steam and hot oil boilers. In this study, we analyze replacement of both steam and hot oil boilers at a typical textile wet-processing facility.

For heat pumps, our results are driven by the modeled coefficient of performance (COP), which is determined by the ratio of the sink temperature to the temperature lift, or the difference between the heat source and sink temperatures.[7] We evaluated the waste heat sources at a typical textile facility, estimating that sufficient waste heat at 60°C is available for heat pump use (Zuberi et al. 2021). To meet the needs of a typical wet-processing facility, steam-generating heat pumps (SGHPs) could be installed to provide steam at two temperatures: 120 °C for scouring, mercerizing, and washing, and 150 °C for sizing, dyeing, and drying/heat setting. Figure 3.1.2. depicts a schematic of potential heat pump applications at a typical textile facility, including their respective COPs, which represent the efficiency gains from each part of the heat pump system. A high-temperature heat pump (HTHP) can be installed to preheat the makeup feed water to 82°C before it enters the condensate tank for steam generation at the two specified temperatures. It should be noted that heat sources available at temperatures above 60°C could lead to a higher COP than currently estimated, thereby reducing the electricity demand of the heat pumps.

FIGURE 3.1.2: INDUSTRIAL HEAT PUMP APPLICATIONS TO MEET STEAM DEMAND AT A TYPICAL WET-PROCESSING TEXTILE FACILITY



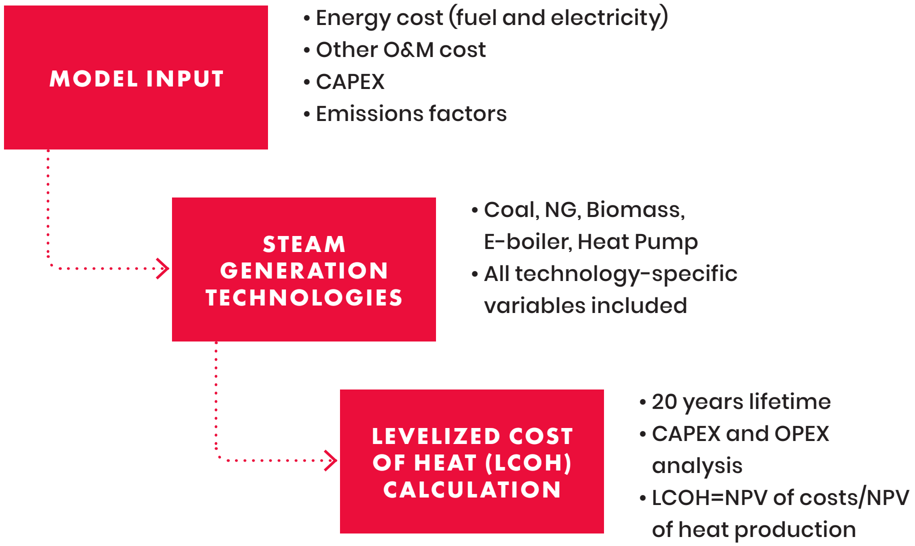
For biomass and natural gas boilers, we assumed similar efficiencies but different emissions factors of combustion. We modeled both sustainable and unsustainable biomass supply sources, assuming a zero emissions factor (carbon neutral) for sustainable biomass and using the IPCC emissions factor for biomass combustion in the case of unsustainable biomass.

For natural gas, we used the emissions factor of direct combustion plus a sensitivity analysis based on the average of multiple literature estimates on upstream methane's impact on the lifecycle emissions factor of natural gas. We used the aforementioned assumed prices for cost analysis of biomass and natural gas boilers relative to coal.

---

[7] Due to losses in thermodynamic processes, the actual COP of a heat pump is lower than its theoretical maximum. An efficiency term is used to relate the actual COP to the theoretical maximum, with typical efficiencies ranging between 40% and 60%. For our analysis, we use a conservative efficiency estimate of 45%.

FIGURE 3.1.3: SCHEMATIC FOR THE LEVELIZED COST OF HEAT FOR STEAM GENERATION CALCULATION USED IN THIS STUDY



We also estimated capital expenditures (CAPEX) and operational expenditures (OPEX) to develop a cash flow model that was used to estimate the levelized cost of heating (LCOH) for steam generation for each technology, with a new coal boiler as a reference (Figure 3.1.3.). The model estimates annual expenditures over the expected lifespan of the technology (assumed to be 20 years for each technology), utilizing net present value (NPV) calculations to bring future costs to present value terms. The model projects annual operational costs, factoring in different inflation rates for various inputs. The overall capital and operational costs are then aggregated annually over a 20-year period, discounted to the present value, then divided by the thermal output for each technology.

This chapter presents the results of our analysis of the five countries of interest to the report, with the following content:

- Low-Carbon Technologies for Steam Generation — energy savings, emissions reductions, and energy costs; levelized cost of heating for all steam technologies in comparison.
- Low-Carbon Technologies for Hot Oil Boilers — energy savings, emissions reductions, and energy costs.
- Potential Impacts of Electrification on the Electricity Grid — estimated load from electrification technologies.
- The energy systems landscape in each country.
- Low-carbon thermal energy actions roadmap.

3.2. Textile Plants in China

3.2.1. The Energy Systems Landscape in China

To preface the quantitative findings in this section, we first dive deeper into key aspects of China's energy systems and policies affecting the viability of low-carbon thermal energy technology adoption. This context also drives our assumptions for the China analysis, as detailed in Section 3.1.

As the world's largest coal producer and consumer, China benefits from abundant, low-cost domestic coal and substantial fossil fuel subsidies — totaling $2.2 trillion in 2022 — which make coal highly affordable and reduce incentives for the textile industry to transition to cleaner energy (Hojgaard et al., forthcoming)). On the other hand, **China has the largest installed capacity of wind and solar energy in the world and its renewable energy supply is also the most rapidly increasing of any country.** RE in China is becoming increasingly affordable, and massive efforts are underway to integrate RE into China's grid. The country's carbon neutrality targets (peaking emissions by 2030 and achieving carbon neutrality by 2060), the national emissions trading system, and a relatively mature top-down regulatory framework for energy and emissions provide strong policy incentives for companies to adopt cleaner technologies when compared to other countries in this study. Additionally, China has significant experience with massive-scale infrastructure development and financing, which makes large-scale deployment of RE and low-carbon technologies feasible. China's recent release of sustainability reporting guidelines for its major stock exchanges — the Shanghai, Shenzhen, and Beijing Stock Exchanges — has created additional pressure on publicly traded companies, including large textile manufacturers, to increase transparency around their environmental impact (Hojgaard et al. forthcoming). This regulatory push encourages companies to improve energy efficiency and sustainably manage their energy consumption.

Notably, around half of China's textile industry energy use is based on purchased heat (e.g. from a centralized steam generating plant) (Hasanbeigi and Zuberi 2022), which would be largely outside the ability of textile industry stakeholders and individual facilities to change. This significantly reduces the potential CO_2 reduction across China's textile industry by half. However, the remaining half of the textile industry's energy use is from onsite coal and natural gas consumption. We modeled a typical plant with this onsite heating arrangement that could adopt low-carbon thermal energy. Below, we discuss alternative fuel availability for biomass and natural gas in China. We also discuss China's electric grid and the availability of renewable electricity for corporate procurement.

Alternative Fuel Availability in China

Currently, only 4% of China's total energy supply comes from biomass and waste sources, due to heavy reliance on established coal markets. However, the government has adopted plans to increase biomass as an energy source over the next few years. Agricultural residues, particularly from cereal crops such as wheat and rice, are expected to be available based on analysis of China's straw resources (agricultural residues from cereal crops such as wheat and rice). As of 2020, China had an estimated 830 million tons of theoretical straw resources, with about 700 million tons deemed collectible. Of this collectible straw, only 90 million tons were utilized as straw fuel, indicating greater potential for collection (BEIPA 2024). Given the steady upward trend of grain production — 1% annually according to the National Bureau of Statistics — total straw resources are also expected to rise.

China's textile industry also uses other sources of biomass due to the low calorific value of agricultural residues like straw. Textile facilities with biomass boilers in China have been reported to use other sources like sawdust and furniture/pallet waste. Furniture waste is also less expensive than crop residues in some areas (BEIPA 2024).

Sourcing biomass for China's textile industry is also challenging due to the country's dense industrial areas. At larger scales, the switch to biomass becomes less feasible. Large-scale industrial operations require vast amounts of energy, necessitating an equally large biomass supply, which can be logistically challenging and economically unfeasible. Broadly speaking, China's textile production tends to be located in Central and

Southeast provinces, while crop residues are primarily generated in the Northeast. Storage requirements for large quantities of biomass are significant, not only in terms of space but also in maintaining quality over time. Moreover, the density of industries in such regions often leads to a competitive demand for limited biomass resources, further complicating the supply chain and escalating costs. While furniture waste may be more energy-dense and lower cost than agricultural residues in China, its long-term supply is uncertain, especially as China's economic growth slows. Furniture waste will also need to be from Forest Stewardship Council- (FSC) certified sources to ensure the sustainability of the source.

Another barrier to sustainable biomass adoption in China is the lack of a uniform regulatory framework, such as dedicated emissions standards or monitoring for biomass boilers. This results in varied management standards across regions and project approval roadblocks. Without comprehensive statistics, it is difficult to track and certify greenhouse gas emission reductions effectively (BEIPA 2024). In addition, a number of provincial governments have banned biomass boilers due to local air pollution concerns. **Overall, we are not able to reach a generalized conclusion or recommendation for biomass potential to reduce CO_2 emissions in China's textile industry due to regional differences in sources and regulatory frameworks. While there are sustainable sources available — and a growing interest from the Chinese government to leverage these, biomass potential for the country's textile facilities will need to be evaluated on a case-by-case basis and account for local regulations and sustainable biomass availability.**

The textile industry's ability to switch to natural gas is limited in China. China derives 8% of its total energy supply from natural gas, and 40% of this consumption comes from imported natural gas. This import reliance subjects industrial consumers to volatile fossil fuel prices that can be disrupted by changes in international markets. In addition, methane emissions monitoring and regulation in China are still emerging (Yang et al. 2022), making upstream emissions a significant risk to the overall climate impact of natural gas adoption.

China's Electricity Grid

Despite being the world leader in installation of renewable energy, China's grid faces challenges in integrating variable renewable energy sources like wind and solar. This integration is key to decarbonization via electrification if the technologies draw solely from the grid. Integrating RE into the grid is a challenge experienced across all economies pursuing electrification. China's grid has faced uncharacteristic reliability challenges in the past several years, when increasing electricity demand occurred at the same time as coal and hydropower shortages. Additional pressure will be placed on the grid system as multiple sectors, including transportation (e.g. electric vehicles) and buildings, move to electrification (Hasanbeigi et al. 2024).

Another issue is RE integration and ongoing electric power market reform, which has been ongoing for many years. The National Development and Reform Commission's Document No. 118, issued in 2022, promotes the establishment of a unified national power market system, encouraging market integration across provinces and regions (International Energy Agency 2024). However, challenges remain, including the need for coordinated cross-province planning of generation and transmission infrastructure, and transparent mechanisms to identify the least-cost mix of resources.

Additional electrification demand in industries could exacerbate this issue, requiring investment in grid upgrades, transmission infrastructure, and market reform — especially to connect renewable-rich regions in the interior with coastal industrial hubs. Textile facilities, typically located in eastern China, lack land to install onsite generation, and their locales are generally limited in installing new renewable capacity. Overall, however, it is important to note that China has a highly stable grid, with a low System Average Interruption Duration Index (SAIDI), which can facilitate the adoption of electrification technologies by providing consistent power to industrial users.

China's electricity grid faces significant challenges in achieving decarbonization through industrial electrification due to its limited inter-provincial electricity trading and market structure. In 2022, only 12% of electricity sales occurred between provinces, mostly through long-term contracts rather than dynamic trading that could balance supply and demand (Lu et al. 2024). This lack of flexibility prevents surplus renewable energy generated in other provinces from reaching the industrial hubs in the eastern provinces. China began piloting an inter-provincial spot power trading program in 2024, but full implementation of a national market is not expected until 2030.

China has a robust policy framework supporting energy storage, which can enhance the viability of electrification technologies. The National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) have issued several guidelines to accelerate the adoption of storage technologies. China's "New Energy Storage Development Implementation Plan" aims for 100 GW of storage by 2030, including pumped hydro storage and batteries, of which it is a dominant manufacturer (Hojgaard et al. forthcoming). Provincial governments, such as those in Guangdong and Jiangsu, have also issued mandates requiring energy storage as part of new renewable installations.

Corporate Renewable Electricity Procurement in China

China continues to lead the world in wind and solar energy development, with 180 GW of utility-scale solar and 159 GW of wind power under construction. By the first quarter of 2024, China's total utility-scale solar and wind capacity reached 758 GW, and the country added more solar in 2023 than in the previous three years combined (Yu et al. 2024). Distributed solar has seen rapid growth, especially through the "whole county solar" model, contributing to China's renewable energy boom. Despite challenges discussed earlier in this report, China is on track to meet its renewable energy targets ahead of schedule.

This massive increase in renewable energy supply is driving China's corporate RE procurement market. Corporate RE procurement in China has also grown significantly due to improved policy frameworks and clear guidance on market mechanisms. The key mechanisms for corporate RE procurement in China include Green Power Trading (GPT), Green Electricity Certificates (GECs), direct investment in utility-scale projects, and on-site distributed wind and solar installations. These mechanisms vary in terms of maturity, scale, and pricing, each offering distinct advantages for companies looking to source green power (Lu et al. 2023).

GPT, where corporate buyers sign contracts directly with renewable energy developers or through a retailer to purchase green electricity (in which case the procurement is certificate-based), is one of the most mature options. The procurement scale is large, and prices are typically negotiated bilaterally. The GPT mechanism has gained momentum, with transaction volumes increasing year on year, reaching 22,780 GWh in 2022. Provincial governments have developed their own GPT rules, and monthly trading sessions are now a feature in multiple provinces. However, challenges such as varying rules across regions make it difficult for companies operating in multiple provinces to standardize their green power procurement strategies. Additionally, the transmission capacity between provinces remains limited, constraining interprovincial transactions.

GECs are a tool for companies in China to certify their green power usage, with each GEC representing 1 MWh of non-hydro renewable energy. GECs are often bundled with green power delivery through GPT. GEC trading is forecast to expand, with new platforms and enhanced integration with carbon pricing mechanisms. There are GECs are available for around RMB 50/MWh (about $7/MWh or 7 cents per kWh), with the possibility of negotiation for bulk purchases (Lu et al. 2023). Although renewable energy certificate (REC)-type mechanisms have sometimes been criticized for not contributing to additional renewable energy, GECs are officially recognized by the Chinese government and gaining international credibility.

Corporations can also directly invest in utility-scale renewable energy projects or acquire established RE projects. However, competition for permits and transmission limitations can make this approach difficult, and potentially unfeasible for smaller textile companies. Provinces increasingly require renewable projects to include energy storage to ensure grid stability, further raising upfront investment costs.

Companies can also directly build their own onsite wind and solar generation to reduce electricity costs and fossil fuel consumption. This mechanism has matured, with distributed solar installations exceeding utility-scale capacity for the first time in 2021. These systems can be self-consumed or sold back to the grid. Onsite generation typically provides a 10%–20% discount on electricity prices, while owning the project could deliver over 10% IRR (Lu et al. 2023). Although this model is becoming more popular, there are implementation challenges and limitations on GEC issuance for distributed projects (Ibid.). In addition, individual textile facilities may not have the land area required for these investments.

In 2024, China charted on top consultancy EY's PPA Renewable Energy Country Attractiveness Index for Corporate Power Purchase Agreements (the PPA Index) for the first time, ranking 19th out of 30 ranked countries (EY 2024). The prominent energy think tank RMI predicts that China's corporate RE market will go through three phases — incubation, rapid growth, and stabilization — and that these phases will be closely related to China's National Emissions Trading System, or carbon market, which was officially launched in 2017 and is rapidly developing (Patel 2024). Initially, the market will increase supply through local pilots and subsidy-free projects, with pricing closely tied to coal power volatility. As the market enters a phase of rapid growth, system costs will rise to accommodate renewable intermittency, and green power pricing will be influenced by carbon market dynamics. Ultimately, the market is expected to stabilize by 2030 with a unified electric market, where green power pricing is more transparent and directly influenced by a mature carbon market (Lu et al. 2023). As the Chinese market for corporate RE procurement is already strong and competitive, we predict this trend will continue. Therefore, we assume corporate RE procurement will be a strong enabler of the low carbon thermal energy transition in China.

Based on this context, we developed assumptions to analyze how adopting low-carbon thermal energy technology in China will affect energy use, emissions, and costs from steam and hot oil heating at a typical textile wet-processing facility. The RE procurement pathways for China are as follows:

TABLE 3.2.1.: RE PROCUREMENT PATHWAYS ASSUMED FOR CHINA IN THIS STUDY

Year	Baseline Grid Plus RE Procurement Scenario	Ambitious RE Procurement Scenario
2030	50%	100%
2035	75%	100%
2040	100%	100%

Results are presented in the next two sections.

3.2.2. Low-Carbon Technologies for Steam Generation

Electric Steam Boilers

Electric steam boilers can save a significant amount of energy relative to conventional boilers. Since our assumed efficiency and production levels are the same across the countries studied, we only present these energy saving results once. We estimate that electric boilers could reduce total energy use by 24% at a typical textile wet-processing facility when compared to conventional coal-fired boilers. This equates to 18 GWh of energy per year. Note that the results in this section and the following sections are based on a case of a typical facility, and real-world results will vary significantly based on each facility's individual process heating requirements.

FIGURE 3.2.1: ANNUAL ENERGY DEMAND FROM COAL-FIRED STEAM BOILERS VS. ELECTRIC STEAM BOILERS AT A TYPICAL TEXTILE WET-PROCESSING FACILITY IN THIS STUDY, ALL COUNTRIES

Note: Since natural gas boilers are assumed to have the same efficiency as coal boilers, the results for energy savings in Bangladesh (i.e. natural gas steam boilers vs. electric steam boilers) are the same.

Note: Conventional boilers use a small amount of electricity, which is visualized in the results throughout this study

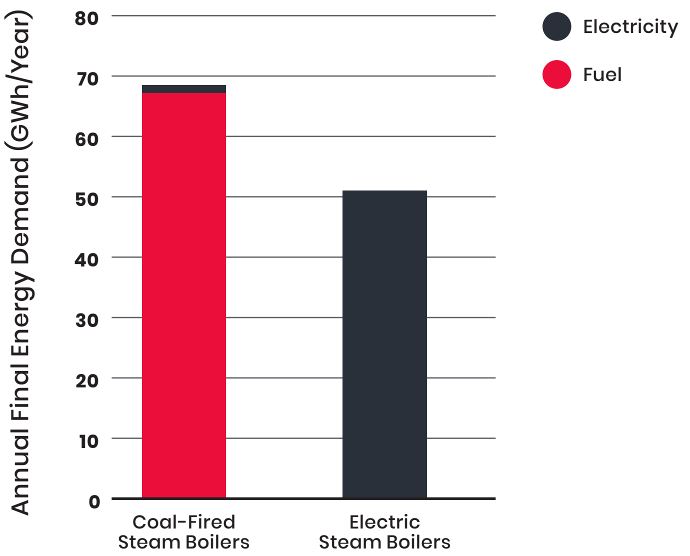
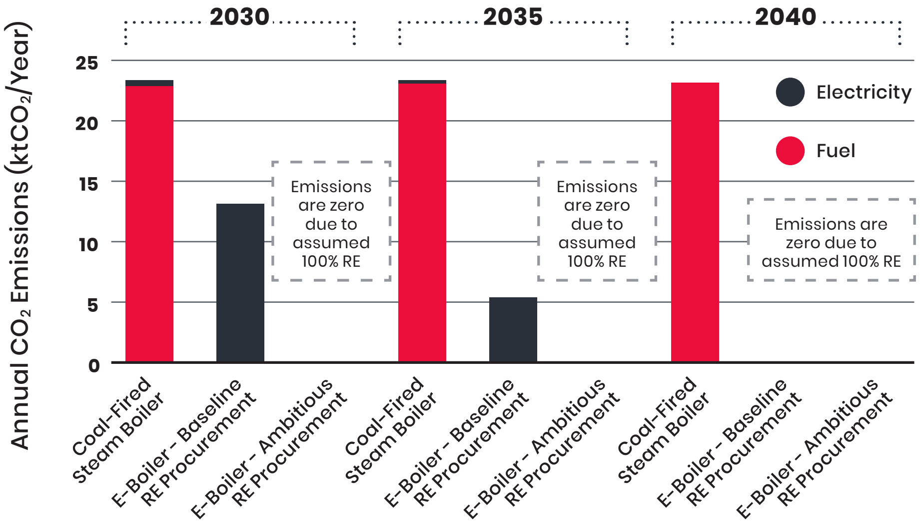


FIGURE 3.2.2: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN CHINA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS.



CO_2 reductions from reduced energy use depend upon the share of RE procurement, which delivers zero-emission electricity. CO_2 emissions from electricity generated by coal or other fuels would result in increased emissions. China has a strongly positive market growth outlook for RE and corporate procurement. Even under baseline circumstances, we project that a typical textile plant would be able to reduce emissions.

In China, steam boiler electrification is expected to increase energy costs, due to the relatively high electricity prices and low coal prices anticipated in 2030. However, electric boiler energy costs become relatively competitive by 2035, especially under the Ambitious RE Procurement pathway, as the projected price ratio of electricity and coal decreases over time (see Section 3.3.). In addition, carbon pricing may increase textile production's energy costs, as shown in gray in Figure 3.2.3. Without carbon pricing, the gray bar would go to zero. Even so, electric boiler energy costs are expected to be competitive relative to conventional coal boilers in 2040 based on decreasing RE procurement costs. Because our results are highly sensitive to fuel and electricity prices, we present error bars of +/- 30% for fuel and electricity prices so that readers can see the potential range of relative energy costs. When considering shifts to electrified technologies, RE availability and cost will be determining factors.

While electric steam boilers reduce emissions from 2030 even with only 50% corporate RE procurement in the Baseline Grid Plus RE Procurement pathway, the cost of RE is unlikely to make this an attractive option until 2035-2040.

FIGURE 3.2.3: ENERGY COSTS OF COAL STEAM BOILERS VS. ELECTRIC STEAM BOILERS, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

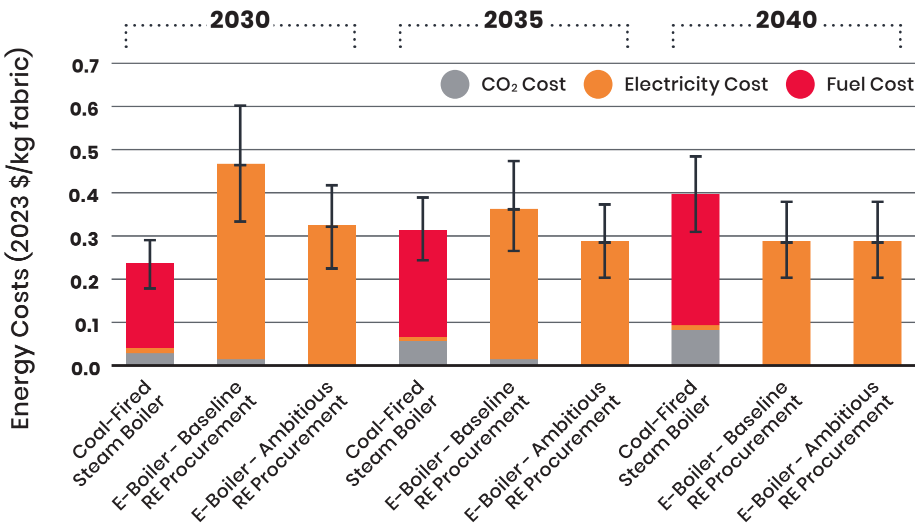
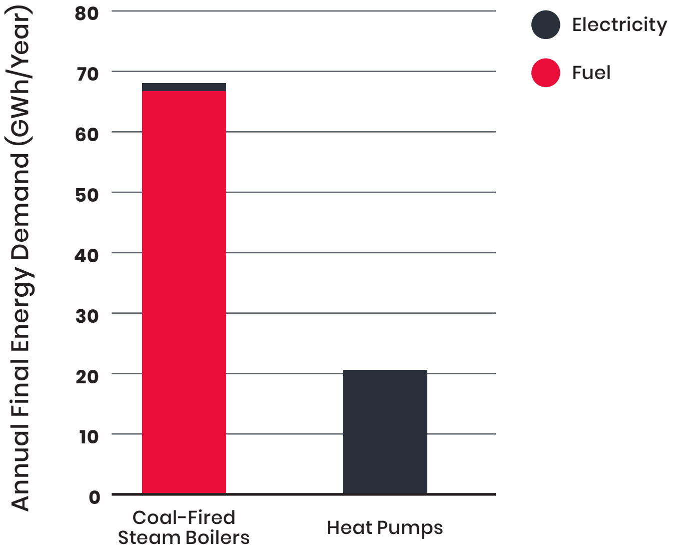


FIGURE 3.2.4: ANNUAL ENERGY DEMAND FROM COAL-FIRED STEAM BOILERS VS. STEAM-GENERATING HEAT PUMPS AT A TYPICAL TEXTILE WET-PROCESSING FACILITY IN THIS STUDY, ALL COUNTRIES

Note: Since natural gas boilers are assumed to have the same efficiency as coal boilers, the results for energy savings in Bangladesh (i.e. natural gas steam boilers vs. electric steam boilers) are the same



Steam-Generating Heat Pumps

Electrification with steam-generating heat pumps can lead to even greater efficiency gains and energy savings relative to conventional boilers, due to the nature of heat pump technology as discussed in Section 2.1. Since our assumed efficiency and production levels are the same across the countries studied, we only present these energy savings results once. **We estimate that heat pumps could reduce total energy by 48 GWh of energy per year, which is much more than modeled for electric steam boilers.**

An important reminder from the first report is that steam-generating heat pumps are not yet widely proven and implemented in the textile industry, but we anticipate a significant increase in adoption by 2030. Heat pumps are already proven and implementable for lower temperatures needed for hot water-based process heating.

In terms of CO_2 emissions, efficiency gains combined with the assumed share of RE procurement in our pathways, enables electrification with heat pumps to achieve significant emissions reductions by 2030. Even under the Baseline RE Procurement pathway (Figure 3.2.5.), emissions can be reduced to nearly 20% of those of conventional boilers by 2030.

Due to their efficiency, heat pumps are expected to reduce energy costs relative to conventional coal-fired boilers in China, even by 2030 and under the Baseline pathway. These energy cost savings grow over time, especially if carbon pricing comes into effect.

With the highest efficiency of all technologies studied, heat pumps can reduce emissions and energy costs by 2030, even with only 50% corporate RE procurement (the Baseline Grid Plus RE Procurement pathway). We therefore recommend feasibility studies along with RE procurement analysis — completed before 2030 — followed by scaled implementation.

FIGURE 3.2.5: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED STEAM BOILERS VS. HEAT PUMPS (HP) IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN CHINA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

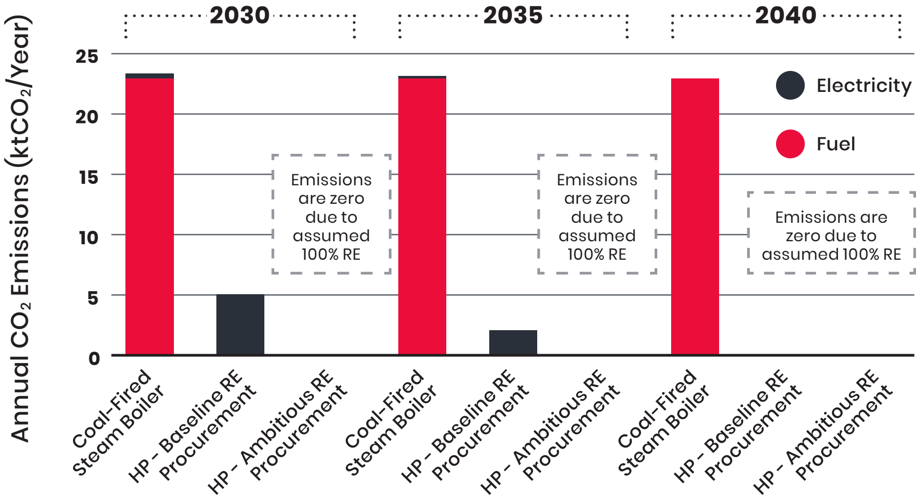
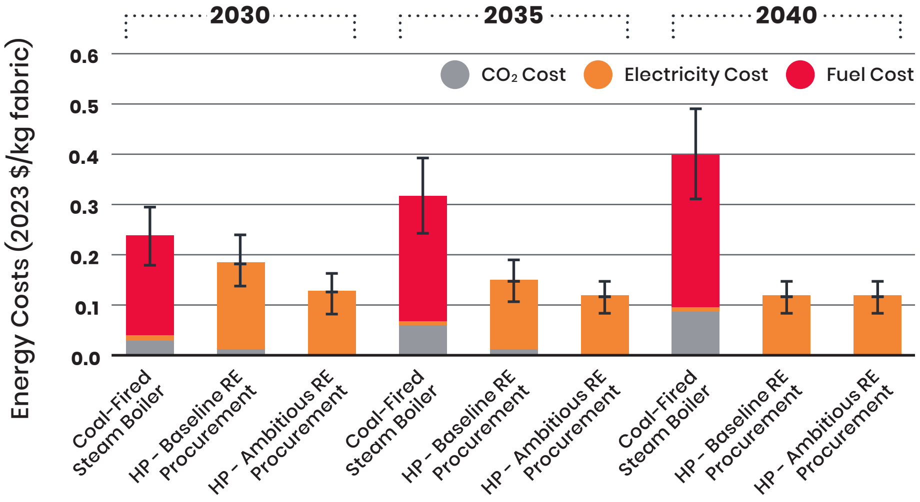


FIGURE 3.2.6: ENERGY COSTS OF COAL STEAM BOILERS VS. HEAT PUMPS, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Biomass Steam Boilers

Biomass boilers are assumed to have the same efficiency and energy demand as conventional coal boilers;[8] therefore, we do not present energy results for biomass boilers. In terms of CO_2 emissions reductions, there is a wide range of impacts depending on whether the biomass is unsustainable or sustainable (i.e. carbon neutral). We used the direct combustion emissions factor for unsustainable biomass, which is slightly higher than that of coal and does not take into account the lifecycle carbon uptake of biomass sources during their growth phase. For sustainable biomass, we assumed that agricultural waste biomass is a sustainable source with overall carbon neutrality (emissions factor = 0), even though biogenic emissions are still produced upon combustion. Additionally, since we assume no change in the fuel emissions factors over time, we present results for a single year, as CO_2 emissions savings remain consistent over time.

FIGURE 3.2.7: ANNUAL CO_2 EMISSIONS FROM COAL BOILERS VS. SUSTAINABLE OR UNSUSTAINABLE BIOMASS STEAM BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN CHINA

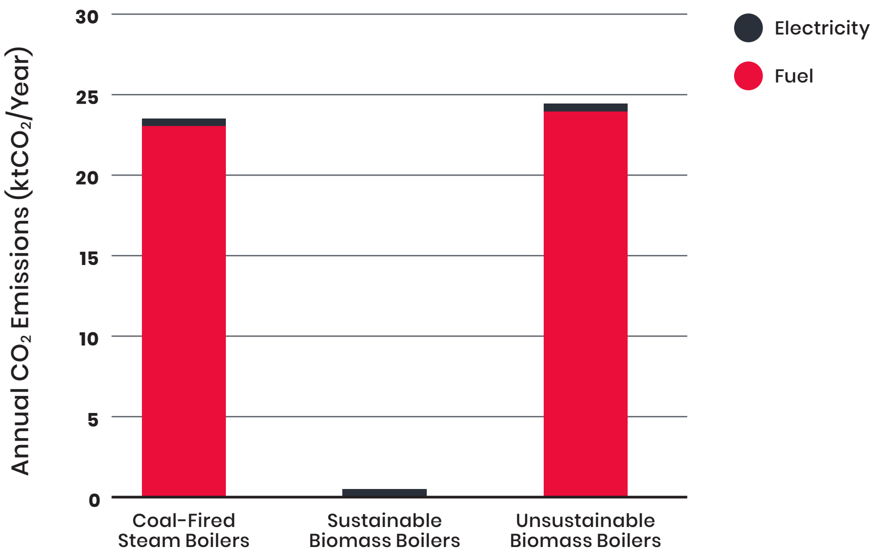
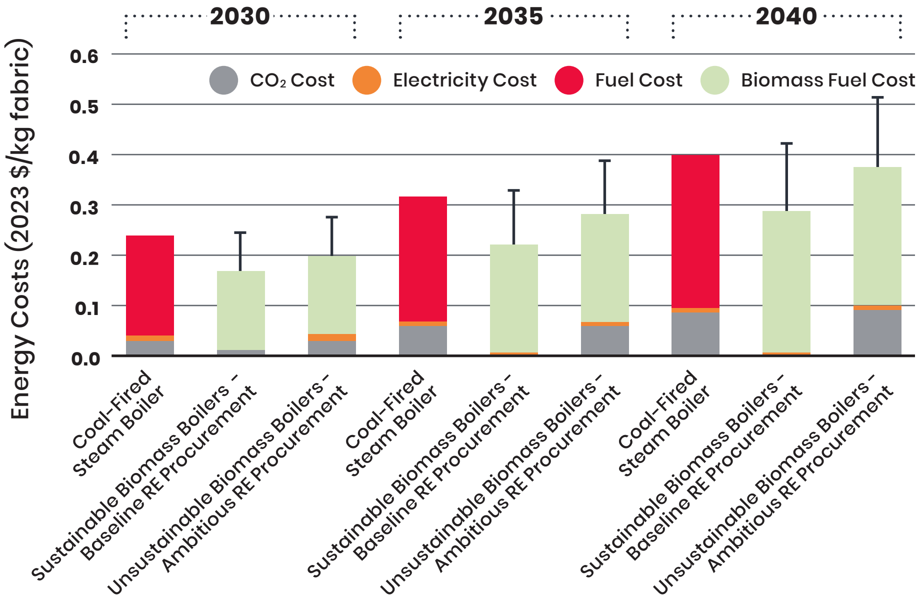


FIGURE 3.2.8. ENERGY COSTS OF COAL STEAM BOILERS VS. BIOMASS STEAM BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN CHINA



Biomass is expected to be cheaper than coal in China, which is a key driver of its adoption in the textile industry (see sections 2.1 and 3.1). However, prices vary by location and are subject to seasonal fluctuation or rapid year-to-year changes based on supply. Therefore, we have also added error bars of +/- 30% to the biomass fuel price to show readers the potential range of impact. In addition, because unsustainable biomass does produce direct combustion emissions, we assumed the application of a carbon price, shown in gray. Over time, biomass prices are expected to rise as demand for sustainable biomass increases while supply remains limited. The energy costs of biomass boilers are expected to be on par with those of conventional boilers when a carbon price is applied.

Since sustainable biomass is a relatively untapped resource in China, we recommend that facilities seeking to transition from coal and located close to sources of certified sustainable biomass evaluate this alternative fuel and technology. Due to the regional variance in biomass availability and local regulations, this should be evaluated on a case-by-case basis.

---

[8] Biomass boilers typically have a slightly lower efficiency compared to coal boilers, ranging between 65-80%. The efficiency can be affected by the type of biomass (e.g., wood chips, pellets, agricultural waste) and moisture content, with drier biomass leading to better combustion and higher efficiency. For the purposes of this study, we assume similar efficiency, and focus on the emissions and cost results, which show greater variation from the conventional technology.

Natural Gas Steam Boilers

Natural gas boilers are assumed to have the same efficiency and energy demand as conventional coal boilers;[9] therefore we do not present energy results for natural gas boilers. CO_2 emissions reductions can vary widely depending on if the upstream methane emissions are considered. If yes, switching to natural gas steam boilers could potentially increase the annual CO_2 emissions relative to coal (additional emissions from methane shown as a range in the dashed bar in Figure 3.2.9. based on data from Clean Air Task Force 2024). Otherwise, emissions from direct combustion are considerably lower relative to coal.

FIGURE 3.2.9: ANNUAL CO_2 EMISSIONS FROM COAL STEAM BOILERS VS. NATURAL GAS STEAM BOILERS IN A TYPICAL TEXTILE WET-PROCESSING FACILITY IN CHINA

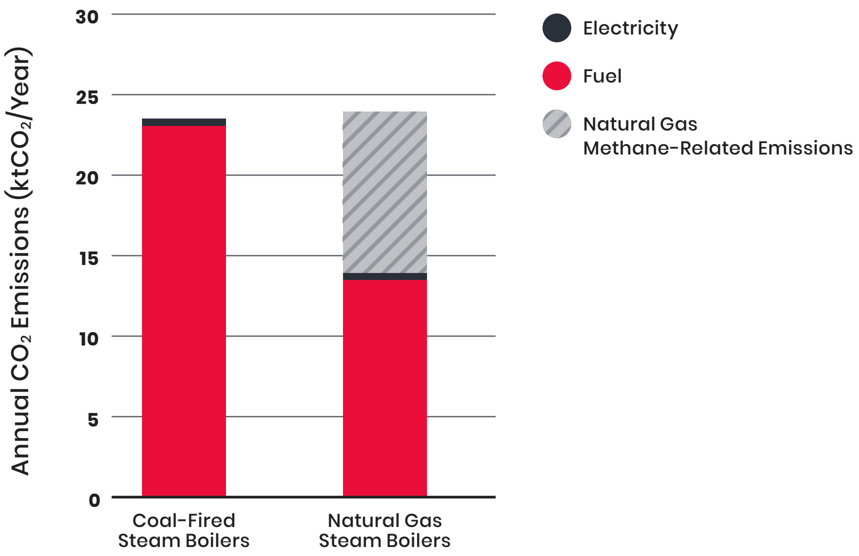
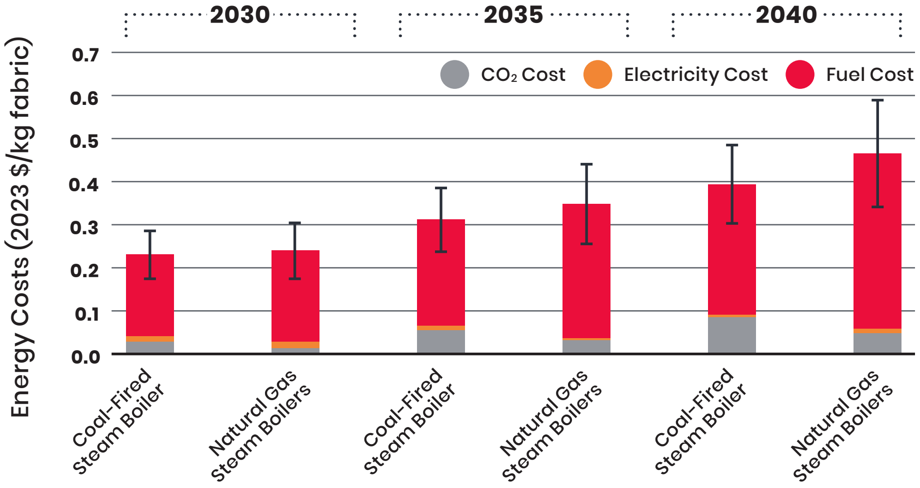


FIGURE 3.2.10: ENERGY COSTS OF COAL STEAM BOILERS VS. NATURAL GAS STEAM BOILERS IN A TYPICAL WET-PROCESSING FACILITY IN CHINA



In China, natural gas is typically more expensive than coal, and prices are expected to rise, limiting the financial attractiveness of a transition in the textile industry. The carbon price in Figure 3.2.10. only applies to direct combustion of each fuel, as upstream methane emissions face challenges in both accounting and pricing.

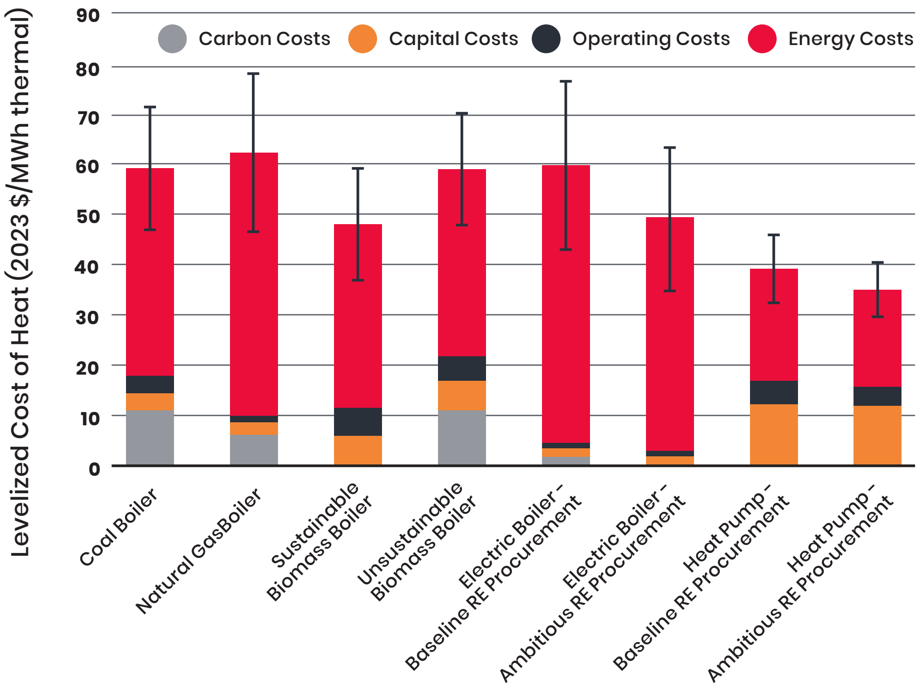
Given the increased energy costs of natural gas across the study, this is unlikely to be a viable alternative fuel for most Chinese facilities.

---

[9] Conventional natural gas boilers without condensing technology typically reach efficiencies between 80-85%, while coal boiler efficiency is 75%-85%. For the purposes of this study, we assume similar efficiency and focus on emissions and cost results, where the difference between coal and natural gas is more significant.

Levelized Cost of Heating for Steam-Generating Technologies
Following the methodology described in Section 3.1, we calculated and compared the levelized cost of heat (LCOH) of all steam technologies and both electricity pathways for the electrification technologies. In China, coal boilers, natural gas boilers, and electric boilers (Baseline RE Procurement pathway) have a similar expected LCOH of around $60/MWh thermal. However, under the Ambitious RE Procurement pathway, electric boilers have lower overall LCOH. Biomass steam boilers have lower LCOH due to the assumed lower fuel cost, which has a greater impact on overall LCOH than the relatively higher CAPEX and OPEX of biomass boilers when compared to the other boiler technologies. Despite their significantly higher CAPEX, heat pumps are expected to have lower LCOH than conventional boilers due to the major efficiency gains and the utilization of lower-cost procured RE over the technology's lifetime. Our results are highly sensitive to energy costs, so we have added an error bar of +/- 30% for overall energy costs for each technology.

FIGURE 3.2.11: LEVELIZED COST OF HEAT (LCOH) FOR STEAM GENERATION OF THE ANALYZED TECHNOLOGIES FOR A TYPICAL TEXTILE WET-PROCESSING FACILITY IN CHINA



3.2.3.Low-Carbon Technologies for Hot Oil Boilers

Electric Hot Oil Boilers

Electrification with electric hot oil boilers can save a significant amount of energy relative to conventional boilers. Since our assumed efficiency and production levels are the same across the countries studied, we only present these energy saving results once. We estimate that electric hot oil boilers could reduce total energy use by 14% at a typical textile wet-processing facility relative to conventional boilers — 8 GWh of energy saved per year. Electrifying hot oil boilers is expected to generate less overall energy savings than electrifying steam boilers for two reasons. First, the efficiency of conventional hot oil boilers is higher than steam boilers, as discussed in the Methodology section. Second, the overall energy consumption of hot oil boilers in a typical textile wet-processing facility is lower than in steam boilers. This also drives a lower overall emissions reduction potential, and lower electric load when electrifying hot oil boilers.

FIGURE 3.2.12: ANNUAL ENERGY DEMAND FROM COAL-FIRED HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS AT A TYPICAL TEXTILE WET-PROCESSING FACILITY IN THIS STUDY, ALL COUNTRIES

Note: Since natural gas boilers are assumed to have the same efficiency as coal boilers, the results for energy savings in Bangladesh (i.e. natural gas hot oil boilers vs. electric hot oil boilers) are the same.

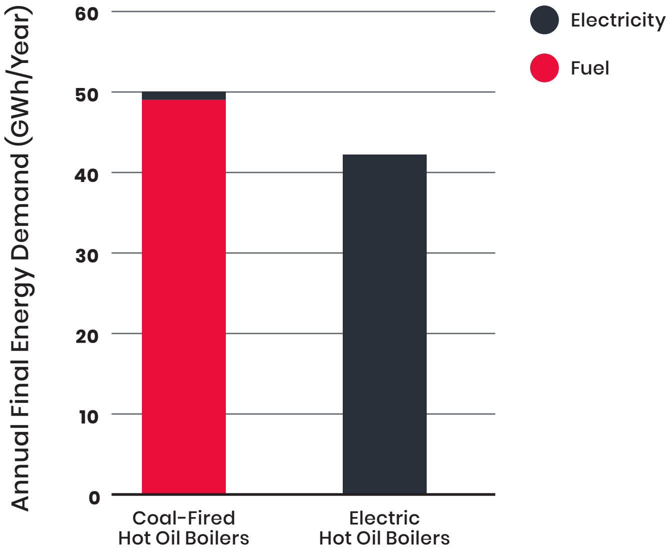
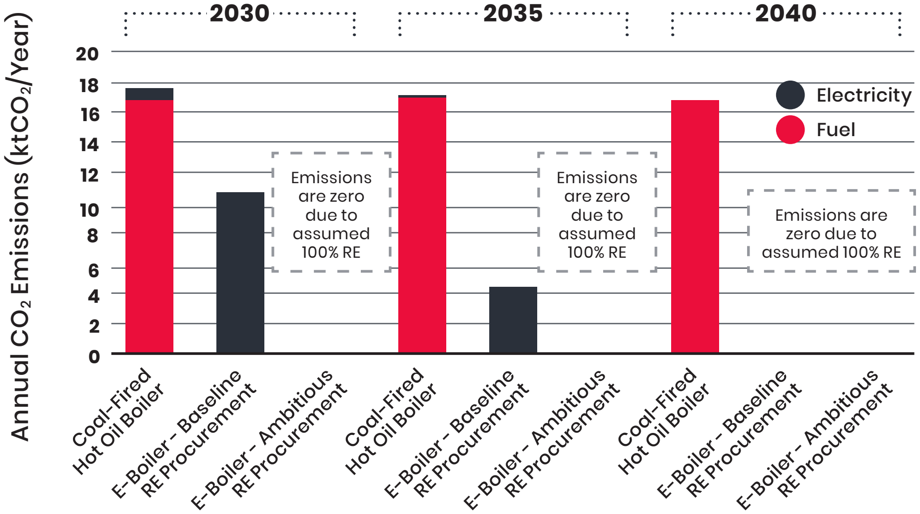


FIGURE 3.2.13: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN CHINA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS.

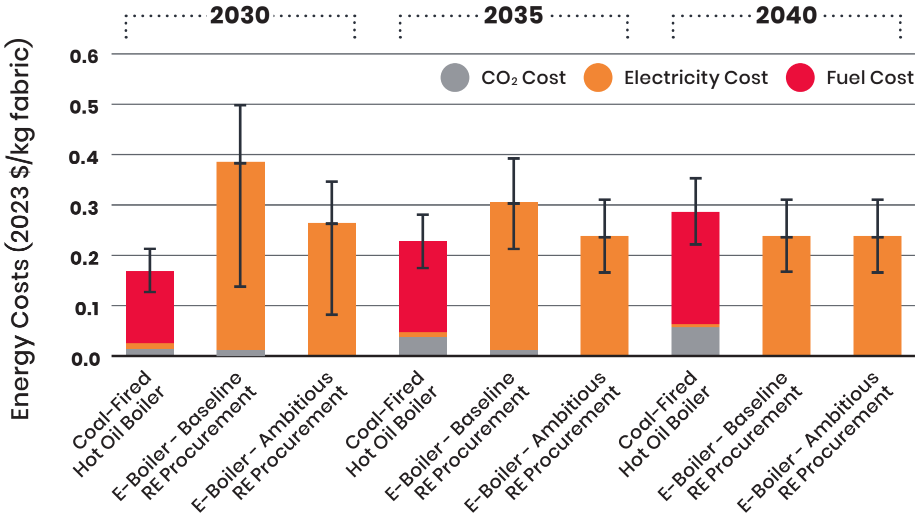


Efficiency gains, combined with the assumed share of RE procurement in our pathways, suggest electrification with electric hot oil boilers can lead to significant emissions reductions by 2030. Under the Ambitious RE Procurement pathway — with the assumption that 100% RE is procured — full decarbonization is achieved across timesteps, leading to a reduction of roughly 17 kilotons of CO_2 emissions per year by 2030.

In the near term, hot oil boiler electrification is expected to increase the energy costs for textile production in China due to the relatively high price of electricity and low price of coal expected for China in 2030. However, under the Ambitious RE Procurement pathway, electric boiler energy costs become relatively competitive by 2035 and will be lower for electric hot oil boilers by 2040. In addition, carbon pricing may increase the energy costs of textile production using coal-fired hot oil boilers.

Electric hot oil boilers reduce emissions from 2030 — even with only 50% corporate RE procurement in the baseline pathway; however, the cost of RE is not likely to make this an attractive option until 2035-2040.

FIGURE 3.2.14: ENERGY COSTS OF COAL HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Biomass Hot Oil Boilers

For hot oil boilers, our analysis is similar to that of steam boilers, presenting results on annual emissions and energy costs. Biomass hot oil boilers are assumed to have the same efficiency and energy demand as conventional coal-fired hot oil boilers; therefore, we do not present energy results. In addition, because we do not assume a change in the fuel emissions factors over time, we only present results for a single year, as annual CO_2 emissions savings results are essentially the same year-over-year.

Biomass hot oil boilers, like biomass steam boilers, are expected to have lower energy costs relative to coal-fired boilers due to the lower price of biomass fuel in China. However, prices are highly location-specific, and we present error bars to show readers the potential range of impact. By 2035, as biomass prices increase, energy costs are expected to be on par with those of conventional boilers when a carbon price is applied.

FIGURE 3.2.15: **ANNUAL CO_2 EMISSIONS FROM COAL BOILERS VS. SUSTAINABLE OR UNSUSTAINABLE BIOMASS HOT OIL BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN CHINA**

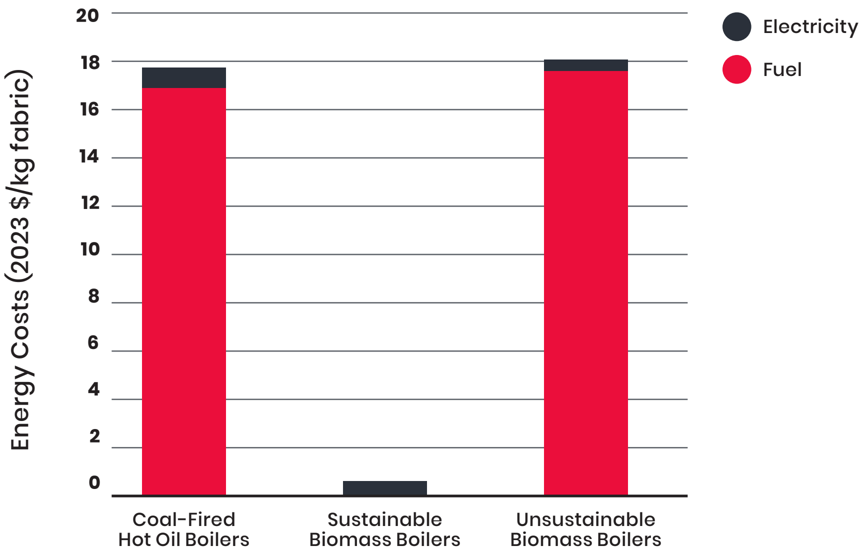
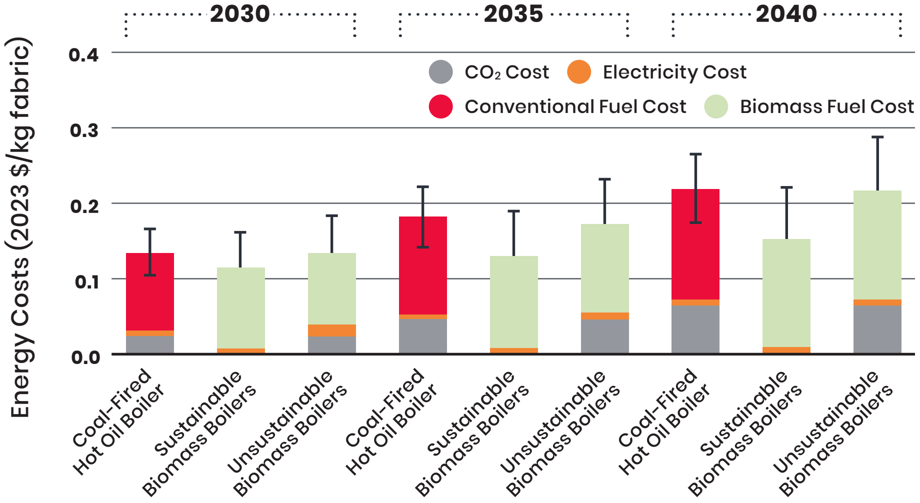


FIGURE 3.2.16: **ENERGY COSTS OF COAL HOT OIL BOILERS VS. BIOMASS HOT OIL BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN CHINA**



As sustainable biomass is a relatively untapped resource in China, we recommend that facilities seeking to transition from coal and located close to sources of certified sustainable biomass evaluate this alternative fuel and technology. Due to the regional variance in biomass availability and local regulations, this should be evaluated on a case-by-case basis.

Natural Gas Hot Oil Boilers

Similar to our steam boiler analysis, there are no energy savings for switching to natural gas hot oil boilers from coal hot oil boilers due to their similar thermal efficiency. In terms of CO_2 emissions reductions, there is a wide range of impacts depending on if the upstream methane emissions are taken into account. If upstream methane emissions are considered, switching to natural gas steam boilers would not lead to a reduction in annual CO_2 emissions relative to coal.

In 2030, natural gas hot oil boilers and coal boilers will have similar energy costs; however, China's natural gas prices are expected to rise faster than coal, limiting the financial attractiveness of natural gas transition in China's textile industry.

Given the increased energy costs of natural gas across the time horizons studied, this is unlikely to be a viable alternative fuel for most Chinese facilities.

FIGURE 3.2.17: ANNUAL CO_2 EMISSIONS FROM COAL HOT OIL BOILERS VS. NATURAL GAS HOT OIL BOILERS IN A TYPICAL TEXTILE WET-PROCESSING FACILITY IN CHINA

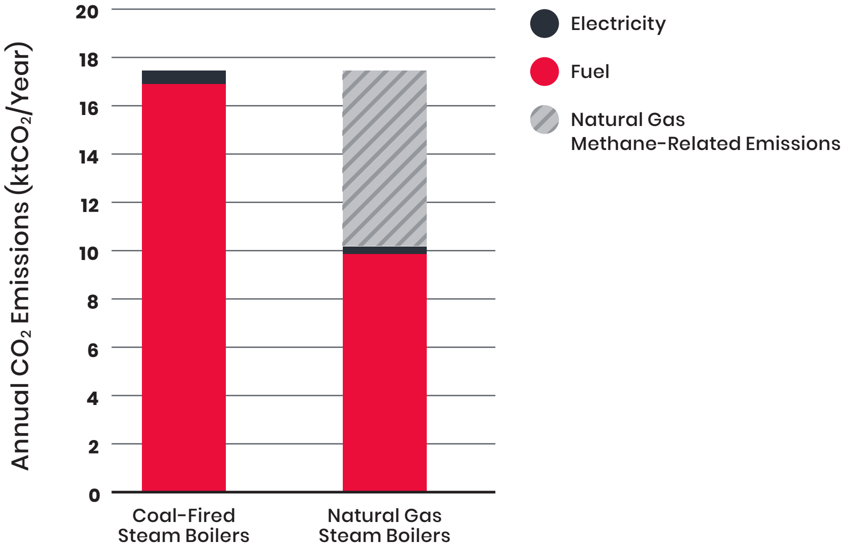
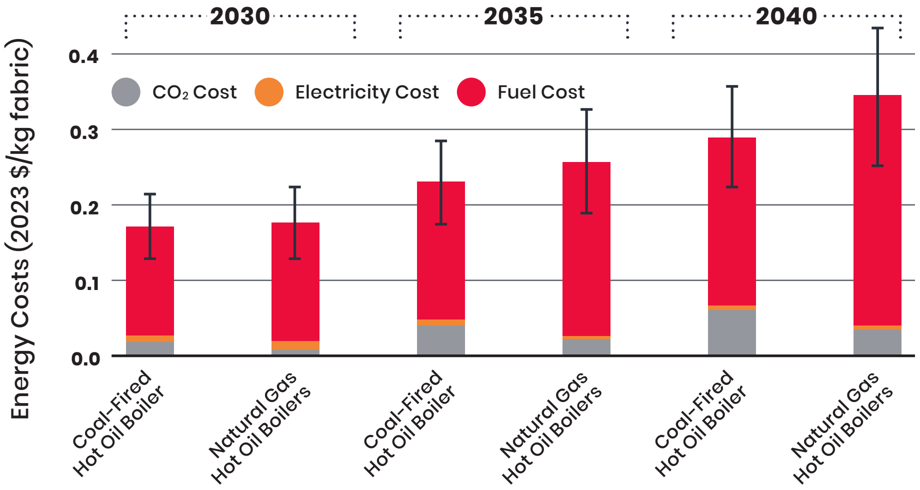


FIGURE 3.2.18: ENERGY COSTS OF COAL HOT OIL BOILERS VS. NATURAL GAS HOT OIL BOILERS IN A TYPICAL WET-PROCESSING FACILITY IN CHINA



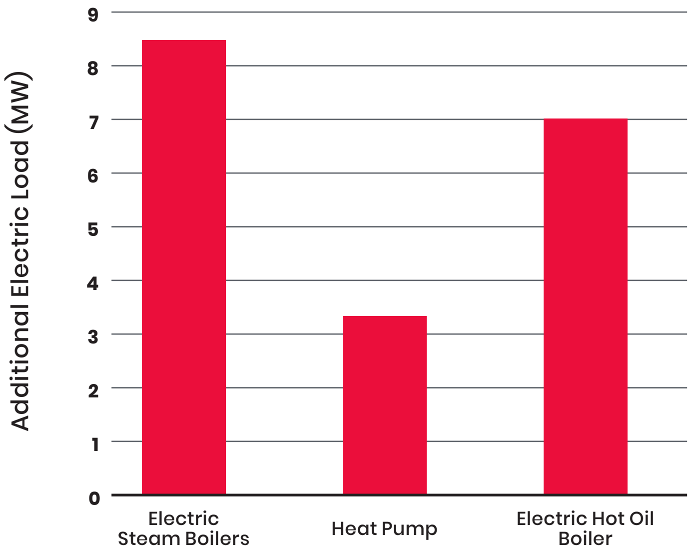
3.2.4. Potential Impacts of Electrification on the Electricity Grid in China

Electrification will increase electricity demand and grid load. Transitioning a significant portion of the textile industry would require careful planning and grid management. Figure 3.2.19. shows the estimated increase in electrical load from electrification at a typical textile facility in China (results are the same for all the studied countries). Electric steam boilers could replace conventional steam boilers — adding around 8 MW of additional electric load from a typical textile facility, while a heat pump could meet this same heat demand while only adding an electric load of around 3 MW. Electric hot oil boilers are expected to add an additional electric load of 7 MW when replacing conventional hot oil boilers.

The installed capacity required to meet this electricity demand will depend on the energy source. Variable renewable energy, with its lower capacity factor, will need to be installed in greater amounts to meet the same demand (or paired with storage technologies). Wind and solar energy have much lower capacity factors than traditional fossil fuel-based power generation (around 20%-30% for solar and 30%-40% for wind).

FIGURE 3.2.19: ADDITIONAL ELECTRICAL LOAD FROM THE ELECTRIFICATION OF STEAM AND HOT OIL BOILERS FOR A TYPICAL TEXTILE FACILITY IN THE STUDIED COUNTRIES

Note: this is the additional load without assuming a capacity factor.



3.3. Textile Plants in India

3.3.1. The Energy Systems Landscape in India

To preface the quantitative findings in this section, we first dive deeper into key aspects of India's energy systems and policies that would affect the viability of low-carbon thermal energy technology adoption. This context also drives our assumptions for the India analysis, as detailed in Section 3.1.

In India, like China, it is important to note that the widespread availability and low cost of domestic coal create a substantial hurdle for low-carbon thermal energy adoption. Coal remains the dominant energy source for many textile facilities due to its affordability, making alternative technologies like electrification comparatively expensive. However, similar to China, **India is experiencing a rapid expansion of its renewable energy supply, particularly solar, which is becoming one of the lowest-cost energy sources in the world. India is also the country with the most developed corporate RE procurement market.**

Below, we further discuss key aspects of the energy system landscape in India relevant to low-carbon thermal energy adoption.

Alternative Fuel Availability in India
India currently derives 22% of its total energy supply from biomass and waste sources, one of the highest of the studied countries. Much of this biomass is used for traditional energy uses, such as cooking. India produces a significant amount of agricultural residues with an estimated annual availability of about 750 million tons of biomass, according to a study by the Ministry of New and Renewable Energy (MNRE) — much of which is already being used for the industrial sector. This biomass includes a diverse range of materials such as sugarcane bagasse (typically used onsite in sugar mills), straw, cotton stalks, rice husks, coconut shells, coffee waste, soya husks, etc. (Chauhan et al. 2022).

The northern states of Punjab, Haryana, and Uttar Pradesh are particularly notable for their high production of wheat and rice, leading to substantial amounts of rice and wheat straw. These residues are frequently burned in fields, causing severe air pollution that has contributed to nearly 100,000 deaths annually (Lan et al. 2022). Using these straws as energy could boost sustainable biomass supplies, reduce air pollution, and improve public health. However, the need to get rid of residues quickly and cheaply makes it challenging to scale the conversion of agricultural residues to industrial fuel sources. Currently, agricultural residues collected for energy are typically used by nearby small-scale, decentralized projects. Nevertheless, **in India, the textile sector's transition to biomass is well underway. A reliable, traceable supply of agricultural waste can be considered a viable alternative fuel to coal.**

A textile facility's ability to switch to natural gas highly depends on the local natural gas infrastructure and if it is feasible to connect to the natural gas distribution system. India's energy supply primarily comes from sources other than natural gas, and import reliance is high (47% of gas consumption comes from imported sources) for the natural gas that is used (6% of total energy supply)(EIA 2024). **Therefore natural gas is not deemed to be a feasible alternative fuel for India.**

India's Electricity Grid
As one of India's significant industrial energy users, the textile sector could cause a surge in electricity demand through electrification. Given India's very high grid emissions factor, electrification could lead to an increase in CO_2 emissions without an increased integration of renewable energy and the addition of installed capacity.

While India has set an ambitious goal to integrate 500 GW of renewable energy by 2030 and achieve 44% generation from RE by 2031, achieving this requires massive infrastructure investments. The rapid growth of solar power has introduced a pronounced "duck curve" effect, with steep ramps in evening electricity demand after solar generation drops. This can affect grid reliability as there may not be sufficient ramping capacity to effectively manage peak loads. Additionally, India's transmission infrastructure is struggling to keep up with rapid RE capacity addition. States with high RE penetration often face congestion, limiting the ability to export surplus power to deficit regions. There are transmission projects underway to link renewable-rich areas such as Ladakh, Rajasthan, and Gujarat to other regions. Gujarat, a major textile hub, is a significant area of opportunity where renewable potential aligns with manufacturing. Additionally, India plans to expand grid-level energy storage, with a target of 74 GW by 2031 through both pumped storage and battery technologies, but current storage capacity is still insufficient to provide round-the-clock renewable energy, especially with increased renewables demand from electrified industries.

India's electricity market is undergoing reforms to better integrate rapidly increasing low-cost renewable energy, but challenges remain. Currently, only 7% of electricity is traded through three exchanges, each setting its own prices, which limits optimal utilization of renewables. To address these inefficiencies, the Central Electricity Regulatory Commission (CERC) has proposed market coupling, which aims to streamline price discovery across exchanges and improve the allocation of renewable electricity (Michael 2024). While the outlook for the Indian grid is positive for renewables, the grid emissions factor may remain too high in the near term to deliver emissions reductions from electrification with electric boilers and grid electricity alone.

Corporate Renewable Electricity Procurement in India

India has had massive growth in renewable energy in recent years, which could be leveraged to decarbonize the textile industry through direct procurement, rather than waiting on grid decarbonization. In 2023, India contributed to 6% of global growth in solar and became the third-largest generator of solar energy (Ember Climate 2024). Corporate RE procurement is also increasing in India, with prominent companies like Infosys and Tata Motors transitioning to 100% renewable electricity. Textile companies have been one of the leading industries for corporate RE procurement (Rao and Agarwal 2022).

India ranks 13th on EY's PPA Index, higher than China and other emerging economies. The estimated corporate contracted RE capacity in India is about 34 GW (Bridge to India 2024). India's PPA market is the most favorable of the countries studied, and contracts for renewable electricity can already deliver lower-cost electricity relative to the grid (although still higher than current coal prices). Key mechanisms for corporate RE procurement in India include self-generation, offsite open access, and Renewable Energy Certificates (RECs). RE self-generation in India has

largely been dominated by rooftop solar due to the falling costs of PV systems and supportive net-metering policies. For a textile facility, however, physical space limits the amount of power that can be generated.

Another mechanism is typically referred to as Offsite Open Access (OA), which includes PPAs. Companies can engage in short-, medium-, or long-term open access contracts to draw RE from the grid as needed. This approach is typically lower cost than grid power, although policy instability and grid connectivity issues pose challenges. India has used RECs in the past, but their role is diminishing due to supply constraints and the higher costs compared to direct renewable power procurement (Aggarwal et al. 2019).

Recent regulatory changes, like some states' discontinuation of banking — an arrangement where generators can inject power into the grid and are permitted to withdraw that power when required — and increased charges, pose challenges for corporate RE procurement. "Banking" is particularly useful for managing the variability of RE, however, availability and terms vary by state and are evolving.

In addition to expanding RE generation, India is investing heavily in energy storage to supply round-the-clock RE. India is targeting 74 GW of storage capacity by 2031, using pumped storage and battery technologies, to manage the variability of renewable energy.

The prospects for India's corporate RE market appear strong, driven by expanding RE supply, ongoing policy and market reform, and strong commitment from major industries towards greener energy sources. Large corporations across sectors like automotive, cement, and IT are increasingly transitioning to 100% renewable electricity, highlighting demand that can help transform the market (Bridge to India 2024). Despite challenges such as policy changes and grid integration issues, the demand for renewable power, particularly through mechanisms like open access and captive generation, continues to rise. Therefore, RE procurement through mechanisms like PPAs presents textile manufacturers with a strong opportunity to deliver emissions and cost reductions through electrification.

Based on this context, we developed assumptions for analyzing how low-carbon thermal energy technology adoption in India will affect energy use, emissions, and costs from steam and hot oil heating at a typical textile wet-processing facility. The RE procurement pathways for India are as follows:

TABLE 3.2.2.: RE PROCUREMENT PATHWAYS FOR INDIA

Year	Baseline Grid Plus RE Procurement Scenario	Ambitious RE Procurement Scenario
2030	50%	100%
2035	75%	100%
2040	100%	100%

Results are presented in the next two sections.

3.3.2. Low-Carbon Technologies for Steam Generation

Electric Steam Boilers
As discussed, the energy savings of electrification technologies are the same across countries based on the efficiency gains of electrification. Therefore, they are not presented here.

The total mitigation potential for electrification technologies with full adoption of RE is the same across countries utilizing coal-fired boilers (i.e., full elimination of nearly 25 kt CO_2 by 2030 with 100% RE procurement, as is assumed in the Ambitious RE Procurement pathway). However, there is variation in the emissions reductions from the Baseline electricity pathway, as some countries have a higher grid emissions factor as well as different trajectories for corporate RE procurement. India has a very high grid emissions factor, but under our Baseline pathway, electric boilers can still lead to emissions reductions due to the assumed share of procured RE. India has rapidly growing RE supply and corporate procurement options, and in our Baseline pathway for India we assume a typical textile facility could procure 50% of its electricity supply from renewable sources by 2030.

Energy costs in India are expected to increase with steam boiler electrification due to the relatively high price of electricity and low price of coal expected in 2030. By 2035, electric boiler energy costs will become relatively competitive, driven by the favorable price of RE in India's corporate procurement market and the increasing share of assumed RE procurement for a typical textile facility in India. **Thus, electrification with electric boilers in India faces near-term energy cost challenges, despite the potential emissions benefits and longer-term energy cost savings by 2040.** While electric steam boilers reduce emissions from 2030 — even with only 50% corporate RE procurement in the Baseline Grid Plus RE Procurement pathway, the relative cost of RE and coal is not likely to make electric boilers an attractive option until 2035-2040.

FIGURE 3.3.1: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN INDIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

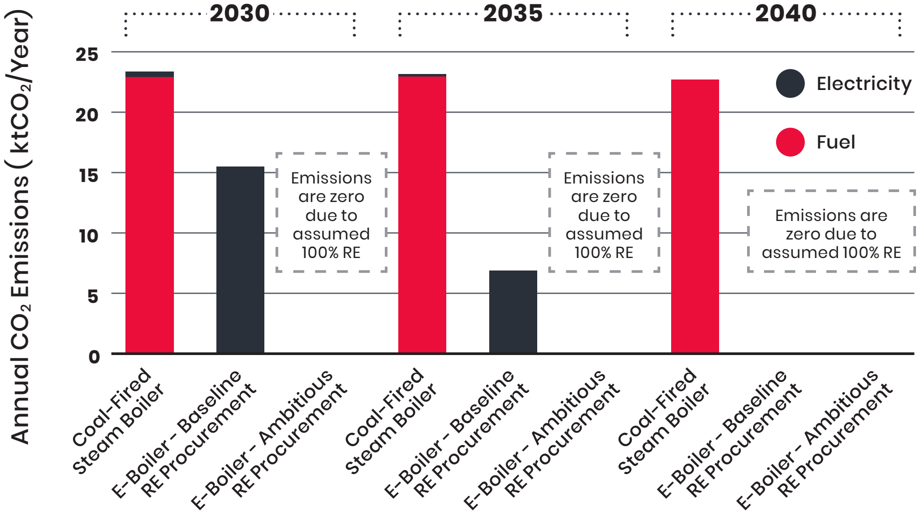
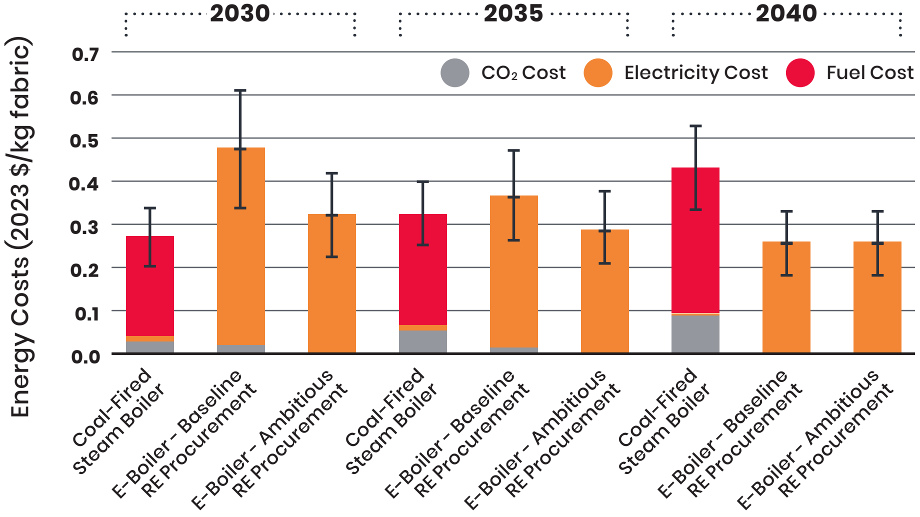


FIGURE 3.3.2: ENERGY COSTS OF COAL STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN INDIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Steam-Generating Heat Pumps

Electrification with steam-generating heat pumps can lead to even greater efficiency gains and energy savings compared to electric boilers. Combined with procured RE, heat pump efficiency gains also drive a steep decrease in CO_2 emissions, even when a portion of the electricity supply comes from India's carbon-intensive grid.

In India, the energy costs of heat pumps are highly favorable relative to conventional coal steam boilers, driven by the rapidly developing, affordable corporate RE options and the significant efficiency gains from electrification with heat pumps.

Due to the highest efficiency of all technologies studied, heat pumps can reduce emissions and cost by 2030 even with only 50% corporate RE procurement of the baseline pathway. We therefore recommend conducting feasibility studies and RE procurement analysis prior to 2030, followed by scaled implementation.

Biomass Steam Boilers

As discussed, biomass boilers are assumed to have the same efficiency and energy demand as conventional coal boilers, thus we do not present energy results for biomass boilers. While carbon-neutral biomass could fully mitigate emissions, unsustainable biomass could slightly increase emissions from steam generation. For the direct biomass emissions factor of unsustainable biomass, we used the emissions factor of crop waste (e.g. rice husks, which are widely generated in India). This is slightly higher than that of coal. If the industry switches to biomass, textile producers in India are likely to use agricultural residues such as rice husks as fuel, maintaining biomass emissions results across countries — assuming the same emissions factor for these agricultural residues. Thus, we only present these emissions results once (see Section 3.2.1., Figure 3.2.7) to avoid any repetition.

FIGURE 3.3.3: **ANNUAL CO_2 EMISSIONS FROM COAL-FIRED STEAM BOILERS VS. HEAT PUMPS (HP) IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN INDIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS**

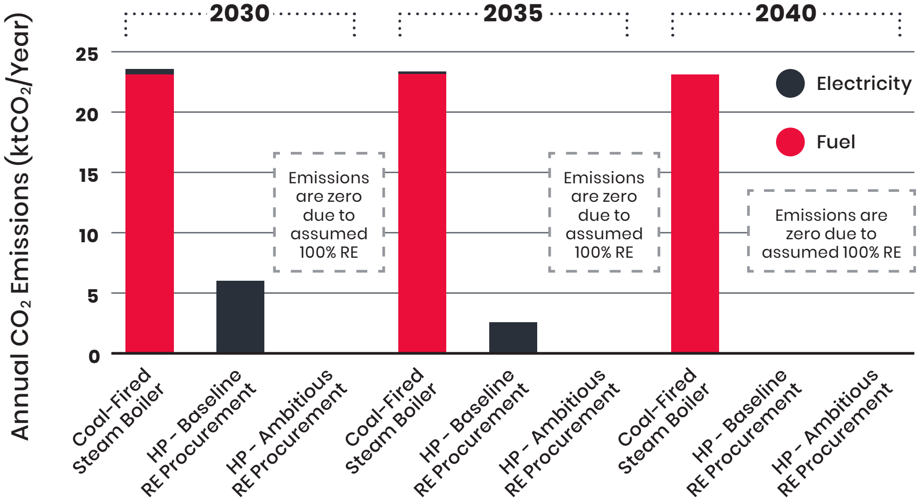
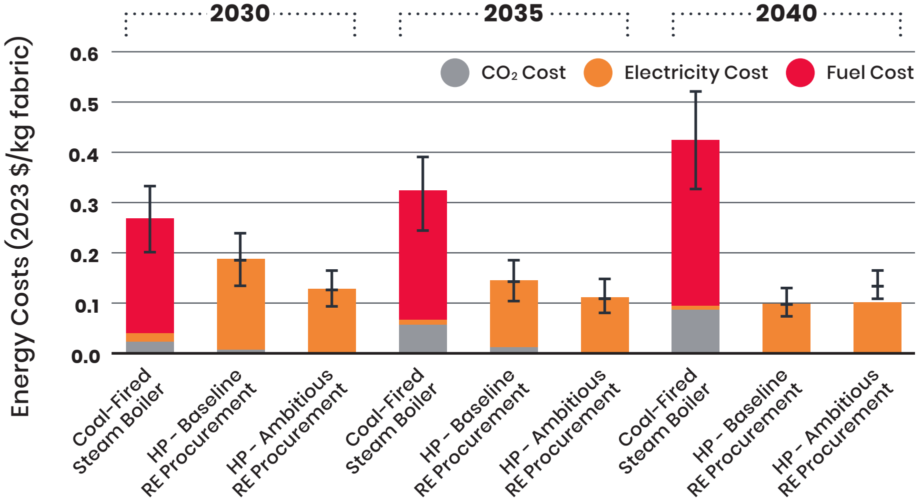


FIGURE 3.3.4: **ENERGY COSTS OF COAL STEAM BOILERS VS. HEAT PUMPS IN INDIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS**



Low-cost byproduct biomass has been a key driver of its adoption in India's textile industry, and a switch to low-cost biomass would reduce energy costs at a typical textile plant in India. However, prices are highly location-specific and subject to seasonal and annual fluctuations depending on supply. Additionally, electric power generation is a major competing use (Chauhan et al. 2022) that will constrain the supply available for the textile industry. Therefore, we have also added error bars of +/- 30% to the biomass fuel price to show readers the potential range of impact. While this analysis considers a single typical facility, sustainable biomass supply in India is likely insufficient for multiple textile facilities to adopt biomass boilers without significantly driving up prices.

If a long-term, price-competitive, certifiable source of sustainable biomass can be sourced and traced, it is a viable alternative fuel for India. The pricing and provenance of the biomass should be carefully monitored over time and be considered against other low-carbon energy sources.

Natural Gas Steam Boilers

As natural gas has roughly the same emissions factor across countries, the potential emissions results are the same as presented in Section 3.2.1. for China. In terms of direct combustion, switching to natural gas can reduce emissions relative to coal-fired boilers; however, upstream methane emissions could cancel out this benefit unless properly monitored and regulated by upstream producers.

Over the study period, natural gas is significantly more expensive than coal for India's industrial facilities (Figure 3.3.6.), which makes transition unlikely.

Given the increased energy costs of natural gas across the study — and infrastructural challenges — it is unlikely to be a viable alternative fuel for most facilities in India.

FIGURE 3.3.5: **ENERGY COSTS OF COAL STEAM BOILERS VS. BIOMASS STEAM BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN INDIA**

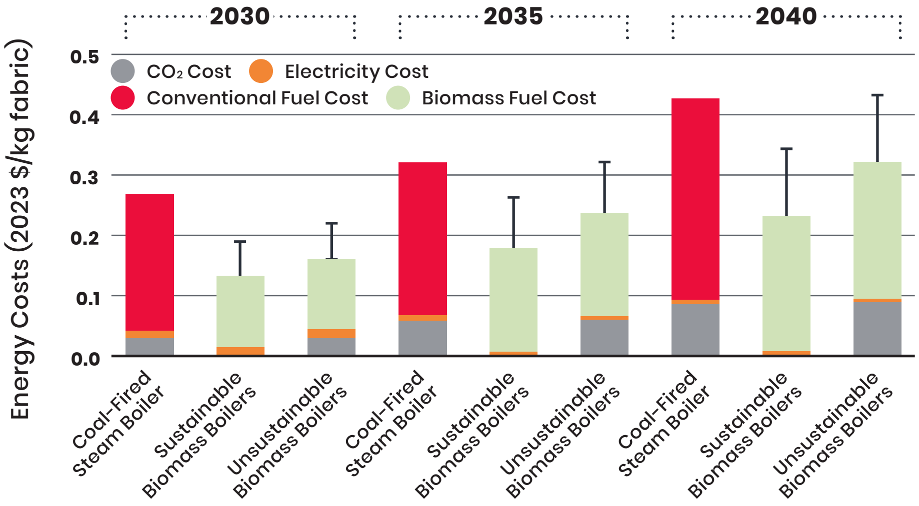
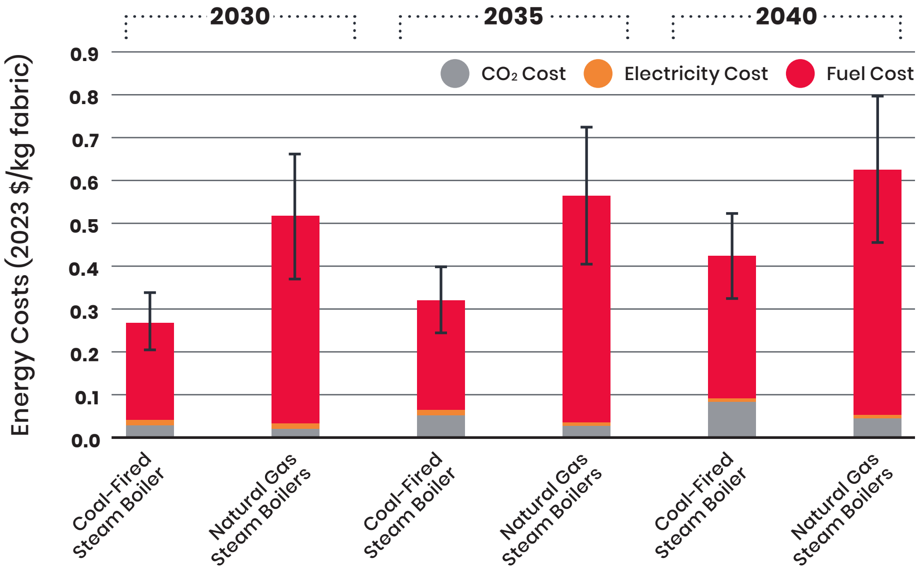
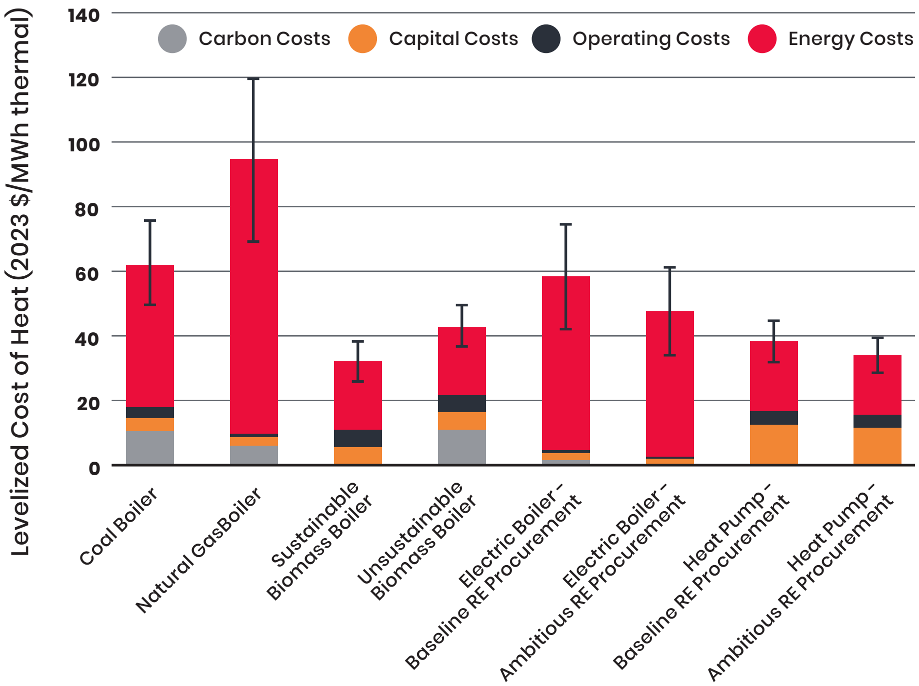


FIGURE 3.3.6: **ENERGY COSTS OF COAL STEAM BOILERS VS. NATURAL GAS STEAM BOILERS IN A TYPICAL WET-PROCESSING FACILITY IN INDIA**



Levelized Cost of Heating for Steam-Generating Technologies
We calculated and compared the levelized cost of heat (LCOH) of all steam technologies, using both electricity pathways, using the methodology described in Section 3.1. In India, natural gas boilers have the highest LCOH of steam production, while coal boilers and electric boilers have similar levelized costs under the Baseline RE procurement pathways. Even though electricity is more expensive than coal, the levelized cost takes into account the discounted value of RE becomes cheaper over time. Moreover, coal boilers would add significant carbon costs as carbon pricing comes into effect. Even with higher CAPEX and without carbon pricing (i.e. the gray bar in Figure 3.3.7. is removed), heat pumps still have a more attractive LCOH of steam generation than coal boilers.

FIGURE 3.3.7: LEVELIZED COST OF HEAT (LCOH) FOR STEAM GENERATION OF THE ANALYZED TECHNOLOGIES FOR A TYPICAL TEXTILE WET-PROCESSING FACILITY IN INDIA



3.3.3. Low-Carbon Technologies for Hot Oil Boilers

Electric Hot Oil Boilers
Since our assumed efficiency and production levels are the same across the countries studied (see 3.2.2.), we do not repeat energy savings from hot oil boilers again. Due to efficiency gains plus the assumed share of RE procurement in our pathways, electrification with electric hot oil boilers can lead to approximately 30% emissions reductions in a typical textile facility in India by 2030. Following the Ambitious pathway of 100% RE procurement, electrification of hot oil boilers could fully eliminate associated emissions by 2030.

Energy costs for producing textiles in India are expected to increase in the near term with hot oil boiler electrification, due to the relatively high price of electricity. However, electric boiler energy costs become closer to competitive by 2035, especially under the Ambitious RE Procurement pathway. With the availability of cheap corporate RE options by 2040, electrification can significantly reduce energy costs relative to coal-fired hot oil boilers.

Electric hot oil boilers reduce emissions from 2030 — even with only 50% corporate RE procurement in the Baseline Grid Plus RE Procurement pathway; however, the cost of RE is not likely to make this an attractive option until 2035-2040.

FIGURE 3.3.8: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN INDIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

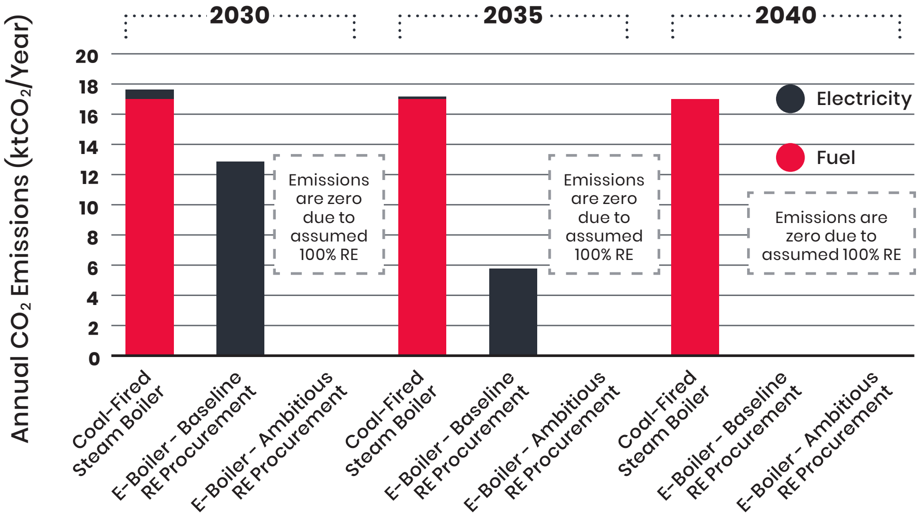
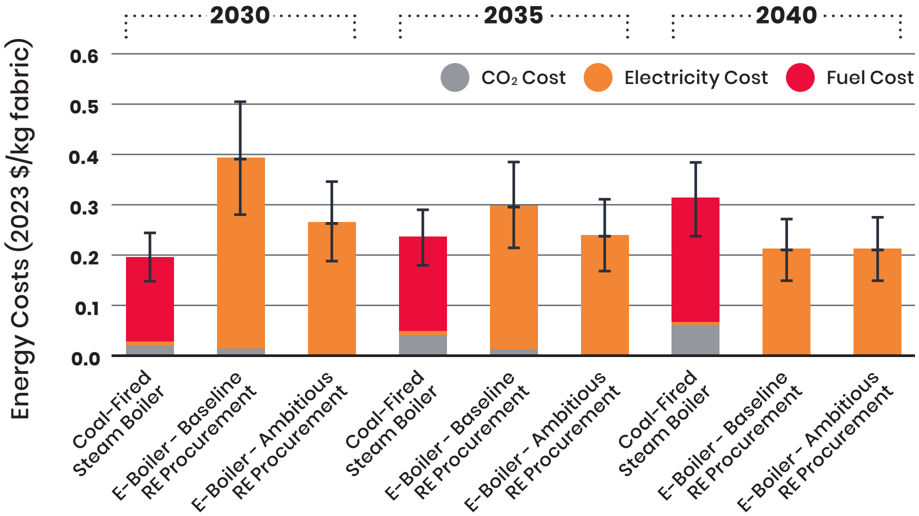


FIGURE 3.3.9: ENERGY COSTS OF COAL HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Biomass Hot Oil Boilers

Like steam boilers, a switch to biomass boilers could increase annual emissions slightly if the biomass comes from unsustainable sources. With fuel emissions factors expected to remain constant, the potential difference between coal hot oil boilers and sustainable and unsustainable biomass boilers is expected to remain unchanged over the study. Results are the same across countries (see Section 3.2.2. for a visualization).

Biomass hot oil boilers, like biomass steam boilers, are expected to have lower energy costs relative to coal-fired boilers due to the significantly lower reported price of biomass fuel in India. However, prices are highly location-specific and could rise steeply with demand increases or supply disruptions.

If a long-term, price-competitive, certifiable source of sustainable biomass can be sourced and traced, it is a viable alternative fuel for India. The pricing and provenance of the biomass should be carefully monitored over time and be considered against other low-carbon energy sources.

Natural Gas Hot Oil Boilers

There are no energy savings for switching to natural gas hot oil boilers or steam boilers from coal hot oil boilers due to their similar thermal efficiency. In addition, emissions results are expected to be the same as for hot oil boiler conversion to natural gas in China.

Like steam boilers, natural gas-fired hot oil boilers would have significantly higher energy costs relative to coal boilers, making the transition financially challenging (Figure 3.3.11).

This is unlikely to be a viable alternative fuel for most Indian facilities given the increased energy costs of natural gas across the study and infrastructural challenges.

FIGURE 3.3.10: ENERGY COSTS OF COAL HOT OIL BOILERS VS. BIOMASS HOT OIL BOILERS (SUSTAINABLE AND UNSUSTAINABLE BIOMASS) IN A TYPICAL WET-PROCESSING FACILITY IN INDIA

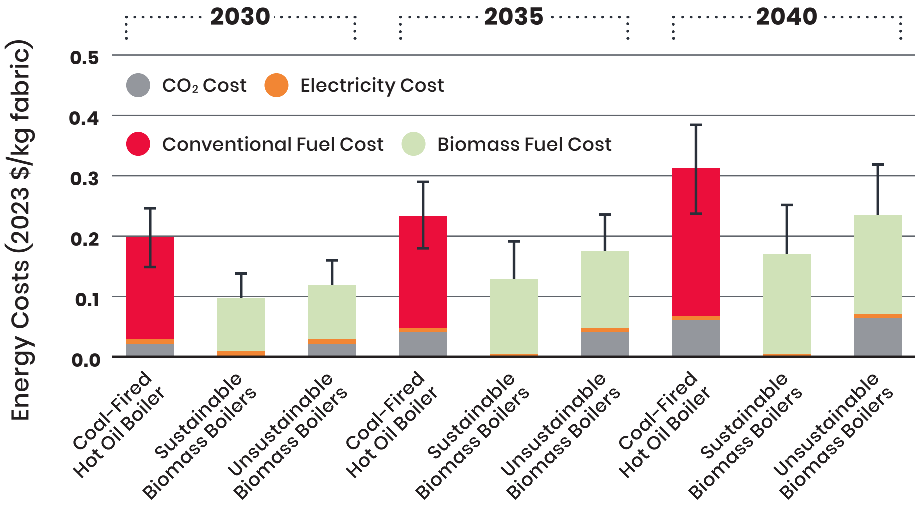
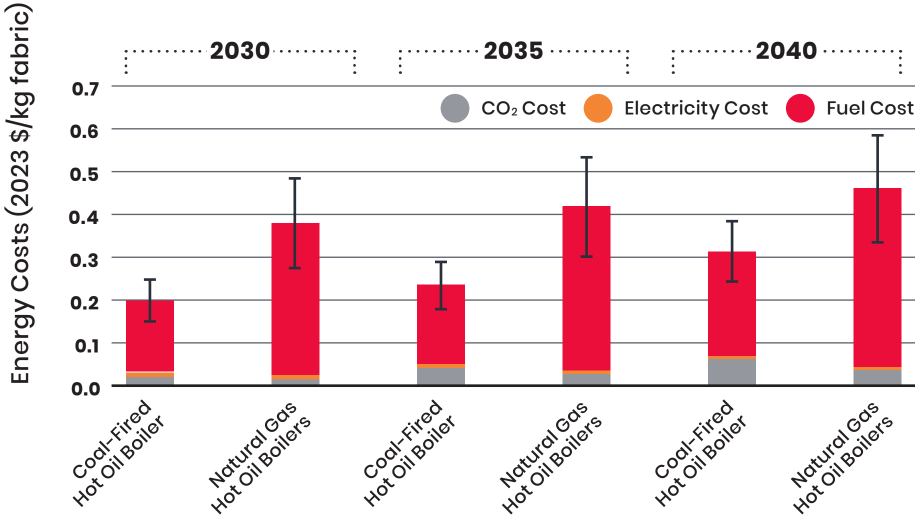


FIGURE 3.3.11: ENERGY COSTS OF COAL HOT OIL BOILERS VS. NATURAL GAS HOT OIL BOILERS IN A TYPICAL WET-PROCESSING FACILITY IN INDIA



3.3.4. Potential Impacts of Electrification on the Electricity Grid in India

Electrification will increase electricity demand and load on the electrical grid. Figure 3.2.19. in Section 3.2.3. shows the results for the estimated electrical load increase from electrification at a typical textile facility in the studied countries. Electric steam boilers could add around 8 MW of additional electric load from a typical textile facility, while a heat pump could meet this same heat demand with an electric load of around 3 MW. Electric hot oil boilers are expected to add an additional electric load of 7 MW when replacing conventional hot oil boilers. **These additional electricity load results are the same across countries due to the same assumed textile production and technology efficiency levels.**

3.4. Textile Plants in Vietnam

3.4.1. The Energy Systems Landscape in Vietnam

To preface the quantitative findings in this section, we first dive deeper into key aspects of Vietnam's energy systems and policies that would affect the viability of low-carbon thermal energy technology adoption. This context also drives our assumptions for the Vietnam analysis, as detailed in Section 3.1.

Like India and China, Vietnam is highly reliant on coal for domestic industry. **However, Vietnam's commitment to achieving net-zero emissions by 2050 — earlier than the other countries in this study — could be a major driver for low-carbon thermal energy adoption in the textile industry.** The country's rapidly growing renewable energy supply, particularly in wind and solar, offers textile producers an increasingly cost-effective alternative to fossil fuels. Supportive government policies around RE development and international commitments to climate targets are creating both regulatory and market conditions conducive to transitioning to low-carbon technologies (e.g. the 2024 introduction of a direct PPA mechanism). Notably, Vietnam currently has a fair amount of affordable and potentially sustainable biomass supply — such as rice husks in southern Vietnam — although future supply is uncertain.

Alternative Fuel Availability in Vietnam
Vietnam currently obtains 10% of its total energy supply from biomass and waste sources. Although Vietnam is a significant global producer of rice, its overall availability of agricultural residues is much lower than in China and India due to the limited farmland. The theoretical potential of harvested crop residues in Vietnam (byproducts left in the field after harvest, such as stalks) is estimated at 60 million tons annually, with an additional 20 million tons from crop processing residues (such as husks and other byproducts of processing in industrial facilities). However, the technical potential for collecting these residues is much lower — about 15 million tons per year. Additionally, farmers in Vietnam may be reluctant to sell their residues or unaware of a market for residues as energy. This is estimated to further reduce the technical potential to 8 million tons per year (World Bank 2018). Nevertheless, Vietnam's textile industry has already seen significant adoption of agricultural residue biomass.

As part of its transition away from coal, Vietnam plans to significantly scale up power generation from biomass, though not necessarily sustainable biomass. Vietnam's Power Development Plan 8 (PDP8) aims to reach 2.3 GW of biomass power capacity by 2030 and 6 GW by 2050. These targets, added to the demand for exports, are driving an increase in forest plantations and wood pellet production (Binh 2024), which are highly controversial in terms of carbon neutrality. **Demand for sustainable biomass sources for power generation may significantly compete with demand from the textile industry. Supply constraints and existing demand from textile facilities that have already switched to biomass leave Vietnam at high risk for sustainable supply and cost challenges if adoption expands. Therefore, electrification should be considered sooner in Vietnam relative to some other countries.**

Vietnam derives 7% of its total energy supply from natural gas, which has historically been provided by domestic production. However, Vietnam's natural gas production peaked in 2015, and the country began importing liquefied natural gas (LNG) in 2023 when the Thi Vai LNG Terminal began operating (Nie et al. 2023). Imported LNG will initially be supplied to the electric power sector, as Vietnam's PDP8 aims to increase natural gas generating capacity from imported LNG to 22 GW (from essentially zero) — limiting the supply available for industry. Greenfield power plants powered by LNG will be located near import terminals to reduce transport and distribution challenges. It is important to note that Vietnam has a limited natural gas distribution infrastructure, with less than 1,000 km of operational gas pipelines (relative to nearly 3,000 km in Bangladesh and 5,500 km in Indonesia) (Global Energy Monitor 2023). **Industrial facilities seeking to switch to natural gas will face declining domestic production, limited imported gas, and minimal distribution infrastructure.** For this reason, natural gas is unlikely to be a feasible alternative fuel for most textile manufacturers.

Vietnam's Electricity Grid
Vietnam's energy and electricity demand are rapidly growing, driven in part by industrial production. Electricity demand is projected to increase 10-12% per year through 2030, and electrification of the textile sector could add to this load. Like China and India, Vietnam has a very high grid emissions factor. Without increased RE integration and availability, near-term electrification with grid electricity could lead to an increase in CO_2 emissions in Vietnam.

Vietnam has made significant progress in integrating renewable energy into the grid, although challenges remain and could affect the prospects of electrification using grid electricity. Vietnam's renewable energy supply — particularly solar power (utility scale plus rooftop) — expanded rapidly over the years, with much of this growth occurring between 2019 and 2021 as a result of a government feed-in tariff mechanism (FIT) (Allotrope Partners 2024).

The government plans to increase generation capacity to 150 GW by 2030 with the goal of 19% from wind (up from the current 5%). However, despite recent rapid growth in solar capacity, solar's share in total electricity generation is projected to decrease from its impressive level of 22% in 2022 due to solar energy curtailment in Vietnam (International Trade Administration 2024). The government discontinued the FIT because the grid was struggling to integrate the influx of renewable power due to limited infrastructure and storage solutions. Power shortages, especially in industrial hubs like Ho Chi Minh City, and a monopoly on transmission by Vietnam Electricity (EVN) limit grid flexibility. Due to these challenges, Vietnam's most recent power development plan does not call for a significant increase in utility-scale solar (Allotrope Partners 2024). Electrification of the textile industry would further increase demand for renewable energy, potentially before curtailment solutions are developed.

Corporate Renewable Electricity Procurement in Vietnam

Direct procurement of RE could allow textile facilities to access low-carbon electricity in the near term. Vietnam has several corporate RE procurement mechanisms: self-generation; RECs; and recently, direct PPAs (DPPAs). Rooftop solar is the most common form of onsite generation due to regulatory and space constraints for ground-mounted systems; however, rooftop solar does not generate enough electricity to meet a typical facility's electrified heating needs. The current REC market in Vietnam faces challenges, including low additionality — most RECs come from FIT solar and wind projects that do not necessarily add new renewable capacity. Prices are low, reflecting oversupply, and the lack of a national REC framework contributes to confusion over ownership and potential double counting, undermining their effectiveness (Allotrope Partners 2024).

Direct PPAs in Vietnam became available in July 2024 after many years of development, allowing corporates to bypass the limitation of procuring only grid utility from EVN. Electricity consumers above a certain threshold (200 MWh or higher per month10) are eligible for DPPAs (Newsdesk 2024). Vietnam offers physical, synthetic, and financial DPPA models. The physical model uses private transmission lines, and producers and companies can negotiate on the supply levels. The synthetic model uses EVN purchasing power from the producers and sells it to the company from the pooled supply at an agreed-upon rate. **However, concerns remain about grid connectivity and a lack of detailed implementation guidelines.**

Vietnam's corporate RE market has significant growth potential, driven by increasing demand for clean energy solutions among industrial and commercial sectors. The new DPPA mechanism is an important marker of progress, and it addresses long-standing limitations in off-site renewable access. On-site generation through turnkey projects or onsite PPAs already offers significant cost savings. The DPPA's rollout and Vietnam's 2050 net zero target indicate corporate RE procurement is likely to grow and become an effective, lower-cost option for companies. However, further improvements in grid connectivity, regulatory details, and market incentives are needed to fully support these opportunities. As the landscape for DPPAs evolves and textile manufacturers and brands become more aware of the possibilities, corporate RE procurement will become a viable component of Vietnam's electrification.

Based on this context, we developed assumptions for analyzing how low-carbon thermal energy technology adoption in Vietnam will affect energy use, emissions, and costs from steam and hot oil heating at a typical textile wet-processing facility. The RE procurement pathways for Vietnam are as follows:

TABLE 3.2.3: RE PROCUREMENT PATHWAYS FOR VIETNAM

Year	Baseline Scenario	Ambitious Scenario
2030	50%	100%
2035	75%	100%
2040	100%	100%

Results are presented in the next two sections.

---

10 A typical textile wet-processing facility after electrification would be well above this threshold.

3.4.2. Low-Carbon Technologies for Steam Generation

Electric Steam Boilers

Given Vietnam's 2050 net zero goal, significant progress towards overall grid decarbonization by 2030 is likely to outpace other countries, despite Vietnam's currently high grid emissions factor (which is between the grid emissions factors of China and India) (IEA 2024). Using the Baseline RE Procurement pathway for Vietnam, with 50% of the assumed textile facility's electricity supply coming from the grid and 50% from procured RE, we project that electrification with electric boilers can roughly halve annual CO_2 emissions from steam generation by 2030. Further integration of RE procurement — 100% under the Ambitious RE Procurement pathway — can eliminate emissions from steam generation altogether.

Vietnam's energy costs are expected to increase with steam boiler electrification due to projected high electricity and low coal prices. However, by 2040, electric boilers are projected to be competitive with coal boilers in terms of energy costs, especially if carbon pricing comes into effect.

Electrification with electric boilers in Vietnam thus faces near- and medium-term energy cost challenges, despite the potential emissions benefits and longer-term energy cost savings by 2040. Although electric steam boilers reduce emissions from 2030 even with only 50% corporate RE procurement in the Baseline Grid Plus RE Procurement pathway, the cost of RE is not likely to make this an attractive option until 2035-2040.

FIGURE 3.4.1: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN VIETNAM, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

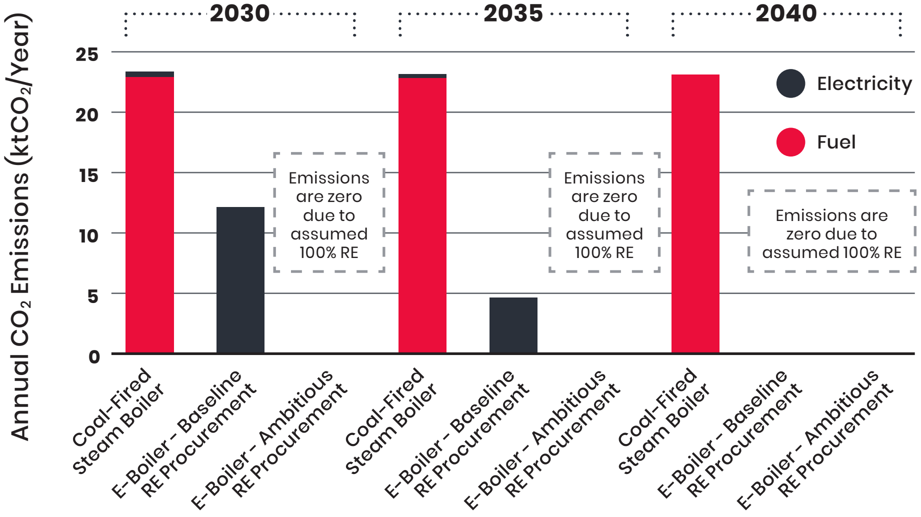
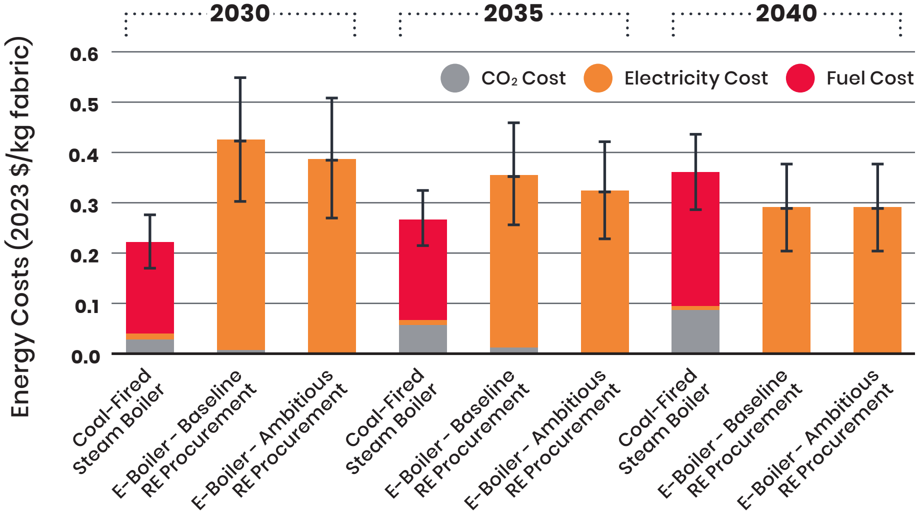


FIGURE 3.4.2: ENERGY COSTS OF COAL STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN VIETNAM, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Steam-Generating Heat Pumps

Electrification with steam-generating heat pumps can lead to even greater efficiency gains and energy savings from electrification compared to electric boilers. Combined with procured RE and Vietnam's ongoing grid decarbonization, heat pump efficiency gains also drive a steep decrease in CO_2 emissions.

By 2030, heat pumps have highly favorable energy costs relative to conventional coal steam boilers in Vietnam — even without carbon pricing (i.e. if the gray bar in Figure 3.4.4. were removed). This is driven by the significant efficiency gains from electrification with heat pumps.

With the highest efficiency of all studied technologies, heat pumps can reduce emissions and energy costs by 2030 — even with only 50% corporate RE procurement under the Baseline Grid Plus RE Procurement pathway. We therefore recommend conducting feasibility studies and RE procurement analysis before 2030, followed by scaled implementation.

FIGURE 3.4.3: **ANNUAL CO_2 EMISSIONS FROM COAL-FIRED STEAM BOILERS VS. HEAT PUMPS (HP) IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN VIETNAM, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS**

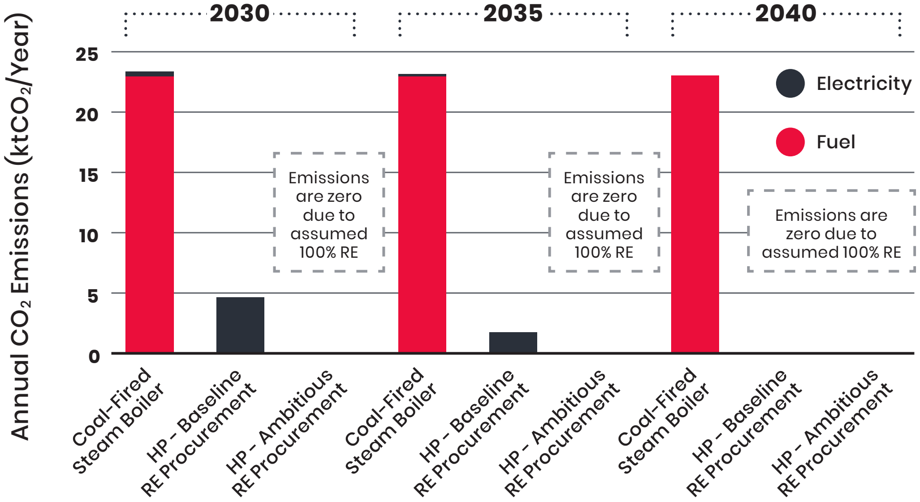
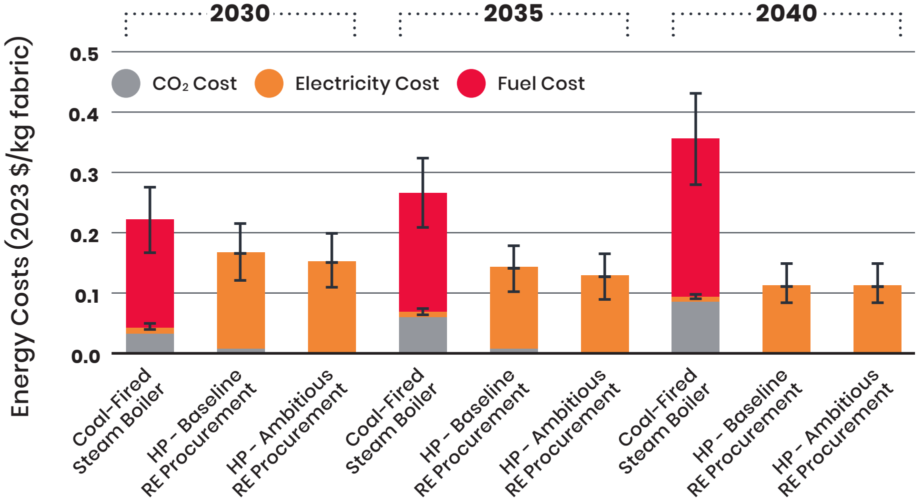


FIGURE 3.4.4: **ENERGY COSTS OF COAL STEAM BOILERS VS. HEAT PUMPS IN VIETNAM, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS**



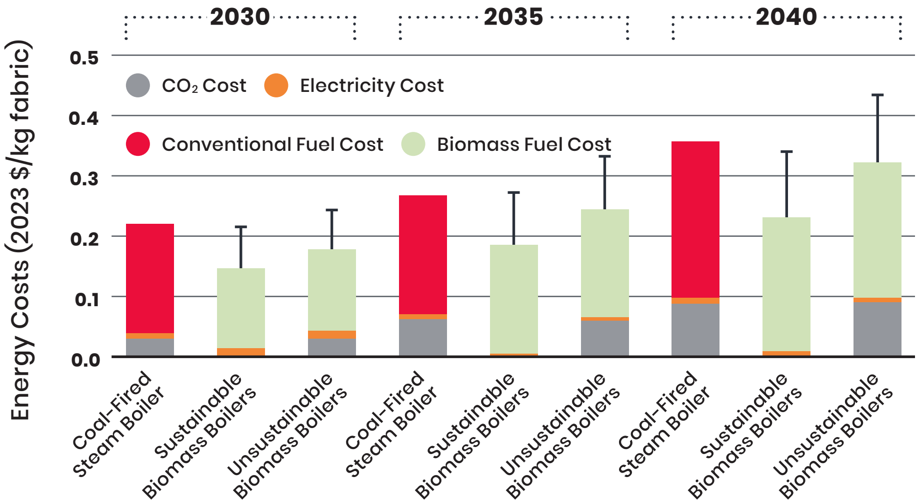
Biomass Steam Boilers

Many textile producers in Vietnam are already using agricultural residues (e.g. rice husks) as biomass fuel. This section evaluates the impacts of switching to biomass for a typical facility that is still using coal. Because the assumed efficiency of biomass boilers and coal boilers is the same across studied countries, we estimate the energy savings and emissions results for switching to biomass boilers\ to be similar. The biomass steam boiler emissions results (Section 3.2.1.) show that the direct combustion of unsustainable biomass could slightly increase emissions.

Low-cost byproduct biomass has driven its adoption in Vietnam's textile industry. If costs remain low, a switch to biomass would reduce energy costs at a typical textile plant in Vietnam as indicated in Figure 3.4.5. Sustainable biomass prices are likely to fluctuate and increase over time; therefore, this alternative fuel source may no longer be cheaper relative to coal on a facility-by-facility basis.

While the cost of biomass remains lower than coal in the near- to medium-term, the availability of certified sustainable biomass is of concern in Vietnam. For this reason, we recommend apparel brands and textile manufacturers explore the phaseout of biomass sooner than in China and India.

FIGURE 3.4.5: ENERGY COSTS OF COAL STEAM BOILERS VS. BIOMASS STEAM BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN VIETNAM

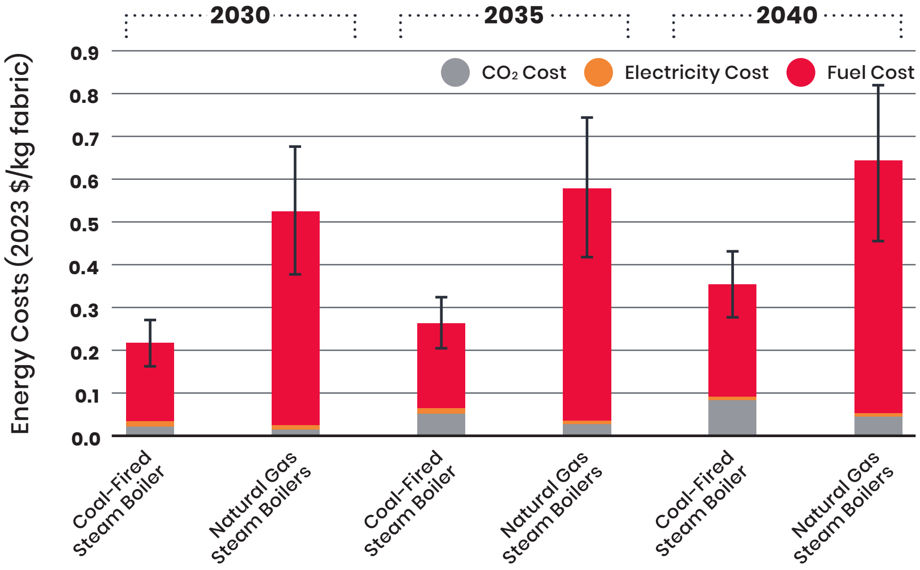


Natural Gas Steam Boilers
As natural gas has roughly the same emissions factor across countries, and natural gas boilers have the same assumed efficiency as coal boilers, the potential energy and emissions results are the same as presented in Section 3.2.1. for China.

In terms of energy costs, natural gas is significantly more expensive than coal for industrial facilities in Vietnam. Furthermore, Vietnam has just begun importing LNG and it is unlikely to be used for industrial facilities, making future supply uncertain (see Section 4.2.1.).

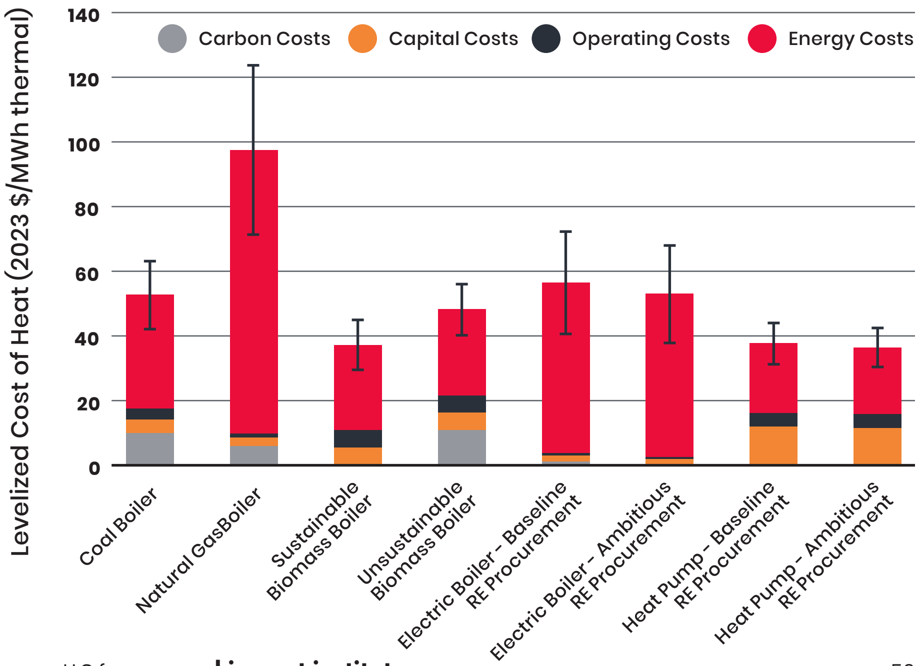
The cost of natural gas is substantially higher in Vietnam compared to coal. Since it offers less emissions reductions than other alternatives, natural gas will not be a viable alternative fuel for textile manufacturers in Vietnam.

FIGURE 3.4.6: ENERGY COSTS OF COAL STEAM BOILERS VS. NATURAL GAS STEAM BOILERS IN A TYPICAL WET-PROCESSING FACILITY IN VIETNAM



Levelized Cost of Heating for Steam-Generating Technologies
Using the methodology described in Section 3.1., we calculated and compared the levelized cost of heat (LCOH) for steam generation for all steam technologies, including for both electricity pathways for the electrification technologies. Coal boilers and electric boilers have similar levelized costs of heating for steam generation, even though electricity is more expensive than coal. This is because of the lifetime energy costs of electric boilers, which benefit from RE becoming cheaper over time. Heat pumps have the lowest LCOH of steam generation of all the technologies considered.

FIGURE 3.4.7: LEVELIZED COST OF HEAT (LCOH) FOR STEAM GENERATION OF THE ANALYZED TECHNOLOGIES FOR A TYPICAL TEXTILE WET-PROCESSING FACILITY IN VIETNAM



3.4.3. Low-Carbon Technologies for Hot Oil Boilers

Electric Hot Oil Boilers

Since our assumed efficiency and production levels are the same across the countries studied, we do not present energy savings from hot oil boilers again (see Section 3.2.2.). Due to efficiency gains plus the assumed share of RE procurement in our pathways, electrification with electric hot oil boilers can lead to about 40% emissions reductions in a typical textile facility in Vietnam by 2030. Following the Ambitious pathway of 100% RE procurement, electrification of hot oil boilers could fully eliminate associated emissions by 2030.

Energy costs at a typical textile wet-processing plant in Vietnam are expected to rise with hot oil boiler electrification in 2030 and 2035 — more than steam boiler electrification — due to the lower efficiency gains of electrifying coal-fired hot oil boilers. Assuming 100% corporate RE procurement is possible at a typical textile facility, energy costs become competitive by 2040.

While electric hot oil boilers reduce emissions by 2030 — even with only 50% corporate RE procurement in the Baseline Grid Plus RE Procurement pathway — the cost of RE is not likely to make this an attractive option until 2040.

FIGURE 3.4.8: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN VIETNAM, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

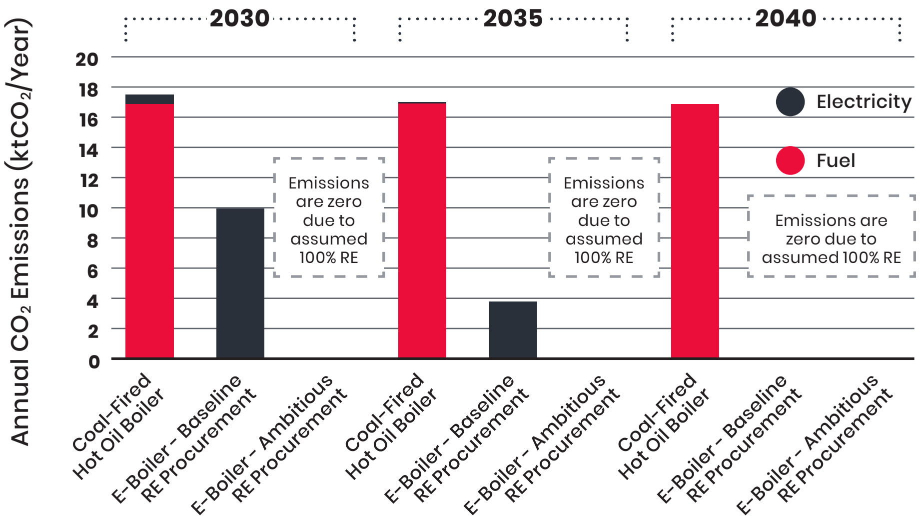
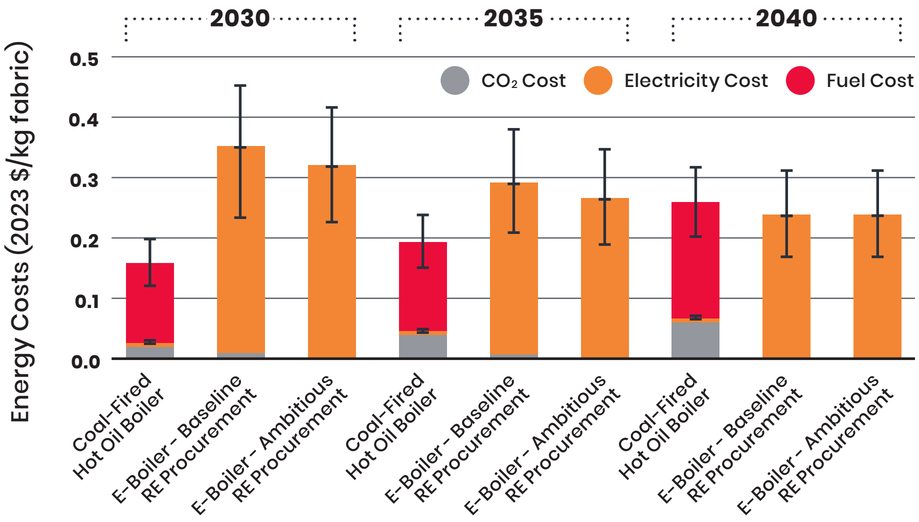


FIGURE 3.4.9: ENERGY COSTS OF COAL HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS IN VIETNAM, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Biomass Hot Oil Boilers
As previously discussed, the emissions impacts of hot oil boiler electrification in Vietnam are expected to be similar to those in India and China (see Section 3.2.2.).

Like biomass steam boilers, biomass hot oil boilers are expected to have lower energy costs relative to coal-fired boilers due to the significantly lower projected price of biomass fuel in Vietnam. However, prices vary by location and would significantly rise if overall demand increases or if there are supply disruptions. In addition, unsustainable biomass could be subject to a carbon price, bringing energy costs in line with those of conventional coal boilers.

While the cost of biomass remains lower than coal in the near- to medium-term, the availability of certified sustainable biomass is of concern in Vietnam. For this reason, we recommend apparel brands and textile manufacturers explore the phaseout of biomass sooner than in China and India.

While the cost of biomass remains lower than coal in the near- to medium-term, the availability of certified sustainable biomass is of concern in Vietnam. For this reason, we recommend apparel brands and textile manufacturers explore the phaseout of biomass sooner than in China and India.

Natural Gas Hot Oil Boilers
Similar to our steam boiler analysis, there are no energy savings for switching to natural gas hot oil boilers from coal hot oil boilers due to their similar thermal efficiency. In Vietnam, emissions results are expected to be the same as for hot oil boiler conversion to natural gas in China.

Natural gas-fired hot oil boilers — like steam boilers — would have significantly higher energy costs relative to coal boilers, making the transition financially challenging (Figure 3.4.11).

Natural gas will not be a viable alternative fuel for textile manufacturers in Vietnam due to its high cost when compared to coal and lower emissions reductions compared to other alternatives.

FIGURE 3.4.10: ENERGY COSTS OF COAL HOT OIL BOILERS VS. BIOMASS HOT OIL BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN VIETNAM

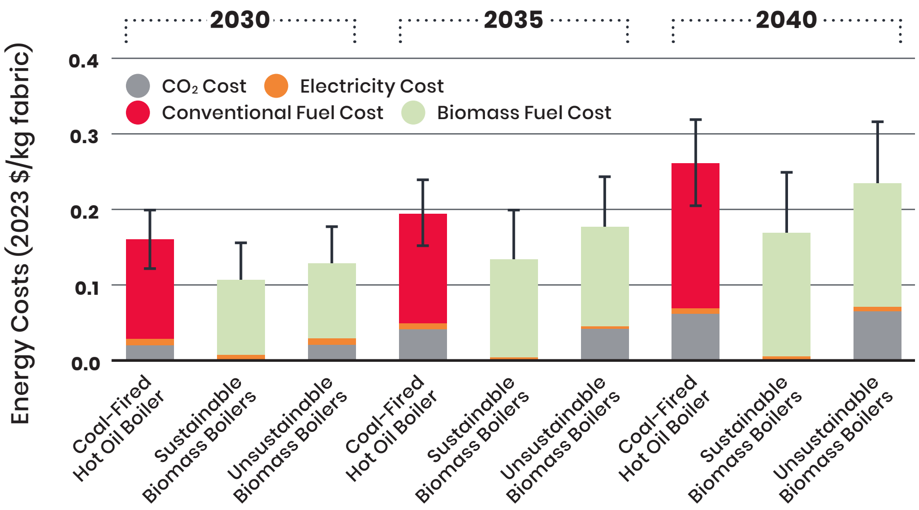
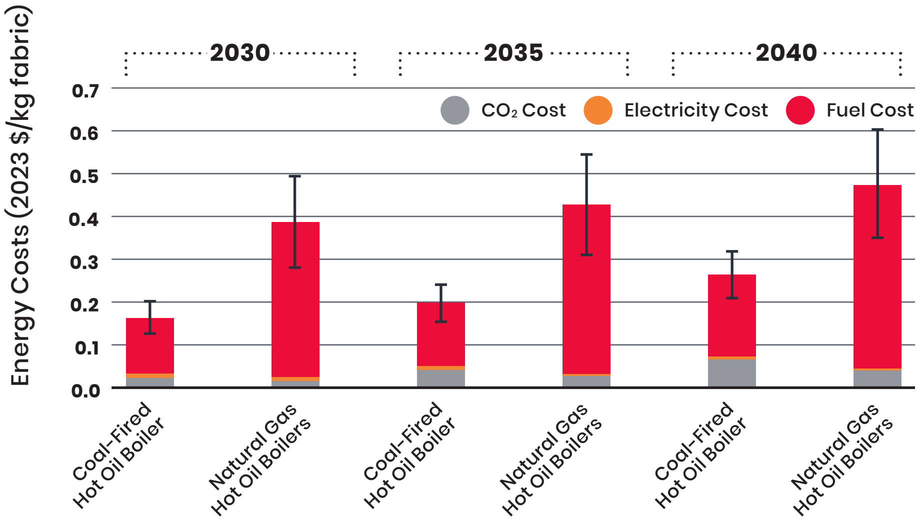
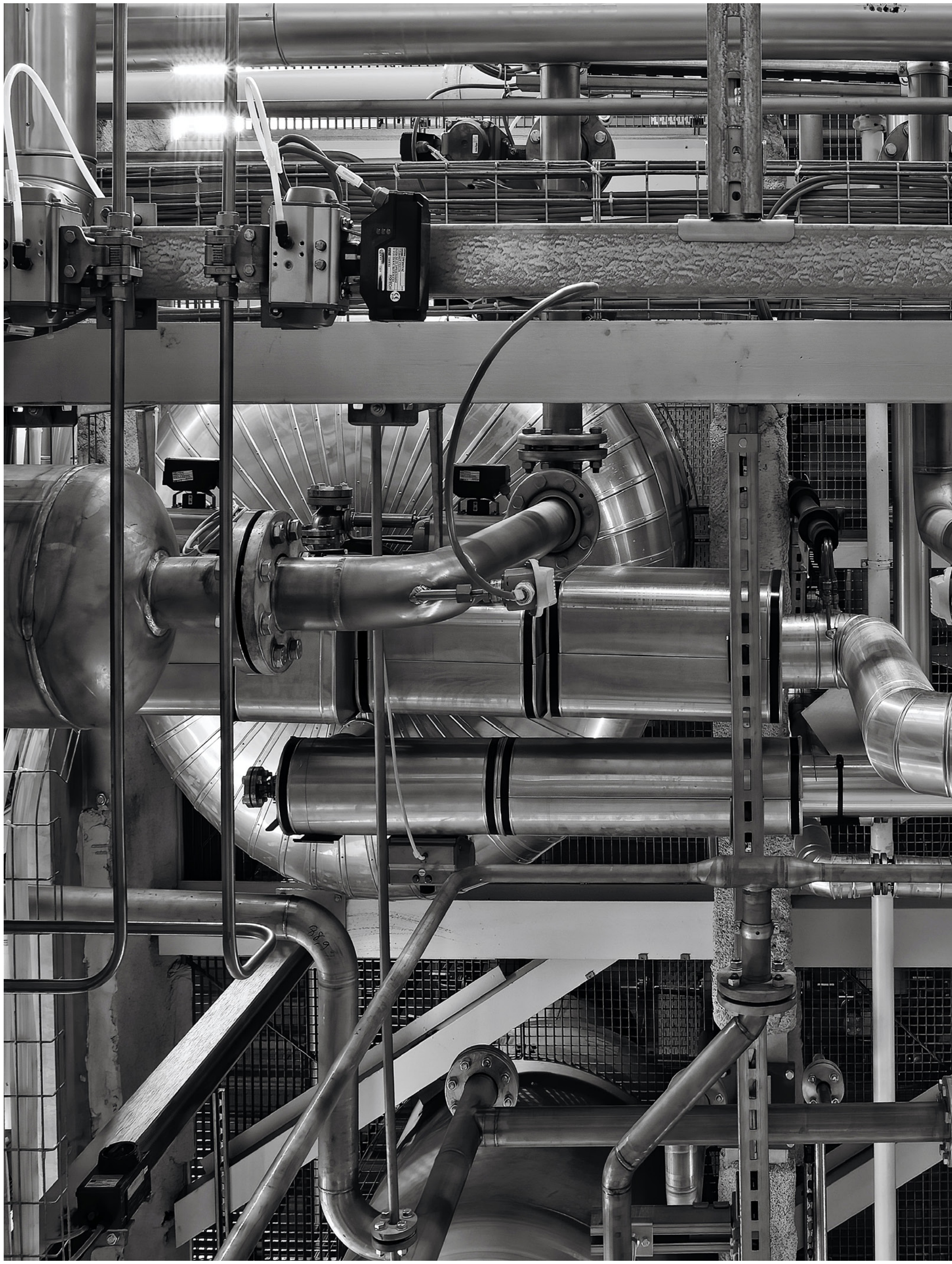


FIGURE 3.4.11: ENERGY COSTS OF COAL HOT OIL BOILERS VS. NATURAL GAS HOT OIL BOILERS IN A TYPICAL WET-PROCESSING FACILITY IN VIETNAM



3.4.4. Potential Impacts of Electrification on the Electricity Grid in Vietnam

Electrification will increase electricity demand and place a greater strain on the grid. Figure 3.2.18 in Section 3.2.3 shows the estimated rise in electrical load from electrification at a typical textile facility in the studied countries. We found that electric steam boilers could add approximately 8 MW of additional electric load for a typical textile facility; a heat pump could meet the same heat demand with only about 3 MW of added load. Similarly, electric hot oil boilers are projected to add an additional 7 MW when replacing conventional hot oil boilers. **These results for electric load from electrification are the same across countries due to the assumed uniform production and efficiency levels** (see Section 3.2.3.).



3.5. Textile Plants in Bangladesh

3.5.1. The Energy Systems Landscape in Bangladesh

To preface the quantitative findings in this section, we first dive deeper into key aspects of Bangladesh's energy systems and policies affecting the viability of low-carbon thermal energy technology adoption. This context also drives our assumptions for the Bangladesh analysis, as detailed in Section 3.1.

Bangladesh faces a unique set of challenges, including an unstable electricity grid, an uncertain economic environment, and highly subsidized fuel prices. Collectively, these factors make it difficult for textile manufacturers to adopt low-carbon thermal energy solutions. In addition, **Bangladesh has very little electricity generation from non-fossil sources and a very limited supply of RE. Many textile producers are not grid-connected; those that are may have a contracted load well under energy demand. Large-scale industrial electrification would strain the country's grid, which is highly dependent on natural gas, and an increasing share coming from imports.** In addition, a centralized power market with a small share of independent power producers (IPPs) and regulatory barriers hinders the growth of corporate RE procurement.

Thus, in Bangladesh, the textile industry's primary driver for adopting low-carbon thermal energy technologies is the need to reduce reliance on unstable and volatile natural gas markets. With frequent energy shortages and price fluctuations, utility-scale renewable energy — particularly solar — offers a more secure and potentially cost-stable alternative. While the renewable energy infrastructure is still developing, the textile industry is beginning to recognize the long-term economic and energy security benefits of transitioning to low-carbon solutions. Although Bangladesh does not currently have a net zero target, it will likely set one in the future.

The following sections provide more context about key aspects of Bangladesh's energy system relevant to electrification and biomass adoption.

Alternative Fuel Availability in Bangladesh

Bangladesh already relies heavily on natural gas for energy, including use in the textile industry's boilers. Unlike other studied countries, natural gas is not an alternative fuel in Bangladesh; it is the dominant fossil fuel source. Estimates of biomass share in Bangladesh's total energy supply vary from 16% (reported by the International Energy Agency) to as high as 46% (Md. T. Islam et al. 2014). This discrepancy likely stems from challenges in collecting data on informal biomass uses. Biomass remains a primary energy source for many in Bangladesh, particularly for household heating and cooking.

In Bangladesh, biomass energy is primarily derived from traditional sources such as agricultural residues, wood wastes, and animal dung. The total biomass residue supply is estimated at about 140 million tons (Butt 2022). However, only about 40 million tons are available as fuel; much of the supply is used for livestock fodder, building materials, and other higher-value uses, making it less attractive for farmers to sell.

Another major competing use for biomass in Bangladesh is power generation, given the current issues with the electricity supply. Bangladesh's Infrastructure Development Company Limited (IDCOL) has financed significant biomass and biogas power generation projects, including a rice husk-to-power project in Kapasia, Gazipur (IDCOL 2014). **Given these competing demands, biomass is impractical as a transition fuel for Bangladesh's textile industry.**

Bangladesh's Electricity Grid

Bangladesh's grid infrastructure is considerably less developed than other studied countries and faces significant challenges in accommodating increased demand from industrial electrification. Indeed, many industrial factories currently rely on diesel generators due to the inability to secure a stable electricity supply. In this analysis, we assumed electrification for an individual facility in 2030 could be paired with grid connection and corporate RE procurement (recognizing that not all facilities may be grid-connected by this time). Electrification for industrial heating is unlikely to be feasible without significant changes to Bangladesh's grid infrastructure and energy supply, although there is a significant opportunity to reduce emissions and energy costs in the long run. International development finance and programs play a major role in addressing electricity-related issues, including EU directives (e.g. the EU-EIB Bangladesh RE Facility) to support the grid and IMF lending that is tied to lower electricity prices.

Fossil fuels generate 92-98% of Bangladesh's electricity, with natural gas accounting for the largest share. The grid struggles with under-generation, transmission losses, and high costs associated with imported fuels like oil and LNG. In 2022, Bangladesh declared that it had achieved 100% electricity access, however, there has since been significant load shedding, severely affecting residential and commercial consumers. Additionally, renewable energy infrastructure remains underdeveloped, with only 2 GW installed capacity (Gulagi et al. 2020). While energy storage policies are nascent, development agencies are increasingly focused on pilot storage projects to enhance energy reliability and support renewable integration.

Bangladesh's power sector faces future uncertainties with domestic natural gas reserves projected to deplete over the next two decades increasing reliance on imports. Coal and natural gas are projected to dominate the energy mix, with the country aiming for only **40% of generation from RE (including nuclear power and imports) by 2041. As a major energy consumer, the textile industry could further strain an already unreliable grid.**

Corporate Renewable Electricity Procurement in Bangladesh
While limited, Bangladesh's renewable energy supply has prospects for growth. The current installed RE capacity is less than 2 GW, with solar being the dominant source; however, there are around 4 GW of solar power projects under development in the country, with another 9 GW in earlier planning and review stages (S. Islam 2024).

The Bangladesh Power Development Board (BPDB) has signed PPAs with solar plants, but there is currently no framework for direct corporate procurement. Additionally, the utility PPAs and limited IRECs are typically priced higher than grid electricity, which is highly subsidized in Bangladesh. Relative to other countries, Bangladesh has a low share of independent power producers, limiting market competition and investment. Ongoing grid reliability challenges and a limited market for REkeep the near-term outlook for corporate RE procurement subdued, as reflected in our assumptions. **However, discussions are underway to establish corporate power procurement mechanisms in Bangladesh, which could increase the viability of electrification with emissions reductions.**

Building on this context, we developed assumptions for analyzing how low-carbon thermal energy technology adoption in Bangladesh will affect energy use, emissions, and costs from steam and hot oil heating at a typical textile wet-processing facility. The RE procurement pathways for Bangladesh are as follows:

TABLE 3.2.4: RE PROCUREMENT PATHWAYS IN BANGLADESH

Year	Baseline Grid Plus RE Procurement Scenario	Ambitious Grid Plus RE Procurement Scenario
2030	0%	30%
2035	30%	50%
2040	50%	100%

The following section details the results of our quantitative analysis of low-carbon thermal energy adoption in Bangladesh.

3.5.2. Low-Carbon Technologies for Steam Generation

Electric Steam Boilers

Bangladesh's textile sector primarily relies on natural gas-fired boilers for steam and hot oil production. Natural gas is the reference technology against which electric boilers, heat pumps, and biomass boilers are compared. We do not evaluate coal boiler adoption in Bangladesh. Energy savings results are consistent with other countries due to the assumption that natural gas and coal boilers have a similar thermal efficiency (see Section 3.2.1.)

In Bangladesh, adopting electric boilers at a typical textile plant is predicted to increase emissions in the near term due to the lower direct combustion emissions factor of natural gas compared to that of Bangladesh's grid. Although electricity mostly comes from natural gas power plants, the grid emissions factor is significantly higher than the natural gas emissions factor due to older power plants; transmission and distribution losses; and Bangladesh's use of more carbon-intensive fuels (e.g. coal, oil, and diesel) for electricity generation.

Given challenges in the corporate RE procurement landscape in Bangladesh (discussed further in the next chapter), we assume that a typical textile facility will not be able to obtain a majority share of RE for its electricity supply until 2035 and beyond. Both the Baseline and Ambitious RE Procurement pathways for Bangladesh assume a significantly lower share of RE can be procured by a typical textile facility compared to China, India, and Vietnam. By 2035, procuring RE for 30% of the electricity supply under the Baseline RE Procurement pathway can lead to electric boilers reducing emissions compared to natural gas boilers. With 100% RE procurement, boiler electrification could mitigate nearly 15 kt CO_2 per year by 2040.

Natural gas and electricity prices for industrial facilities in Bangladesh are highly subsidized. Based on current and projected ratios, we predict that electric boilers would have higher energy costs than natural gas steam boilers in a typical textile facility in Bangladesh. However, in 2040, when lower-cost RE may be available for corporate procurement, the energy

FIGURE 3.5.1: ANNUAL CO_2 EMISSIONS FROM NATURAL GAS-FIRED STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN BANGLADESH, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

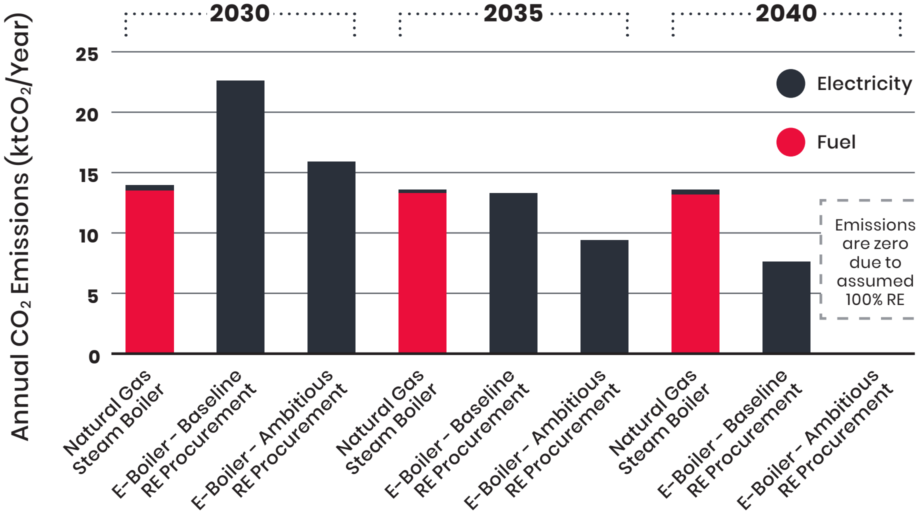
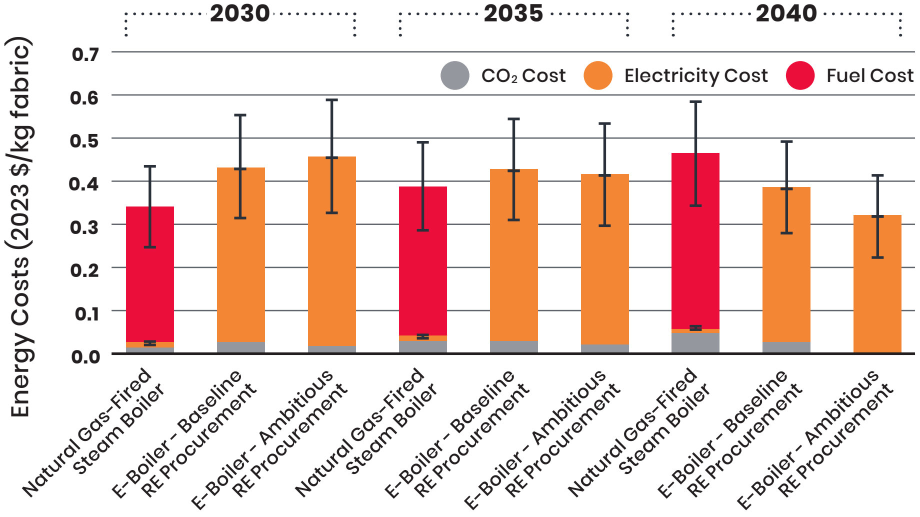


FIGURE 3.5.2: ENERGY COSTS OF NATURAL GAS STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN BANGLADESH, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



costs of electric boilers could be competitive with natural gas boilers. In 2030 and 2035, the Baseline and Ambitious Grid Plus RE Procurement pathways will have slightly higher and similar energy costs, respectively, due to procured RE prices being slightly higher than subsidized grid electricity in Bangladesh in the near term.

In the absence of a corporate RE purchasing framework, electric steam boilers will not be economically feasible and deliver emissions reductions until 2040 under either RE Procurement pathway. Policy advocacy is key to shifting this outlook. Ongoing discussions show that change is possible.

Steam-Generating Heat Pumps
Electrification with steam-generating heat pumps would reduce emissions in the near term, despite the relative emissions factors of natural gas and the grid, due to the very high efficiency of heat pumps. Emissions reductions could be even greater with future corporate RE procurement.

In Bangladesh, heat pumps are highly favorable in terms of energy costs relative to natural gas steam boilers, driven by the significant efficiency gains from electrification with heat pumps — even without carbon pricing (i.e. without the gray bar in Figure 3.5.4.). In 2030 and 2035, the Baseline and Ambitious Grid Plus RE Procurement pathways have slightly higher and similar energy costs for heat pumps, respectively, due to procured RE prices being slightly above subsidized grid electricity in Bangladesh in the near term.

Despite the limited RE in Bangladesh's grid or for procurement, heat pumps can already deliver emissions savings and energy cost reductions in 2030 due to their efficiency. This presents a significant opportunity for Bangladesh textile manufacturers to reduce their dependence on volatile natural gas prices. While not covered in this roadmap, energy storage in Bangladesh is critical to enable this.

FIGURE 3.5.3: ANNUAL CO_2 EMISSIONS FROM NATURAL GAS-FIRED STEAM BOILERS VS. HEAT PUMPS (HP) IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN BANGLADESH, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS.

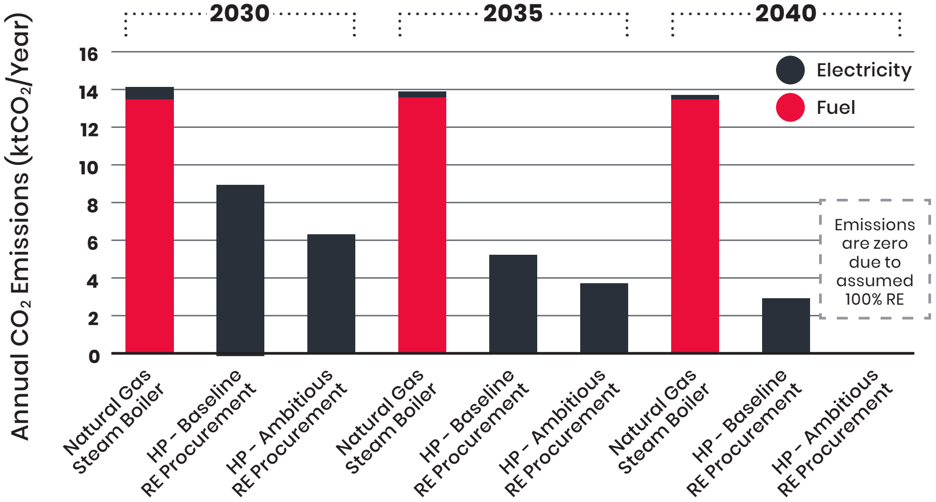
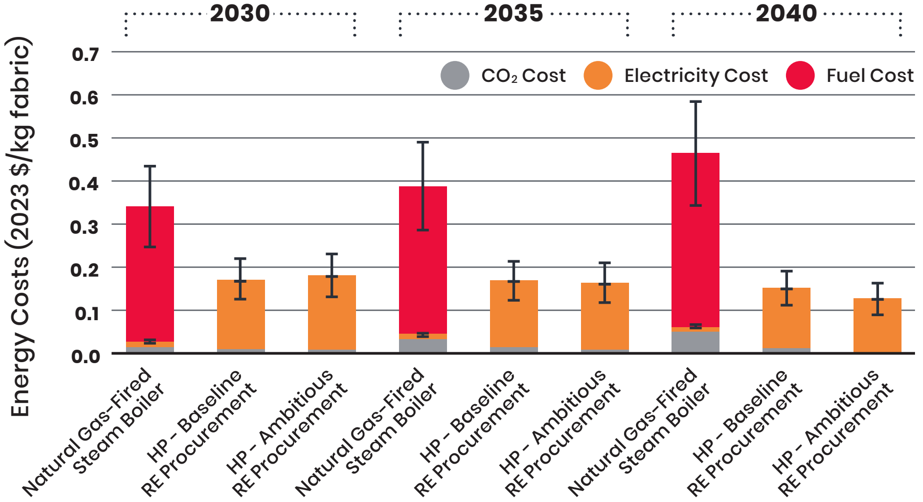


FIGURE 3.5.4: ENERGY COSTS OF NATURAL GAS STEAM BOILERS VS. HEAT PUMPS IN BANGLADESH, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Biomass Steam Boilers

As the direct combustion emissions factor of natural gas is much lower than that of biomass, the use of unsustainable biomass sources would significantly increase emissions from steam boilers (Figure 3.5.5.). However, the use of sustainable biomass with a lifecycle emissions factor of zero (i.e. carbon neutral) would eliminate fuel-related emissions. Note that fuel emissions factors are expected to stay consistent over time, so we only present results for a single year.

The low cost of byproduct biomass has been a key driver of its adoption in Bangladesh's textile industry, especially since natural gas is a relatively expensive fuel. Switching to low-cost assumed biomass would reduce energy costs at a typical textile plant in Bangladesh; however, as discussed further in Chapter 2 and Chapter 4, biomass prices are likely to fluctuate and increase if demand significantly grows. Biomass available for industry is particularly low in Bangladesh due to competing traditional uses.

While sustainable biomass offers emissions and cost savings compared to natural gas, the availability of sustainable biomass in Bangladesh is low and competes with other end uses. Transitioning from natural gas to biomass requires a thorough evaluation of the stable availability of certified sustainable biomass.

FIGURE 3.5.5: ANNUAL CO_2 EMISSIONS FROM NATURAL GAS BOILERS VS. SUSTAINABLE OR UNSUSTAINABLE BIOMASS STEAM BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN BANGLADESH

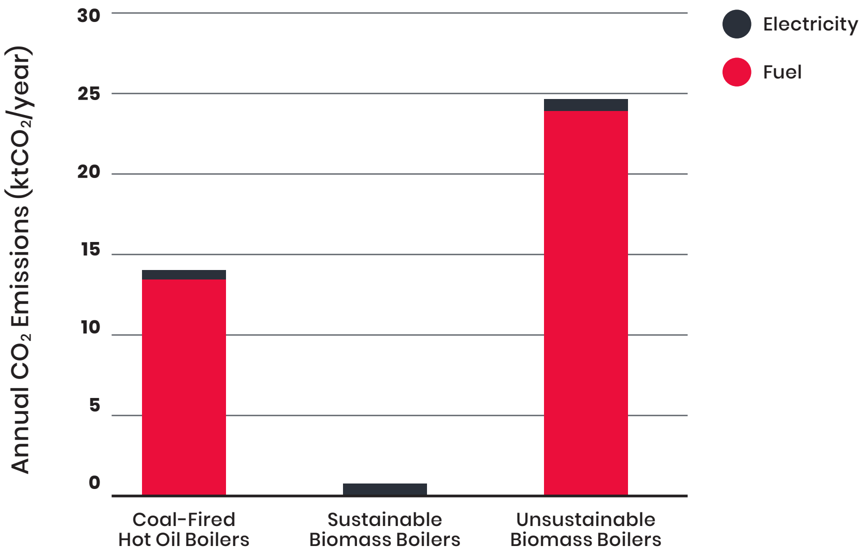
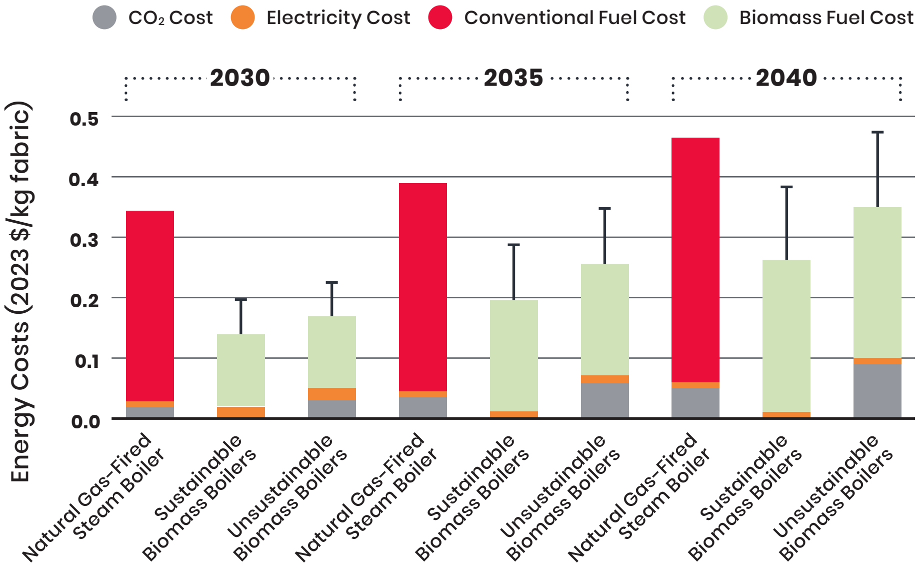
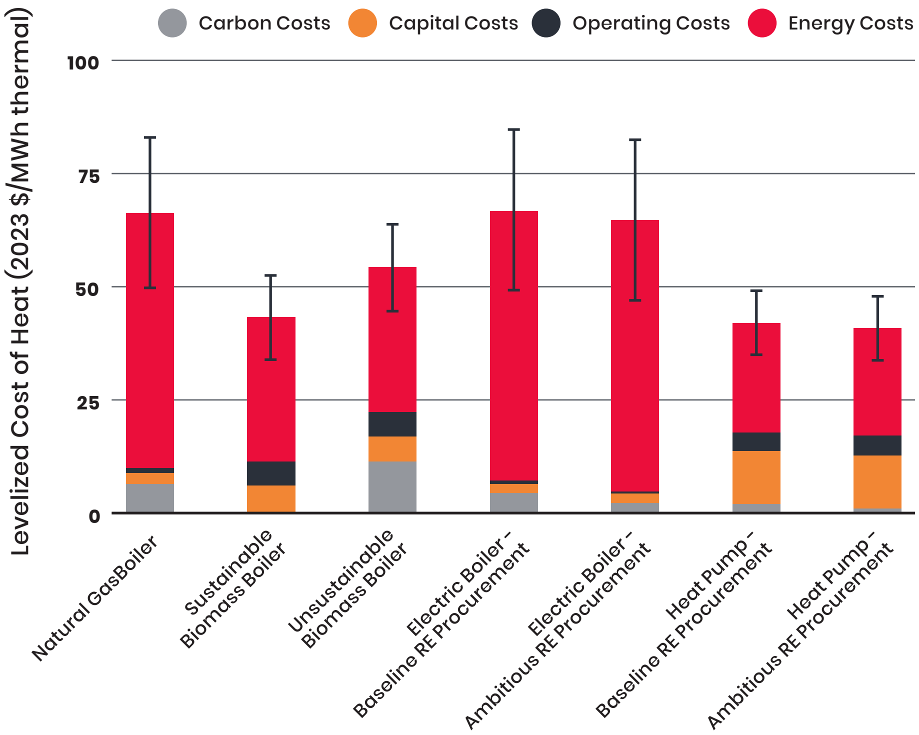


FIGURE 3.5.6: ENERGY COSTS OF NATURAL GAS STEAM BOILERS VS. BIOMASS STEAM BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN BANGLADESH



Levelized Cost of Heating for Steam-Generating Technologies
We calculated and compared the levelized cost of heat (LCOH) for steam generation for all steam technologies, including for both electricity pathways for the electrification technologies, following the methodology described in Section 3.1. In Bangladesh, natural gas boilers and electric boilers have similar levelized cost of heating for steam generation. Biomass and heat pumps offer lower and similar LCOH of steam generation, respectively, due to the low cost of biomass fuel and the high efficiency of heat pumps. Since our results are highly sensitive to fuel and electricity prices, we present an error bar of +/- 30% for the technologies' levelized energy costs.

FIGURE 3.5.7: LEVELIZED COST OF HEAT (LCOH) FOR STEAM GENERATION OF THE ANALYZED TECHNOLOGIES FOR A TYPICAL TEXTILE WET-PROCESSING FACILITY IN BANGLADESH



3.5.3. Low-Carbon Technologies for Hot Oil Boilers

Electric Hot Oil Boilers

Since our assumed efficiency and production levels are the same across the countries studied, we do not present energy savings from hot oil boilers again (see Section 3.2.2.). Due to the relatively low emissions factor of natural gas and the high grid emissions factor, electrification with electric hot oil boilers would significantly increase emissions in a typical textile facility in Bangladesh in 2030. Without corporate RE procurement, electrification with electric boilers is challenging; however, with corporate RE procurement (30% of electricity supply by 2030 in the Ambitious pathway), electrification of hot oil boilers could fully eliminate associated emissions by 2040 under the Ambitious pathway.

Energy costs at a typical textile wet-processing plant in Bangladesh are expected to increase with hot oil boiler electrification. Energy costs become competitive by 2040 — assuming corporate RE procurement will become available at a typical textile facility in Bangladesh.

In the absence of a corporate RE purchasing framework, electric hot oil boilers will not deliver emissions reductions in either the Baseline or Ambitious RE Procurement pathways. The lower efficiency gains in comparison to steam boilers will keep pricing unfavorable — even in 2040.

FIGURE 3.5.8. **ANNUAL CO_2 EMISSIONS FROM NATURAL GAS HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN BANGLADESH, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS**

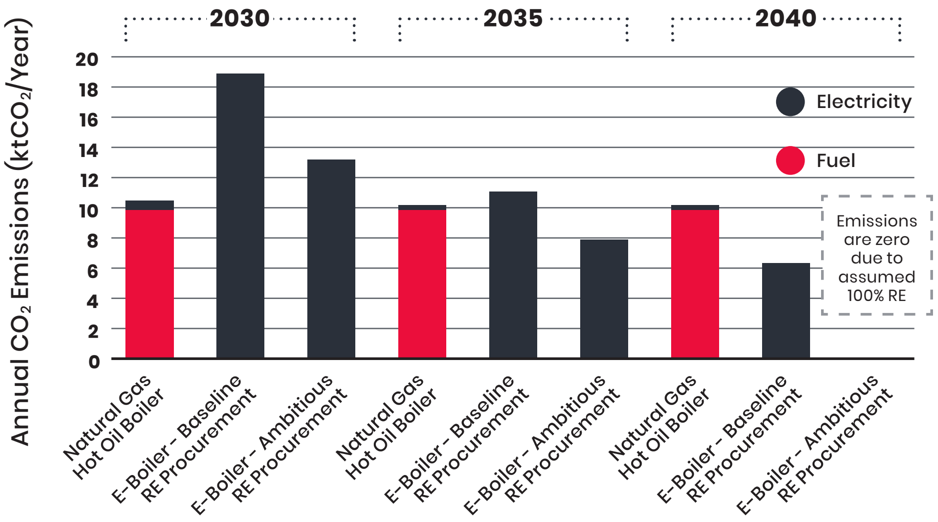
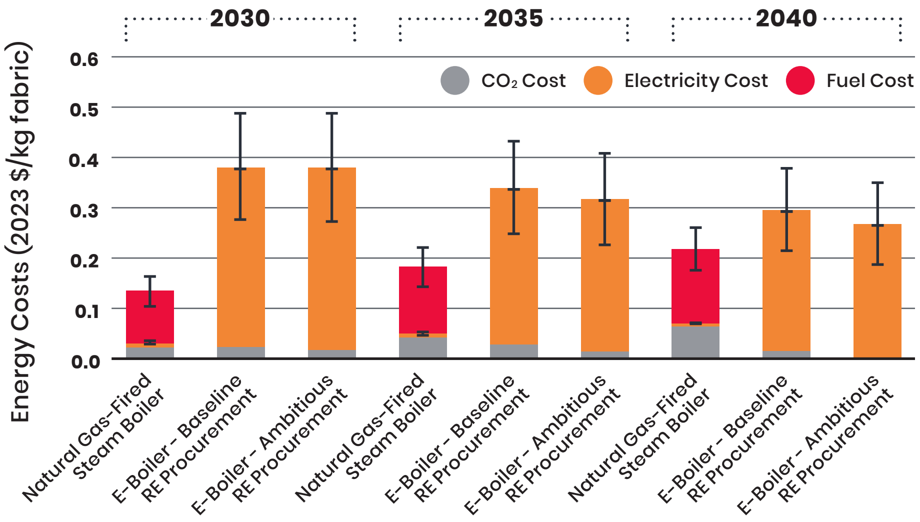


FIGURE 3.5.9. **ENERGY COSTS OF NATURAL GAS HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS IN BANGLADESH, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS**



Biomass Hot Oil Boilers

As with steam boilers, switching to biomass for hot oil boilers would significantly increase emissions due to the relatively low emissions factor of natural gas direct combustion. However, if carbon-neutral and sustainable biomass can be sourced, emissions could be reduced to zero in the near term. This is challenging in practice, as discussed in Section 4.2.1.

Like biomass steam boilers, biomass hot oil boilers have similar energy costs as coal-fired boilers, especially if carbon pricing is applied. However, prices vary by location and could increase significantly with a rise in demand or supply disruptions.

Sustainable biomass can present emissions and cost savings compared to natural gas; however, the availability of biomass in Bangladesh is low and there is heavy competition from other end uses. Transitioning from natural gas to biomass will require a stable, certified sustainable supply.

FIGURE 3.5.10. ANNUAL CO_2 EMISSIONS FROM NATURAL GAS HOT OIL BOILERS VS. BIOMASS HOT OIL BOILERS (SUSTAINABLE AND UNSUSTAINABLE) AT A TYPICAL TEXTILE PLANT IN BANGLADESH

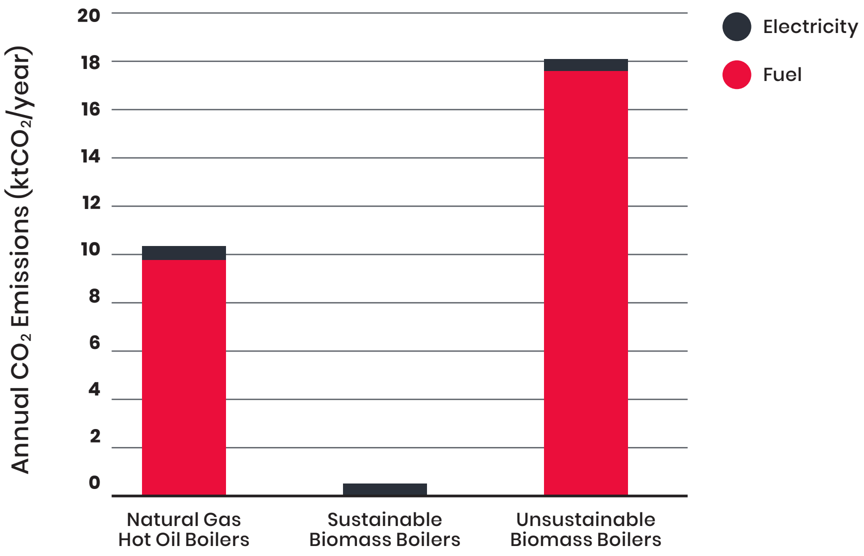
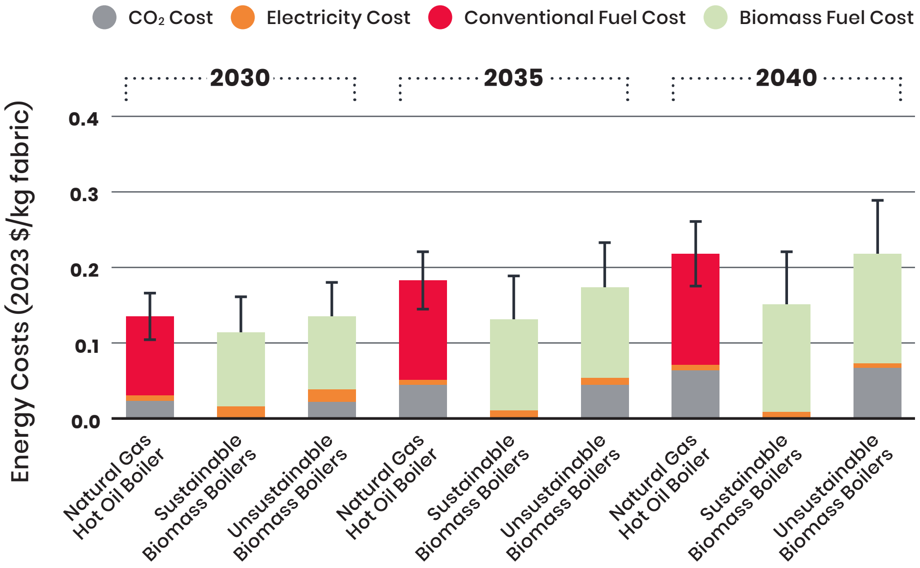


FIGURE 3.5.11. ENERGY COSTS OF NATURAL GAS HOT OIL BOILERS VS. BIOMASS HOT OIL BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN BANGLADESH



3.5.4. Potential Impacts of Electrification on the Electricity Grid in Bangladesh

Electrification will increase electricity demand and place a greater load on the grid, presenting a greater challenge to Bangladesh when compared to the other studied countries. Figure 3.2.18 in Section 3.2.3 shows the estimated increase in electrical load from electrification at a typical textile facility in the studied countries. Switching to electric steam boilers could add approximately 8 MW of extra electric load at a typical textile facility, while a heat pump could meet the same heating needs with around 3 MW of additional load. Similarly, electric hot oil boilers are expected to add around 7 MW of extra load compared to conventional hot oil boilers. **This estimated additional electricity load is consistent across all studied countries because the model assumes plants in each location will have similar production levels and technology (see Section 3.2.3).**

3.6. Textile Plants in Indonesia

3.6.1. The Energy Systems Landscape in Indonesia

To set the stage, we're first exploring key aspects of Indonesia's energy systems and policies impacting the viability of low-carbon thermal energy technology adoption. This context also drives our assumptions for the Indonesia analysis (see Section 3.1).

Indonesia's abundant, low-cost domestic coal — which makes it one of the world's top coal exporters — is one of the key barriers to low-carbon energy adoption in the textile sector. The nation's energy policies are heavily influenced by coal interests, making alternative energy technologies less appealing both financially and politically. Indonesia caps the coal price for industrial consumers, leaving other fuels financially uncompetitive in the near term. Additionally, the grid emissions factor is the highest among the countries studied, meaning that near-term electrification with grid electricity could actually increase CO_2 emissions.

Although highly dependent on coal, Indonesia has expressed policy commitments to transition towards renewables and has entered into international agreements (e.g. the Just Energy Transition Partnership) to leverage international support for this transition.

In the following sections, we explore key aspects of Indonesia's energy system impacting electrification and alternative fuel adoption.

Alternative Fuel Availability in Indonesia
As the world's largest producer of palm oil, Indonesia has a large availability of byproduct palm kernel husks — a viable source of biomass fuel. However, palm oil plantations have historically been one of the largest drivers of deforestation, generating significant CO_2 emissions from the destruction of tropical rainforests and peatlands. **Additionally, Indonesia exports palm kernel shells to other countries, especially Japan and South Korea, for use as fuel. Demand for palm kernel shells could face competition from other markets and drive up prices, given supply constraints.** The use of palm kernel husks and palm oil byproducts must be managed carefully to avoid increasing demand for the agricultural product itself.

Biomass may be sourced from corporations with no-deforestation commitments or certification by the Roundtable on Sustainable Palm Oil (RSPO); however, RSPO-certified biomass has a very limited supply. Brands and textile manufacturers should require the use of certified palm kernel husks **to ensure the purchased biomass is sustainable.**

Beyond palm oil, Indonesia's agricultural sector produces other residues with potential for biomass use, such as rice husks, coconut shells, and sugarcane bagasse. Rice production, particularly in Java and Sumatra, generates substantial quantities of husks, and coconut production in regions like Sulawesi, yields shells and husks that can serve as biomass feedstock. Total agricultural residues are estimated at 155 million tons per year (Rhofita et al. 2022), though the potential amount available for industry use is unknown. Most of Indonesia's textile production is on Java, and transportation of residues from other islands is likely not cost-effective.

Indonesia faces limits in its current renewable electricity supply and aims to significantly increase biomass power generation as part of a coal transition. The country aims to achieve 5.5 GW of biomass power generation capacity by 2025 and 26 GW by 2050 (Rhofita et al. 2022). Given the risks associated with biomass in Indonesia, textile facilities using it must demonstrate that the source is sustainable, certified, and carbon neutral. Given supply constraints, sustainable biomass may only be available in the short term. It is essential for facilities to prepare for electrification.

Indonesia is a significant natural gas producer, with natural gas supplying 14% of total energy needs with less than 3% coming from imports. However, Indonesia's domestic gas production has been declining in recent years, increasing reliance on imported LNG. Additionally, the country's gas infrastructure, particularly for distribution, remains underdeveloped in many regions, limiting industrial access. **This results in uneven availability and potentially higher costs, making the large-scale adoption of natural gas for heating in the textile sector challenging.**

Indonesia's Electricity Grid

Indonesia's grid is heavily reliant on coal, and the transition to electrified industrial processes, particularly in textiles, will necessitate a substantial shift towards renewables. Indonesia's Ministry of Energy and Mineral Resources (MEMR) has acknowledged that less than 0.3% of Indonesia's renewable energy potential has been harnessed thus far (Tanahair.net 2024). However, even with an increased RE supply, the country's electricity grid is not yet equipped to handle this demand — especially in remote areas. Expanding transmission infrastructure, particularly in renewable-rich regions, and investing in energy storage systems are essential to supporting the electrification transition. Indonesia's Just Energy Transition Partnership aims to leverage international support for the transmission infrastructure necessary for renewables integration.

Indonesia has ambitious plans to become a global battery exporter by 2030, by leveraging its abundant nickel reserves. The government is fostering investment from South Korean and Chinese companies to build domestic battery manufacturing capabilities. While direct energy storage targets remain limited, these investments could reduce battery capital costs domestically, supporting future energy storage projects and enabling renewable integration.

While the progress to date on decarbonizing the grid has been limited, Indonesia endeavors to modernize its grid and leverage international financing to decarbonize and position itself internationally as an exporter of key electrification-enabling technology.

Corporate Renewable Electricity Procurement in Indonesia

In 2023, Fossil fuels accounted for 81% of Indonesia's electricity generation. The remaining 19% came primarily from hydropower, with a very small fraction of wind and solar generation. Indonesia continues to rapidly build coal-fired power plants(Global Energy 2024).

India's corporate RE procurement market is in its early stages due to low supply; however, it is gaining momentum. In 2022, Amazon signed an agreement with PLN, Indonesia's state-owned utility, to supply solar energy to its AWS division. PLN has also signed an agreement with a RE producer (Enerdatics 2022). That same year Nickel Industries signed a 25-year PPA for a 200 MW solar project in Indonesia, which includes a 20 MWh battery for energy storage. Notably, Nickel Industries will not fund the project, and the contract includes energy prices that are lower than current rates (RenewablesNow 2022).

PLN has sold Renewable Energy Certificates (RECs) in Indonesia since 2020, primarily serving industrial sectors in Java and Jakarta. Levels remain low overall; however, in 2023, PLN recorded a 75% rise in REC usage from 2022, with total sales reaching 5 TWh since 2020 (Antara News 2024).

Despite recent progress, challenges persist, including restrictions on private electricity suppliers in areas served by PLN's grid. This hampers the scalability of renewable projects. **Overall, limited RE supply and nascent mechanisms for corporate RE procurement make Indonesia's outlook for the corporate RE market more moderate than that of China, India, and Vietnam.**

Using this context, we developed assumptions to analyze how the adoption of low-carbon thermal energy technology in Indonesia will affect energy use, emissions, and costs from steam and hot oil heating at a typical textile wet-processing facility. The RE procurement pathways for Indonesia are as follows:

TABLE 3.2.5: RE PROCUREMENT PATHWAYS IN INDONESIA

Year	Baseline Scenario	Ambitious Scenario
2030	25%	50%
2035	50%	75%
2040	75%	100%

Our results for the quantitative analysis of low-carbon thermal energy adoption in Indonesia follow.

3.6.2. Low-Carbon Technologies for Steam Generation

Electric Steam Boilers

While Indonesia has the highest grid emissions factor of the countries studied, electrification with electric boilers results in annual CO_2 emissions that are a similar level to emissions from coal boilers in 2030. This is due to the increased efficiency of electric boilers and the assumed potential for corporate RE procurement for individual textile facilities in Indonesia. Under the country's Baseline RE Procurement pathway, we assume that 25% of electricity could be directly procured RE. Under the Ambitious pathway, with 50% RE procurement by 2030, emissions from boiler electrification are significantly lower than those from coal-fired boilers by that year.

Near-term (i.e. in 2030), the energy costs for electric boilers are a challenge. Industrial coal prices are capped at low levels and electricity, including RE, is relatively expensive. By 2040, electric boilers could come closer to being competitive with coal boilers across various pricing scenarios (Figure 3.6.2.).

While we see emissions reductions beginning in 2035, costs remain higher, even in the 2040 scenario, due to the low prices of coal in Indonesia.

FIGURE 3.6.1: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN INDONESIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

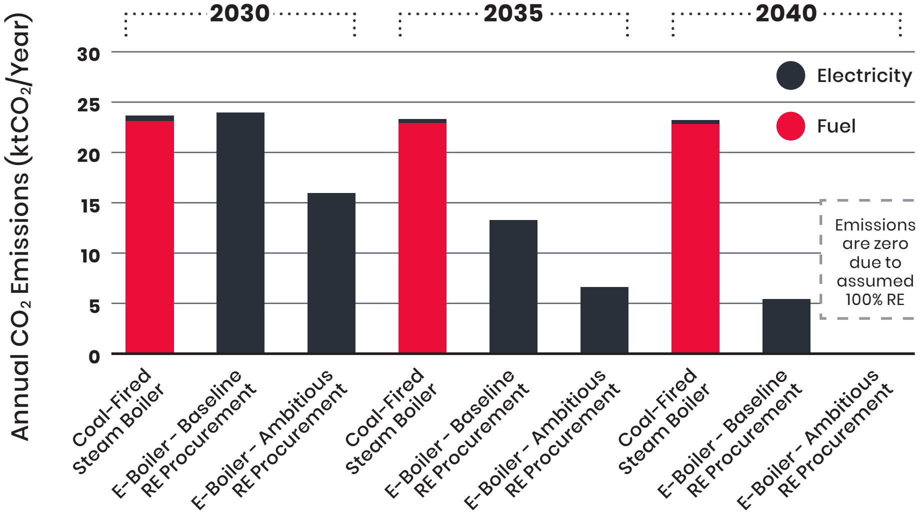
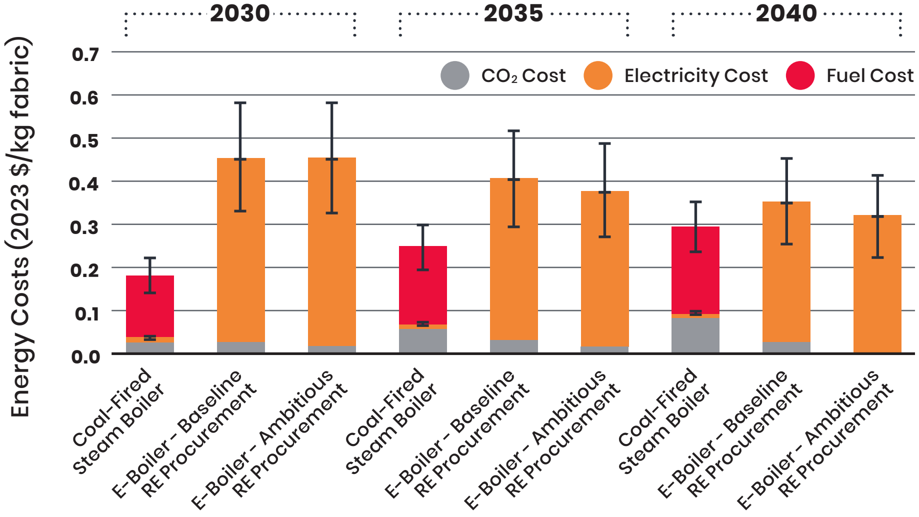


FIGURE 3.6.2. ENERGY COSTS OF COAL STEAM BOILERS VS. ELECTRIC STEAM BOILERS IN INDONESIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Steam-Generating Heat Pumps

In contrast, electrification with steam-generating heat pumps can lead to significant near-term emissions reductions. Heat pump efficiency gains — with a moderate share of RE procurement under our outlined pathways (25% by 2030 in the Baseline RE Procurement pathway and 50% by 2030 under the Ambitious RE Procurement pathway) — drive a steep decrease in CO_2 emissions.

Despite the energy cost challenges outlined for electric boilers, efficiency gains from heat pumps make them competitive with coal steam boilers in terms of energy cost by 2030. This energy cost advantage continues over time, even if carbon pricing in Indonesia does not apply to the studied facility.

Similarly to Bangladesh, heat pumps can deliver immediate emissions savings — even with a less decarbonized grid. However, due to Indonesia's coal subsidies, the solution will reach cost parity in 2030 and begin delivering savings in 2035. Given environmental benefits and improved business performance, textile manufacturers should pursue heat pumps starting in 2030.

FIGURE 3.6.3: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED STEAM BOILERS VS. HEAT PUMPS (HP) IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN INDONESIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

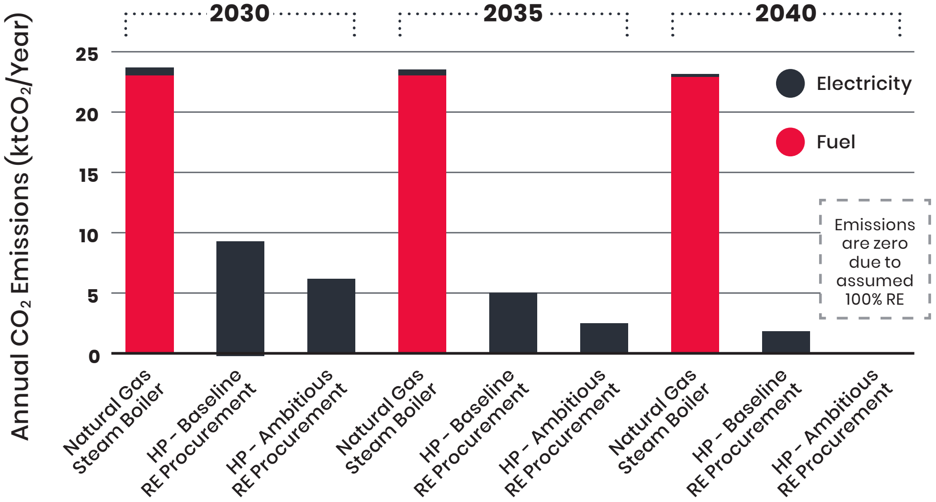
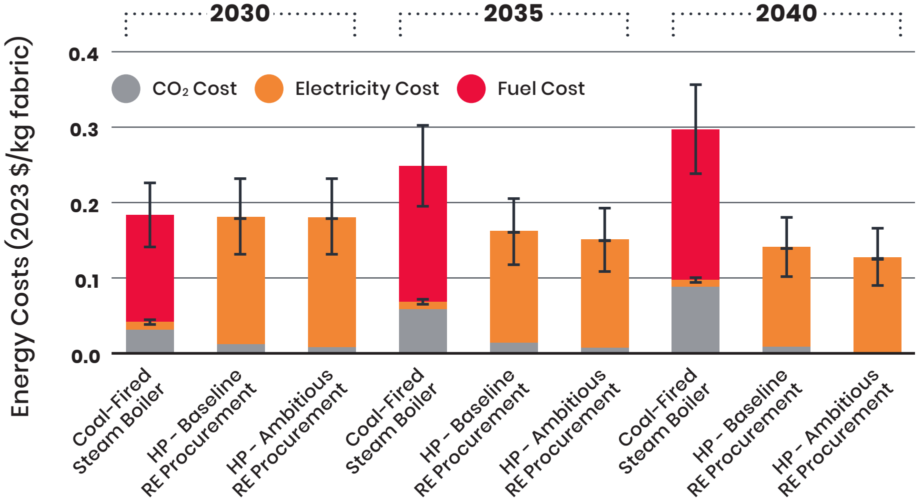


FIGURE 3.6.4: ENERGY COSTS OF COAL STEAM BOILERS VS. HEAT PUMPS IN INDONESIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Biomass Steam Boilers

Since textile producers in Indonesia are likely to use agricultural residues as biomass fuel, and biomass and coal boilers are assumed to have the same efficiency across countries, the energy savings and emissions outcomes of switching to biomass boilers are expected to be similar. See Section 3.2.1. for biomass steam boiler results across the studied countries.

The cost gap between biomass and coal in Indonesia is slightly less than in the other countries studied. Our projections show biomass boilers do not lead to energy cost decreases — assuming biomass boilers are also subject to carbon pricing based on emissions from direct combustion. However, as discussed further in Chapter 2 and Chapter 4, biomass prices are likely to fluctuate and increase over time. Given challenges with tropical deforestation, Indonesia faces the biggest sustainability challenges among the studied countries, making responsible biomass sourcing essential for decision-making.

While sustainable biomass delivers emissions savings and energy cost savings, the limited availability of sustainable biomass and the risks of unsustainable biomass are higher in Indonesia than in the other countries studied. Biomass should be explored very carefully on a case-by-case basis.

Natural Gas Steam Boilers

As natural gas has roughly the same emissions factor across countries, and natural gas boilers have the same assumed efficiency as coal boilers, the potential energy and emissions results are the same as presented in Section 3.2.1. for China.

Natural gas is slightly more expensive than coal for industrial facilities in Indonesia. However, since the country produces a significant amount of natural gas for domestic consumption, energy cost differentials are relatively small compared to the other countries in this analysis.

While natural gas steam boilers deliver emissions savings in Indonesia, higher energy costs and infrastructural limitations make it unlikely to be a viable alternative fuel.

FIGURE 3.6.5. ENERGY COSTS OF COAL STEAM BOILERS VS. BIOMASS STEAM BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN INDONESIA

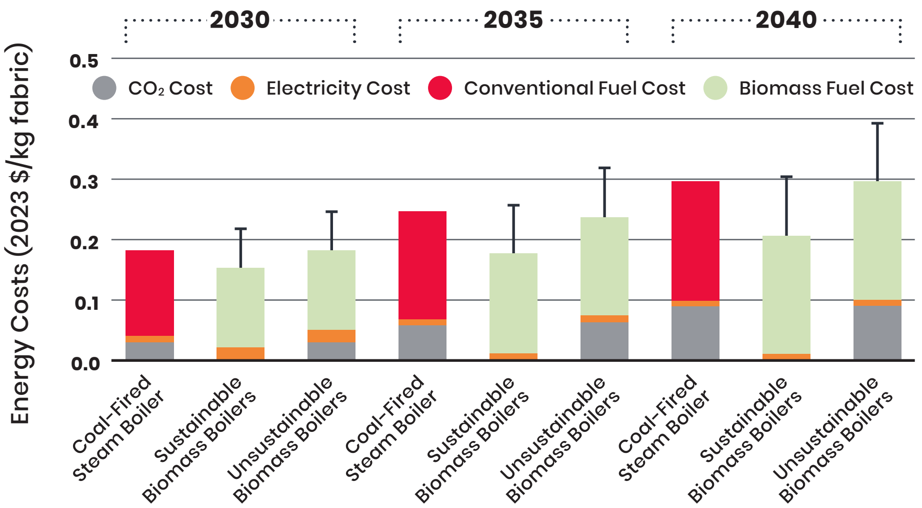
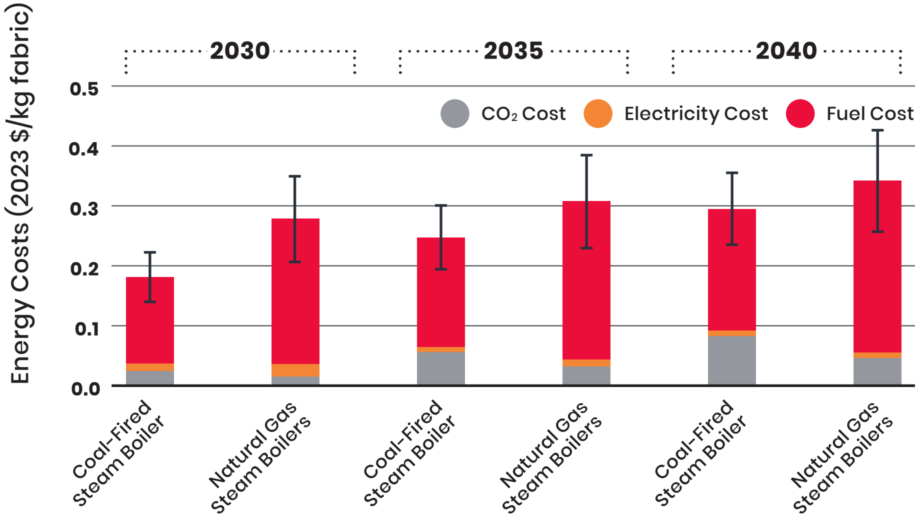


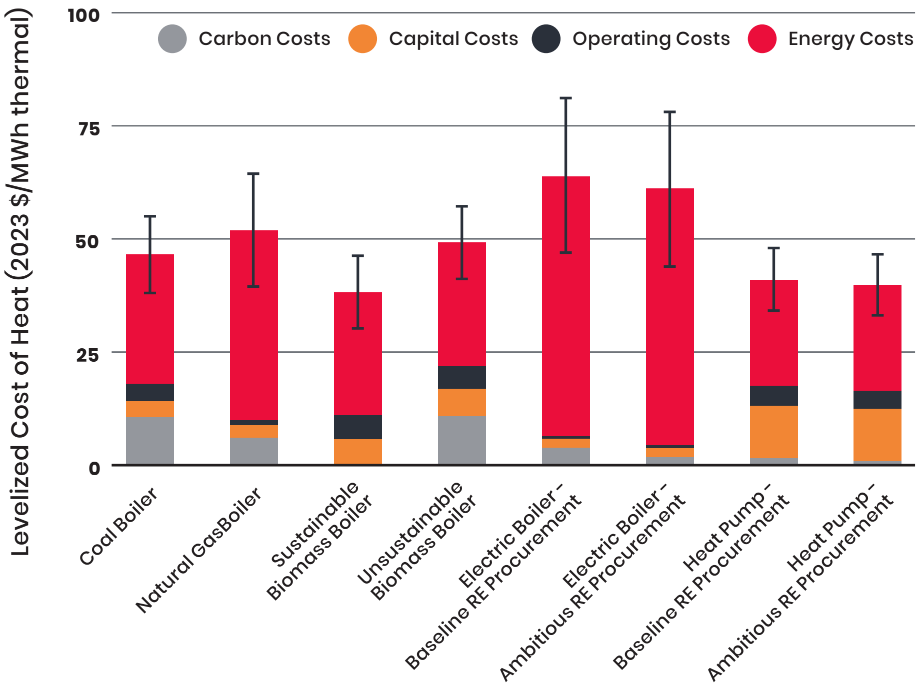
FIGURE 3.6.6. ENERGY COSTS OF COAL STEAM BOILERS VS. NATURAL GAS STEAM BOILERS IN A TYPICAL WET-PROCESSING FACILITY IN INDONESIA



Levelized Cost of Heating for Steam-Generating Technologies

We calculated and compared the levelized cost of heat (LCOH) for steam generation for all steam technologies, including for both electricity pathways for the electrification technologies, following the methodology described in Section 3.1. Due to Indonesia's relatively high electricity costs compared to coal and biomass, electric boilers have the highest LCOH for steam generation for the technologies studied. However, the difference is less pronounced when comparing the direct annual energy cost (see above). Heat pumps are highly competitive with fuel boilers over their technology lifetime due to their high efficiency and the prospect of corporate RE procurement in Indonesia.

FIGURE 3.6.7: LEVELIZED COST OF HEAT (LCOH) FOR STEAM GENERATION OF THE ANALYZED TECHNOLOGIES FOR A TYPICAL TEXTILE WET-PROCESSING FACILITY IN INDONESIA



3.6.3. Low-Carbon Technologies for Hot Oil Boilers

Electric Hot Oil Boilers

Since our assumed efficiency and production levels are the same across the countries studied, we do not present energy savings from hot oil boilers again (see Section 3.2.2.).

Electrification with electric hot oil boilers would lead to a slight emissions increase in 2030 under the Baseline RE Procurement pathway due to Indonesia's very high grid emissions factor and the low share of available RE for direct procurement. However, as shares of RE procurement increase, emissions can be reduced over time.

Energy costs at a typical textile wet-processing plant in Indonesia are expected to rise significantly with hot oil boiler electrification, even more than steam boiler electrification, due to the lower efficiency gains of electrifying coal-fired hot oil boilers. Decarbonizing hot oil-based heating in Indonesia is thus a challenge from an energy cost perspective and deserves further attention from the perspective of other decarbonization pillars, for example focusing on energy efficiency.

Since electric hot oil boilers deliver fewer efficiency gains than electric steam boilers, they begin emissions reductions in the Ambitious RE procurement pathway in 2030 and the Baseline pathway in 2035. They do not, however, achieve energy cost savings compared to coal in the studied period.

FIGURE 3.6.8: ANNUAL CO_2 EMISSIONS FROM COAL-FIRED HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS IN A TYPICAL TEXTILE WET-PROCESSING PLANT IN INDONESIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS

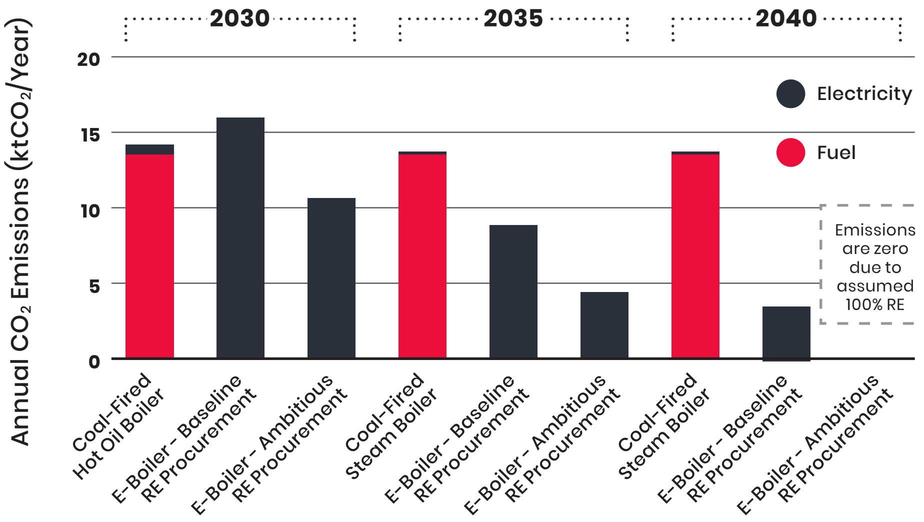
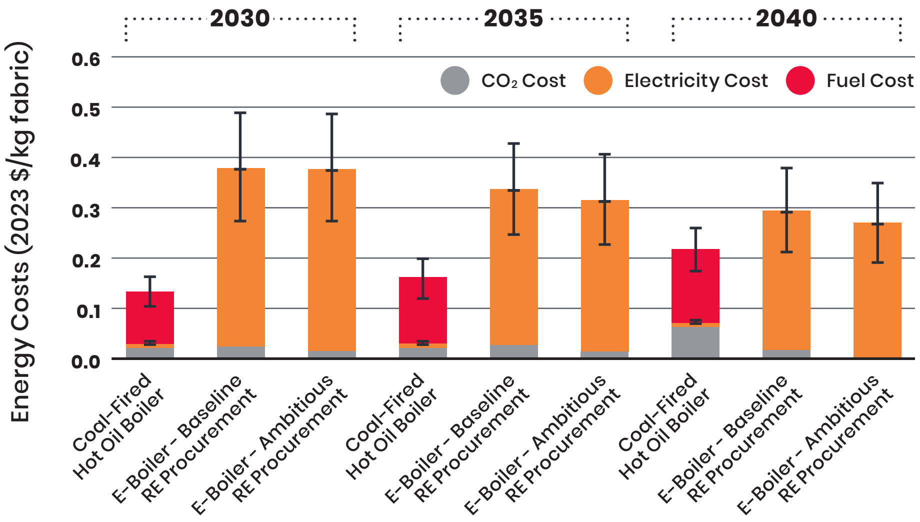


FIGURE 3.6.9: ENERGY COSTS OF COAL HOT OIL BOILERS VS. ELECTRIC HOT OIL BOILERS IN INDONESIA, BASELINE AND AMBITIOUS RE PROCUREMENT PATHWAYS



Biomass Hot Oil Boilers

The emissions impacts of hot oil boiler electrification in Indonesia will be the same for a typical textile facility across the studied countries (see Section 3.2.2.).

Like biomass steam boilers, biomass hot oil boilers are expected to have lower energy costs relative to coal-fired boilers, although biomass and coal prices are expected to be more comparable in Indonesia than in some other countries. However, prices vary significantly by location and could rise significantly with demand increases or supply disruptions.

While sustainable biomass delivers emissions savings and marginal cost savings, sustainable biomass availability is limited and the risks of unsustainable biomass are higher than in the other countries studied. Biomass should be explored very carefully on a case-by-case basis.

Natural Gas Hot Oil Boilers

Similar to our steam boiler analysis, there are no energy savings for switching to natural gas hot oil boilers from coal hot oil boilers due to their similar thermal efficiency. Additionally, emissions results are expected to be the same for hot oil boiler conversion to natural gas in China (see Section 3.2.3). For this reason, we have not repeated the emissions chart.

Like steam boilers, natural gas-fired hot oil boilers would have slightly higher energy costs relative to coal boilers (Figure 3.4.11). Although facilities using coal will face a higher carbon price, it's expected to be lower than the long-term price difference between coal and natural gas fuel.

While natural gas steam boilers deliver emissions savings in Indonesia, higher energy costs and infrastructural limitations make it unlikely to be a viable alternative fuel.

FIGURE 3.6.10: ENERGY COSTS OF COAL HOT OIL BOILERS VS. BIOMASS HOT OIL BOILERS (SUSTAINABLE AND UNSUSTAINABLE) IN A TYPICAL WET-PROCESSING FACILITY IN INDONESIA

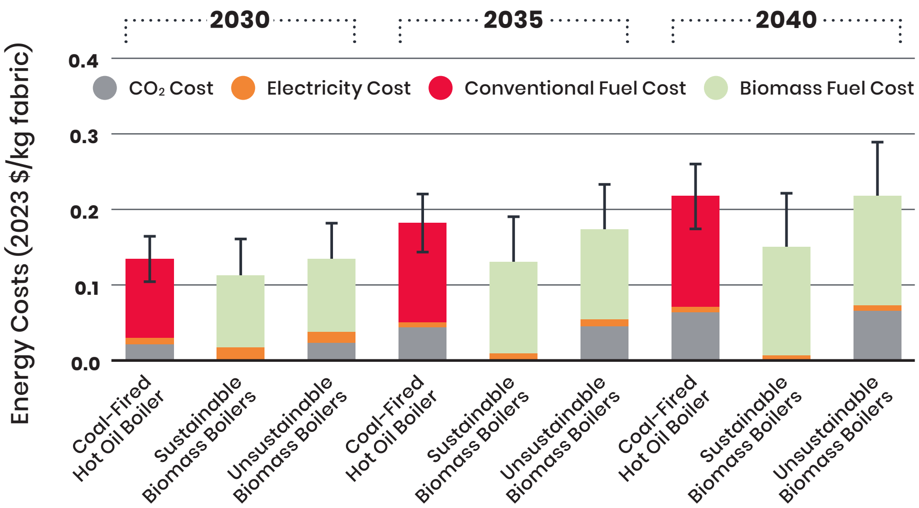
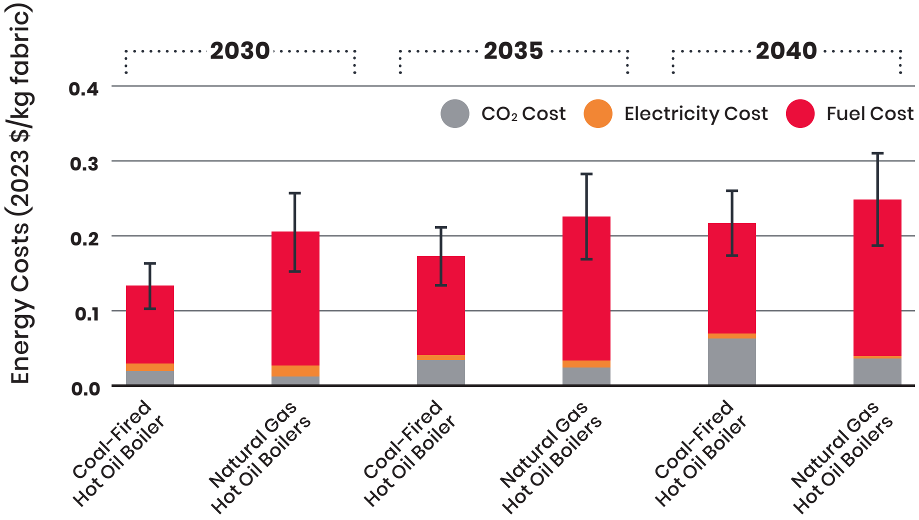


FIGURE 3.6.11. ENERGY COSTS OF COAL HOT OIL BOILERS VS. NATURAL GAS HOT OIL BOILERS IN A TYPICAL WET-PROCESSING FACILITY IN INDONESIA



3.6.4. Potential Impacts of Electrification on the Electricity Grid in Indonesia

Electrification will increase electricity demand and place a greater load on the grid (Figure 3.2.18 in Section 3.2.3 shows the estimated rise in electrical load from electrification at a typical textile facility in the studied countries). Our analysis shows switching to electric steam boilers could add approximately 8 MW of extra electric load at a typical textile facility. A heat pump could meet the same heating needs with only around 3 MW of additional load. Similarly, electric hot oil boilers are expected to add around 7 MW of extra load compared to conventional hot oil boilers. These findings are consistent across the studied countries (see Section 3.2.3.) because our analysis is based on a similar facility in each country based on production levels and technological efficiency.

4. Implementation Guidelines for Electrification Technologies in Textile Plants

Given the advantages of electrification technologies in many cases, a key part of a roadmap for textile plants adopting electric boilers or heat pumps is a detailed, step-by-step process to develop the necessary supporting systems for electrification. The other technologies evaluated in this study, namely biomass and natural gas boilers, are widely adopted and do not require additional implementation guidance. Similarly, while energy efficiency innovations are also crucial to enabling electrification, these are not included in the implementation guidelines.

We have outlined the steps for transitioning to electrification from initial data gathering about the existing electrical system to the final implementation and commissioning of new electric loads. This section outlines a suggested process for implementing an electrification project at a typical textile facility and can be applied to industrial electrification in other sectors.

STEP 1: Data Gathering and Assessment

Thorough data gathering and assessment is the first step in adopting electrification technologies in textile plants. The process begins with collecting detailed information on the local electrical system, including power generation equipment, electrical substations, distribution systems, and end users. Identifying onsite electricity consumption and generation is vital.

Additionally, an inventory of all fuel-fired systems within the facility should be conducted. This includes on-site inspections; reviewing facility blueprints; consulting with engineers to ensure all relevant equipment is identified, and gathering key system information such as design and operating parameters (e.g., heat input capacity, operating temperature, and age of equipment) (Nandy et al. 2023). This enables the evaluation of existing systems for compatibility with electric options and helps prioritize equipment for electrification.

Another component is determining the fuel use and emissions for each thermal process. This roadmap serves as a starting point, having provided estimates for steam and hot oil boiler fuel use and emissions for a typical plant in each country. Additional data — collected through measurements, utility bills, engineering estimations, and external data sources (e.g. typical emissions factors) — is required (Price et al. 2020).

STEP 2: Planning for Electrical Load Increase

The next step is planning for the increased electrical load from electrification — a necessary step to ensure smooth integration and avoid system overloads.

Building on data from Step 1, the process begins with a comprehensive study of the current electrical charge distribution, using network analysis software to evaluate load conditions under normal, minimum, and maximum scenarios. This analysis identifies necessary upgrades, including cables, transformers, and other key components. The data should be used to create a system map or a single-line diagram that visually represents the facility's electrical network and demonstrates electricity flow across the plant. A single-line diagram (also called a one-line diagram) is a simplified representation of an electrical system, showing the flow of power and key components of the system (e.g. transformers, generators, circuit breakers, loads, switches, and distribution panels). It uses single lines and standard symbols to depict power generation, distribution, and consumption, as well as details such as ratings for transformers and voltage levels.

Once the baseline data has been gathered, it is important to calculate the additional load that will be introduced by the electrification technologies. This step involves specifying the types of new equipment, their operating conditions, and their energy consumption. This roadmap serves as a starting point, as we have estimated the additional load from electric boilers and heat pumps for a typical wet-processing facility in each country. Integrating additional loads into the network necessitates a revised network analysis to determine the impact of these new demands on the existing system. Understanding how the new equipment will affect electrical distribution under varying operational conditions is essential to ensure the system can handle peak loads without risking outages or inefficiencies. This is especially important in regions with grid reliability challenges, such as Bangladesh.

A short circuit study is also part of this planning process, assessing the existing network's capacity to handle potential faults and short circuits once the new equipment is installed. This analysis will determine whether the current infrastructure can safely support the increased demand or if modifications — such as the installation of new equipment or upgrades to transformers, switchgear, distribution panels, and other key components — are required (O'Neil et al. — forthcoming). Advanced analysis tools such as ETAP, MicroStation, and others can help facilities with drafting, electrical load calculations, short circuit studies, relay coordination, and other analyses.

After assessing the infrastructure readiness and performing the necessary analyses, facilities and utilities can explore opportunities to optimize electricity management techniques. Strategies such as load management, power factor correction, and integrating renewable energy sources can improve system efficiency to better support the new loads. Facilities must work closely with utilities to understand whether grid capacity upgrades are needed to accommodate electrification.

STEP 3: Feasibility Assessment for Electrification Technologies

Once the potential electrification technologies have been identified, the next step is to conduct a comprehensive feasibility assessment. An initial assessment could be done with Global Efficiency Intelligence's Textile Heating Electrification Tool. This Excel-based tool is designed to help textile manufacturers evaluate the energy, emissions, and cost benefits of switching from fossil fuel-based heating to electric technologies (see section 6.1.3. for more).

Deeper feasibility assessments evaluate key factors such as the technical feasibility, energy requirements, infrastructure compatibility, cost-effectiveness, and environmental and operational impacts of the electrification technologies. This step ensures that the selected technologies are both feasible for the facility and capable of delivering long-term operational and environmental benefits.

Technical feasibility involves analyzing the heating or power requirements of the facility's processes and ensuring that the selected electric technologies can meet these demands (e.g. identifying specific technology providers to see if their equipment can meet process heating requirements). The facility's process requirements must be mapped in detail, and identify parameters like heat input, operating temperatures, and throughput needs, which could be different for electrified systems. As an example, electric systems often offer more precise control over temperature, which could improve the quality and consistency of the end product. However, adjustments may be needed to ensure compatibility with upstream and downstream processes.

Next, a cost-benefit analysis should be conducted to evaluate if electrification technologies are economically feasible. Facilities must compare the capital and operating costs of the new electric systems with those of existing fuel-fired systems, accounting for factors like maintenance costs, energy savings, and potential reductions in scrap and waste. Our levelized cost of heat (LCOH) of steam production, presented in the previous chapter, is a useful starting framework for such analysis.

Assessing the environmental impact of the electrification project, particularly the potential for CO_2 emissions reductions and the availability of corporate RE procurement, is key. As shown in our analysis, the electricity supply determines whether or not electrification will reduce or decrease emissions. Corporate RE procurement is necessary for near-term decarbonization in countries with carbon-intensive grids that transitioning to electrification. To identify locally available corporate RE procurement mechanisms, facilities should review national policies and regulations, which we briefly profiled in the previous section. Companies may also consider investing in self-generation. Once viable mechanisms are identified, they should engage with brands, utilities, RE developers, or consultants to explore the feasibility of RE procurement.

Once the feasibility assessment is completed, electrification projects should be selected based on technical feasibility, cost-effectiveness, and environmental benefits — prioritizing those with the highest overall impact. Projects that require minimal infrastructure upgrades or that can be easily integrated with existing systems may also be prioritized for faster implementation.

STEP 4: **Implementation**

Based on the selected technology, several general implementation guidelines apply to electrification in textile plants. Securing project funds will involve working with internal finance departments and external funding sources like local and international banks or development funds. The financing landscape and mechanisms in the studied countries are discussed in Chapter 5.

Securing the necessary permits before installing the electrification technologies is essential to ensure compliance with local, state, and national regulations. This involves navigating electrical, safety, and environmental regulations, which can vary by jurisdiction. Securing building permits and adhering to electrical codes can prevent legal issues, penalties, or project delays. Some technologies and grid modifications may require special permits. Early engagement with local authorities is recommended to streamline the process.

Once permits are secured, the procurement stage begins: drafting technical specifications for equipment, conducting competitive bidding, and selecting vendors based on technical, financial, and sustainability requirements. Ensuring that the selected equipment is compatible with the facility's existing infrastructure and operational needs is key. Working closely with vendors and financial institutions can also help secure favorable payment terms or financing arrangements. Additionally, procurement should factor in delivery timelines, particularly for custom-built equipment, to align with the project's implementation schedule.

Installation is a critical phase where the new electrification technologies are integrated into the existing infrastructure. Collaboration with contractors or in-house teams will ensure the systems are installed safely and efficiently following the designs created during planning. After installation, thorough testing is crucial to verify the performance and reliability of the systems. This includes stress testing under various load conditions and ensuring that the new technologies meet efficiency and productivity targets. Initial test runs under operational conditions can identify issues early, allowing for adjustments before full-scale operation begins.

Workforce training is essential to ensure proper operation and maintenance of the newly installed systems. This can be done in collaboration with apparel brands, government institutions, utilities, and equipment vendors, which may be able to provide training sessions or certification programs tailored to the specific technologies. Training should cover both day-to-day operational procedures and long-term maintenance requirements, including safety protocols, troubleshooting, and efficiency optimization techniques.

Post-implementation, the electrification technologies should be continually monitored to detect performance issues, ensure efficiency, and prevent unexpected downtime. This may include setting up remote monitoring systems to track energy consumption, equipment status, and system performance in real time. Establishing regular maintenance schedules is essential to ensure the longevity of the equipment, and periodic reviews should be conducted to assess the system's integration with ongoing operations. Additionally, as energy demands evolve, the electrification plan should be revisited to ensure the infrastructure can accommodate future upgrades or expansions.

These guidelines outline specific facility-level steps based on our analysis in Chapter 3.

5. The Financing Landscape for Low-Carbon Technologies

Financing is a critical element in enabling the shift toward low-carbon technologies, especially electrification. The complexity of financing mechanisms for low-carbon technology adoption — along with the need for capital investment in renewable energy infrastructure, grid modernization, and on-site renewable energy generation — creates both challenges and opportunities for textile producers. As more global brands commit to reducing their supply chain emissions, textile producers are increasingly incentivized to seek financing to adopt sustainable technologies. A range of financing options is available, ranging from traditional bank loans to innovative green bonds. The following sections explore these financing mechanisms in more detail, highlighting their applications for funding electrification technologies in textile plants across key regions.

In September 2024, Aii published "The Brand Playbook for Financing Decarbonization," a guide to help brands explore various financial options that can support or incentivize producers to invest in decarbonization projects. Designed to bridge the gap between sustainability, sourcing, and finance teams, the report outlines twelve distinct financial tools, referred to as "plays," that brands can use to contribute to these investments. It uses a hypothetical facility improvement project to evaluate each play using consistent criteria and highlighting the risks and benefits from the brand's perspective. Though the playbook may also benefit suppliers and financial institutions, it is primarily designed for brand decision-makers.

5.1. Financing Mechanisms for Low-Carbon Technologies

Several financing tools are available to textile companies to implement electrification technologies, ranging from traditional bank debt to innovative solutions like sustainability-linked loans, green bonds, and guarantees. The financing landscape is rapidly evolving as governments, development banks, and private investors prioritize low-carbon initiatives. The following section highlights several key financing options for capital expenditure for textile producers in the major production regions.

Bank Debt, Bonds, and Loan Funds

Bank debt, or traditional lending, is the most commonly used form of financing for industrial projects, including those aimed at electrification. Textile companies, particularly in emerging economies like India and Bangladesh, can access loans from local, regional, and international banks. However, textile producers, particularly SMEs, often struggle to secure favorable loan terms due to limited credit histories or the perceived risk of adopting new technologies. To address this, international development banks and export credit agencies are increasingly offering low-interest loans and guarantees to reduce financial risk for lenders and borrowers.

Bonds represent another financing option for larger textile companies. Bonds, particularly green bonds, are publicly traded instruments earmarked specifically for environmentally friendly projects. These bonds typically offer lower interest rates than traditional debt due to their sustainability focus, attracting socially conscious investors. Development-oriented banks may issue green bonds to finance large-scale electrification projects. Green bonds have seen growing interest in regions with developed financial markets, like China.

Loan Funds are private investment funds targeting lower-risk projects that promise stable returns, such as upgrading to energy-efficient equipment or installing renewable energy capacity at textile plants. Textile producers in Vietnam and Indonesia can benefit from loan funds that are increasingly seeking to invest in projects with clear sustainability outcomes. The rise of climate-focused investment vehicles has improved funding availability for projects with proven technologies, reducing the financial burden on companies seeking to transition to low-carbon thermal energy.

Venture Capital and Private Equity
Venture Capital (VC) and Private Equity (PE) firms play a crucial role in financing more innovative and higher-risk electrification technologies. While bank loans and bonds tend to support projects with proven outcomes, VC and PE firms are more willing to invest in nascent technologies with the potential for high returns. For textile producers, especially in regions with emerging renewable energy markets (e.g. Indonesia and Bangladesh), VC and PE funding can help finance high-temperature heat pumps, which currently face major CAPEX hurdles but offer significant energy savings that could translate into rapid payback and an internal rate of return (IRR).

VC and PE investors provide not only capital but also strategic expertise, helping textile companies navigate the complexities of scaling new technologies. In return, the investors seek high returns, which often come with higher risks. For instance, in Vietnam, where the government has begun opening a market for PPAs, PE firms could play a pivotal role in financing infrastructure projects that help textile producers transition to renewable electricity and align with Vietnam's regulatory framework.

Brand and Manufacturer Capital
Another important source of funding can be brand and manufacturer capital, wherein global apparel brands co-invest alongside textile manufacturers to achieve sustainability goals. In the context of supply chain decarbonization, many global fashion brands have pledged to lower the carbon intensity of their operations, and are increasingly willing to co-invest in electrification projects to meet that goal.

Brands that have adopted long-term sustainability commitments often use their own funds to co-finance pilot projects and feasibility studies for low-carbon technologies. These investments are mutually beneficial: brands reduce their supply chain emissions while producers can upgrade their facilities without bearing the full financial burden.

Brand Premiums
Brands can also address the challenges of higher energy costs from electrified technologies, which are the key drivers of overall operating cost differentials. One approach is a sustainability premium, with brands paying a higher price per unit of product to facilities implementing low-carbon heating technologies, helping to offset OPEX linked to electrified heating. **Premiums may be necessary in countries where the price of electricity does not drop until after 2035/2040. For brands with 2040 net zero targets, electrification is required to meet those goals, and this cost increase should be considered in their planning.**

Government, Development Bank, and Philanthropy Support
Governments, development banks, and philanthropic organizations are key players in de-risking early-stage technologies and providing capital for projects that align with broader societal goals, such as decarbonization and improving energy efficiency. Textile producers in emerging economies like India, Vietnam, Bangladesh, and Indonesia can access development financing through concessional loans, grants, or subsidies. For example, the Asian Development Bank (ADB) and World Bank have played leading roles in funding infrastructure projects related to renewable energy and energy efficiency in the studied countries.

Government programs, such as the Green Development Fund in China, are crucial for offsetting the high upfront costs of electrification technologies. Philanthropic organizations can also provide grant funding to support the initial research and development of low-carbon technologies, helping textile producers pilot these innovations. Additionally, development banks often provide loan guarantees or blended finance, lowering the risk for private investors and commercial banks willing to invest in electrification projects.

Governments and development banks can also work with manufacturers to commit to longer-term PPAs when procuring renewable electricity, offering more favorable and stable prices. In practice, these institutions could provide a letter of commitment or guarantee to support the manufacturer's PPA with a renewable energy provider, though the PPA contract itself would typically be signed directly between the manufacturer and the provider. This arrangement stabilizes energy costs for the manufacturer and de-risks the investment for both the energy provider and the manufacturer.

Sustainability-Linked Loans and Corporate Guarantees
Sustainability-Linked Loans (SLLs) and Corporate Guarantees are innovative financing mechanisms that have gained traction in the textile sector. SLLs are structured so that the interest rate is linked to the borrower's ability to meet specific environmental or social targets. For example, a textile company in Vietnam could receive a loan with a reduced interest rate if it successfully reduces its energy consumption or shifts a significant portion of its energy use to renewable sources.

Corporate guarantees, on the other hand, involve a brand or large manufacturer guaranteeing a loan to a producer, which can lower the risk profile of the loan and make it easier for the producer to secure financing. These mechanisms are particularly useful in countries like Bangladesh and Indonesia where textile SMEs often face difficulties in obtaining loans due to their size and limited credit history. With the backing of a well-known brand or multinational corporation, producers can access the capital needed to transition to electrification technologies.

5.2. Country-Specific Financing Mechanisms for Textile Industry Decarbonization

China

In China, the government will play a critical role in providing financial support for the textile sector's adoption of low-carbon technologies. The China Development Bank (CDB) and the Industrial and Commercial Bank of China (ICBC) are among the largest financiers of renewable energy projects and low-carbon technologies. With policy and regulatory support, China's large development and commercial banks can offer loans with favorable interest rates to textile producers investing in electrification technologies like electric boilers, heat pumps, and renewable energy systems. These institutions are also able to access government guarantees, which can help de-risk lending for small and medium-sized textile producers. Additionally, China has a well-established green bond market, which could be extended to textile manufacturers. The National Green Development Fund, under multiple ministries, could be directed to provide subsidies and grants to textile producers that prioritize energy efficiency and electrification.

In China, utilizing special funds and subsidies to support energy transition initiatives is a common practice. The government has introduced a top-down support strategy to promote electrification. In April 2024, the Ministry of Industry and Information Technology (MIIT) and six other government departments jointly issued "The Implementation Plan for Promoting Equipment Upgrades in the Industrial Sector." The plan emphasizes enhancing financial and tax support for industrial equipment upgrades and technological transformations. Key projects that meet specified criteria will be eligible for funding under the central government's budgetary investment framework.

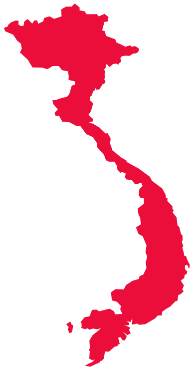
Among the countries studied, a unique financing possibility for China is the potential of its institutions to provide overseas finance and investment for low-carbon technology adoption in the textile industry. China is a major financier of global infrastructure development through its Belt and Road Initiative — driven by CDB and CHEXIM and major outflows of private capital. Recent policy announcements to green the Belt and Road have highlighted renewable energy and grid infrastructure development in partner countries, and there is ambition to increase funding for low-carbon technologies. Initiatives such as the Green Innovation and Financing Partnership represent emerging mechanisms for channeling China's overseas finance towards greener investments. With policy support and guidance, China's overseas development finance and other forms of capital could be incentivized to support the textile industry in partner countries.

India

India's textile sector should receive significant support from both public and private financing initiatives focused on decarbonization and electrification. The Ministry of Textiles, in collaboration with the Ministry of New and Renewable Energy (MNRE), can offer subsidies and grants for textile producers investing in electrification technologies (e.g. electric boilers and rooftop solar). Through the Perform, Achieve, and Trade (PAT) scheme, industries in India — including textiles — are incentivized to adopt energy-efficient practices and can trade energy-saving certificates to provide an additional revenue stream. Development banks, such as the State Bank of India (SBI) and the National Bank for Agriculture and Rural Development (NABARD), can provide concessional loans to textile producers for electrification and renewable energy projects.

SIDBI (Small Industries Development Bank of India) provides specialized financing for energy efficiency (EE) and decarbonization projects in industrial SMEs through concessional loans and grants under its Sustainable Finance Scheme, which could be extended to the textile sector. International financing mechanisms are also available in India and could be leveraged by the textile sector with policy support. Global development institutions such as the International Finance Corporation (IFC) and the Asian Development Bank (ADB) have made long-term financing available for low-carbon projects, offering direct loans, equity investments, and co-funding arrangements for companies adopting renewable energy and low-carbon technologies.

Another notable financing mechanism for India is green loans offered by major international brands committed to reducing their supply chain emissions. These brands offer incentives, including lower interest rates, to suppliers who adopt electrification and other low-carbon technologies, bridging the financing gap for producers. A consortium of brands launched the Future Supplier Initiative in partnership with DBS, a bank, to help suppliers access green loans for infrastructure. The Initiative has reported success in unlocking collaborative financing for infrastructure upgrades in India and has supplier cohorts in Bangladesh and Vietnam, with plans to expand to China (Stroh 2024). For a more comprehensive overview of financing opportunities in India, please refer to Aii's report in collaboration with Development Finance International (DFI), "Landscape and Opportunities to Finance the Decarbonization of India's Apparel Manufacturing Sector." which explores how to mobilize sustainable financing and support the decarbonization of India's textile and apparel industry.



Vietnam

Although Vietnam has relatively less developed capital markets, it does have options for development finance, such as the Vietnam Development Bank (VDB). The Ministry of Industry and Trade (MOIT) provides subsidies for energy-efficient technologies through the Vietnam National Energy Efficiency Program (VNEEP). As Vietnam's capital markets are still maturing, international finance may be a better prospect for financing the textile industry's transition to low-carbon thermal energy.

The Asian Development Bank (ADB) and other international development banks are collaborating with the Vietnamese government to fund renewable energy and industrial decarbonization projects. In addition, both Vietnam and Indonesia have established Just Energy Transition Partnerships (JETPs) with a group of international partners that will support low-carbon transition. This could have spillover effects for the textile industry.

Bangladesh

Bangladesh, as one of the world's largest textile producers, has a growing demand for financing low-carbon technologies. However, textile manufacturers in Bangladesh face several hurdles, including limited access to affordable financing for electrification projects. The Bangladesh Bank offers concessional financing under its Green Transformation Fund, which provides low-interest loans for renewable energy and energy efficiency projects. In addition, the Infrastructure Development Company Limited (IDCOL), a government-owned financial institution, offers financing for solar energy installations and other low-carbon technologies. Textile producers, particularly in key production hubs like Dhaka and Chittagong, could access these funds to implement electrification projects.

International development institutions play a pivotal role in financing Bangladesh's transition to low-carbon technologies. The International Finance Corporation (IFC), in partnership with the World Bank, supplies financing for energy efficiency and renewable energy projects in Bangladesh. Key bilateral financiers include Germany, France, Japan, and multilaterals include the Asian Development Bank. These institutions offer a combination of grants, loans, technical assistance, and engagement with various stakeholders, steering them towards a textile industry low-carbon transition.

Indonesia

Compared to India and China, Indonesia's textile industry faces more significant challenges in accessing financing; however, there are several mechanisms in place to encourage electrification. The Ministry of Industry and the Ministry of Energy and Mineral Resources (MEMR) offer subsidies and incentives for renewable energy and low-carbon technologies. The government, in partnership with state-owned banks such as Bank Negara Indonesia (BNI) and Bank Rakyat Indonesia (BRI), could provide concessional loans to textile producers. These banks also collaborate with international development institutions like the International Finance Corporation (IFC) and the Asian Development Bank (ADB) to offer long-term financing for renewable energy integration.

Indonesia has also seen the emergence of green bonds as a financing tool for renewable energy projects. While the green bond market is still in its infancy, major textile manufacturers or industry associations, particularly those exporting to international markets, could explore issuing green bonds to finance electrification and renewable energy projects, with underwriting from the government and financial institutions.

6. Low-Carbon Thermal Energy Roadmap for the Textile Industry

The textile industry's transition to low-carbon thermal energy is achievable by 2040 if concerted efforts are made to implement the assumptions outlined in this report.

The following roadmap outlines a phased approach for apparel brands and textile manufacturers across China, India, Vietnam, Bangladesh, and Indonesia. Each phase of the roadmap — Plan & Pilot (2025–2030), Deployment (2030–2035), and Scale-Up (2035–2040) — focuses on specific actions for brands, manufacturers, and other stakeholders across countries, highlighting the necessary strategies for each region's unique energy landscapes, resource availability, and policy contexts (Figure 6.1.).

FIGURE 6.1: LOW-CARBON THERMAL ENERGY ROADMAP FOR THE TEXTILE INDUSTRY IN THE FIVE STUDIED COUNTRIES

	Plan & Pilot Stage: 2025-2030	Deployment Stage: 2030-2035	Scale-Up Stage: 2035-2040
Apparel Brands	• Work with suppliers on energy efficiency and reducing energy needs, using the best available technologies and innovations. • Initiate pilot electrification projects paired with RE procurement where it is available (China and India). • Work with textile manufacturers to plan for and procure RE. Focus on navigating DPPA in Vietnam and engaging in advocacy for corporate RE procurement in Bangladesh and Indonesia. • Standardize industry definitions of sustainable biomass using existing guidelines. • Verify sustainable biomass sourcing and assess supply over time. • Leverage agricultural residue supply in China; verify any additional biomass use in India and Vietnam; discourage biomass in Indonesia; carefully assess impacts in Bangladesh. • Support RE development and RE grid integration. • Advocate for grid infrastructure and corporate procurement mechanisms in Bangladesh and Indonesia.	• Facilitate biomass phase-out due to projected cost increase and decreased availability of sustainable biomass in India, Vietnam, and Indonesia. • Assess electrification feasibility and adopt where possible, recognizing that heat pumps as the most efficient electrification technology. • Accelerate RE procurement in China, India, and Vietnam. • Establish RE goals in Bangladesh; encourage RE adoption in Indonesia • Provide technical and financial support for electrification deployment, especially heat pumps. • Seek out additional funding for electrification and financing partnerships (e.g., CDB in China, SBI in India). • Advocate for improved RE frameworks and cost-competitive PPAs.	• Fully transition away from biomass across all countries. • Work with Bangladesh on natural gas phaseout and electrification adoption. • Scale electrification with RE adoption. • Continue to advocate for improved RE frameworks and cost-competitive PPAs in all countries. • Support policies that align with fully decarbonized thermal energy in the textile industry.
Textile Manufacturers	• Continue energy efficiency work and explore innovative solutions to reduce thermal energy needs. • Assess RE procurement feasibility. • With brand support, begin pilot projects in China, India, and Vietnam. • Request standardized definitions and approaches to sustainable biomass from brands. • Ensure verifiable and sustainable biomass sourcing. • Plan for medium-term electrification as biomass becomes less viable and prices increase. • Advocate for access to existing RE procurement mechanisms in China, India, and Vietnam. • Collaborate with brands to advocate for RE procurement mechanisms in Indonesia and Bangladesh. • Promote policies for sustainable biomass MRV.	• Phase out biomass as sustainable and affordable sources decline in India, Vietnam, and Indonesia. • Secure long-term RE procurement agreements. • Prioritize emerging RE opportunities in Bangladesh and Indonesia. • Seek technical and financial assistance from brands for electrification, especially heat pumps. • Participate in financing initiatives with brands and government. • Advocate for grid-ready infrastructure and RE affordability in Bangladesh.	• Fully phase out biomass across all countries. • Phase out natural gas in Bangladesh. • Fully adopt electrification technologies powered by 100% RE in all countries. • Seek additional efficiency and cost-saving measures that can leverage electrification (e.g. demand response programs) in China and India. • Continue collaboration with a wide-range of entities, including apparel brands, financial institutions, utilities, and policymakers.
Policymakers	• Provide incentives and grants for electrification pilot projects in the textile sector. • Work on harmonizing standards and regulations for sustainable biomass across regions.	• Provide capacity building and multi-stakeholder convenings to share knowledge around successful electrification deployments. • Move from government grants towards tax incentives and market mechanisms to encourage wider deployment.	• Allocate ongoing resources for grid modernization and RE integration in plants. • Plan for integrated textile production and RE clusters where possible, such as in low-carbon industrial parks in China and Vietnam.
Financial Institutions	• Establish pilot project financing mechanisms for textile manufacturers, particularly for heat pump CAPEX. • Support capacity building and preparatory activities for electrification in Bangladesh and Indonesia.	• Incorporate pilot project results to develop a business case for electrification technologies. • Leverage private sector finance	• As low-carbon technologies are increasingly competitive, focus on favorable commercial finance. • Provide financing for associated infrastructural upgrades, e.g. grid modernization.
Utilities	• Work with policymakers to ensure grid readiness for industrial electrification. • Streamline corporate RE procurement mechanisms. • Offer favorable rates, at a minimum for T&D charges for electrification projects.	• Seek financing for grid modernization projects. • Offer electrification technical support to textile manufacturers. • Implement smart grid technologies.	• Work with other stakeholders to manage additional load from industrial electrification. • Deploy programs to effectively manage load (e.g. time-of-use pricing and demand response).

6.1. Plan & Pilot Stage: 2025-2030

6.1.1. Actions for Apparel Brands

The Plan & Pilot stage (2025-2030) will focus on enabling actions to prepare energy, policy, and infrastructure landscapes across China, India, Vietnam, Bangladesh, and Indonesia for the long-term adoption of electrification technologies and near-term adoption of biomass in the most viable locations. Following is an outline of actions apparel brands should take during this phase:

Thermal load reduction: Reducing a site's thermal energy load will have the greatest impact — after RE availability — on the economic viability of electrification. Brands must work closely with textile manufacturers to set long-term targets and action roadmaps to improve energy efficiency and reduce overall consumption. This can be supported by Aii's programs and Climate Solutions Portfolio. Brands should collaborate with textile manufacturers to identify any needed technical and financial support and establish appropriate timelines. This is also the time for brands to pilot advanced thermal load-reducing technologies to share learnings and enable scaled deployment in the next stage.

BIOMASS AS A TRANSITION FUEL?

The results of this study indicate that due to risks inherent in scaling up biomass sourcing, biomass may be an appropriate transition fuel in some places, but it is not as good as electrification for long-term decarbonization. The report recommends verifying sustainable biomass sources for facilities that adopt biomass in the near-term, while beginning to phase out biomass in 2030 and beyond based the availability of corporate RE procurement by then to support electrification.

Initiate pilot electrification projects paired with RE procurement: Apparel brands can drive electrification by collaborating with textile manufacturers to initiate pilot projects, especially heat pumps, paired with corporate RE procurement when feasible in the near term.

- **China and India** have the most developed corporate RE procurement markets of the countries studied. Brands can leverage various mechanisms to procure RE and adopt electrification technologies.
- **Vietnam's** recently introduced DPPA mechanism allows brands the opportunity to help eligible suppliers navigate the framework, build familiarity with the regulatory landscape, and gain experience with RE procurement for Vietnamese textile manufacturers.
- **Bangladesh** has many textile facilities that are not grid-connected, and RE procurement mechanisms are nascent. Brands should focus their efforts on advocating for RE policy frameworks, such as the proposed Corporate Power Procurement legislation, and general improvement of grid infrastructure and RE supply.
- **Indonesia** also has a relatively limited corporate RE procurement market. During this stage, brands should prioritize advocating to build this market, paving the way for future electrification.

Verify sustainable biomass sourcing: Sustainable biomass use requires careful assessment across all regions. Brands can offer technical support to facilitate sustainable sourcing and financing for biomass-switching projects. Brands should refer to the Institute for Sustainable Communities Guidelines or other industry-recognized definitions of sustainable biomass. There is a need to standardize brand requirements to textile manufacturers for biomass sourcing across the industry. This should align to standard bodies for a common message to shared suppliers to amplify impact. Additionally, due diligence is necessary for all biomass sources — even if they meet the definition of sustainable in these guidelines. Brands can advocate for transparent MRV frameworks and verification methods that can help ensure biomass is sustainably sourced to improve policy.

- **China** has relatively abundant sources of agricultural residues and waste biomass, making it a potential transition fuel. Brands can explore this option if their suppliers are located in regions that allow biomass boilers and have a sustainable supply.
- **India and Vietnam** already have many textile facilities that rely heavily on agricultural biomass. Brands should ensure that any additional biomass adoption requires suppliers to source verifiable and sustainable agricultural residues, while also developing electrification plans as biomass availability is expected to decrease and costs may rise.
- **Indonesia's** biomass sourcing poses a high risk of deforestation. Brands should discourage large-scale biomass use and prioritize electrification readiness.
- **Bangladesh** faces significant competition for agricultural residues from local farmers and communities, requiring a thorough examination of social and environmental impacts before biomass adoption. Ultimately, brands and manufacturers must work together to assess their own biomass supply chains and conduct long-term risk assessments on sustainability. For this reason, we recommend brands pursue traceability and that textile manufacturers only purchase certified sustainable sources of biomass.

Advocate for an enabling environment for low-carbon thermal energy: In all studied countries, brands should advocate alongside organizations like the Asian Clean Energy Coalition for increased access to renewable energy and the necessary infrastructure to support it.

- **China and India** present opportunities for brands to push for improved RE integration and lower-cost RE (relative to grid electricity).
- **Vietnam's** advocacy should focus on implementing the DPPA mechanism and increasing RE supply.
- **Indonesia and Bangladesh** are regions where brands should advocate to establish corporate RE procurement mechanisms, strengthen grid infrastructure, and increase RE supply.

Establish clear low-carbon thermal energy plans, progress metrics, and budgets: Apparel brands should demonstrate their commitment to low-carbon thermal energy by publishing clear roadmaps and progress metrics. They should also allocate budget to support textile manufacturers in financing this transition. This will provide a unified market signal to aid advocacy efforts and strengthen demand for governments, utilities, financial institutions, and other stakeholders to accelerate the transition to low-carbon thermal energy.

6.1.2. Actions for Textile Manufacturers

During the Plan & Pilot stage, textile manufacturers in the studied countries should prioritize actions that align with their regional energy landscapes and available resources to prepare for a low-carbon transition. Following are key actions for textile manufacturers:

Thermal Load Reduction: Prior to RE procurement, textile manufacturers will benefit from reducing their thermal energy load. Textile manufacturers should work closely with brands to improve energy efficiency and reduce overall. In this time stage, textile manufacturers should prioritize solutions that are well-established with shorter payback periods. By implementing best practices and optimizing processes, textile manufacturers can significantly reduce emissions and cost. Where possible, more innovative solutions like waterless dyeing can be piloted with brand support. Textile manufacturers should communicate investment plans to brands, enabling them to offer technical and financial support for these initiatives.

Explore RE procurement feasibility: Textile manufacturers should explore RE procurement options based on local mechanisms. Where mechanisms exist (e.g. China, India, and Vietnam), textile manufacturers should pursue options that will lower costs relative to grid electricity. In regions where RE infrastructure is still developing (e.g. Bangladesh and Indonesia), textile manufacturers should collaborate with apparel brands, policymakers, and utilities to advocate for frameworks enabling corporate RE procurement.

Evaluate electrification feasibility and work with technology suppliers: Electrification pilot projects should begin in this stage. Textile manufacturers must use tools like the decision tree to identify the most suitable electrification technology based on emissions and cost, and then evaluate process-level electrification opportunities. Implementing pilot projects alongside brands is key to driving success.

Verify sustainable biomass sources: In the near term, textile manufacturers must ensure sourcing from verifiable and sustainable biomass sources before adoption. Textile manufacturers should call for standardized definitions from brands that align with existing guidelines (e.g. Institute for Sustainable Communities Guidelines). Across all countries, textile manufacturers should assess medium- to long-term supply and pricing trends to plan for electrification transitions when biomass assets reach retirement or become less economically viable.

Thermal load reduction is a very important option for textile manufacturers without access to RE or sustainable biomass, along with RE policy advocacy.

6.1.3. Textile Heating Electrification Tool

During this planning stage, we encourage brands and textile manufacturers to use the Textile Heating Electrification Tool. Developed by Global Efficiency Intelligence with support from OIA's Clean Heat CoLab and leading apparel brands, it is an open-source, Excel-based tool designed to help textile manufacturers evaluate the energy, emissions, and cost benefits of switching from fossil fuel-based heating to electric technologies. The tool provides country-specific data for key textile-producing regions, analyzes the impact of electricity decarbonization, and provides implementation guidance to support the transition. Additionally, it includes a database of industrial heat pump and electric boiler manufacturers to support textile facilities in decision-making and investment in clean heat technologies.

6.2. Deployment Stage: 2030-2035

6.2.1. Actions for Apparel Brands

During the deployment stage, apparel brands need to direct financial and technical support toward the widespread adoption of electrification technologies while also phasing out biomass due to rising costs and supply chain risks.

Scale thermal load reduction innovations: Completing key actions from 2025-2030 should decrease the CAPEX for thermal load-reducing technologies. Regardless, textile manufacturers will still require implementation support to ensure that their thermal load is sufficiently reduced to optimize electrification. At this time, brands will need to expand funding, technical support, and human resources to support suppliers undertaking continuous thermal load reduction initiatives.

Provide technical support for electrification: By 2030, our study assumes RE procurement will be sufficiently available and heat pumps will be price-competitive with coal in China, India, and Vietnam — enabling a more widespread transition to electrification technologies. Supporting suppliers through technical support for electrification technologies is essential.

- **India's** textile manufacturers may be transitioning from biomass. Brands' efforts should support regions with the most accessible and low-cost PPA markets.
- **Vietnam's** corporate RE procurement market is expected to be more mature by 2030, permitting brands to support manufacturers in electrification while expanding access to PPAs for smaller facilities.
- **Bangladesh's** corporate RE market may be emerging at this stage. Brands must actively establish RE procurement goals and support manufacturers in entering new PPA frameworks as they become available.
- **Indonesia's** RE supply may still be low at this stage. Early electrification efforts can be supported by brands through partnerships with local and international financiers. Brands should also encourage suppliers to phase out biomass as viable RE options expand.

Drive biomass phaseout: Sustainable biomass sources are likely to face limitations during this stage. Brands should help suppliers retire uneconomical biomass boilers and transition to electrified alternatives. Brands' continued advocacy for strict procurement guidelines can help discourage unsustainable biomass sourcing and make the business case for electrification — particularly for facilities facing biomass price increases.

Leverage multiple financing sources financing for electrification: Scaling electrification and RE adoption will require various financing models.

- **China and India** offer pathways for brands to collaborate with financial institutions (e.g. CDB and SBI/SIDBI, respectively) to develop joint financing mechanisms that reduce the financial burden on textile manufacturers.
- **India, Vietnam, Bangladesh, and Indonesia**, which are supported by multilateral development bank finance, offer the opportunity for brands to leverage local partnerships and facilitate large-scale deployment. **However, a key ongoing source of financing for electrification should be direct support and premiums from the brands themselves.**

6.2.2. Actions for Textile Manufacturers

During the deployment stage, textile manufacturers should prioritize procuring long-term RE contracts to provide a stable foundation for the lifetime of electrification projects. Simultaneously, rising biomass prices may require some textile manufacturers to phase it out while preparing for electrification.

Secure Long-Term Renewable Energy Agreements: **A key action for** textile manufacturers across all countries is to secure longer-term RE procurement agreements (such as PPAs), which will form the foundation for electrification efforts.

- **China and India's** RE and electricity spot markets are expected to be well-developed by this stage. Textile manufacturers can consider integrating energy storage systems to participate in grid services like demand response, enhancing both energy cost-efficiency and grid stability.
- **Vietnam, Bangladesh, and Indonesia's** manufacturers should capitalize on emerging RE procurement opportunities as corporate energy markets mature, prioritizing longer-term agreements.

Transition to Electrification and Phasing Out Biomass and Fossil Fuels: As biomass boilers are phased out and sustainable biomass becomes less available, electrification will be the long-term decarbonization solution. Bangladesh, with its heavy reliance on natural gas and developing grid infrastructure, faces a unique challenge in transitioning to electrification. Facilities that can procure RE should conduct techno-economic feasibility studies to identify suitable electrification technologies and integrate these findings into their planning processes.

6.3. Scale-Up Stage: 2035-2040

6.3.1. Actions for Apparel Brands

During the scale-up stage from 2035 to 2040, apparel brands need to support textile manufacturers in transitioning to fully electrified processes powered by renewable energy. By this stage, renewable energy is assumed to be widely available and cost-competitive.

Scale up RE procurement and electrification deployment:

- **China, India, and Vietnam** are assumed to have well-established RE availability and cost-competitive electrification by 2035. Brand collaboration with textile manufacturers to streamline financing mechanisms and ensure the successful deployment of electrification technologies is essential. In India and Vietnam, particular attention must be paid to transitioning from biomass assets reaching the end of their lifecycle.
- **Bangladesh and Indonesia** will require brand support to transition textile manufacturers away from natural gas, coal (Indonesia), and biomass while also backing large-scale renewable energy projects to expand RE supply.

6.3.2. Actions for Textile Manufacturers

Fully Transition to Electrification with 100% RE: Textile manufacturers across all five countries should fully transition their operations to electrification, powered by 100% RE. This phase requires manufacturers to implement electrification technologies at scale while addressing country-specific challenges and opportunities.

- **China, India, Vietnam, and Indonesia**, the transition will be facilitated by the anticipated development of well-established RE procurement systems and grid infrastructure.
- **Bangladesh's** RE availability may lag behind. Manufacturers can focus on hybrid systems or electrification at facilities meeting previously described criteria.

7. Conclusion and Summary of Recommendations

This report has analyzed four different thermal energy technologies for the textile industry, presenting quantitative analysis and an action-oriented roadmap for five major textile-producing countries. Our analysis shows that electrification technologies, heat pumps and electric boilers, hold the most promise for reducing CO_2 emissions from textile and apparel manufacture in all countries. However, their success relies on several assumptions that were difficult to accurately estimate and may not be achievable. Successful electrification will require all stakeholders (manufacturers, brands, governments, etc.) to collaborate and prioritize progress towards clean electricity, RE procurement, and other enabling conditions.

Electricity grids in the studied countries are expected to incorporate higher shares of renewable energy over time. Corporate RE procurement markets in China, India, and Vietnam are poised for strong growth and lower-cost RE for individual facilities in the near future. While corporate RE procurement in Bangladesh and Indonesia is still emerging, mechanisms such as RE PPAs could expand, supporting decarbonization via electrification.

Economically, heat pumps and electric boilers prove to be cost-competitive when factoring in long-term savings from decreasing electricity costs, carbon pricing, and other factors. In all countries studied, heat pumps deliver near-term emissions reductions and cost savings. Piloting steam between now and 2030 and implementing warm water heat pumps presents the biggest emissions and economic opportunity. Electrification is particularly promising in China, India, and Vietnam in the near to medium term, and Bangladesh and Indonesia in the longer term.

Sustainable biomass can reduce CO_2 emissions if sourced from certified sustainable waste, but verifying origins and accounting is a challenge. As demand and price increase, emissions reductions from biomass adoption are less certain than via electrification. **Near-term, sustainable biomass (e.g. agricultural residues) can deliver reductions. Long-term, the supply of sustainable biomass will be limited. It is for this reason that we see electrification as the more viable low-carbon solution for the industry.**

Natural gas may have lower emissions than coal if methane emissions from production are negligible. **However, the limited availability of natural gas in many countries disqualifies it as a practical matter, notwithstanding cost or environmental performance compared to coal.** Our analysis indicates only sustainable biomass is a practical alternative fuel, as natural gas supply and infrastructure are predicted to be in place only in Bangladesh between now and 2040 (Table 7.1.).

Given the policy support for energy storage in many of the studied countries and its role in enabling electrification paired with RE, energy storage can be a key factor for electrification at individual facilities; however, quantitative analysis of storage technologies was outside of the scope of this study.

COUNTRY COMPARISON & SUMMARY: CHINA

	Biomass		**Natural Gas**		**Electrification**					
Overview	**Biomass Availability**	**Impacts of Biomass Steam/ Hot Oil Boiler Adoption**	**Natural Gas Availability**	**Impacts of Natural Gas Steam/Hot Oil Boiler Adoption**	**Grid Electricity**	**Availability of RE for Procurement**	**Impacts of Adopting Steam-Generating Heat Pumps**	**Impacts of Adopting Electric Steam/Hot Oil Boilers**	**Baseline Scenario RE Procurement**	**Ambitious Scenario RE Procurement**
Status	4% of current total national energy supply, but large volumes unused waste sources.	CO_2 emissions reductions depend on biomass source. Unsustainable biomass increases emissions compared to coal.	8% of total energy supply.	Natural gas has a higher cost than coal; less emissions savings relative to sustainable biomass adoption.	Fastest expanding RE capacity globally.	Corporate RE procurement is growing with emerging policy and market mechanisms.	Leads to greater efficiency gains and energy savings relative to electric boilers. Can already result in substantial emissions and energy cost savings by 2030.	CO_2 emission reductions depend on share of RE procurement, and economic feasibility depends on RE cost.	2030 - 50% 2035 - 75% 2040 - 100%	2030 - 100% 2035 - 100% 2040 - 100%
Future Opportunities & Challenges	Government plans to increase utilization; however, biomass boilers regulations vary by province.	Low biomass prices relative to coal may drive near-term adoption. However, prices will increase if demand grows significantly.	40% of natural gas comes from imports and therefore has price volatility and risks.	Natural gas prices are expected to rise, and switching to natural gas boilers will not lower energy costs.	Challenges with RE integration, including transmission constraints and lack of inter-provincial electricity trading and market structure.	GPT and GECs very promising, growing in scale and suitable for textile manufacturers. PPA attractiveness rates 19/30 in a list of majority mature economies.	Steam generating heat pumps still need to be piloted and proven for the textile industry.	Not energy cost competitive in 2030, but can reduce emissions in the near term. Electric steam boilers have lower energy costs by 2035. By 2040, both types of electric boilers expected to be fully competitive with coal boilers.		
Recommen-dation	Explore certified sustainable biomass as an alternative fuel in regions where cheap and certified sustainable biomass is available. Evaluate on a case-by-case basis due to the large regional differences		Limited opportunity as alternative fuel - supply and cost challenges; not aligned to net zero as it is still a fossil fuel		The grid is decarbonizing, but this will not be the main source of electricity for facilities in the near future due to volume of RE needed, market flexibility, and price.	Pursue corporate RE procurement to support electrification, improve the enabling environment.	Implement lower temperature hot water heat pumps from 2025 onwards; pilot steam generating heat pumps so scaled deployment can occur by 2030.	Explore transition to electric steam boilers from 2035 and electric hot oil boilers from 2040 onwards.		

COUNTRY COMPARISON & SUMMARY: INDIA

	Biomass		**Natural Gas**		**Electrification**					
Overview	**Biomass Availability**	**Impacts of Biomass Steam/ Hot Oil Boiler Adoption**	**Natural Gas Availability**	**Impacts of Natural Gas Steam/Hot Oil Boiler Adoption**	**Grid Electricity**	**Availability of RE for Procurement**	**Impacts of Adopting Steam-Generating Heat Pumps**	**Impacts of Adopting Electric Steam/Hot Oil Boilers**	**Baseline Scenario RE Procurement**	**Ambitious Scenario RE Procurement**
Status	22% of energy in India is derived from biomass and waste sources.	Sustainable biomass can deliver energy cost and emissions savings.	6% of total energy supply with 47% coming from imports.	Natural gas has a higher cost than coal and prices are expected to rise.	Rapid expansion of solar energy, becoming one of the lowest-cost sources of energy globally. Despite this, current grid emission factor is still very high.	Most developed corporate RE procurement of all countries studied. India ranks 13/30 on the global PPA index. Third largest generator of solar energy in 2023.	Leads to greater efficiency gains and energy savings relative to electric boilers. Can already result in substantial emissions and energy cost savings by 2030.	CO_2 emission reductions depend on share of RE procurement, and economic feasibility depends on RE cost.	2030 - 50% 2035 - 75% 2040 - 100%	2030 - 100% 2035 - 100% 2040 - 100%
Future Opportunities & Challenges	Large volumes of agricultural waste biomass available and already being used by textile manufacturers.	Not a long-term decarbonization solution as supply is limited. After 2030, focus on phase out as as electrification becomes widely implementable and biomass prices increase.	Reliance on imports results in high price volatility. Ability to switch to natural gas is dependent on local infrastructure.	More expensive than coal in all time horizons, less emissions savings than sustainable biomass.	Grid decarbonizing, but still not fast enough to meet textile industry demand and will have to be coupled with corporate RE procurement mechanisms. Grid infrastructure upgrades needed to deal with this increase in RE and electrification of industry.	PPA market is most favorable of the countries studied and RE can deliver lower-cost electricity relative to the grid. Requires policy stability and improved grid connectivity to maintain this trend.	Steam generating heat pumps still need to be piloted and proven for the textile industry.	Not energy cost competitive in 2030, but can reduce emissions in the near term. Electric steam boilers have lower energy costs by 2035. By 2040, both types of electric boilers expected to be fully competitive with coal boilers.		
Recommendation	Textile manufacturers should procure traceable and certifiable sustainable biomass sources. Monitor biomass price compared to corporate RE procurement. Transition away from biomass once the assets retire, sustainable sources of biomass run out, or the economics of electrification with RE procurement becomes economically feasible.		Due to substantially higher costs compared to coal, minimal emissions reductions compared to other sources, and logistical challenges for facilities to access, do not recommend as an alternative fuel in India.		The grid is decarbonizing, but this will not be the main source of electricity for facilities in the near future due to volume of RE needed, market flexibility, and price.	Pursue corporate RE procurement to support electrification, improve the enabling environment.	Implement lower temperature hot water heat pumps from 2025; pilot steam generating heat pumps so that by 2030 scaled deployment can occur.	Explore transition to electric steam boilers from 2035 and electric hot oil boilers from 2040 onwards.		

COUNTRY COMPARISON & SUMMARY: VIETNAM

	Biomass		**Natural Gas**		**Electrification**					
Overview	**Biomass Availability**	**Impacts of Biomass Steam/ Hot Oil Boiler Adoption**	**Natural Gas Availability**	**Impacts of Natural Gas Steam/Hot Oil Boiler Adoption**	**Grid Electricity**	**Availability of RE for Procurement**	**Impacts of Adopting Steam-Generating Heat Pumps**	**Impacts of Adopting Electric Steam/Hot Oil Boilers**	**Baseline Scenario RE Procurement**	**Ambitious Scenario RE Procurement**
Status	10% of national energy comes from biomass and waste sources, with government plans to increase.	Biomass is widely used as an alternative fuel to coal, delivering energy cost and emissions savings.	7% of national energy supply comes from natural gas.	Natural gas has a higher cost than coal and is expected to rise.	Vietnam has a 2050 net zero target, and will likely transition to a clean grid earlier than other studied countries.	Direct PPAs were established in July 2024.	Leads to greater efficiency gains and energy savings relative to electric boilers. Can already result in substantial emissions and energy cost savings by 2030.	CO_2 emission reductions depend on share of RE procurement, and economic feasibility depends on RE cost.	2030 - 50% 2035 - 75% 2040 - 100%	2030 - 100% 2035 - 100% 2040 - 100%
Future Opportunities & Challenges	Availability of sustainable biomass (rice husks) is limited. Biomass adoption is well under way for textile plants. Textile mills will compete with other industries.	2030 - Monitor provenance and commence phase out due to higher risk of unsustainable biomass than other countries. 2035 - Phase out biomass as electrification becomes widely implementable. 2040 - Complete phase out of biomass.	Government is increasing natural gas imports for the power sector. Increased infrastructure is limited to port areas. Natural gas is unlikely to be available to textile manufacturers.	Substantially more expensive than coal in all time horizons, less emissions savings than sustainable biomass.	Electricity demand growing rapidly. Government has reduced solar incentives to mitigate grid challenges.	New mechanism means regulatory challenges for implementation. Ease of implementation should increase over time.	Steam generating heat pumps still need to be piloted and proven for the textile industry.	Not energy cost competitive in 2030 or 2035, but both electric steam and hot oil boilers can deliver emissions reductions. By 2040, energy costs are competitive with coal boilers, especially for electric steam boilers.		
Recommendation	Less available sustainable biomass than India and China due to high existing utilization. Higher risk of sourcing unsustainable biomass. Sourcing should be carefully monitored and certifications required. Monitor availability of certified sustainable biomass and transition to electrification when availability decreases and price increases. May need to transition sooner than other geographies to avoid increased emissions and other environmental impacts through unsustainable biomass.		Due to substantially higher costs compared to coal, minimal emissions reductions compared to other sources, and logistical challenges for facilities to access. Do not recommend as an alternative fuel in Vietnam.		Brands and textile manufacturers should encourage continued grid development to enable the planned increase of RE.	Brands and textile manufacturers should explore current feasibility of DPPAs and continue to collaborate to expand their scope and accessibility.	Implement lower temperature hot water heat pumps from 2025 onwards; pilot steam generating heat pumps so scaled deployment can occur by 2030.	Explore transition to electric steam and hot oil boilers by 2040.		

COUNTRY COMPARISON & SUMMARY: BANGLADESH

	Biomass		**Electrification**					
Overview	**Biomass Availability**	**Impacts of Biomass Steam/ Hot Oil Boiler Adoption**	**Grid Electricity**	**Availability of RE for Procurement**	**Impacts of Adopting Steam-Generating Heat Pumps**	**Impacts of Adopting Electric Steam/Hot Oil Boilers**	**Baseline Scenario RE Procurement**	**Ambitious Scenario RE Procurement**
Status	Availability of sustainable biomass is lowest of countries studied.	The use of unsustainable biomass would result in more emissions increase relative to other countries due to the lower emission factor of natural gas, the currently used fuel.	92-98% of electricity is powered by fossil fuels. The grid already has major stability issues without an influx of RE or electrification. Significantly less mature grid structure than the other countries studied.	RE supply is limited. There are some ad hoc examples of PPAs, but no formal framework.	Leads to greater efficiency and energy savings relative to electric boilers. Can already result in substantial savings by 2030, even with minimal RE procurement.	Reducing emissions through electric boilers requires at least 50% share of procured RE. This is only achieved by 2040 in our Baseline Grid Plus RE Procurement pathway.	2030 - 0% 2035 - 30% 2040 - 50%	2030 - 30% 2035 - 50% 2040 - 100%
Future Opportunities & Challenges	Biomass availability competes with residential use and growing demand for power generation. Sustainable biomass supply cannot meet the textile industry's demand.	While biomass prices increase over time, so do natural gas prices. If sustainable biomass can be secured, this is a viable alternative fuel from an emissions perspective across the time horizons.	Increasing reliance on price-volatile fuel imports for electric power generation. Growing interest in energy storage and RE to increase grid capacity.	Discussions are underway to develop a Corporate Power Purchasing (CPP) framework for RE. Our analysis assumes RE will be widely available by 2035 based on current trajectories. This may change with a CPP framework.	Significant emissions and cost savings over time, but the technology needs to be piloted and demonstrated in Bangladesh.	2030- Emissions and costs would rise substantially for electric steam and hot oil boilers in 2030. 2035 - RE becomes available and we start to see emissions decreasing but costs remain slightly higher than natural gas for both technologies. 2040 - With RE widely available both steam and hot oil boilers see emissions reductions. Only steam boilers are price competitive.		
Recommendation	Due to limited sustainable supply, biomass will rarely be a viable alternative to natural gas.		Engage with policy makers to support grid decarbonization and modernization.	Engage with policy makers to support CPP implementation and enable electrification.	Evaluate the potential for heat pumps in the short-medium term. Despite the efficiency, there will be challenges associated with grid connectivity and reliability. This needs to be assessed site-by-site, and energy storage is likely to be a core feature to enable this technology.	Electric steam boilers under current assumptions can deliver emissions and cost savings from 2040. Electric hot oil boilers deliver emissions savings but remain more expensive even in 2040. Policy advocacy on corporate RE availability is key to unlocking electric boilers in Bangladesh.		

COUNTRY COMPARISON & SUMMARY: INDONESIA

	Biomass		**Natural Gas**		**Electrification**					
Overview	**Biomass Availability**	**Impacts of Biomass Steam/ Hot Oil Boiler Adoption**	**Natural Gas Availability**	**Impacts of Natural Gas Steam/Hot Oil Boiler Adoption**	**Grid Electricity**	**Availability of RE for Procurement**	**Impacts of Adopting Steam-Generating Heat Pumps**	**Impacts of Adopting Electric Steam/Hot Oil Boilers**	**Baseline Scenario RE Procurement**	**Ambitious Scenario RE Procurement**
Status	As the world's largest producer of palm oil, palm kernel husks are readily available. This commodity, however, has an extremely high deforestation risk.	Sustainable biomass reduces emissions but offers limited cost savings (compared to other countries) due to subsidized coal prices.	14% of energy comes from natural gas. Only 3% is imported.	Natural gas is more expensive than coal and is expected to increase in price.	The grid is heavily reliant on coal. Less than 3% of the country's RE potential has been harnessed so far.	PPAs are being signed in other sectors, but the market is nascent.	Leads to greater efficiency and energy savings relative to electric boilers. Can already result in substantial savings by 2030, even with minimal RE procurement.	CO_2 emission reductions depend on RE procurement, and feasibility depends on RE cost.	2030 - 25% 2035 - 50% 2040 - 75%	2030 - 50% 2035 - 75% 2040 - 100%
Future Opportunities & Challenges	This biomass source is exported and targeted for power generation, increasing competition for supply.	Very high risk of unsustainable biomass; provenance must be carefully monitored.	Domestic production is declining and reliance on imported LNG is increasing, potentially impacting costs. Infrastructure for distribution is also less mature, limiting access for industrial facilities.	More expensive than coal in all time horizons; less emissions savings than sustainable biomass for steam boilers.	The Just Energy Transition Partnership will leverage international support to develop transmission infrastructure for RE integration. With plans to become a global battery exporter by 2030, energy storage should be cheaper, and grid and manufacturers will be able to adopt this technology.	Corporate RE mechanisms are emerging; however, scaling challenges persist. Limitations on private electricity suppliers and lack of regulatory frameworks continue.	Energy cost parity with coal is reached in 2030, and becomes more competitive after that. Emissions reductions begin in 2030.	2030 - Emissions and energy costs increase in the Baseline RE Procurement pathway. 2035 - Emissions decrease, but energy costs remain uncompetitive - even in 2040.		
Recommendation	Due to deforestation risks, biomass should be carefully evaluated to ensure certified sustainable sources are used. Only RSPO and other certified husks should be procured; however, these are in limited supply and more expensive.		Adopting natural gas as an alternative fuel is likely to be logistically challenging and increase cost. This will not be a large scale solution.		Engage with policy makers to support grid decarbonization and modernization.	Engage with policy makers to broaden possibilities for corporate RE procurement.	Explore heat pumps as a cost neutral but emissions saving solution from 2030 onwards.	Coal subsidies must be removed to make electric boilers economically feasible. Recommend to engage in policy advocacy.		

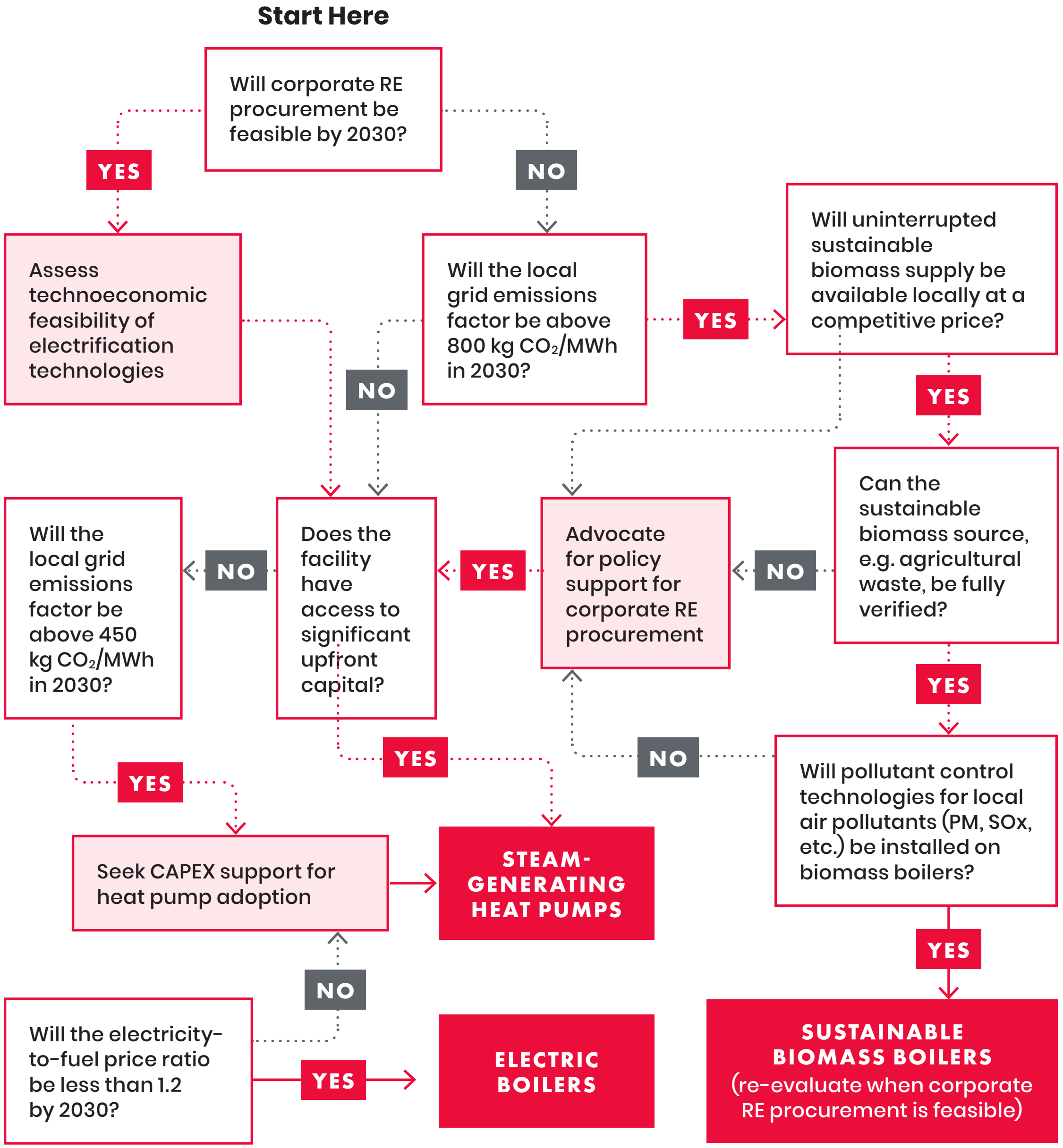
7.1. Decision Tree For Textile Facilities Seeking To Adopt Low-Carbon Thermal Energy Technologies

Based on these considerations, we have developed a simplified decision tree to help decision-makers at textile facilities in the studied countries assess their best-fit low-carbon thermal heating option.

1. Facilities must first evaluate corporate RE procurement feasibility by 2030, as our analysis has shown that this is a key enabler of electrification decarbonization.
2. If RE procurement is available, facilities should assess electrification options. The choice between electric boilers and heat pumps depends on the electricity-to-fuel price ratio and access to upfront capital. Electric boilers may be competitive in terms of energy costs with conventional boilers at an electricity-to-fuel price ratio of about 1.2 based on their efficiency gains, while heat pumps may require additional CAPEX support — even without significant energy savings. Electric boilers only deliver reductions if the grid emissions factor is below 450 kgCO_2/MWh.
3. If corporate RE procurement is not feasible, heat pumps can still reduce emissions — even with a carbon-intensive grid — due to their efficiency.
4. If the current grid emissions factor is too high and heat pumps are not financially feasible, the decision moves towards sustainable biomass. Biomass adoption is contingent on an uninterrupted, competitively priced supply with verified sustainability and the use of pollutant control technologies.
5. Facilities unable to meet these criteria should consider advocating for stronger RE procurement policies.

Applying this decision tree, heat pumps could deliver emissions reductions in all studied countries — even with the current grid emissions factor, while electric boilers would not reduce emissions and would require additional RE procurement. This decision tree is a simplification: age and efficiency of existing boilers, available space, maintenance capabilities, specific process heat requirements, and other facility-level considerations also influence the choice of technology. While this decision tree is a high-level guide, decisions will require a detailed, facility-specific evaluation.

FIGURE 7.1: DECISION TREE FOR TEXTILE FACILITIES IN THE STUDIED COUNTRIES SEEKING TO ADOPT LOW-CARBON THERMAL ENERGY TECHNOLOGIES



7.2. Recommendations

Each low-carbon thermal energy option in this report holds the potential for CO_2 emissions reductions but faces serious challenges. Unaddressed, emissions and costs for textile manufacturing could increase in a worst-case scenario. To prevent this and ensure success, it's critical to understand each technology's techno-economic potential and the policies, regulations, programs, and incentives required to deliver their success. The prior sections assessed the energy and policy landscape in each country. Here, we present stakeholder recommendations for the next 15 years, applicable for low-carbon thermal energy transition in textile plants across the studied countries. We divide the roadmap into the Plan & Pilot Stage (2025 to 2030); Deployment Stage (2030-2035); and the Scale-Up Stage (2035-2040).

2025 TO 2030 (Near Term — Plan & Pilot Stage)

Apparel Brands: Between 2025 and 2030, brands must lead funding to pilot heat pump projects in textile plants, particularly in China and India where RE is the most available RE. Brand support in the following areas is pivotal: investing in the adoption of low-carbon technologies such as heat pumps; working with textile manufacturers to reduce thermal load through best practice energy efficiency, and piloting innovative technologies. Brands can also promote renewable energy use by helping supply chain partners adopt cleaner energy solutions and advocating for RE in key regions. Apparel brands should also verify sustainable biomass sourcing.

India and Vietnam must be cautious in expanding the textile industry's biomass use, and Bangladesh and Indonesia face significant environmental and social risks, respectively, for biomass adoption. Brands and manufacturers must collaborate to assess their biomass supply chains and conduct a risk assessment on supply over time. Policy advocacy is essential to alleviate regulatory, market, and infrastructural barriers to electrification.

Textile Manufacturers: To lay the foundation for electrification, textile manufacturers should continue to improve energy efficiency and pilot innovative thermal load reduction technologies. Brands should provide manufacturers with technical and financial support for pilot projects on low-carbon technologies, focusing on heat pumps in China and India near-term and in the longer term in the other countries. The role of textile manufacturers will include implementing these technologies in their operations to test feasibility and identify potential challenges. Manufacturers should train their workforce to use and maintain new technologies, ensuring a smoother scale-up transition in the following stages.

Manufacturers should collaborate with apparel brands and other stakeholders to create long-term investment plans and secure brand commitment.

2030 TO 2035 (Deployment Stage)

Apparel Brands: From 2030 to 2035, apparel brands should prioritize scaling successful pilots by promoting adoption within their supply chains. They should encourage a broader set of suppliers to adopt low-carbon technologies and continue to provide financial support for expansion across regions. As sustainable biomass supply declines and supply increases, brands should recommend phaseout.

Textile Manufacturers: Textile manufacturers must scale successful pilot projects and integrate renewable energy procurement into their operations. Manufacturers should also analyze data from pilots to justify further electrification investment. Continued workforce development is essential as technologies expand. Biomass phaseout should begin, with electrification plans for boilers reaching end-of-life or supply and cost issues.

2035 TO 2040 (Scale-Up Stage)

Apparel Brands: By 2040,l brands must integrate low-carbon thermal technologies into their supply chains. They should collaborate with manufacturers to share lessons learned and support technology scaling across facilities. Ongoing technical, financial, and advocacy support will ensure textile manufacturers fully transition to electrification paired with RE.

Textile Manufacturers: In this final stage, textile manufacturers must complete the transition to 100% or near-100% RE-powered heating. The transition is enabled by procuring only 100% RE from 2030 onwards and will require optimized operations, maximum energy and emissions reductions and engagement in utility programs such as demand response and time-of-use pricing. Collaboration with other stakeholders will support the full adoption of electrification technologies.

8. References

Aggarwal, Varun, Bhavna Prasad, Aastha Makhija, Vinay Rustagi, and Raghvendra Upadhyaya. 2019. "Global Corporate Renewable Power Procurement Models: Lessons for India." WWF India. d2391rlyg4hwoh.cloudfront.net/downloads/global_corporate_renewable_power_procurement_models.pdf

Allotrope Partners. 2024. "Vietnam Corporate Clean Energy Procurement: Market Overview Report for Commercial and Industrial Energy Customers." Clean Energy Buyers Institute. cebi.org/wp-content/uploads/2024/03/CEBI-Global-Vietnam-Market-Assessment-Report-Deck.pdf

Antara News. 2024. "Use of Renewable Energy Certificates Increased by 75 Percent: PLN." Antara News. January 2, 2024. en.antaranews.com/news/302238/use-of-renewable-energy-certificates-increased-by-75-percent-pln

BEIPA. 2024. "3060零碳生物质能潜力蓝皮书." beipa.org.cn/productinfo/945230.html

Binh, Tran Duy. 2024. "Power Development Plan 8 – Key Developments in Renewable Energy for Vietnam - KPMG Vietnam." KPMG. July 12, 2024. kpmg.com/vn/en/home/insights/2023/09/pdp-8-key-developments-in-renewable-energy-for-vietnam.html

Butt, Muhammad Salman. 2022. "Evaluating Renewable Thermal Energy Options for Textile and Garments Sectors in Bangladesh and Pakistan: Prefeasibility Study." GIZ.

Chauhan, Anurag, Subho Upadhyay, Gaurav Saini, and N. Senthilkumar. 2022. "Agricultural Crop Residue Based Biomass in India: Potential Assessment, Methodology and Key Issues." *Sustainable Energy Technologies and Assessments* 53 (October):102552. doi.org/10.1016/j.seta.2022.102552

Clean Energy Solutions Center, dir. 2019. Corporate Solar PV Adoption: *Case Studies from Developing Countries* youtube.com/watch?v=Zi7nnp5WHcc

Ember Climate. 2024. "India | Electricity Trends." Ember. 2024. ember-climate.org/countries-and-regions/countries/india

Enerdatics. 2022. "Corporate PPA: Amazon Signs First Renewable Energy PPA in Indonesia...," 2022. enerdatics.com/blog/corporate-ppa-amazon-signs-first-renewable-energy-ppa-in-indonesia-agrees-to-off-take-210-mw-of-solar-power

EY. 2024. "EY PPA Index 2024." ey.com/content/dam/ey-unified-site/ey-com/en-gl/insights/energy-resources/documents/ey-gl-recai-63-ppa-index-06-2024.pdf

Global Energy. 2024. "Indonesia to Facilitate Grid Access for Independent Power Producers - The Global Energy Association." Global Energy (blog). July 12, 2024. globalenergyprize.org/en/2024/07/12/indonesia-to-facilitate-grid-access-for-independent-power-producers

Global Energy Monitor. 2023. "Global Gas Infrastructure Tracker." Global Energy Monitor (blog). December 19, 2023. globalenergymonitor.org/projects/global-gas-infrastructure-tracker

Gulagi, Ashish, Manish Ram, A. A. Solomon, Musharof Khan, and Christian Breyer. 2020. "Current Energy Policies and Possible Transition Scenarios Adopting Renewable Energy: A Case Study for Bangladesh." *Renewable Energy* 155 (August):899–920. doi.org/10.1016/j.renene.2020.03.119

Hasanbeigi, Ali, Cecilia Springer, and Dennis Wei. 2024. "Low-Carbon Thermal Energy Technologies for The Textile Industry." Global Efficiency Intelligence. apparelimpact.org/resources/report-low-carbon-thermal

Hasanbeigi, Ali, Cecilia Springer, Jibran Zuberi, Hongyou Lu, and Nan Zhou. 2024. "Electrifying Industrial Heating in China." Global Efficiency Intelligence. globalefficiencyintel.com/electrifying-industrial-heating-in-china

Hasanbeigi, Ali, and Jibran Zuberi. 2022. "Electrification of Heating in the Textile Industry." Global Efficiency Intelligence. globalefficiencyintel.com/electrification-of-heating-in-the-textile-industry

Intergovernmental Panel on Climate Change. 2006. "IPCC Guidelines for National Greenhouse Gas Inventories." .ipcc-nggip.iges.or.jp/public/2006gl

International Energy Agency. 2022. "World Energy Outlook 2022." iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf

International Trade Administration. 2024. "Vietnam - Power Generation, Transmission, and Distribution." U.S. Department of Commerce. January 30, 2024. trade.gov/country-commercial-guides/vietnam-power-generation-transmission-and-distribution

Islam, Md. Tasbirul, S. A. Shahir, T. M. Iftakhar Uddin, and A. Z. A Saifullah. 2014. "Current Energy Scenario and Future Prospect of Renewable Energy in Bangladesh." *Renewable and Sustainable Energy Reviews* 39 (November):1074–88. doi.org/10.1016/j.rser.2014.07.149

Islam, Syful. 2024. "IB Vogt Secures PPA for 50 MW Solar Power Plant in Bangladesh." *Pv Magazine International*, August 1, 2024. pv-magazine.com/2024/08/01/ib-vogt-secures-ppa-for-50-mw-solar-power-plant-in-bangladesh

Lan, Ruoyu, Sebastian D. Eastham, Tianjia Liu, Leslie K. Norford, and Steven R. H. Barrett. 2022. "Air Quality Impacts of Crop Residue Burning in India and Mitigation Alternatives." *Nature Communications* 13 (1): 6537. doi.org/10.1038/s41467-022-34093-z

Lu, Hongyou; Rissman, Jeffrey; Swae, Nikhil; Tian, Zhiyu; Zhou, Nan. 2024. "Clean Industry in China: A Techno-Economic Comparison of Electrified Heat Technologies, Barriers, and Policy Options." doi.org/10.20357/B70894

Lu, Shutong (Lucy), Yihan Hao, Yi Jiang, and Ting Li. 2023. "Corporate Green Power Procurement in China: Progress, Analysis, and Outlook." RMI. rmi.org/insight/corporate-green-power-procurement-in-china

McKinsey and Company. 2024. "Industrial Heat Pumps: Five Considerations for Future Growth." mckinsey.com/industries/industrials-and-electronics/our-insights/industrial-heat-pumps-five-considerations-for-future-growth?cid=soc-web

Michael, Saloni Sachdeva. 2024. "Fixing India's Power Market to Help Add More Renewables." IEEFA (blog). 2024. ieefa.org/resources/fixing-indias-power-market-help-add-more-renewables

Mitrova, Tatiana, and et al. 2016. "Global and Russian Energy Outlook." researchgate.net/publication/314216143_Global_and_Russian_Energy_Outlook_2016

Nandy, Paulomi, Kiran Thirumaran, Chris Price, Ahmad Abbas, Sachin U. Nimbalkar, Thomas Wenning, Hannah Kramer, et al. 2023. "Framework for Greenhouse Gas Emissions Reduction Planning: Industrial Portfolios." ORNL/SPR--2023/3009, 2251616, DOE/EE-2745. doi.org/10.2172/2251616

Newsdesk, Vietnam. 2024. "Vietnam Approves Direct Power Purchase Agreement Mechanism for Renewables Projects." *S&P Global*, July 5, 2024. spglobal.com/commodityinsights/en/market-insights/latest-news/lng/070524-vietnam-approves-direct-power-purchase-agreement-mechanism-for-renewables-projects

Nie, Shangyou, Anne-Sophie Corbeau, and Diego Rivera Rivota. 2023. "Understanding Vietnam's Emergence as the World's Newest LNG Importer." *Center on Global Energy Policy at Columbia University SIPA* | CGEP (blog). 2023. energypolicy.columbia.edu/qa-understanding-vietnams-emergence-as-the-worlds-newest-lng-importer

O'Neil, John, Kiran Thirumaran, Kalie Miera, Blake Billings, Paulomi Nandy, Thomas Wenning, Baskar Vairamohan, Scott Bishop, Brandon Johnson, and Stephen Perry. Forthcoming. "Industrial Electrification Assessment Framework." Oak Ridge National Laboratory.

Price, Chris R., Sachin U. Nimbalkar, and Thomas J. Wenning. 2020. "Energy Intensity Baselining and Tracking Guidance." ORNL/SPR-2020/1566. Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States). doi.org/10.2172/1649123

Qiu, Yue, Suyang Zhou, Wei Gu, and Xiao-Ping Zhang. 2024. "Analysis of China's Electricity Price and Electricity Burden of Basic Industries Under the Carbon Peak Target Before 2030." CSEE Journal of Power and Energy Systems 10 (2): 481–91. doi.org/10.17775/CSEEJPES.2021.07620.

Rahman, Asifur. 2023. "Big Hike in Gas Prices for Bangladesh's Power Plants, Industry." Asia News Network, 2023. asianews.network/big-hike-in-gas-prices-for-bangladeshs-power-plants-industry

Rahman, Azizur. 2024. "Bangladesh Raises Domestic Natural Gas and Electricity Prices." S&P Global Commodity Insights, January 3, 2024. spglobal.com/commodity-insights/en/news-research/latest-news/lng/030124-bangladesh-raises-domestic-natural-gas-and-electricity-prices

Rao, Harsha, and Disha Agarwal. 2022. "Corporate Renewable Energy Procurement Continues to Face Challenges | CEF Analysis." CEF | CEEW (blog). 2022. ceew.in/cef/quick-reads/analysis/corporate-renewable-energy-procurement-continues-to-face-challenges

RenewablesNow. 2022. "Nickel Industries Signs Term Sheet for 200-MWp Solar Project in Indonesia." *Renewablesnow.Com*, 2022. renewablesnow.com/news/nickel-industries-signs-term-sheet-for-200-mwp-solar-project-in-indonesia-795149

Rhofita, Erry Ika, Ridwan Rachmat, Michel Meyer, and Ludovic Montastruc. 2022. "Mapping Analysis of Biomass Residue Valorization as the Future Green Energy Generation in Indonesia." *Journal of Cleaner Production* 354 (June):131667. doi.org/10.1016/j.jclepro.2022.131667

Stroh, Kelly. 2024. "H&M's 'Green' Financing Tool Supports Supplier Sustainability." *Supply Chain Dive*, 2024. supplychaindive.com/news/hm-sustainable-sourcing-collaborative-financing-future-supplier-initiative/714378

Tanahair.net. 2024. "Indonesia Focuses on Building Super Grid as Renewable Energy Utilisation Is Still Minimal." March 8, 2024. tanahair.net/indonesia-focuses-on-building-super-grid-as-renewable-energy-utilisation-is-still-minimal

U.S. Department of Energy. 2022. "Industrial Decarbonization Roadmap." energy.gov/eere/doe-industrial-decarbonization-roadmap

World Bank. 2024. World Development Indicators. databank.worldbank.org/source/world-development-indicators

World Bank. 2018. "Biomass Resource Mapping In Vietnam." documents1.worldbank.org/curated/en/428301536212059608/pdf/Final-Report-on-Biomass-Atlas-for-Vietnam.pdf

Yu, Aiqun, Sophie Lu, Kasandra O'Malia, and Shradhey Prasad. 2024. "China Continues to Lead the World in Wind and Solar, with Twice as Much Capacity under Construction as the Rest of the World Combined." Global Energy Monitor. globalenergymonitor.org/report/china-continues-to-lead-the-world-in-wind-and-solar-with-twice-as-much-capacity-under-construction-as-the-rest-of-the-world-combined

Zuberi, M., Ali Hasanbeigi, and William Morrow. 2021. "Electrification of Boilers in U.S. Manufacturing." doi.org/10.2172/1867393