ACCELERATING INDUSTRIES' CLIMATE RESPONSE SRI LANKA

INDUSTRIAL ENERGY EFFICIENCY AND DECARBONIZATION IN SRI LANKA

A DIAGNOSTIC ASSESSMENT REPORT

UNITED NATIONS
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Executive summary

The industry sector in Sri Lanka is a crucial part of the country's socio-economic fabric, contributing significantly to GDP and providing substantial employment to people in Sri Lanka. Similar to many developing nations, Sri Lanka's industrial sector is undergoing rapid expansion and transformation, which has implications for energy use and carbon emissions. These implications pose challenges to the country's energy security and commitment to meeting its Paris Agreement goals outlined in Sri Lanka's Nationally Determined Contribution (NDC).

In response to this situation, we are conducting an analysis of Sri Lanka's industry sector, particularly focusing on its energy efficiency and decarbonization policies and opportunities. Collaborating with the Ministry of Industries, we are studying the feasibility of reinforcing NDCs in the industrial sector through various measures. Our findings illuminate the current landscape of policies and regulations related to industrial energy efficiency and decarbonization and highlight the institutional needs and capacity gaps that must be addressed to move Sri Lanka towards its climate goals.

Our analysis shows that the industrial sector in Sri Lanka, inclusive of mining, construction, and manufacturing, has grown substantially from 2000 to 2021. The industrial energy intensity decreased from 2003-2017 but experienced an increase from 2017-2021. In analyzing CO2 emissions, we calculated both electricity- and fuel-related emissions, noting that if biomass is deemed carbon-neutral, associated emissions would not be accounted for. However, the carbon neutrality of biomass is increasingly under scrutiny. To the extent we could obtain data, we analysed industrial energy use by subsector. In addition, we estimated industrial motor systems energy use using various international studies.

There are a range of pressing challenges to industrial decarbonization in Sri Lanka. There's an urgent need for a comprehensive policy framework dedicated to promoting energy efficiency and decarbonization, an effective measurement, reporting, and verification (MRV) system, and a transparent system of data collection and dissemination concerning industrial energy use and emissions. The shortage of a skilled workforce and limited technical knowledge in energy management and sustainable industrial processes pose further impediments. Moreover, the infrastructure deficit and lack of accessible financing mechanisms create barriers for the adoption of energy-efficient technologies.

We also analyzed various energy-efficiency technologies and measures for different industrial motor systems. Using the bottom-up energy-efficiency cost curve model, we estimated cost-effective electricity-savings potentials for each industrial motor systems type in Sri Lanka, separately. We also estimated total technical electricity-savings potentials (what is technologically possible), assuming 100% adoption of series of efficiency measures.
Table ES-1 summarizes the energy-savings results.

Table ES-1. Industrial motor systems electricity-savings potential in Sri Lanka in 2021

	Cost-Effective Energy Saving Potential (GWh/yr)	Technical Energy Saving Potential (GWh/yr)
Pump systems	272	283
Fan systems	170	178
Compressed air systems	151	192

The share of total technical electricity-savings potential for industrial pump systems compared to total industrial pump systems energy use is 45%. The share of total technical electricity-savings potential for industrial fan systems compared to total industrial fan systems energy use in Sri Lanka is 36%. Furthermore, the share of total technical electricity-savings potential for industrial compressor systems compared to total industrial compressor systems energy use is 39%. The CO2 emissions reduction associated with the electricity-savings potential will help the country to meet its greenhouse gas (GHG) emissions reduction targets.

To achieve the deep decarbonization goal for industry, five industrial decarbonization pillars must be vigorously pursued in parallel: energy efficiency, material efficiency and demand management, electrification, low-carbon fuels, feedstocks and energy sources (LCFFES), and carbon capture, utilization, and storage (CCUS). These industrial decarbonization pillars are explained in more detail in this report.

The report also outlines a set of policy recommendations and action plans to address significant challenges hindering industrial energy efficiency and decarbonization in Sri Lanka. The proposed measures encompass the development of energy standards, innovative funding mechanisms, and target agreements with financial incentives, aiming to accelerate the adoption of decarbonization technologies. Skills and capacity building programs are emphasized to cultivate a proficient cohort of experts, supported by international organizations like UNIDO. The establishment of a robust data collection framework is recommended to track progress, while sector-specific net-zero roadmaps and awareness campaigns are proposed for key industries. A monitoring and evaluation framework is highlighted to ensure program effectiveness, and institutional arrangements, including the formation of a National Industrial Energy Efficiency and Decarbonization Committee, are suggested to facilitate policy formulation and implementation.

We also introduce the "Top-100 Energy-Consuming Enterprise Program," a proactive policy proposal aimed at significantly enhancing industrial energy efficiency and decarbonization in Sri Lanka. Drawing inspiration from successful international best practices in both developing and developed countries, the program involves agreements between the government and the top 100 energy-intensive enterprises, establishing targets and commitments over five-year periods. These enterprises are expected to form energy management working groups, conduct energy audits, benchmark efficiency, implement energy management systems, and adopt decarbonization measures. The government's role includes organizing training workshops, providing incentives, and collaborating with international entities for support. Financing mechanisms, information dissemination, and a comprehensive monitoring and evaluation framework further contribute to the program's effectiveness.

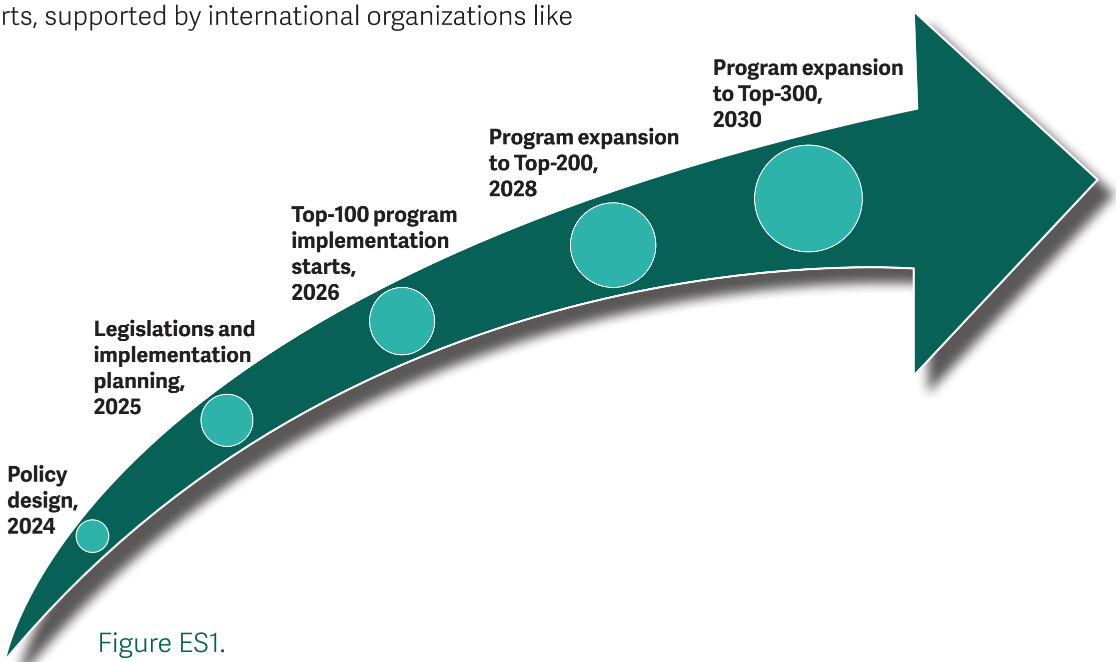

Figure ES1.
The suggested timeline for design, implementation, and expansion of Top-100 Energy-Consuming Enterprise Program in Sri Lanka

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1 Introduction

In the year 2022, Sri Lanka was confronted with the most severe economic crisis in its history. This was provoked by a confluence of political and economic elements, leading to a deficit in foreign reserves, which in turn resulted in shortages in imported fuel. The industrial sector of the country, like many others, was deeply impacted by this crisis. One of the significant repercussions was regular power cuts experienced by industries due to the scarcity of imported fossil fuel, which also precipitated a shortage of fuel oil, diesel, and liquid petroleum gas.

Moreover, the dearth of foreign reserves-imposed limitations on the importation of raw materials required for local industries. To add to the complexity, the economic crisis induced high inflation rates, which negatively influenced the demand for various products and services due to inflated prices and reduced purchasing power of consumers.

Prior to the crisis, Sri Lanka was already burdened with one of the highest average costs of power generation when compared to other nations in the region. This led to increased exposure to the volatility of international energy prices and markets. As a statistic, the industrial sector consumes approximately 15% of imported oil products and 33% of electricity, thereby being directly affected by escalating energy costs and an unreliable power supply.

Furthermore, Sri Lanka has also become increasingly susceptible to the detrimental impacts of climate change. The country is witnessing a rising frequency of heatwaves and droughts, followed by floods and landslides. Industries have been subjected to significant losses due to damages to critical infrastructures such as access roads, factories, and electricity transmission and distribution networks caused by these extreme weather events.

Sri Lanka's total national CO_2 emissions has doubled in the past 20 years driven by economic growth and also increased share of coal in national energy mix (IEA 2022). Since Sri Lanka is a developing country and is expected to grow and industrialize even more, the demand for energy is expected to increase. This will result in an increase in national GHG emissions in the absence of concrete energy efficiency and decarbonization policies and programs in Sri Lanka.

In the updated Nationally Determined Contributions (NDCs) issued by the Ministry of Environment in 2021, Sri Lanka has pledged to raise its forest cover to 32% by the year 2030. Simultaneously, the country has set an ambitious goal of decreasing greenhouse gas (GHG) emissions by 14.5% from 2021 to 2030. This target spans across several sectors, including Power (specifically electricity generation), Transport, Industry, Waste, Forestry, and Agriculture.

The establishment of these goals is guided by the nation's aspiration to generate 70% of its electricity from renewable energy sources by 2030. This progression is aimed at achieving carbon neutrality in electricity generation by 2050, based on the assumption that the country will not be adding any more coal power plants to its energy mix. Given these strategies and commitments, Sri Lanka envisions realizing its carbon neutrality by 2050.

According to the Department of Census and Statistics' Annual Survey of Industries (ASI) for 2021, there were over 23,000 industrial establishments in Sri Lanka. Many of these establishments are small businesses. As per the Central Bank Annual Report of 2022, industrial production is the second most substantial contributor to the nation's GDP at 14.1% (CBS, 2023). Additionally, it is notable that the industrial sector employs nearly 30% of Sri Lanka's workforce. The sub-sectors that are most oriented towards export include textiles, apparel, and tea manufacturing (MOE, 2021)[1]. Therefore, the industry sector is a key contributor to the economy as well as national GHG emissions. Decarbonizing the industry sector will be critical for Sri Lanka in achieving its climate goals.

In response to this, the 'Accelerating Industries' Climate Response in Sri Lanka' is a 5-year Project set in motion under the European Union GCCA+ initiative. This initiative is designed to aid the world's most vulnerable countries in responding to climate change. The project's primary objective is to contribute to climate change mitigation by assisting in the implementation of Sri Lanka's Nationally Determined Contributions (NDCs) for the industrial sector. The specific aim is to amplify the climate change response of Sri Lanka's industrial sector by designing and implementing technical, policy, regulatory, and financial tools and mechanisms. This would hasten the development of renewable energy and improve energy and resource efficiency technologies and best practices.

The activities and sub-activities of this UNIDO Project are geared towards encouraging local industries to enhance their energy and resource efficiency. This, in turn, would reduce production costs, providing medium- and long-term economic benefits, which would also contribute to sustainability and resilience in the face of the ongoing economic crisis and future challenges.

1 Ministry of Environment (MOE). 2021. Updated Nationally Determined Contribution (NDC) of Sri Lanka.

The aims of the project are to support the implementation of Sri Lanka's industry-related NDC targets through: 1) development and implementation of a Measurement, Reporting and Verification (MRV) system for industrial sector GHG emissions and emissions reductions, with the establishment of baseline emissions for the industry sector and sub-sectors. 2) validation of an industrial sector plan for implementing NDCs, where activities are prioritized according to mutually agreed criteria. 3) improvement of policy and regulatory frameworks and the enhancement of stakeholder awareness and capacity to implement these frameworks. 4) building capacity related to climate change mitigation practices in the industrial sector. 5) test pilot technologies and methodologies that lead to improved energy efficiency and a reduction in GHG emissions, with an end goal of replication.

The implementation of this project is carried out by the United Nations Industrial Development Organization (UNIDO), working in a collaborative partnership with the Ministry of Environment, the Ministry of Industries, and the Ministry of Power and Energy in Sri Lanka. This report presents information on industrial energy use and CO_2 emissions in Sri Lanka and also discusses the policy landscape and barriers to industrial energy efficiency and decarbonization in Sri Lanka. We also discuss institutional needs and gap based on the result of the survey we conducted in Sri Lanka. In addition, we have conducted quantitative analysis to estimate energy efficiency potential in industrial motor systems in Sri Lanka. Also, we discuss qualitatively the main deep decarbonization pillars for industry in Sri Lanka. Furthermore, we discuss international best practices in industrial energy efficiency and decarbonization policies. Finally, we present policy recommendations and action plan to enhance industrial energy efficiency in Sri Lanka.

2 Industrial value added, energy use and CO_2 emissions in Sri Lanka

2.1. Overview

Like many other developing countries, the industry sector in Sri Lanka has been growing. Figure 1 shows that the Industry value added in Sri Lanka (in billion 2015 US$) increased by over 2.5 times between 2000 and 2021. It should be noted that the industry sector includes mining and construction sectors in addition to the manufacturing sector.

Figure 1. Industry value added in Sri Lanka (Billion 2015 US$) (World Bank 2021)

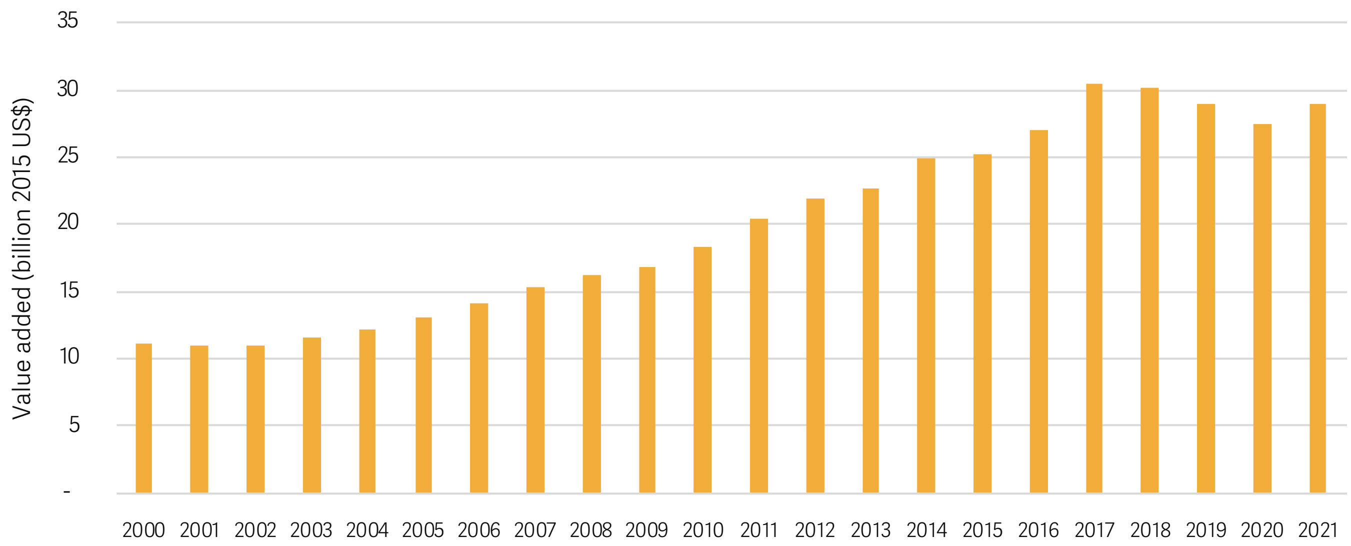


Figure 2 shows the energy use mix in industry sector in Sri Lanka during in 2021 (GEI analysis based on SLSEA, 2023). Biomass is the dominant type of energy used in Sri Lanka industries and accounted for around 58% of total final energy used in industry in 2021. Petroleum products, electricity, and coal accounted for 15%, 21%, and 6% of total industrial energy use in 2021, respectively.

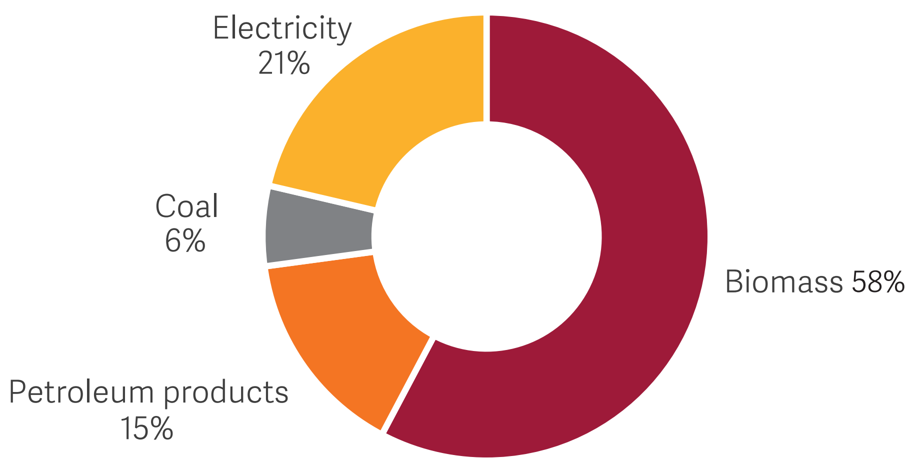


Figure 2. Final energy use mix in industry sector in Sri Lanka (GEI analysis based on SLSEA 2023)

From the industrial energy use and value-added data, we calculated the energy intensity of industry sector in Sri Lanka during 2010-2021. Figure 3 shows that the industrial energy intensity (in MJ/2015 US$) in Sri Lanka declined during 2003-2017 and increased between 2017 and 2021.

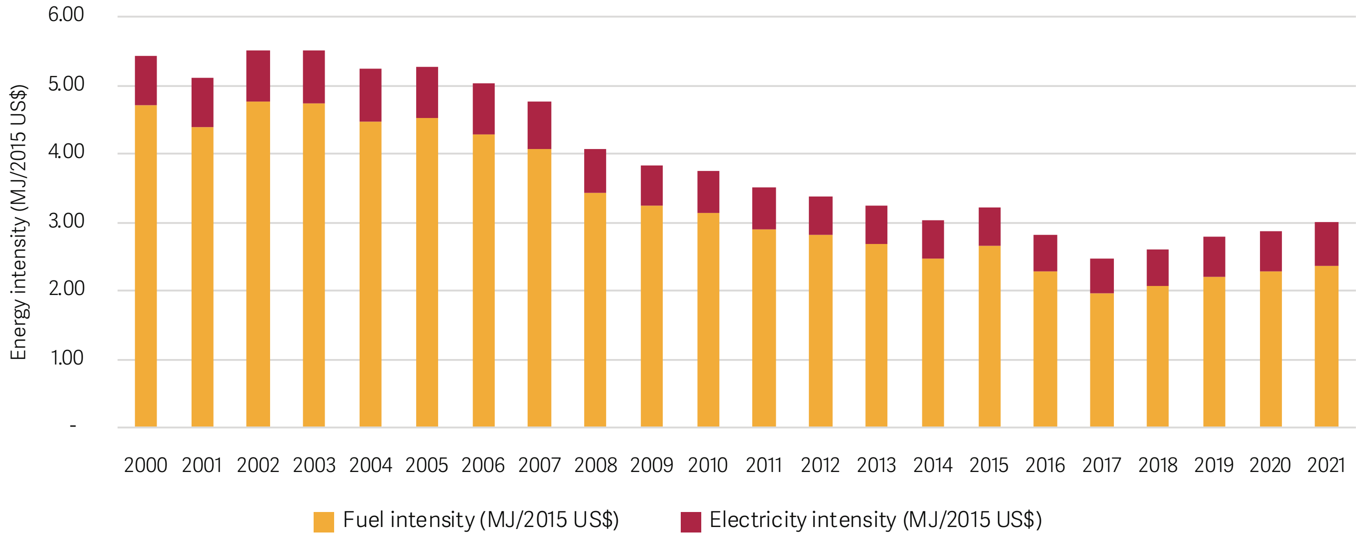


Figure 3. Energy intensity of industry in Sri Lanka (MJ/2015 US$) (GEI analysis based on data from SLSEA 2023 and World Bank 2021)

Using the CO_2 conversion factors for fuel and electricity in Sri Lanka, we estimated the total energy-related CO_2 emissions of industry in Sri Lanka. In 2021, energy-related CO_2 emissions from the industry sector in Sri Lanka was around 9.5 Mt CO_2. This is equal to 25% of the national GHG emission in Sri Lanka (World Bank, 2023). Figure 4 shows the calculated energy-related CO_2 emissions intensity of industry in Sri Lanka (in kg CO_2 /2015US$). The industrial CO_2 emissions intensity has a similar trend as the energy intensity shown above with a decrease till 2017 and a slight increase afterwards. Also, Sri Lanka uses substantial amount of biomass as fuel in industry. Figure 4 shows the CO_2 emissions related to burning biomass in industry in Sri Lanka using the Intergovernmental Panel on Climate Change's (IPCC's) emissions factor for biomass. However, if biomass is considered carbon-neutral, then there are no CO_2 emissions associated with it. But the carbon-neutrality and sustainability of biomass is increasingly questioned by many scientists.

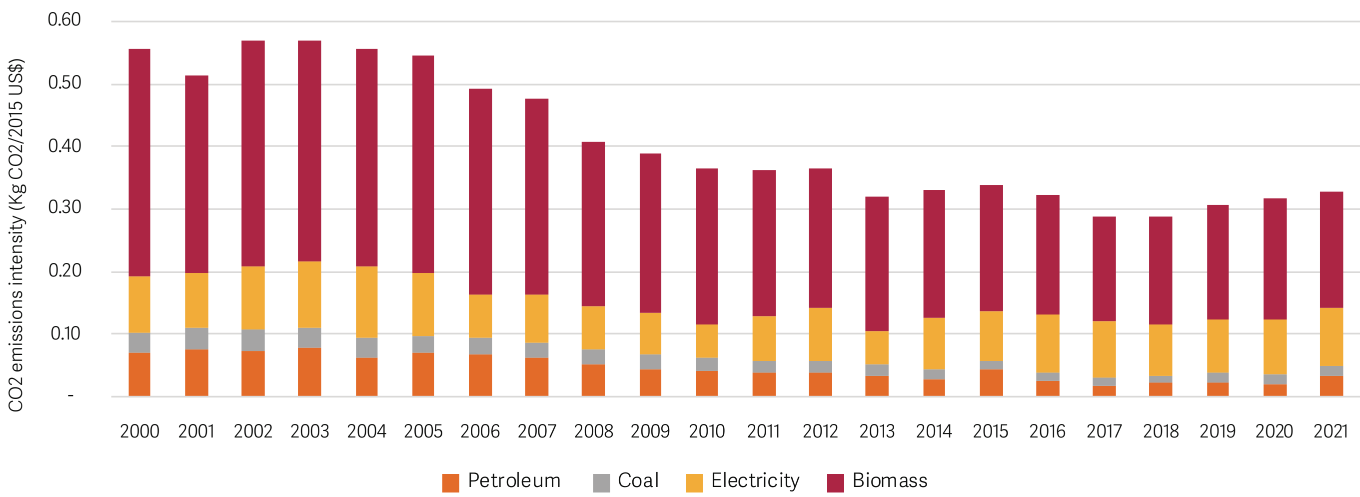


Figure 4. Energy-related CO_2 emissions intensity of industry in Sri Lanka (kg CO_2 /2015US$) (GEI analysis based on data from SLSEA 2023 and World Bank 2021)

Note: If biomass is from sustainable sources and considered carbon neutral, then the emissions related to biomass shown in the figure should not be taken into account.

2.2. Manufacturing electricity use by subsector

We obtained sub-sector level manufacturing electricity use data from Ceylon Electricity Board (table 1). The food and beverage, textile and garment, rubber and plastic, Metals, non-metallic minerals (e.g. cement industry), and refinery and chemicals industries are the top six electricity-consuming sectors in Sri Lanka, which together account for 72% of total manufacturing electricity use. Figure 5 shows the share of major electricity consuming sectors from total manufacturing electricity use in Sri Lanka.

Table 1. Annual electricity use in manufacturing subsectors in Sri Lanka (MWh/year) (Ceylon Electricity Board, 2023)

	2020	2021
Food and beverage	838,755	912,037
Textile and garment	616,455	741,062
Rubber and plastic	351,534	428,630
Metals	299,791	386,524
Non-metallic minerals	290,918	361,094
Refinery and chemical	272,118	335,674
Electrical and electronic	69,611	79,306
Timber and coir	70,355	80,766
Printing	69,158	78,217
Pulp and paper	41,391	46,832
Furniture and other manufacturing	24,665	30,626
Pharmaceuticals	20,255	33,034
Machinery and transport equipment	11,430	13,878
Leather and footwear	8,213	9,303

Notes:
1) The data shown in the table are only for manufacturing electricity use. There are non-manufacturing industrial electricity use (e.g. mining, construction, waste management, etc.) which are not included here.

2) Ceylon Electricity Board data only covers around 90% of total industrial electricity use in Sri Lanka. The remainder is supplied by other smaller power producers for which we could not obtain the data.

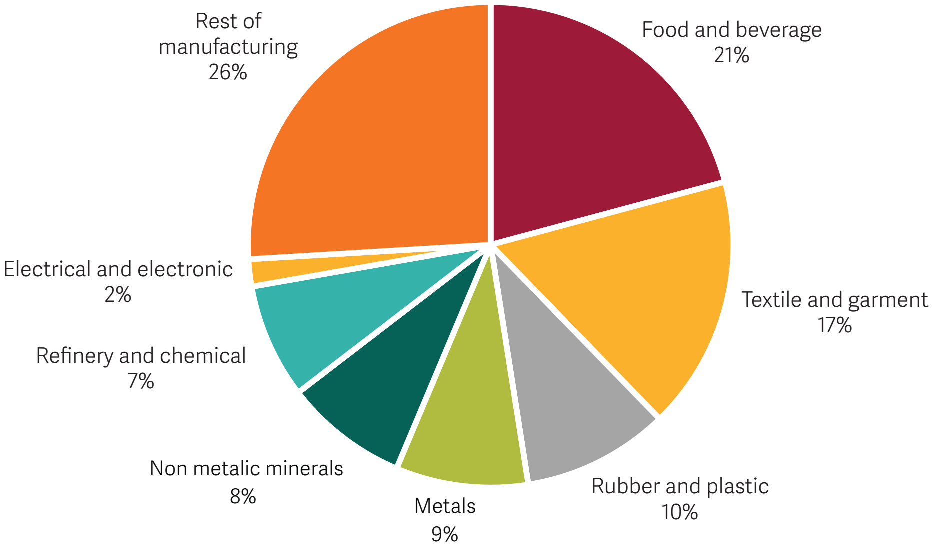


Figure 5. The share of major electricity consuming sectors from total manufacturing electricity use in Sri Lanka (Ceylon Electricity Board, 2023)

There is no electricity use data for industrial systems (motor systems, steam systems, process heating systems, etc.) in Sri Lanka. We have made an attempt below to estimate the electricity use for industrial motor systems and steam systems in Sri Lanka based on several international studies and sources (McKane and Hasanbeigi 2010; US DOE 2022; IEA, 2016a).

According to the International Energy Agency (IEA), industrial electric motor systems account for about 70% of total global industrial electricity usage (IEA, 2016a). Also, the data from US DOE (2022) and analysis by Hasanbeigi and McKane (2011) of industrial motor systems energy use and energy efficiency potential in different countries and regions provide similar range for industrial motor systems energy use. Since there is no electricity use data for industrial systems (motor systems, steam systems, process heating systems, etc.) in Sri Lanka, we used this 70% share to estimate industrial motor systems electricity use from total electricity use in industry in Sri Lanka (Figure 6).

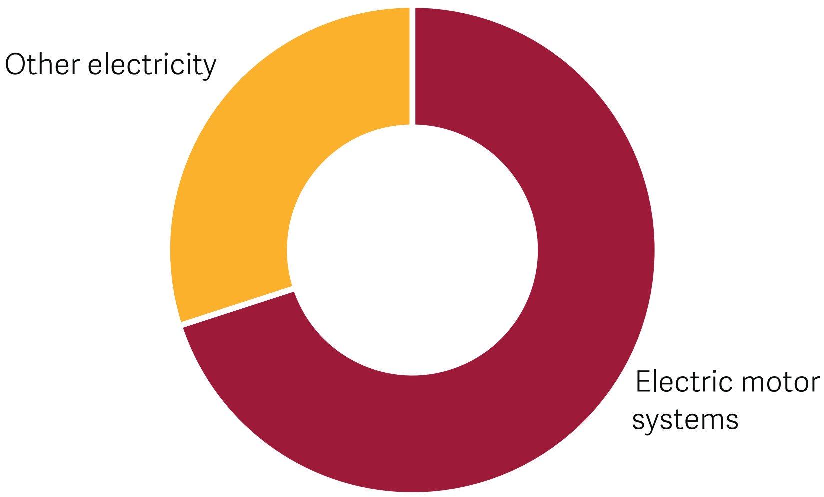


Figure 6. Estimated electricity use in industrial motor systems in Sri Lanka in 2021 (values in GWh) (GEI analysis based on data from SLSEA 2023)

Note: This figure shows the total electricity use in industry sector in Sri Lanka reported for both manufacturing and non-manufacturing industry sectors provided by (SLSEA 2023). It includes electricity that is supplied by all power producers and not only Ceylon Electricity Board.

2.3. Manufacturing fuel use by subsector

As shown in Figure 2, the main types of fuel used in the industry sector in Sri Lanka are biomass, petroleum products (fuel oil, diesel, LPG), and coal (SLSEA 2023).

Biomass:

Despite biomass being the dominant fuel source for Sri Lanka's industrial sector, obtaining reliable data on its specific use across different manufacturing subsectors remains a challenge. This is primarily due to the prevalence of an informal market. Many small and medium-sized enterprises (SMEs) rely on informal channels for acquiring biomass, like purchasing directly from farmers or collecting wood waste independently. This lack of formal transactions makes it difficult to track and quantify the exact amount of biomass used by each subsector.

Furthermore, there is a limited data collection efforts specifically focused on disaggregating biomass usage within the manufacturing sector. Additionally, the diverse nature of biomass feedstock (including various types of wood, agricultural residues, etc.) can complicate the process of categorization and data collection.

Coal:

While coal primarily serves as a fuel source for Sri Lanka's cement industry, its use extends, although to a lesser extent, into other sectors such as the textile and food industries. However, these other sectors are gradually transitioning towards cleaner alternatives like sustainable biomass due to climate concerns, economic considerations, and the availability of domestic biomass.

Petroleum products:

After biomass, petroleum products (fuel oil, diesel, LPG) are the second largest type of fuels used in the industry sector in Sri Lanka. We obtained the breakdown of petroleum products use in manufacturing subsector from Ceylon Petroleum Corporation (CPC) (for fuel oil and diesel) and Litro Gas (for LPG). Figure 7 below shows the share of petroleum products used in manufacturing subsectors in Sri Lanka in 2021. It should be noted that while Ceylon Petroleum Corporation (CPC) market share is around 93% and Litro Gas market share is around 83% in Sri Lanka.

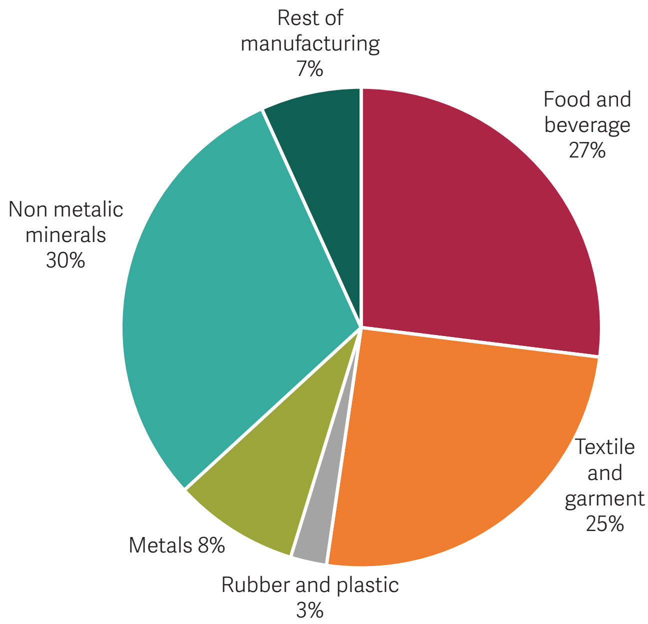


Figure 7. The share of petroleum products used in manufacturing subsectors in Sri Lanka in 2021 (GEI analysis based on data from CPC 2023; Litro Gas 2023)

Industrial boilers and steam systems are important industrial energy systems that use fuel. Steam is used extensively as a means of delivering energy to industrial processes. Steam holds a significant amount of energy on a unit mass basis that can be extracted as mechanical work through a turbine or as heat for process use. In addition, steam can be used to control temperatures and pressures during chemical processes, strip contaminants from process fluids, dry paper products, and in other miscellaneous applications. Equipment that uses steam varies substantially among industries and is generally process- and site-specific.

There is no data reported on energy use in industrial boilers and steam systems in Sri Lanka. However, various studies from other countries show that industrial boilers and steam systems (including combined heat and power) can account for about half of total fuel used in industry (US DOE 2022, Hasanbeigi et al. 2014). The share of boilers and steam systems from total fuel use is higher in non-heavy industries such as food and beverage, textile, rubber, etc. Since these industries account for a larger share of industry sector in Sri Lanka and there are not many heavy industrial plants such as cement and primary steelmaking plants in the country, it is possible that the fuel used in industrial boilers and steam systems in Sri Lanka account for over 60% of the total fuel used in the industry sector.

2.4. Key manufacturing sectors in Sri Lanka

Based on the breakdown of manufacturing energy use by subsector discussed above and other factors such as contribution to GDP, share of country's export, employment, etc. we identify the following four industry subsectors as key manufacturing sectors in Sri Lanka:

1 - Textile and apparel industry

2 - Food and beverage industry

3 - Rubber production industry

4 - Cement industry

The textile and apparel sector in Sri Lanka stands as an undisputed champion, contributing around 20% to the GDP and 50% to exports. Globally recognized for garment manufacturing, it employs over a million people, predominantly women, making a substantial impact on social development (Sri Lanka Export Development Board 2022; World Bank 2023; International Labour Organization 2023). The textile industry is also among the top energy-consuming manufacturing sectors in Sri Lanka.

The food and beverage sector encompasses tea, coconut, spices, seafood, fruits, and dairy products, has 8% GDP contribution to Sri Lankan economy. It is one of the top energy-consuming manufacturing sectors in Sri Lanka. With strong links to agriculture, this sector provides employment to over 600,000 people, playing a vital role in export diversification (Sri Lanka Export Development Board 2022; International Food Policy Research Institute 2022).

The rubber products industry, a major exporter of natural rubber, contributes 2% to GDP and employs over 100,000 people, capitalizing on its proximity to Southeast Asian markets (Sri Lanka Export Development Board 2022). The sector is also among the top electricity-consuming manufacturing sectors in Sri Lanka.

The cement industry, heavily influenced by ongoing infrastructure projects, is the backbone of the development in Sri Lanka. It also is a major consumer of coal and fossil fuels in industry and one of the largest contributor to industrial GHG emissions in Sri Lanka. The cement industry is one of the top energy-consuming sectors and is the main consumer of carbon-intensive coal in the industry sector in Sri Lanka.

3 Industrial energy efficiency policy landscape in Sri Lanka

3.1. Stakeholder mapping in Sri Lanka

This chapter provides an overview of the industrial energy efficiency and decarbonization stakeholders landscape in Sri Lanka. The decarbonization and energy efficiency in the country's industrial sector is shaped by a diverse network of stakeholders, ranging from governmental policy decision-makers to individual companies adopting solutions. These stakeholders contribute at various levels and in different capacities to shape, influence, and implement policies aimed at enhancing industrial energy efficiency and driving the nation towards a its climate goal. As we navigate the complexities of this landscape, it is essential to understand the distinct roles these entities play, and their interactions within the broader policy ecosystem.

Our approach to stakeholder mapping encompasses diverse sectors and organizations, categorizing them into key groups including policy makers, contributors and advisors to policy formulation, industry associations, financial sector participants, individual industrial companies leading by example, energy efficiency/renewable energy associations, energy service companies (ESCOs), and organizations that provide support for policy development and implementation. Each of these stakeholders possesses a unique role in the Sri Lankan industrial energy efficiency landscape, their contributions collectively paving the way for a low-carbon industrial sector. In the following table, we outline these stakeholders.

Table 2. Stakeholder mapping in Sri Lanka

Category	Organizations	
Policy makers	Ministry of Power and Energy Ministry of Industry Ministry of Finance	Ministry of Environment Ministry of Plantations
Policy formulation contributors and advisors	Sri Lanka Sustainable energy authority (SLSEA) Sector experts Academia in local universities Institute of policy studies Lakshman Kadiragamar Institute International development agencies (WB, ADB, UNIDO, UNDP, etc.) International policy experts	
Industry associations	FCCISL, CNCI, Planters Association, FAAMA, Sectoral and sub sectoral associations	
Financial sector	Sri Lanka Bankers Association – Sustainable Banking Initiative DFCC bank, NDB bank, Commercial Bank, Sampath Bank, BOC, Peoples Bank, etc.	
EE/RE Associations	Sri Lanka Energy Managers Association (SLEMA), Bio Energy Association of Sri Lanka	
Energy service companies (ESCOs)	SLSEA, NCPC, ESCOs registered at SLSEA	
Policy development and implementation support	CEA, National Enterprise Development Authority (NEDA), UNIDO, UNDP, EU, WB, ADB	

SLSEA – Sri Lanka Sustainable Energy Authority, FCCISL - Federation of Chambers of Commerce and Industry of Sri Lanka, CNCI Ceylon National Chamber of Industries, FAAMA – Fabric & Apparel Accessory Manufacturers Association, DFCC - Development Finance Corporation (DFCC Bank), NDB – National Development Bank, BOC – Bank of Ceylon, TJ Lanka (Teejay Lanka PLC – Fabric manufacturing company), NCPC – National Cleaner Production Centre, ESCO – Energy Service Companies, CEA – Central Environment Authority, NEDA - National Enterprise and Development Authority, ADB – Asian Development Bank, EU – European Union, EE – Energy Efficiency, RE – Renewable Energy, WB – World Bank, UNDP – United Nation Development Program, UNIDO – United Nation Industrial Development Organization

3.2. Overview of existing regulations, policies, and programs in Sri Lanka

As mentioned earlier, in its updated NDCs from 2021, Sri Lanka commits to enhance its forest cover to 32% and curtail greenhouse gas emissions by 14.5% across diverse sectors - Power, Transport, Industry, Waste, Forestry, and Agriculture - from 2021 to 2030. These objectives are part of a broader strategy to achieve 70% renewable energy-based electricity generation by 2030 and to attain Carbon Neutrality by 2050, all under the presumption of no further additions to coal power plant capacity.

Some of the key policies in Sri Lanka that tries to address energy efficiency and decarbonization in the industry sector are:

- National policy for industry development (NaPID) and strategic implementation road map (unpublished and in development / draft stage)
- National Energy Policy (2019)
- National Climate Change Policy (2023)
- National environmental policy (NEP) 2022
- National environmental action plan (NEAP) 2022 – 2030
- Draft national policy and strategy on sustainable development (2020)
- National policy on sustainable consumption and production (2019)
- National Policy and Strategy for Cleaner Production (2005)
- National Plantation Industry Policy Framework (2006)

The Ministry of Industry is currently engaged in developing a National Policy for Industrial Development (NaPID), alongside a five-year Strategic Implementation Plan to bring the NaPID into action. In parallel, the Ministry is also investigating the potential of enforcing industry sector NDCs through the design and execution of policies, regulatory measures, and technical & financial mechanisms and tools. The goal is to expedite the adoption of renewable energy sources and resource-efficient technologies, as well as best practices in energy efficiency. The actions listed in the NDCs (Table 2) will work towards augmenting mitigation efforts, while simultaneously integrating internationally recognized concepts such as resource efficiency and circular economy. It is expected that the actions listed in the updated NDCs will reduce industry sector's GHG emissions against the BAU scenario by 7% in 2030 (MOE 2021).

Table 3. Actions listed for the industry sector in Sri Lanka's NDCs (MOE 2021)

NDCs and actions	Timeline
NDC 1. Continue fuel-switching to sustainable biomass energy and improve user efficiency in selected industrial sub-sectors (tea, rubber, apparel, hotel & tourism, rice processing)	**2021-2030**
1.1 Convert industry furnaces to steam boilers and hot-water systems	2021-2030
1.2 Improve biomass user efficiency by increasing feedstock quality, operation and maintenance practices, system design and automation	2021-2030
1.3 Introduce biomass "co-generation" in industries	2021-2030
1.4 Switch from fossil fuel to biomass energy in government insztitutions for thermal energy requirements	2021-2030
NDC 2. Enhance the application of resource efficient cleaner production (RECP) practices in selected industrial sub-sectors	**2021-2030**
2.1 Conduct RECP and energy audits and develop baselines based on industry classifications & the importance	2021-2023
2.2 Adopt RECP practices including low carbon technologies and processes	2021-2030
2.3 Improve water use efficiency in selected industrial subsectors	2021-2030
2.4 Promote energy-efficient appliances and technologies such as High-Efficient Motors (HEM), Variable Frequency Drives (VFD), efficient chillers and refrigeration technologies	2021-2030
NDC 3. Establish eco-industrial parks and villages	**2021-2030**
3.1 Transform existing industrial parks (IPs) incorporating maximum possible green industrial concepts	2021-2030
3.2 Introduce policy and regulatory regime, including guidelines to ensure all new IPs will be set up as Eco IPs	2021-2023
NDC 4. Introduce Circular Economy concept to selected industrial sub-sectors and selected industrial zones	**2021-2030**
4.1 Conduct a survey to identify and determine the potential subsectors to implement the circular economy concept	2021-2023
4.2 Introduce the life cycle approach for selected subsectors for greening the supply chain	2021-2030
4.3 Practice industrial symbiosis concept in selected industrial parks and industrial sub-sectors	2021-2030
4.4 Establish a pilot project on the zero-waste concept in selected industrial parks or industrial subsectors	2021-2025
4.5 Adopt ISO standards for the circular economy concept (ISO/TC 323)	2021-2030
4.6 Build industry capacity to adopt the circular economy concept	2021-2030
NDC 5. Introduce tri-generation facilities to selected industrial parks	**2021-2030**
5.1 Carry out a rapid assessment of tri-generation potential in 10 industrial parks	2021-2023
5.2 Carry out a detailed assessment in one of the BOI industrial parks for piloting	2021-2022
5.3 Develop business models and funding options	2021-2023
5.4 Implement one Tri-generation facility as a pilot project	2021-2027

NDCs and actions	Timeline
5.5 Depending on the success of the pilot project, expand it into BOI and other industrial parks and other prospective applications	2021-2030
5.6 Make provisions through policy instruments to have Tri-generation for new industrial zones	2021-2030
NDC 6. Incentivize GHG reduction of clinker production in the cement industry	**2021-2023**
6.1 Make necessary amendments to Sri Lanka Standard Institute (SLSI) standards for cement production enabling the increase of ash and other similar materials as substitutes for clinker in line with industry standards and trends worldwide	2021-2023
NDC 7. Generic enabling activities	**2021-2023**
7.1 Facilitate industries in selected sub-sectors to adopt relevant ISO systems having a focus on GHG emissions reduction	2021-2023
7.2 Introduce and promote suitable tax incentives to promote the acquiring of sustainable technologies	2021-2023
7.3 Facilitating the entry of ISO certified companies to the Green Public Procurement system of Sri Lanka	2021-2023
7.4 Facilitating transformational investment and favorable loans through financing institutions linking with green financing	2021-2023
7.5 Introduce a national policy to address siting of industrial parks and stand-alone industries, new concepts like circular economy, industry ecology, RECPs, digitalization, etc.	2021-2023
7.6 Ensure the availability of sustainable biomass for industry use	2021-2023
7.7 Promote National Green Reporting System (NGRS)	2021-2023

Despite the suite of policies and programs outlined above, there are notable policy gaps that necessitate further recommendations. Firstly, there is a lack of integration and coherence among the various policies, which can lead to inefficiencies and missed opportunities. While some policies lay a solid foundation, they often operate in silos, lacking a unified framework that synergizes efforts across different sectors. This fragmentation can result in overlapping initiatives, inconsistent standards, and a lack of clear direction for industries, hindering the effective implementation of decarbonization strategies. Furthermore, there is an apparent gap in the enforcement mechanisms and incentives. Policies largely rely on voluntary compliance and lack robust monitoring and enforcement mechanisms, which are crucial for ensuring adherence and measuring progress. The absence of strong incentives or disincentives for industries to adopt decarbonization measures also limits the potential impact of these policies.

Additionally, the current policy landscape does not adequately address the need for technological innovation and capacity building in the industrial sector. While there are initiatives aimed at promoting cleaner production and resource efficiency, there is a significant gap in supporting industries to adopt advanced technologies and practices that are crucial for deep decarbonization. This includes technologies related to electrification of heating, advanced renewable energy systems and low-carbon feedstock, and digitalization for energy management. The lack of a focused approach to developing skills and technical know-how within the industry acts as a barrier to the adoption of these advanced technologies. Moreover, the policies do not sufficiently address the financial barriers that industries face in transitioning to energy-efficient and low-carbon technologies. There is a need for more targeted financial mechanisms, such as subsidies, grants, and low-interest loans, to support industries, especially small and medium-sized enterprises (SMEs), in making this transition. These policy gaps justify the need for a set of recommendations, as outlined in Chapter 8 of this report, that address these shortcomings, ensuring a more cohesive, enforceable, and technologically advanced approach to industrial energy efficiency and decarbonization in Sri Lanka. The institutional and policy gaps are discussed in more detail in the following chapters.

4 Assessment of institutional needs and capacity gaps

In the ongoing journey towards industrial energy efficiency (EE) and decarbonization in Sri Lanka, the assessment of institutional needs and capacity gaps stands as a crucial step. This chapter is dedicated to a comprehensive evaluation of these essential components that have a profound influence on the progress and effectiveness of the decarbonization efforts in the country's industrial sector. A meticulous understanding of these needs and gaps would serve as a foundation for policy makers and stakeholders, equipping them to formulate and implement strategies that are both effective and efficient in achieving their sustainability goals.

To ensure a deep and holistic understanding of the situation, we have initiated a thorough survey engaging a broad spectrum of participants, including government institutions and other stakeholders. This survey is designed to unravel the prevailing policy needs and gaps in the current scenario. The results obtained will be discussed in detail in this section, aiming to provide an enlightening overview of the current landscape of institutional requirements and shortcomings. The insights derived will then be utilized to strategize a road map that addresses these gaps and leverages opportunities for accelerating the pace of industrial energy efficiencyand decarbonization in Sri Lanka.

We met with various stakeholders from both government and non-government organizations and private sector to discuss institutional needs and capacity gaps for industrial energy efficiency and decarbonization in Sri Lanka. Our approach towards the interviews was to maintain a balance between structured and open-ended questions, aiming to extract comprehensive insights from policy makers and stakeholders about the institutional needs and capacity gaps. The focus was on understanding the prevailing challenges, opportunities, and trends in industrial energy efficiency and decarbonization. We encouraged interviewees to share their perceptions, experiences, and suggestions in order to reveal valuable insights that may otherwise remain hidden in a strictly structured interview setting.

Some of the key institutional needs and capacity gaps that emerged from these interviews were:

Lack of comprehensive policy framework:
Sri Lanka's industry sector lacks a comprehensive policy framework specifically dedicated to promoting and guiding energy efficiency and decarbonization. While some isolated policy measures exist, there is an urgent need for a unified, holistic policy approach. This policy should cover various aspects of energy efficiency, decarbonization, and clean technology adoption, including standards, funding mechanisms, incentive structures, and enforcement mechanisms. A robust policy framework would not only provide clear guidelines for industries, but also signal the government's commitment to sustainable industrial development.

Absence of effective measurement, reporting, and verification (MRV) systems:
For industries to continually improve their energy efficiency and decrease their carbon emissions, an effective MRV system is crucial. Such a system would allow industries to track their progress, identify areas for further improvement, and provide a basis for incentive programs or compliance with regulations. At present, Sri Lanka lacks a comprehensive MRV system in the industrial sector, emphasizing the need for its development.

Lack of publicly available data on industrial energy use and emissions:
There is a marked deficiency in the public availability of comprehensive and reliable data regarding energy use and emissions from the industrial sector. This lack of transparency makes it challenging for policymakers, researchers, and the public to understand the current situation and make informed decisions about necessary interventions. There's a need to develop mechanisms for systematic data collection and public dissemination, which could involve enhancing industrial reporting requirements and creating a publicly accessible database or platform where this information is regularly updated and made accessible.

Need for enhanced coordination:
The challenge of industrial energy efficiency and decarbonization spans multiple government departments, industry sectors, and academic disciplines. However, currently, the coordination between these diverse entities is suboptimal. Strengthening these relationships could lead to improved alignment of goals, sharing of resources and information, and pooling of efforts towards common objectives. This would entail a systematic effort to bring stakeholders together, possibly through the establishment of a dedicated coordinating body or mechanism.

Skilled workforce deficit:
The transition towards energy efficiency and decarbonization in the industrial sector requires a workforce with specialized skills and knowledge in areas such as energy management, clean technologies, emissions monitoring, and sustainable industrial processes. Currently, such skills are in short supply in Sri Lanka. Addressing this gap will likely involve initiatives to enhance education and training in relevant areas, perhaps through partnerships with academic institutions, vocational training programs, or industry-sponsored training initiatives. In this context, it is crucial to integrate gender equity into these training and educational programs. Ensuring equal access and opportunities for women in these fields not only promotes diversity but also taps into a wider pool of talent, which is essential for fostering innovation in decarbonizing the industry sector. Additionally, targeted efforts to encourage and support women in pursuing careers in energy management and clean technologies can help bridge the gender gap in these traditionally male-dominated fields, contributing to a more inclusive and equitable workforce.

Insufficient infrastructure:
The lack of sufficient infrastructure is a major constraint to the adoption of energy-efficient and decarbonizing technologies in the industrial sector. This includes both the physical infrastructure (like grid capacity for renewable energy or transport facilities for alternative fuels) and the supportive infrastructure (such as testing and certification facilities for energy-efficient technologies or data management systems for tracking energy use and emissions). Investments in improving this infrastructure would greatly facilitate Sri Lanka's industrial energy transition.

Limited technical knowledge:
Even when the necessary infrastructure is in place, the benefits of energy efficiency and decarbonization cannot be fully realized if industrial operators lack the technical knowledge to use the infrastructure effectively. This includes knowledge about energy-efficient technologies and practices, understanding of the environmental and economic benefits of energy efficiency, and skills in areas such as energy auditing and management, emissions monitoring, and sustainable process design. Efforts to disseminate this knowledge and build these skills are therefore a critical need.

Inadequate financing mechanisms:
There is a significant need for robust, accessible financing mechanisms to support the industrial sector in adopting energy-efficient technologies and practices. The upfront costs associated with such measures can be substantial and could deter many industries from making necessary changes. Possible solutions could include low-interest loans, grants, tax incentives, or novel mechanisms like green bonds. Public-private partnerships could also be explored as a means to share the financial burden and reduce risks associated with these investments.

Regulatory enforcement and compliance:
Policies and regulations promoting industrial energy efficiency and decarbonization are only as effective as their enforcement. Currently, Sri Lanka experiences challenges in ensuring industries' compliance with existing regulations. This gap may be due to limited resources, lack of expertise, or the absence of penalties sufficient to deter non-compliance. Strengthening enforcement mechanisms, possibly through increased inspection capacity, stricter penalties, or the introduction of incentives for compliance, is a critical area of need.

Public awareness and perception:
There is a general lack of awareness among the public and within industries about the importance of energy efficiency and the need for decarbonization. Many may be unaware of the potential cost savings and environmental benefits, leading to a lack of pressure on industries to improve their practices. This highlights the need for a concerted effort to raise public awareness, possibly through educational campaigns, public forums, or engagement with the media.

Insufficient research and development (R&D):
The industrial sector's transition towards energy efficiency and decarbonization requires continuous innovation. This could be achieved through developing new technologies, improving existing ones, or discovering more efficient industrial processes. However, current investment in R&D in this area is insufficient in Sri Lanka. More support is needed for universities, research institutes, and industries to conduct relevant research. This could be achieved through direct funding, establishment of research partnerships, or tax incentives for R&D.

5 Survey results: Barriers to and drivers of industrial energy efficiency and decarbonization in Sri Lanka

In Sri Lanka the uptake of energy efficiency and decarbonization practices in industries are slow. It is therefore imperative to understand the specific barriers that hinder the implementation of industrial energy efficiency and decarbonization in Sri Lanka. In this section, we present some findings on challenges and barriers to industrial energy efficiency and decarbonization in Sri Lanka. Analysis of the barriers to the uptake of industrial energy efficiency as presented here is based on information obtained from survey conducted in some industries and also other public and non-government organizations in Sri Lanka in 2023. The results from the survey are presented in the following sections.

In total, 45 responses were received from 40 different institutions. Surveys were tailored for either government or industry respondents.

5.1. Policymakers survey results

The survey had 22 respondents from 19 different institutions that formulate policy and/or provide support that could influence policy regarding aspects of industrial energy efficiency issues. Example institutions surveyed include the Sri Lanka Standards Institution, the Ministry of Industries, the Public Utilities Commission, and the Central Environmental Authority.

The survey seeks to identify the most significant barriers hindering energy efficiency and the decarbonization process in Sri Lanka's industrial sector. The survey also asks respondents to assess the primary motivations driving companies to adopt energy efficiency measures. Respondents also rate potential activities and strategies that could bolster energy efficiency across industries. The survey also asks respondents to rate the effectiveness of various energy efficiency policies currently in place or proposed.

Policymaker and government respondents were asked their opinions on the most important obstacles to energy efficiency and decarbonization of industry in Sri Lanka, with the prompt to provide 5-10 open-ended responses. We grouped these responses into seven different categories of barriers, from most- to least-mentioned.

Infrastructure and resource constraints:
Survey results indicate that infrastructure and resources top the list of concerns for the government sector. In Sri Lanka, various actors face limitations in accessing infrastructure tailored for energy efficiency and decarbonization, further compounded by insufficient resources and budgetary constraints. Many respondents highlighted the high upfront costs associated with procuring energy-efficient technologies and machinery. One respondent noted, "The upfront costs associated with adopting energy-efficient technologies, such as equipment upgrades and renewable energy systems, can be a major deterrent, particularly for small and medium-sized enterprises (SMEs) with limited budgets." Additionally, the absence of specific financial incentives and supportive schemes, including R&D, further suppresses interest. Also related to infrastructure, some respondents mentioned a reliance on low-quality raw materials due to an over-dependence on cheaper power sources.

Knowledge and awareness:
Respondents felt there was a lack of knowledge and awareness about energy efficiency and decarbonization across government, firms, and other stakeholders. There seems to be a notable deficit in stakeholder education on the subject. This lack of knowledge and awareness permeates various levels, from the general population's understanding of energy efficiency benefits, to "lack of awareness among managers of industrial and commercial facilities about energy efficiency opportunities and benefits". The shortage of skilled professionals in energy management and related fields exacerbates this challenge.

Policies, regulations, and government intervention:
Another significant challenge identified by respondents is the lack of robust policies and regulations that support energy efficiency and decarbonization. The survey reveals the absence of effective ground-level policies, compounded by weak regulatory frameworks and lax law enforcement. A monopolistic role played by certain entities further stymies the growth of energy efficiency and decarbonization technologies. Government restrictions on imports, often driven by economic concerns, also limits the domestic technology market. One respondent also noted that government procurement could be a lever for demand for greener products, but currently, "procurement rules are guided by the lowest price and not the best cost/benefit ratio".

Organizational and cultural barriers:
Another challenge is the organizational and cultural barriers hindering the adoption of energy-efficient practices. Technical inefficiencies, coupled with a resistance to change, are major impediments. There may also be a fear of failure when considering new energy initiatives and a general reluctance to modify existing technologies – as one respondent said, there is a "lack of confidence in obtaining energy savings resulting from energy efficiency projects". Safety concerns and limited commitment from operational-level employees further exacerbate these barriers. Some respondents also mentioned social, cultural, and even religious facets can play a role in the perception and adoption of decarbonization measures.

Economic and financial challenges:
Sri Lanka's ongoing economic crisis was also mentioned as key context by survey respondents, influencing the government sector's ability to champion energy efficiency and decarbonization. High costs, whether for conducting audits or implementing projects, make it difficult for stakeholders to see immediate financial benefits. This may also be related to firm capacity, as one respondent mentioned the "poor financial capacity of the industries".

Technological challenges:
Technological limitations are another barrier brought to light by the survey, especially the unavailability of suitable technologies tailored for specific industrial needs. As one respondent elaborated, "Industries may face difficulties in finding appropriate technologies that are specifically designed for their operational requirements, especially in sectors with unique energy demands, such as heavy industries or manufacturing processes." Relatedly, there is a lack of data and effective tools for performance analysis, suggesting a need for greater investment in R&D and infrastructure to support new technological implementations.

Management and prioritization:
Lastly, the survey underscores challenges related to management and prioritization. Lack of commitment from management was mentioned, combined with an emphasis on profit-driven projects. The findings also hint at the barriers arising from the confidentiality of some industrial processes, which makes external collaboration difficult.

To understand why companies have implemented energy efficiency measures in Sri Lanka, respondents were asked to rate the importance of a set of reasons (Figure 7). The top three reasons that had the strongest level of agreement were reduced energy costs, reduced energy consumption, and reduced production costs, indicating that companies in Sri Lanka are highly sensitive to cost considerations. On the other hand, the three reasons that respondents agree least with were improved staff health and safety, reduction of other emissions (namely air pollutants), and improved staff pride/morale. This could indicate that staff concerns were not a driver of energy efficiencyadoption, and that greenhouse gas emissions received more attention than air pollutants.

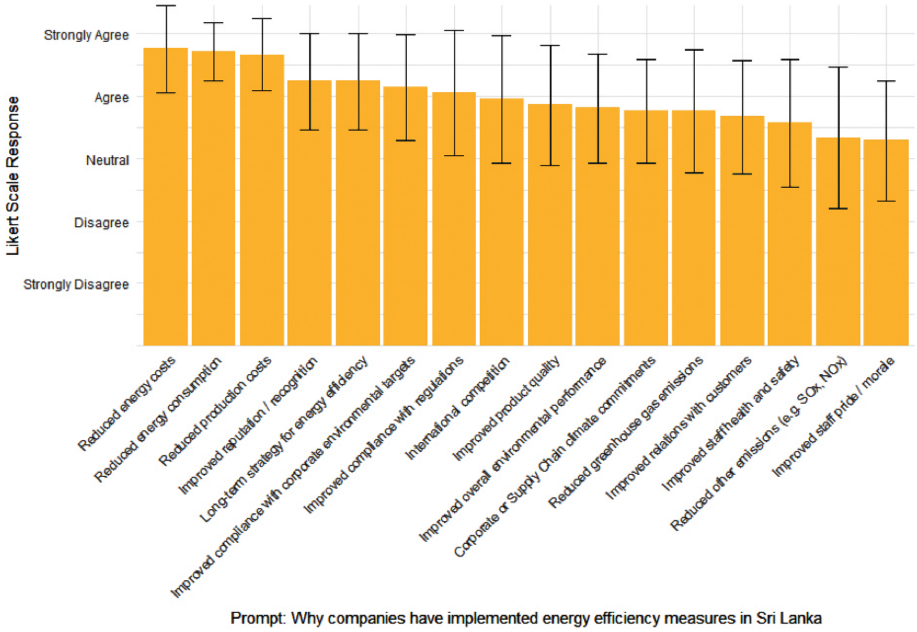
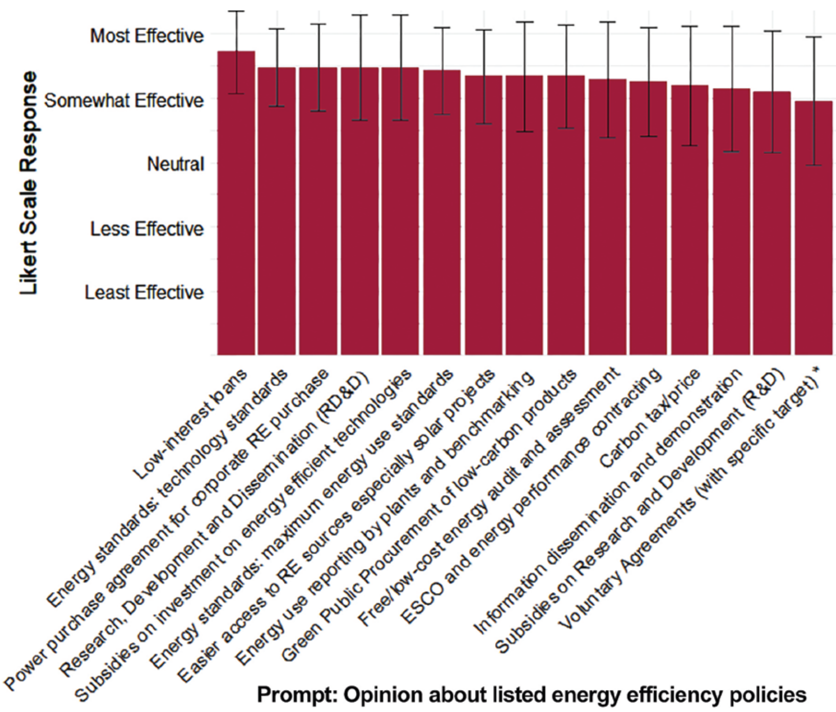


Figure 7: Ranked responses on drivers of energy efficiency implementation

The next section of the survey focused on activities that could assist companies to improve their energy efficiency. These activities were sorted into trainings and courses, information, and other activities, including loans, programs, and tools. Within the trainings and courses category, the activity ranked most useful was training on energy management systems (ISO 50001). Within the information-related activities, case studies of other companies was ranked as the most useful activity – in fact, everyone who ranked this activity gave it the highest possible score for usefulness. Finally, within the "other" category, loans and subsidies for energy efficiency received the highest score for usefulness. Across categories, training-type activities received the highest usefulness score, followed by information-related activities, and then other activities.

Finally, government respondents were presented a list of energy efficiency policies and asked to rate them on how effective they were. The top five most effective policies rated by respondents were low-interest loans for energy efficiency and decarbonization technologies, followed by energy standards and technology standards, power purchase agreements for corporate renewable energy purchases, RD&D, and subsidies on investment in energy efficient technologies. Notably, several of these top policies were related to government-provided or -facilitated financial resources. Voluntary agreements were ranked as the least effective policy relative to others.



In summary, government respondents and those from publicly-oriented institutions in Sri Lanka highlighted infrastructure and resource constraints, a knowledge gap, and inadequate policies as key barriers to industrial energy efficiency and decarbonization. Cost considerations, specifically reduced energy and production costs, emerged as primary drivers for adopting energy efficiency measures. However, staff-related benefits were viewed as less significant. Solutions such as training on energy management systems, showcasing other companies' successes through case studies, and financial support in the form of loans and subsidies were identified as impactful. Notably, many favored policies revolved around financial resources facilitated by the government, while voluntary agreements were deemed least effective.

5.2. Industry Survey Results

The survey had 23 respondents from 21 different companies across a wide range of industrial subsectors. Within the companies, the survey was sent to key decision-makers about energy efficiency and decarbonization. Companies came from sectors such as food and beverages, hospitality, chemicals, textiles, and electronics manufacturing. Across companies, the average number of production sites was 3.5, with a standard deviation of 2.6 (after removing outliers). Most companies tended to be larger, with the greatest share of respondents coming from companies with over 500 employees (Figure 8)

Companies were asked to rank their agreement with the same set of prompts about drivers of energy efficiency as was posed to policymaker and government respondents, although the prompt was framed around the drivers for their specific company. Interestingly, reduced energy consumption, reduced energy costs, and reduced production costs were in the top four most agreed with drivers for industry respondents, and these drivers were the top three responses for government respondents. Industry respondents also indicated that compliance with corporate environmental targets were also a major driver of energy efficiency in their companies, indicating the effectiveness of mandatory company-level target-setting. Reduction of air pollutants ranked as a less important driver for both industry and government respondents, though industry respondents ranked preparation for the Kyoto Protocol and Clean Development Mechanism (CDM) as the least effective driver of energy efficiency. This may be due to the emergence of newer international systems and incentives for decarbonization, and/or lack of understanding of how the Kyoto Protocol and CDM would affect the surveyed companies.

The survey also focused on energy practices within the survey companies. All except one company indicated that they had adopted at least one relevant standard, with ISO 14001: Environmental Management System being the most frequently adopted standard. Other standards not specified in our survey that respondents mentioned included some sector-specific standards, such as the Higg Index or Rainforest Alliance

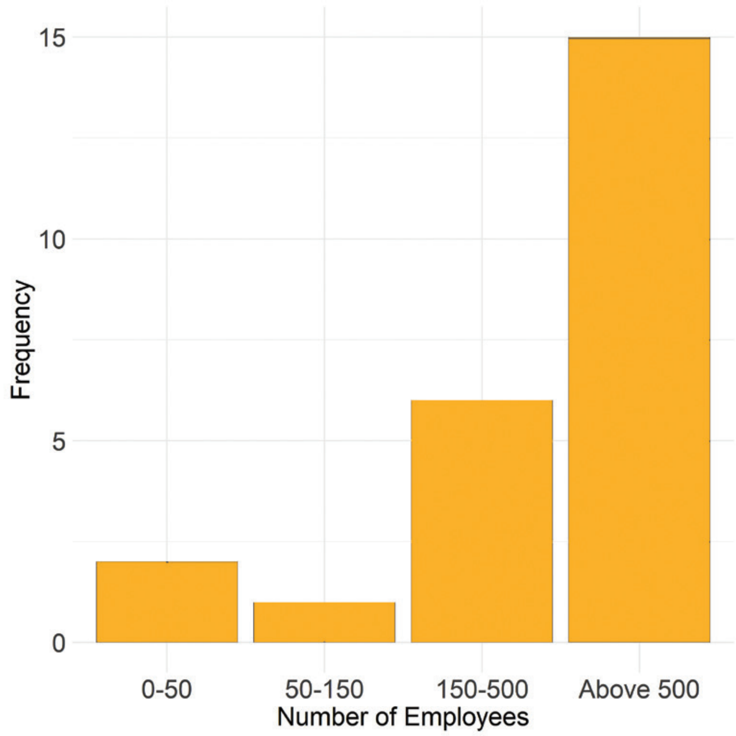
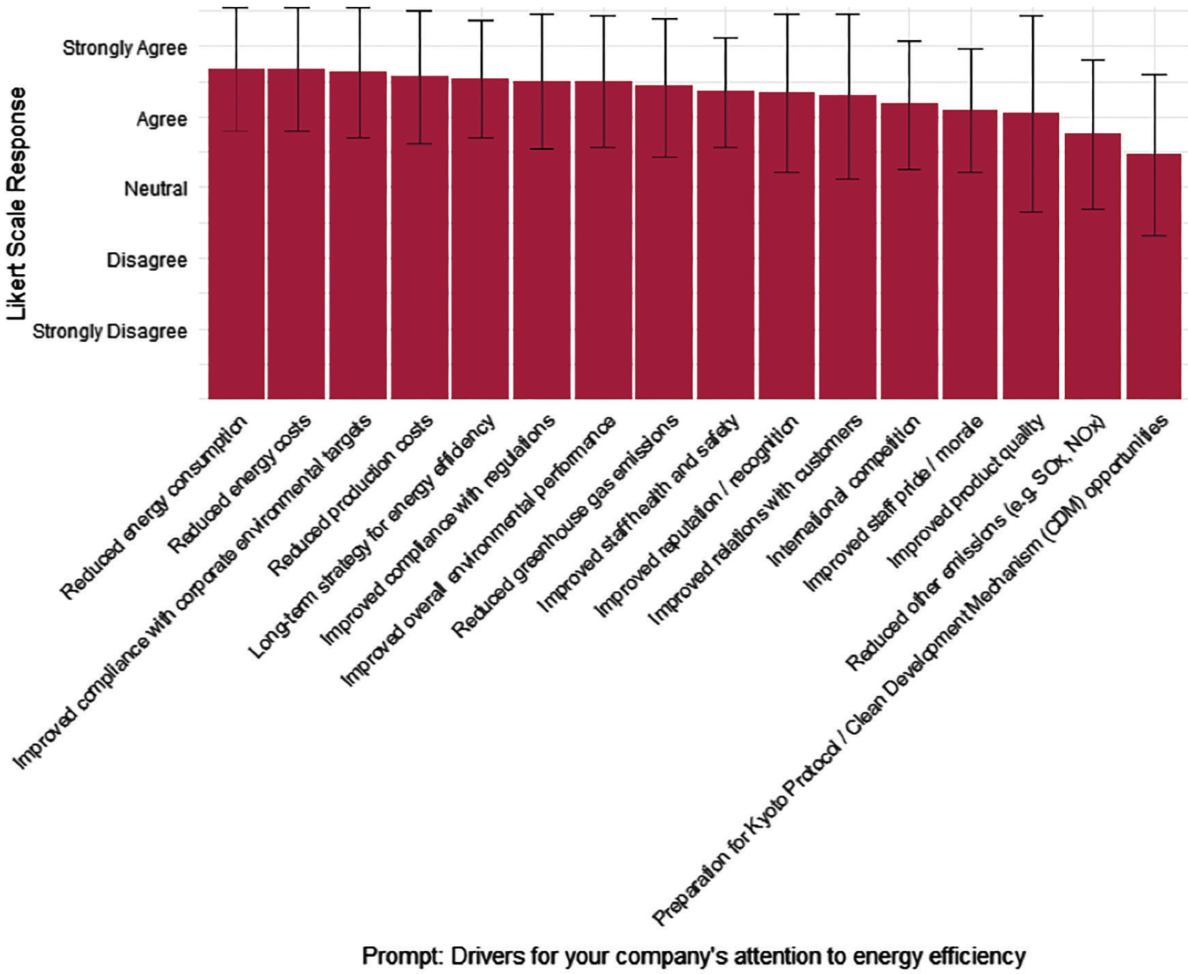


Figure 8: Distribution of number of employees across surveyed companies.



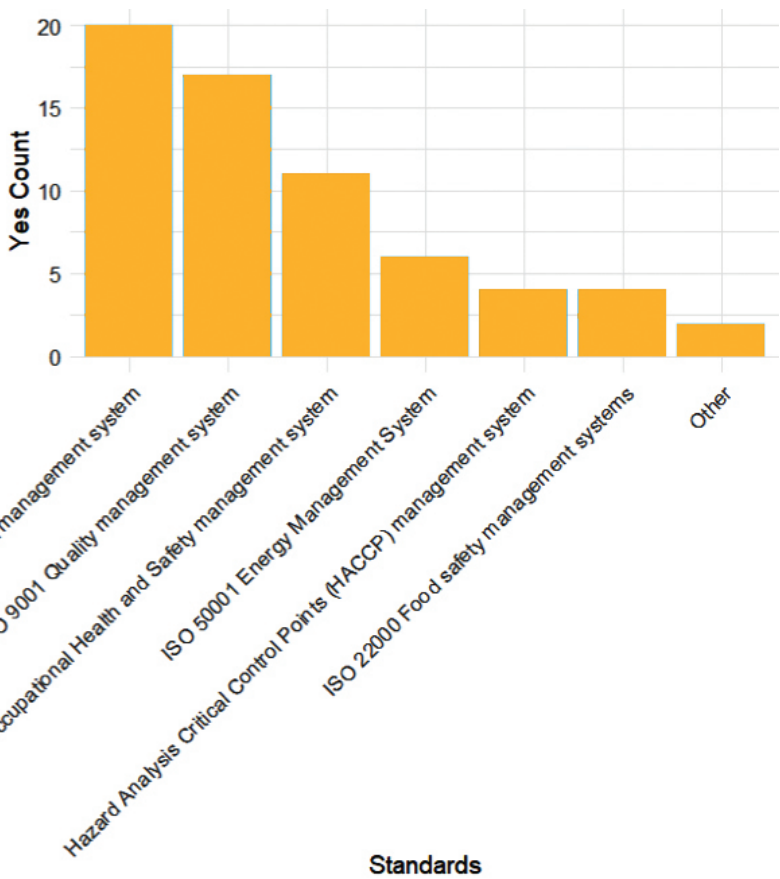


Figure 9: Count of standards indicated adopted at respondents' companies

When asked how important energy efficiency was to top management and how involved top management were in the company's drive for energy efficiency, all respondents ranked their management as placing high importance on energy efficiency, with high involvement. However, the policymaker survey results in the prior section indicated that management prioritization was sometimes at odds with energy efficiency adoption. 22 respondents indicated that their company had designated personnel for energy management and efficiency, while only 2 respondents said their company did not. The most commonly cited level for energy managers was the Director General/ Managing Director level, with 15 responses. Regarding the skills and experience level of technical staff, the average competency was rated as medium. The skill level of staff in estimating energy and resource savings and calculating payback periods being the most highly rated skill, and knowledge of best practices and available technologies being the lowest rated skill by respondents about technical staff at their companies. All respondents indicated that company staff would be interested in learning more about energy efficiency technologies.

Respondents were also asked how often they measured or monitored energy consumption, if at all. Only one respondent indicated that their company did not measure energy consumption. Otherwise, all respondents indicated that their company measured energy consumption at least monthly, although annually and less frequent were also presented as options. 11 respondents indicated their company measured energy consumption daily. All respondents who answered the question also indicated that their company measured energy consumption through the different sections of the production process.

Presented with a list of auxiliary energy systems, respondents were asked which systems they measured efficiency for. The most measured systems were compressed air systems, and the least-measured systems were pumping systems (Figure 10). Some respondents noted that certain systems and processes were not relevant for their sector.

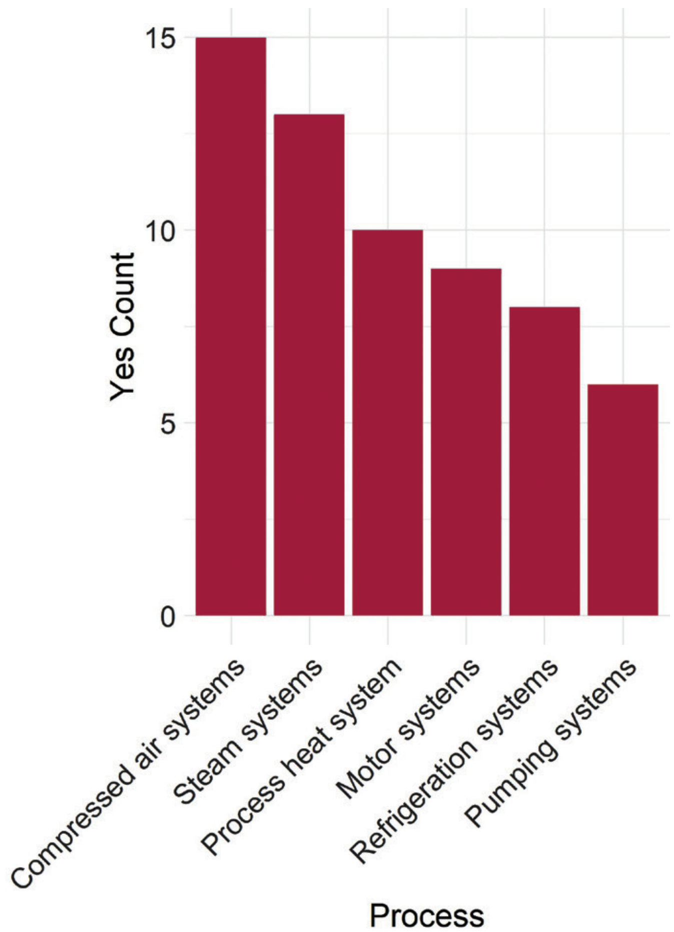


Figure 10: Number of respondents indicating company measurement of system efficiency

Regarding energy audits, 17 respondents indicated that their company carries out energy audits, and only one respondent said that their company did not. The frequency of audits was fairly balanced across the provided brackets, with 26% of respondents indicating that audits happened every year or less, 30% every 2-3 years, 22% every 3-4 years, and 22% every 5 years or more. Respondents generally felt that the energy audits were useful and led to implementation of energy efficiency measures and resulting energy savings.

Respondents were also asked to estimate the potential total energy efficiency improvement their company could achieve with and without investments in equipment and process technology. Many respondents felt there could be improvements even without dedicated investments, but investments could increase the amount of efficiency achieved (Figure 11).

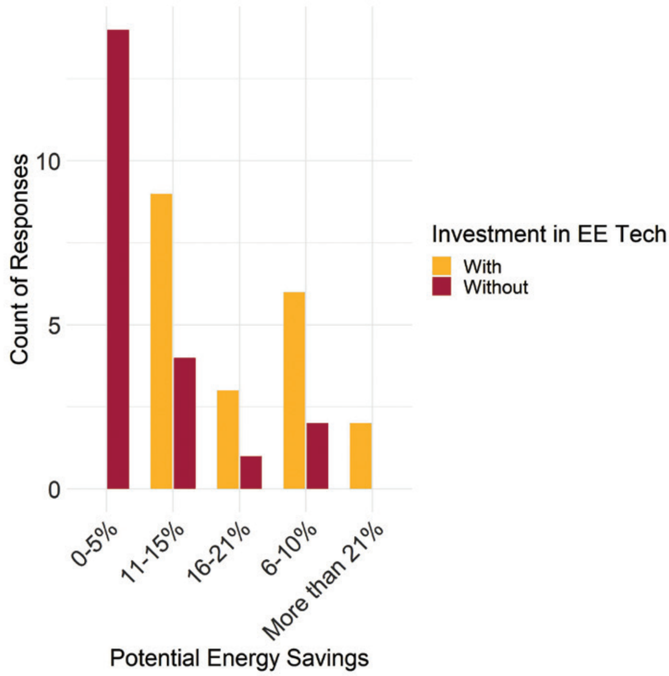


Figure 11: Count of responses on energy savings with and without investments in energy efficiency technology

Respondents were also asked about plans for capital investment and changes in production facilities at their company in the next 2-3 years. Nearly all respondents indicated that auxiliary equipment would be replaced and specific energy efficiency measures would be taken (Figure 12). Plant openings and closures were more rare, although eight respondents indicated they expected production expansions through an additional plant.

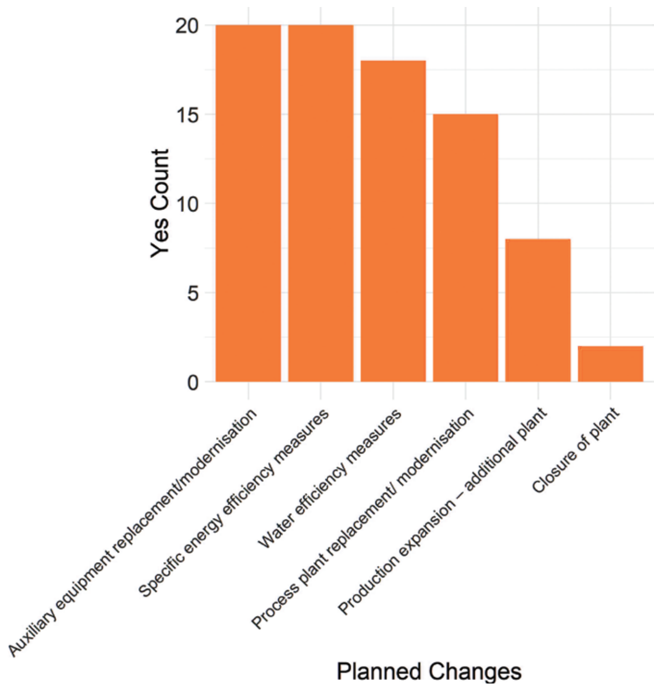


Figure 12: Planned capital investment and changes over the next 2-3 years

Respondents were also asked if they were planning or considering investing in new efficient systems, plants, or equipment over the next 2-3 years. The vast majority of respondents indicated their company would pursue improvements in compressed air systems and lighting systems, including energy efficient lighting (Figure 13). Combined heat and power received the least number of responses, potentially due to the scale of investment and retrofitting required.

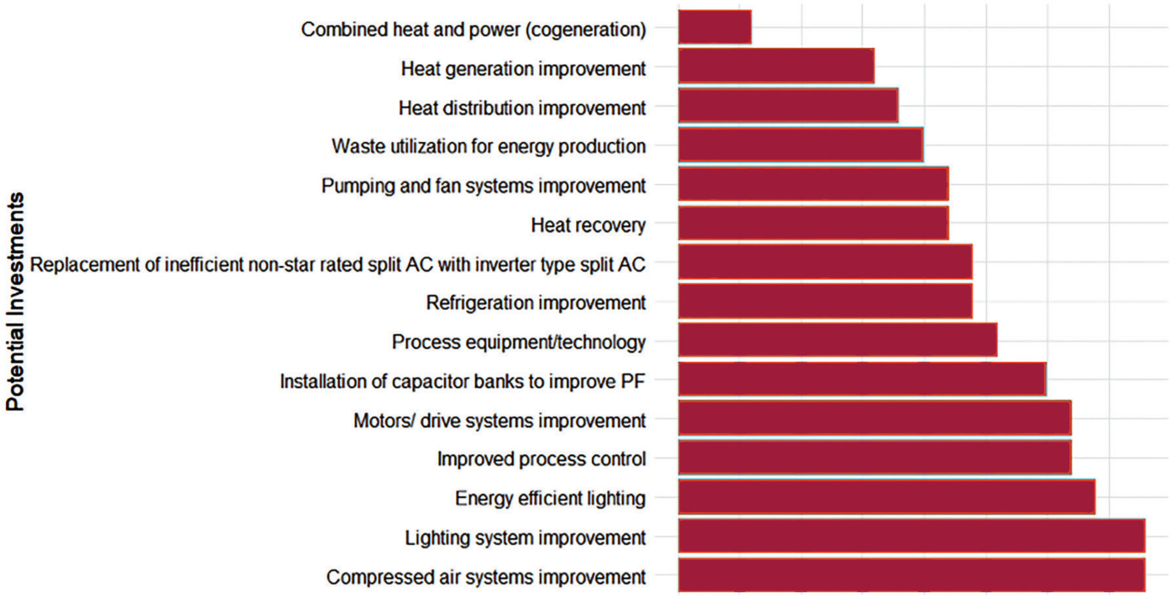


Figure 13: Potential investments in new systems, plants, and equipment over the next 2-3 years

When asked to rate the value of support services if they could be provided at no cost to the respondents' companies, most respondents had high ratings across support services (Figure 14). However, the top 4 most valuable support services were availability of energy efficiency implementation manuals for different energy systems, technical training, energy audits, and support and training in establishing energy management systems. This reflects earlier survey results of being enthusiastic about trainings for staff and the need for additional knowledge and capacity.

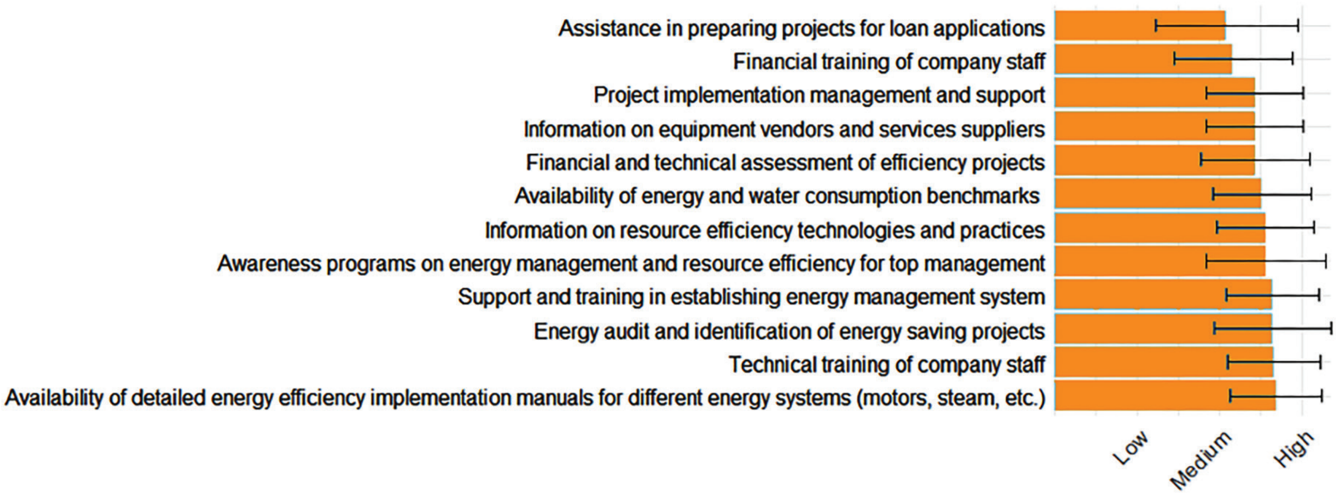


Figure 14. The value of support services if they could be provided at no cost to the respondents' companies

The survey also asked if companies used renewable energy sources. Most companies indicated they did, although there was a wide range of types of energy specified. Biomass and solar were the most frequently mentioned renewable energy sources, although it should be noted that the sustainability and carbon content of biomass depends on many factors. Some respondents indicated their companies had a high share of biomass in total energy use, ranging form 40-90% of thermal energy. Many companies indicated that they had solar projects ongoing, coming online soon, or that they wanted to assess the feasibility of solar energy. For companies already using solar, the amount of solar ranged from 3-40% of final energy demand. Two companies mentioned waste and micro-hydro as other renewable energy sources.

Both government and industry respondents were asked about barriers to energy efficiency, though industry respondents were asked to answer from the perspective of why improving energy efficiency at their company was difficult. In general, respondents expressed disagreement with many of the statements, indicating the survey may not have identified the correct barriers to energy efficiency or framed them in an effective way. However, one barrier stood out in terms of how many respondents agreed about its significance as a barrier – the lack of government financial incentives for energy efficiency (Figure 15). This correlates with earlier findings from both government and industry respondents about financial barriers to EE.

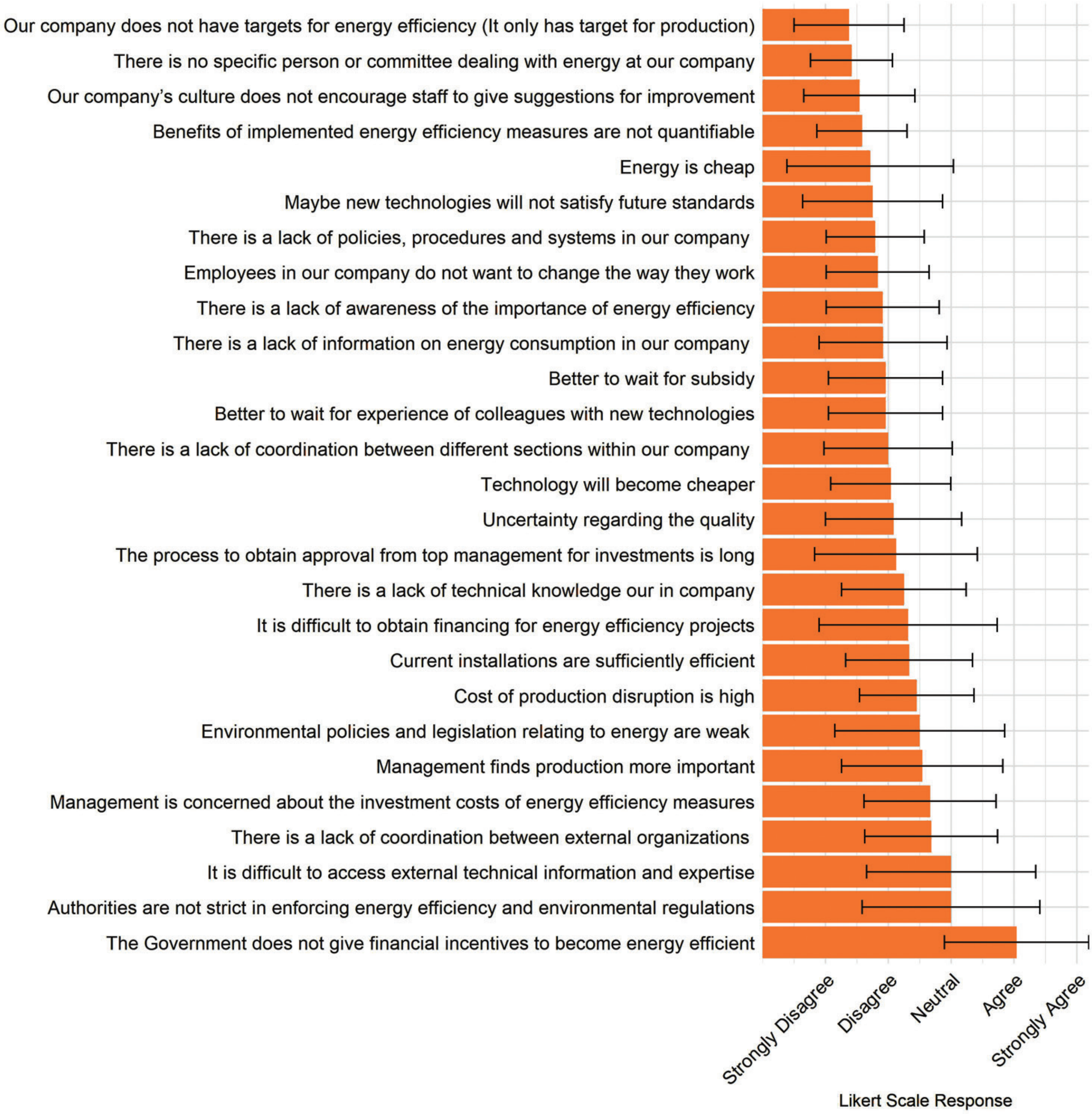


Figure 15: Responses to prompt on why improving energy efficiency is difficult

Finally, respondents were asked about the approximate average age of their main process technology and auxiliary energy systems. The most commonly reported age for both systems was 5-10 years, with auxiliary energy systems being on average slightly newer than main process technologies.

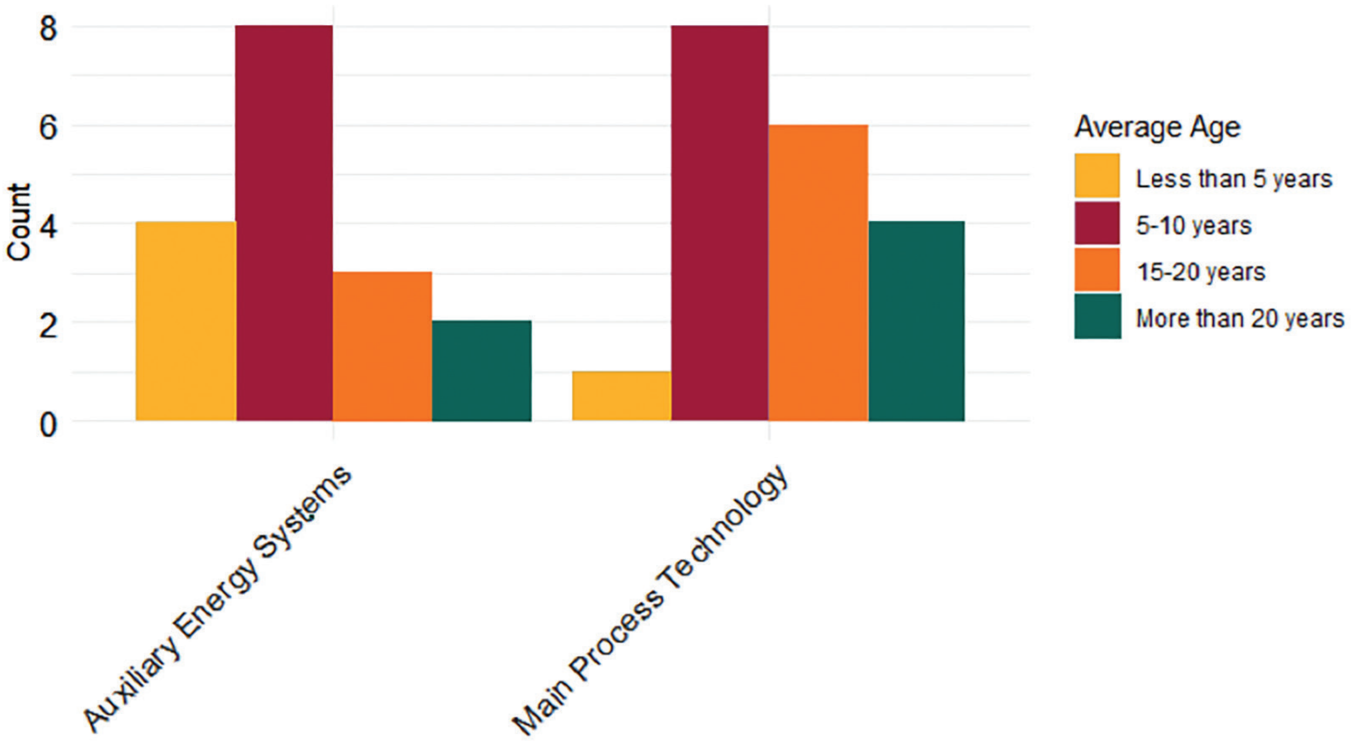


Figure 16. Average age of their main process technology and auxiliary energy systems.

The survey of government respondents provided a comprehensive view on the challenges and motivations surrounding energy efficiency and decarbonization in Sri Lanka's industrial sector. Infrastructure and resource constraints stood out as the most pressing concern. Respondents emphasized the high costs associated with transitioning to energy-efficient technologies, especially challenging for SMEs. A significant knowledge gap across various sectors, from the general populace to industry managers, hampers energy efficiency endeavors. Moreover, the current policy framework is not sufficiently robust to drive change, with weak regulations and challenges like a monopolistic market hindering progress. While economic barriers are evident, mainly due to Sri Lanka's prevailing economic challenges, technological barriers, such as the unavailability of industry-specific solutions, also persist. Respondents recognized the financial benefits of energy efficiency, namely reduced energy and production costs. For enhancing energy efficiency, training on energy management systems, real-world case studies, and financial incentives like loans and subsidies were deemed most effective.

The survey of industry respondents indicates a strong alignment between governmental and industrial objectives when it comes to the primary drivers for energy efficiency, with a mutual emphasis on reduced energy consumption and costs. Significantly, the effectiveness of mandatory corporate environmental targets as a key driver was highlighted, suggesting that top-down directives within the corporate world play an influential role. However, while the majority of the respondents underscored the importance of energy efficiency within their organizations and have adopted relevant standards like ISO 14001, a noticeable gap emerged in the understanding and prioritization of global climate policies. The responses also emphasized the appetite for further knowledge, with enthusiasm shown towards the prospect of training in energy efficiency technologies. When considering barriers, the lack of government financial incentives stands out as a primary hurdle for many companies. This ties back to a larger theme echoing throughout the survey: the intertwining of financial considerations, both as drivers and barriers, in the pursuit of energy efficiency in the industrial sector.

Taken together, the survey results underline a clear need for comprehensive interventions addressing infrastructure, knowledge dissemination, and policy formulation, with a keen focus on financial incentives and supports.

6 Industrial energy efficiency and decarbonization potential in Sri Lanka

In this chapter, we first take a deep dive in analyzing energy efficiency and decarbonization potential in industrial motor systems which are key energy systems in industry in Sri Lanka and account for around 70% of total electricity use in Sri Lanka. We will then discuss a framework for deep decarbonization of industry in Sri Lanka and five key pillars that need to be implemented for decarbonization of industry in Sri Lanka.

6.1. Energy efficiency and decarbonization potential in industrial motor systems Sri Lanka

The industrial electric motor systems represent approximately 70% of the total industrial electricity consumption worldwide (IEA, 2016). These industrial motors are typically integral to broader systems, and a principal strategy for reducing their electrical power usage involves optimizing the various other elements within the system alongside the motor itself. The losses incurred within the electric motors constitute merely a minor fraction of the aggregate losses sustained by the entire system of which the motor is a component. Figure 17 depicts a standard industrial motor system, encompassing interconnected components. It is crucial for the efficiency of the entire system that each individual component operates optimally.

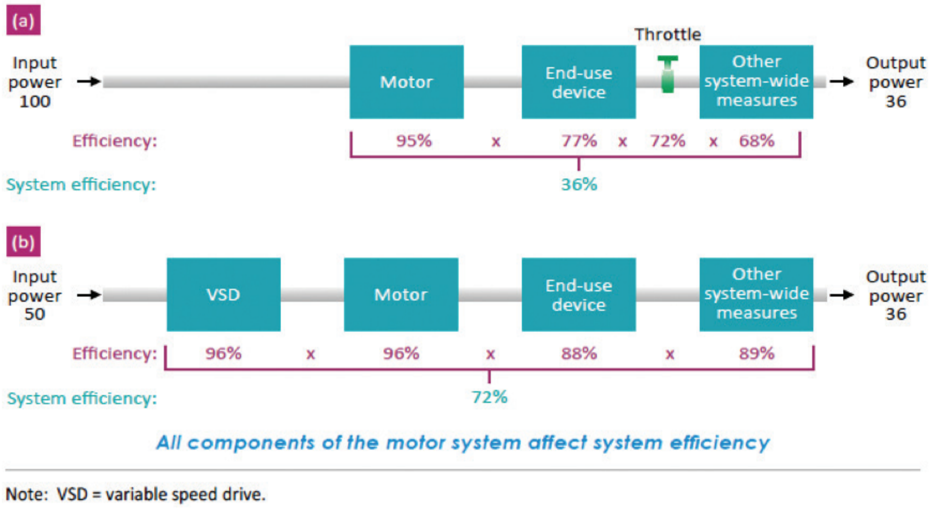


Figure 17. Illustration of two industrial electric motor-driven systems: (a) normal and (b) efficient (IEA, 2016a)

Typically, motors are quite efficient, particularly in developed and emerging nations that uphold robust minimum energy performance standards (MEPS). An increasing number of countries are adopting MEPS, and these standards are becoming more rigorous in regions where they have been in place for some time. The International Energy Agency (IEA) anticipates that by the year 2040, motors adhering to the premium efficiency standard (IE3) or higher will constitute around 60% of the electricity consumption of motor systems. Given that enhancements in motor efficiency will contribute only slightly to the overall efficiency of the motor system, the industrial sector must shift its focus to refining the efficiency of equipment powered by motors. Implementing optimization strategies such as predictive maintenance, steering clear of oversized motors, and tailoring motor systems to meet specific requirements can lead to substantial improvements in the energy efficiency of motor-driven systems (IEA, 2016). Further savings could be realized by extending the focus from the motor and the entire motor system to the end-use device, as depicted in Figure 17.

In our analysis for industrial motor systems, we focus on pump systems, fan systems and compressed air systems which represent three main types of motor systems that together account for around half of electricity use in industrial motor systems. The share of electricity used by pump, fan, and compressed air systems varies among manufacturing subsectors.

One of the main barrier to crafting effective policies and amplifying worldwide initiatives to enhance energy efficiency in industrial motor systems is the absence of comprehensive data and insights regarding the extent and cost-effectiveness of the energy-saving potential within industrial motor systems across various nations. This scarcity of information poses a challenge to devising an all-encompassing strategy and roadmap for boosting the efficiency of motor systems. It is considerably simpler to calculate the incremental energy savings achieved by replacing a standard motor with an energy-efficient alternative in a motor system than it is to assess the energy savings derived from implementing additional energy-efficiency measures to an existing motor system.To address these barriers, we conducted a study on industrial motor systems in Sri Lanka. This analysis focuses on energy use, energy efficiency, and CO_2 emissions-reduction potential in industrial motor systems in Sri Lanka.

Utilizing the methodology explained in the Appendix, we developed energy-efficiency cost curves for industrial motor systems in Sri Lanka. Our objective was to distinctly show the cost-effective potential and the complete technical potential for electricity efficiency improvement potential in these systems through the application of eight energy efficiency measures. Additionally, we determined the potential reduction in CO2 emissions resulting from the electricity savings. These potentials represent the entire available scope for energy efficiency improvements in industrial motor systems for the year 2021, implying a hypothetical 100% adoption rate. We recognize that achieving a 100% adoption rate is improbable and that nearing a high adoption rate could only transpire over an extended duration. Nonetheless, considering varying penetration rates for the energy-efficiency measures in future scenarios fell outside the parameters of our study. It is important to note that the analysis of energy savings presented in this report does not encompass motor systems utilized for process cooling and refrigeration.

6.1.1. Energy-efficiency cost curve for industrial pump systems in Sri Lanka

Figure 18 displays the energy-efficiency cost curve for the industrial pump systems in Sri Lanka. On the graph, the y-axis represents the cost of conserved electricity (CCE), while the x-axis illustrates the cumulative annual electricity savings potential achievable through various efficiency measures. Table 4 details these measures, providing insights into their cumulative annual electricity savings potential, final CCE, and the potential reduction in CO_2 emissions. The measures listed within the grey section of the table are deemed cost-effective, meaning their CCE is below the 2021 unit price for industrial-sector electricity in Sri Lanka. Conversely, the measures placed in the white section of the table are not considered cost-effective.

Among the eight energy-efficiency measures evaluated, seven prove to be cost-effective. The measure topping the list for cost-effectiveness in pump systems in Sri Lanka is "isolating flow paths to non-essential or non-operating equipment". Following closely are "Use pressure switches to shut down unnecessary pumps" and "Fix leaks, damaged seals, and packing" as the second and third most cost-effective measures, respectively. Notably, the implementation of variable-speed drives (VSDs) on pumps not only stands out as cost-effective but also presents the largest potentials for energy savings.

The measure with the least cost-effectiveness (i.e., the highest CCE) for industrial pump systems in Sri Lanka is a frequently talked about option: "replacing motors with more efficient models." An observation, which may seem counter-intuitive, is that the potential for energy savings from motor replacement is less than the potential associated with all other efficiency measures evaluated. Moreover, the replacement of motors does not prove to be a cost-effective strategy. It is crucial to underscore that this analysis aims to assist policy makers; however, it should not serve as a replacement for tailored assessments of motor system efficiency opportunities at specific facilities.

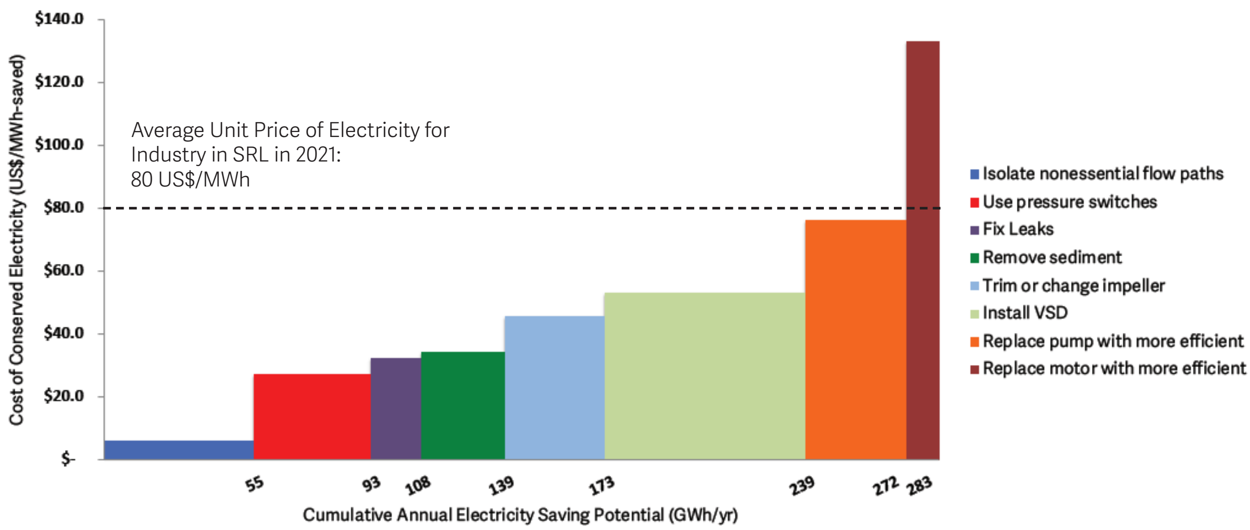


Figure 18. Energy efficiency cost curve for industrial pump systems in Sri Lanka
(Source: GEI analysis- Methodology in the Appendix)

Table 4. Cumulative annual electricity saving and CO_2 emission reduction potential for efficiency measures in industrial pump systems in Sri Lanka ranked by final CCE

	Energy efficiency measures	Cumulative annual electricity saving potential (GWh/yr)	Final cost of conserved energy (US$/MWh-Saved)	Cumulative annual CO_2 emission reduction potential (kton CO_2 /yr)
1	Isolate flow paths to nonessential or non-operating equipment	55	6	29
2	Use pressure switches to shut down unnecessary pumps	93	28	48
3	Fix leaks, damaged seals, and packing	108	33	56
4	Remove sediment/scale buildup from piping	139	35	72
5	Trim or change impeller to match output to requirements	173	46	90
6	Install variable speed drive	239	53	124
7	Replace pump with more energy efficient type	272	76	142
8	Replace motor with more efficient type	283	133	147

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) The energy and CO_2 savings presented for each measure are the cumulating savings from that measure and all previous measures with lower CCE. 3) This analysis provides an indication of the cost-effectiveness of system energy efficiency measures at the country level. The cost-effectiveness of individual measures will vary based on plant-specific conditions. Source: Global Efficiency Intelligence's Analyses (Methodology in Appendix)

Table 5 illustrates that the total technical potential for energy savings accounts for 45% of the industrial pumping system's electricity consumption in Sri Lanka for the year 2021. This substantial potential for savings is primarily attributed to our assumption that pump systems in Sri Lanka operate at a LOW efficiency baseline. This finding is consistent with our previous research conducted in other developing nations, such as Thailand, Brazil, Vietnam, and Egypt. In terms of cost-effectiveness, Sri Lanka's industrial pump systems exhibit a potential that equates to 43% of the total electricity usage by industrial pumping systems in the country for 2021.

As detailed in the methodology section of the Appendix, the implementation of one measure can impact the efficiency gains realized from subsequent measures. In essence, when one measure is applied, it enhances the base-case efficiency, resulting in lower efficiency gains from any subsequent measures, had they been implemented first or considered independently. Due to this, our analysis approached the measures collectively, rather than in isolation. This means that the efficiency gains from implementing a specific measure are contingent upon the gains achieved by prior measures. This phenomenon is referred to as the "Synergy Effect".

Table 5. Total annual cost-effective and technical energy saving and CO2 emissions reduction potential in industrial pump systems in Sri Lanka

	Cost-effective potential	Technical potential
Annual electricity saving potential for pump systems in Sri Lanka's industry (GWh/yr)	272	283
Share of saving from the total pump system energy used in Sri Lanka's industry in 2021	43%	45%
Share of saving from the total electricity used in Sri Lanka's industry in 2021	5.3%	5.5%
Annual CO_2 emission reduction potential from Sri Lanka's industry (kton CO_2/yr)	142	147

Notes: 1) Savings are based on 100% adoption of the energy efficiency measures. 2) Systems larger than 1000 hp are excluded from the energy saving and cost analyses. 3) The energy saving potential exclude pump systems that are in process cooling and refrigeration.

In this approach, we calculate cumulative electricity savings by accounting for the synergy effect of the measures, as opposed to evaluating each measure in isolation. For example, the cumulative annual electricity savings resulting from the implementation of measure #3 encompasses the efficiency improvements from all preceding measures (measures #1 and #2).

However, should policy makers wish to evaluate the impact of a singular efficiency measure, independent of other measures, the savings should be calculated for that specific measure when implemented alone. Figure 19 shows the energy savings potential of each efficiency measure when implemented independently against the potential when implemented concurrently with other measures. It is the latter scenario that informs our energy-efficiency cost curve.

Notably, measures that are less cost-effective on the efficiency cost curve, appearing towards the top of the graph in Figure 19, exhibit the most significant discrepancies between the energy savings calculated for isolated implementation versus combined implementation with other measures. It is imperative to understand that simply summing up the energy savings of individual measures, when implemented in isolation, will yield an inaccurate total due to the synergy effect previously explained.

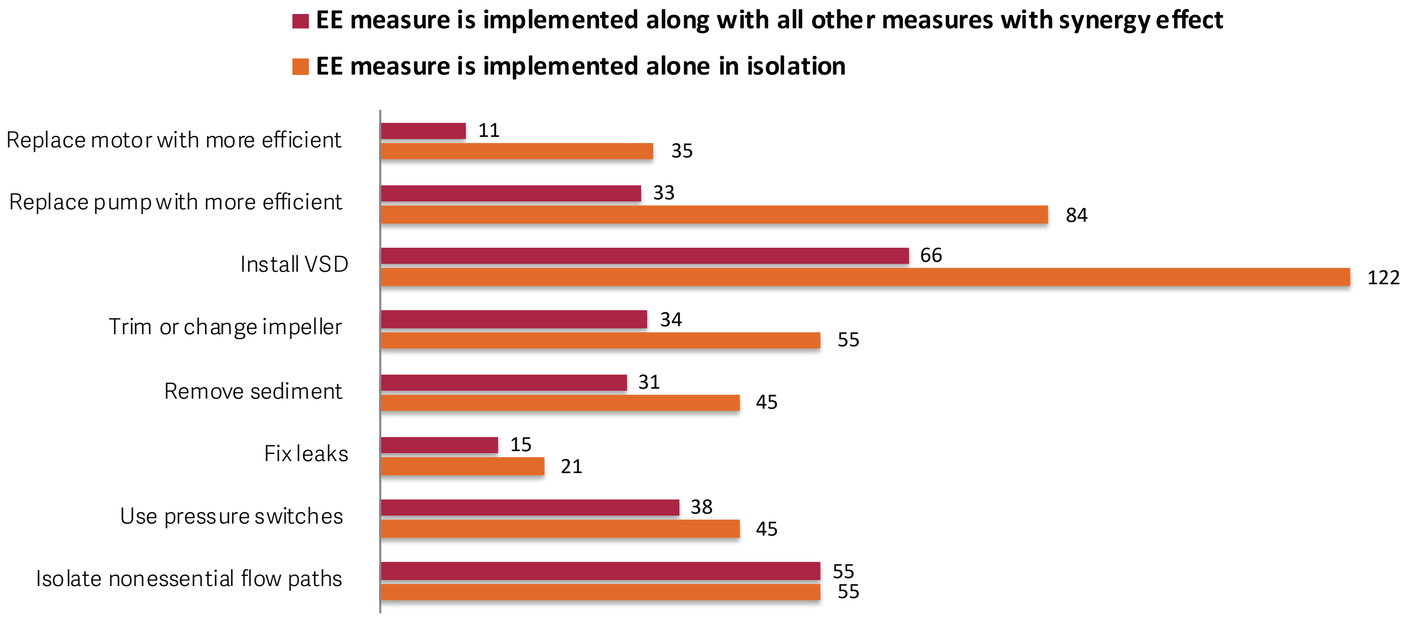


Figure 19. Comparison of energy saving potential (GWh/yr) for each efficiency measure in industrial pump systems in Sri Lanka when each measure is implemented in isolation or is implemented along with other measures (Source: GEI analysis- Methodology in the Appendix)

6.1.2. Energy-efficiency cost curve for industrial fan systems in Sri Lanka

Figure 20 presents the energy-efficiency cost curve for industrial fan systems in Sri Lanka. The y-axis of the graph represents the cost of conserved electricity (CCE), while the x-axis depicts the cumulative annual electricity savings potential achievable through various efficiency measures. Table 6 details these measures, outlining their cumulative annual electricity savings potential, final CCE, and the potential reduction in CO_2 emissions. The measures listed within the grey section of the table are deemed cost-effective, meaning their CCE is below the 2021 unit price for industrial-sector electricity in Sri Lanka. On the other hand, the measures placed in the white section are not considered cost-effective.

Out of the eight energy-efficiency measures evaluated, seven prove to be cost-effective. The measure topping the list for cost-effectiveness in fan systems in Sri Lanka is "Fix leaks and damaged seals," which exhibits the lowest CCE. Additionally, implementing variable-speed drives (VSDs) on fans stands out not only for its significant energy savings potential but also for its cost-effectiveness.

On the flip side, the least cost-effective measure (i.e., the one with the highest CCE) for fan systems in Sri Lanka is a popular choice: replacing motors with more efficient models. Conversely, installing a VSD on fan systems, despite resulting in the highest savings potential, proves to be a cost-effective solution in Sri Lanka. Another intriguing and perhaps unexpected observation is that the energy savings potential from motor replacement is lower than that of all other efficiency measures examined, and this particular measure does not qualify as cost-effective.

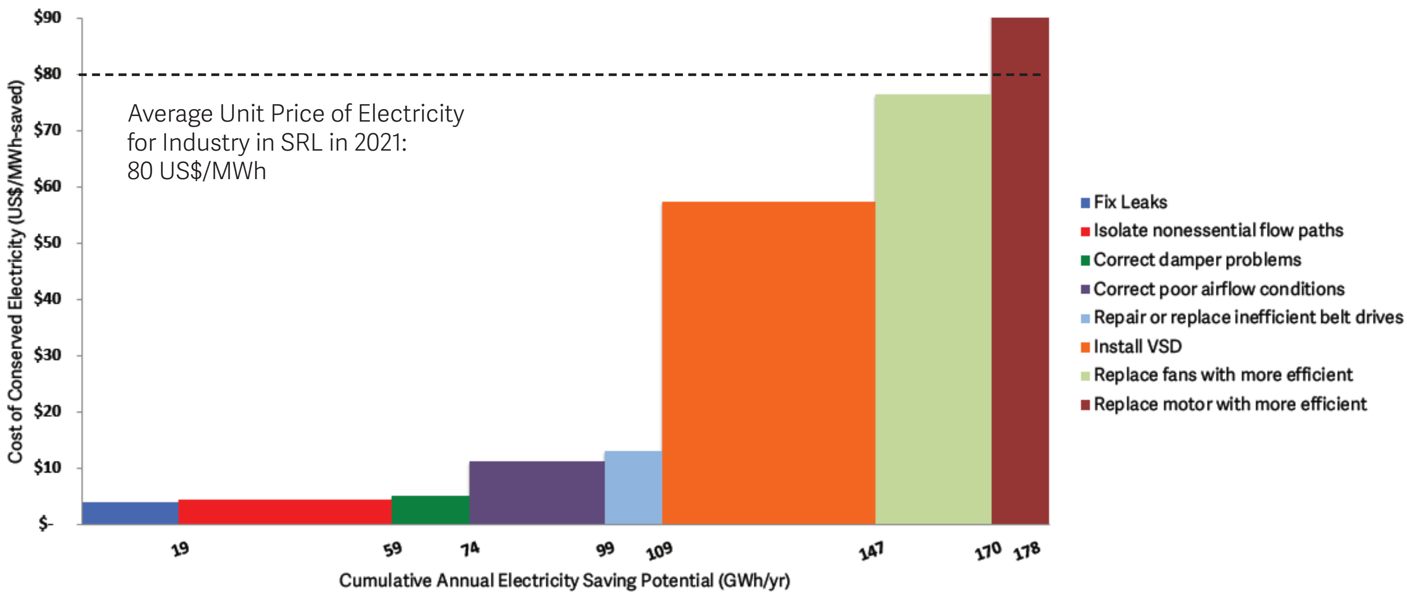


Figure 20. Energy efficiency cost curve for industrial fan systems in Sri Lanka
(Source: GEI analysis- methodology in the appendix)

Table 6. Cumulative annual electricity saving and CO2 emission reduction potential for efficiency measures in industrial fan systems in Sri Lanka ranked by final CCE

	Energy efficiency measures	Cumulative annual electricity saving potential (GWh/yr)	Final cost of conserved energy (US$/MWh-saved)	Cumulative annual CO_2 emission reduction potential (kton CO_2 /yr)
1	Fix Leaks and damaged seals	19	4.0	10
2	Isolate flow paths to nonessential or non-operating equipment	59	4.4	31
3	Correct damper problems	74	5	38
4	Correct poor airflow conditions at fan inlets and outlets	99	11	51
5	Repair or replace inefficient belt drives	109	13	57
6	Install variable speed drive	147	58	77
7	Replace oversized fans with more efficient type	170	77	88
8	Replace motor with more energy efficient type	178	116	93

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) The energy and CO2 savings presented for each measure are the cumulating savings from that measure and all previous measures with lower CCE. 3) This analysis provides an indication of the cost-effectiveness of system energy efficiency measures at the country level. The cost-effectiveness of individual measures will vary based on plant-specific conditions.

Source: Global Efficiency Intelligence's Analyses (Methodology in Appendix)

Table 7 provides the estimated energy savings and emissions reduction potential for fan systems within Sri Lanka's industrial sector. The cost-effective potential for annual electricity savings is estimated at 170 GWh/year, which constitutes 35% of the total energy used by fan systems in the country's industry for the year 2021. This translates to 3.3% of the total electricity consumed by Sri Lanka's industrial sector in the same year. In terms of emissions reduction, implementing cost-effective measures could potentially lead to an annual reduction of 88 kilotons (kton) of CO_2 emissions. The close proximity of the values between the cost-effective and technical potentials highlights the significant and almost fully accessible energy savings and emissions reduction opportunities within the industrial fan systems in Sri Lanka.

Table 7. Total annual cost-effective and technical energy saving and CO2 emissions reduction potential in industrial fan systems in Sri Lanka

	Cost-effective potential	Technical potential
Annual electricity saving potential for fan systems in Sri Lanka's industry (GWh/yr)	170	178
Share of saving from the total fan system energy used in Sri Lanka's industry in 2021	35%	36%
Share of saving from the total electricity used in Sri Lanka's industry in 2021	3.3%	3.5%
Annual CO_2 emission reduction potential from Sri Lanka's industry (kton CO_2/yr)	88	93

Notes: 1) Savings are based on 100% adoption of the energy efficiency measures. 2) Systems larger than 1000 hp are excluded from the energy saving and cost analyses. 3) The energy saving potential exclude fan systems that are in process cooling and refrigeration and non-process facility Heating, ventilation and air conditioning (HVAC).

Source: Global Efficiency Intelligence's Analyses (methodology in appendix)

The measures that are less cost-effective on the efficiency cost curve and that appear at the top of the graph in Figure 21 show the largest differences between the energy savings calculated for the measure in isolation versus the energy savings calculated for the measure in combination with other measures. Note that summing up the energy savings of individual measures implemented in isolation will give an inaccurate result because of the synergy effect explained above.

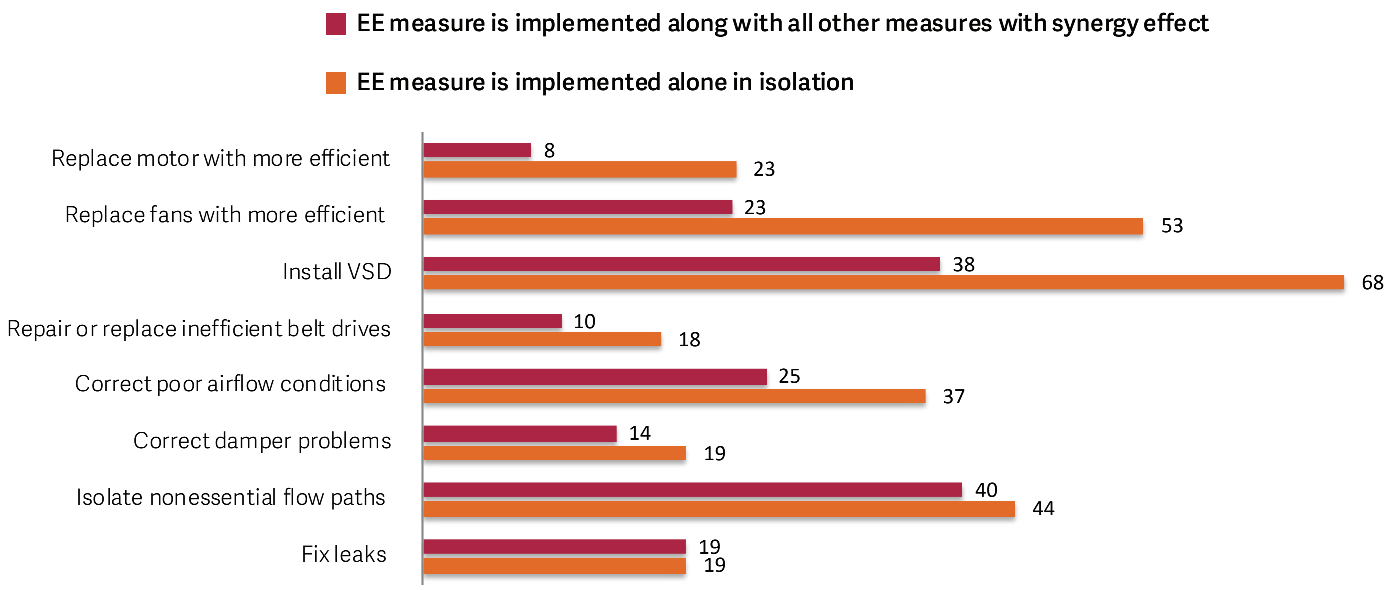


Figure 21. Comparison of energy saving potential (GWh/yr) for each efficiency measure in industrial fan systems in Sri Lanka when each measure is implemented in isolation or is implemented along with other measures (Source: GEI analysis- methodology in the appendix)

6.1.3. Energy-efficiency cost curve for industrial compressed air systems in Sri Lanka

The energy-efficiency cost curve depicted in Figure 22 for industrial compressed air systems in Sri Lanka provides valuable insights into the cost-effectiveness and energy savings potential of various efficiency measures. The y-axis displays the cost of conserved electricity (CCE), while the x-axis demonstrates the cumulative annual electricity savings potential attributable to different efficiency measures. Both figure 22 and Table 8, which is associated with the cost curve, shows that six out of the ten energy-efficiency measures are deemed cost-effective, as their CCE values are lower than the unit price of industrial-sector electricity in Sri Lanka for the year 2021. These cost-effective measures are represented in the grey area of the table.

Among all the measures evaluated, "Fix leaks, adjust compressor controls, establish ongoing plan" emerges as the most cost-effective option for compressed air systems in Sri Lanka, with the lowest CCE and also offering one of the largest potential for energy savings. Following this, "Eliminate inappropriate compressed air uses" is another measure that stands out in terms of cost-effectiveness and saving potential. On the other hand, the measure with the highest CCE and thus considered the least cost-effective is "Size replacement compressor to meet demand." This analysis underscores the significance of not only considering the cost-effectiveness of energy-efficiency measures but also their potential impact on energy savings for industrial compressed air systems in Sri Lanka.

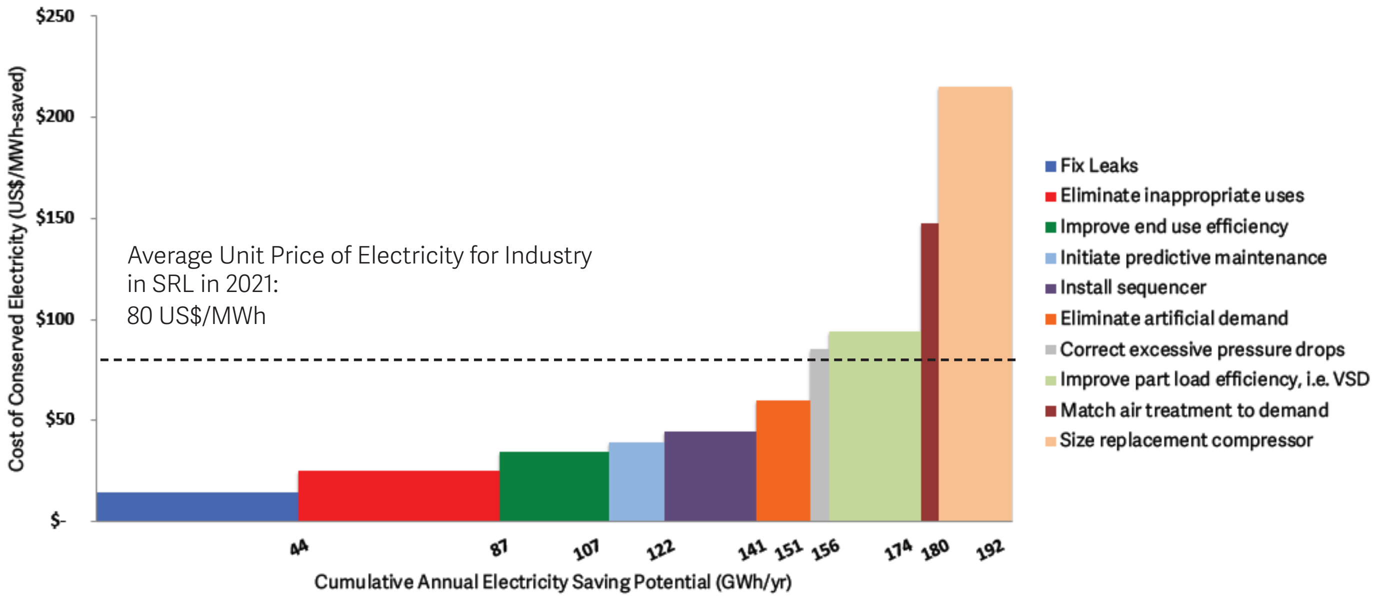


Figure 22. Energy efficiency cost curve for industrial compressed air systems in Sri Lanka (Source: GEI analysis- Methodology in the Appendix)

Table 9 shows that the total technical energy-savings potential is 39% of total industrial compressed air system electricity use in Sri Lanka in 2021. This is a significant saving potential primarily because we assumed that compressed air systems in Sri Lanka have LOW efficiency base case. Sri Lanka's industrial compressed air systems have a cost-effective potential of 33% of total industrial compressed air system electricity use in Sri Lanka in 2021.

Table 8. Cumulative annual electricity saving and CO2 emission reduction potential for efficiency measures in industrial compressed air systems in Sri Lanka ranked by final CCE

	Energy efficiency measures	Cumulative annual electricity saving potential (GWh/yr)	Final cost of conserved energy (US$/MWh-Saved)	Cumulative annual CO_2 emission reduction potential (kton CO_2 /yr)
1	Fix leaks, adjust compressor controls, establish ongoing plan	44	14	23
2	Eliminate inappropriate compressed air uses	87	25	45
3	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	107	34	56
4	Initiate predictive maintenance program	122	39	63
5	Install sequencer	141	44	73
6	Eliminate artificial demand with pressure optimization/ control/ storage	151	60	79
7	Correct excessive pressure drops in main line distribution piping	156	85	81
8	Improve trim compressor part load efficiency; i.e. variable speed drive	174	94	90
9	Match air treatment to demand side needs	180	148	93
10	Size replacement compressor to meet demand	192	215	100

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) The energy and CO2 savings presented for each measure are the cumulating savings from that measure and all previous measures with lower CCE. 3) This analysis provides an indication of the cost-effectiveness of system energy efficiency measures at the country level. The cost-effectiveness of individual measures will vary based on plant-specific conditions.

Source: Global Efficiency Intelligence's Analyses (Methodology in Appendix)

Table 9. Total annual cost-effective and technical energy saving and CO2 emissions reduction potential in industrial compressed air systems in Sri Lanka

	Cost-effective potential	Technical potential
Annual electricity saving potential for compressed air systems in Sri Lanka's industry (GWh/yr)	151	192
Share of saving from the total compressed air system energy used in Sri Lanka's industry in 2021	31%	39%
Share of saving from the total electricity used in Sri Lanka's industry in 2021	2.9%	3.7%
Annual CO_2 emission reduction potential from Sri Lanka's industry (kton CO_2/yr)	79	100

Notes: 1) Savings are based on 100% adoption of the energy efficiency measures. 2) Systems larger than 1000 hp are excluded from the energy saving and cost analyses. 3) The energy saving potential exclude compressed air systems that are in process cooling and refrigeration and non-process facility Heating, ventilation and air conditioning (HVAC).

Source: Global Efficiency Intelligence's Analyses (Methodology in Appendix)

The measures that are situated higher on the efficiency cost curve, and thus are less cost-effective, are depicted at the top of the graph in Figure 23. These measures exhibit the most substantial discrepancies between the energy savings calculated when the measure is applied independently and the energy savings determined when the measure is implemented alongside other measures. It is crucial to emphasize that aggregating the energy savings of individual measures, when each is applied in isolation, will lead to an inaccurate total due to the synergy effect previously described.

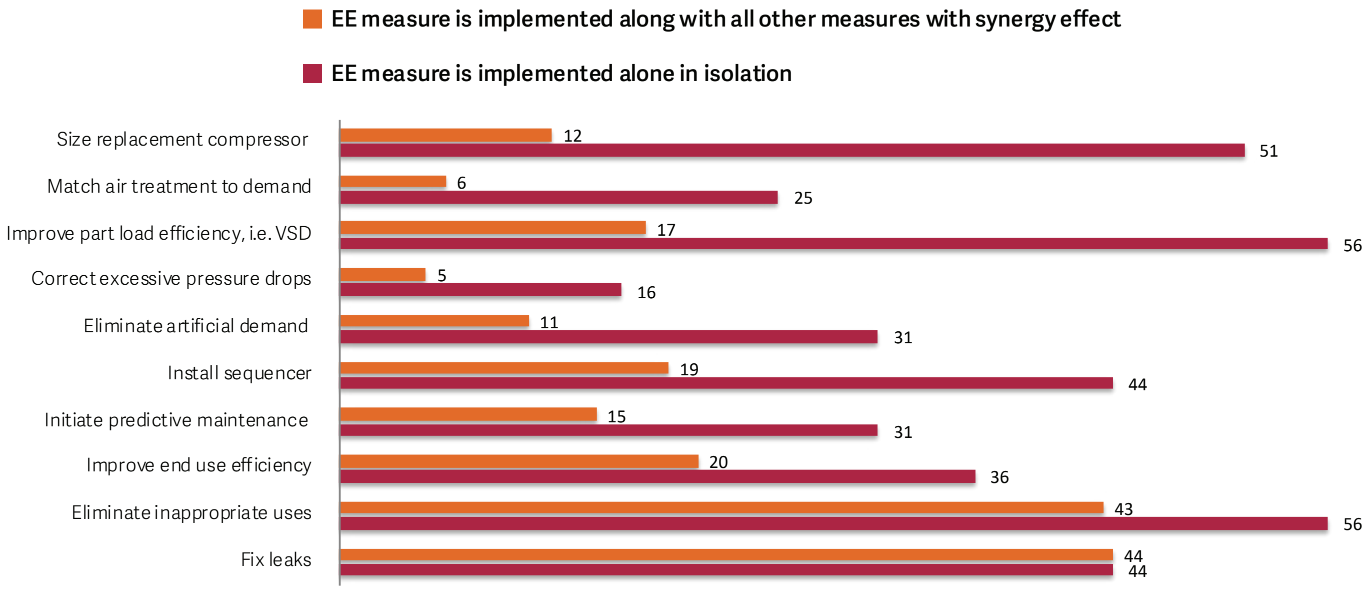


Figure 23. Comparison of energy saving potential (GWh/yr) for each efficiency measure in industrial compressed air systems in Sri Lanka when each measure is implemented in isolation or is implemented along with other measures (Source: GEI analysis- Methodology in the Appendix)

Generally, the Cost of Conserved Electricity (CCE) shares a direct correlation with the discount rate, as outlined in the methodology section of the Appendix, which details the application of the discount rate in various formulas. For instance, decreasing the discount rate tends to lead to a reduction in CCE, potentially increasing the potential for cost-effective energy savings, contingent on the industrial energy prices. An increase in energy prices can render additional energy-efficiency measures cost-effective, causing their CCEs to drop below the threshold of the energy price line.

It is pertinent to acknowledge that some energy-efficiency measures yield benefits beyond energy savings, encompassing enhancements in productivity, environmental impacts, and other areas. However, the quantification of these additional advantages is a complex task, falling outside the scope of this report. Incorporating quantified approximations of these ancillary benefits could lead to a decrease in CCE for the efficiency measures, subsequently increasing the tally of measures classified as cost-effective. Moreover, it is crucial to underscore that electricity represents a final energy form. Converting the electricity savings documented in this report to primary energy savings, while accounting for average power generation efficiency and transmission and distribution losses, reveals that the primary energy savings could be approximately three times the calculated electricity savings when electricity coms from thermal power generation.

The methodology employed in this study, along with the developed model, should be regarded as a screening tool designed to pinpoint energy-efficiency measures, along with their associated energy savings potential and costs. This tool serves as a resource for the government, policy makers, and utilities in the formulation of industrial energy-efficiency and decarbonization strategies. It is important to note that the actual energy savings potential and costs associated with energy-efficiency measures and technologies may vary based on the specific conditions of each industrial plant. To realize and potentially surpass the identified cost-effective potentials, the implementation of effective energy-efficiency policies and programs is imperative.

6.2. Industrial decarbonization pillars for Sri Lanka

Industry faces numerous drivers and challenges to transform its energy and CO_2 footprint, reduce carbon dependence (decarbonization), and grow while meeting new climate goals. The variation of energy sources, multiple uses (energy, feedstock, reductant), diverse product mix and reliance on carbon for products is part of the challenge. To achieve the deep decarbonization goal for industry, five decarbonization pillars will need to be vigorously pursued in parallel in coming decades in Sri Lanka. The five decarbonization pillars are:

1. **Demand management and material efficiency**:
   This involves optimizing the use of materials in production processes, including strategies like light-weighting, reducing waste during manufacturing, and enhancing recycling and reusability of products.

2. **Energy efficiency**:
   Focused on reducing energy consumption in industrial processes through the application of energy-efficient technologies and practices, thereby lowering associated CO_2 emissions.

3. **Electrification**:
   Transitioning from fossil fuel-based energy sources to electricity, preferably sourced from renewable energy, for industrial heating.

4. **Low-carbon fuels, feedstocks, and energy sources (LCFFES)**:
   Shifting to energy sources and feedstocks that produce lower or zero carbon emissions during their production or use, such as renewable electricity, green hydrogen, and biofuels.

5. **Carbon Capture, Utilization, and Storage (CCUS)**:
   Technologies and processes designed to capture CO_2 emissions from industrial processes, followed by either utilizing the captured CO_2 or storing it underground to prevent its release into the atmosphere.

In Sri Lanka, the adoption of the five decarbonization pillars is particularly critical for key industries such as food and beverage, textiles, and rubber, which are integral to the nation's economy but also significant contributors to its GHG emissions. Each of these pillars are discussed in more detail below.

Demand management and material efficiency

Demand management and material efficiency pillar plays a pivotal role in industrial decarbonization in Sri Lanka, particularly in high-impact sectors such as food and beverage, textiles, rubber, and cement. Figure 24 shows the material efficiency circular economy diagram by (Ellen MacArthur Foundation, 2019). For the food and beverage industry, this involves optimizing packaging design to reduce material use while maintaining product integrity. Techniques like lightweight packaging, using biodegradable or recyclable materials, and redesigning packaging for minimal excess material can significantly reduce the sector's material footprint. Additionally, process optimization to minimize food waste during production and implementing more efficient, closed-loop systems for water and waste management can further enhance material efficiency (Ellen MacArthur Foundation & Material Economics, 2019).

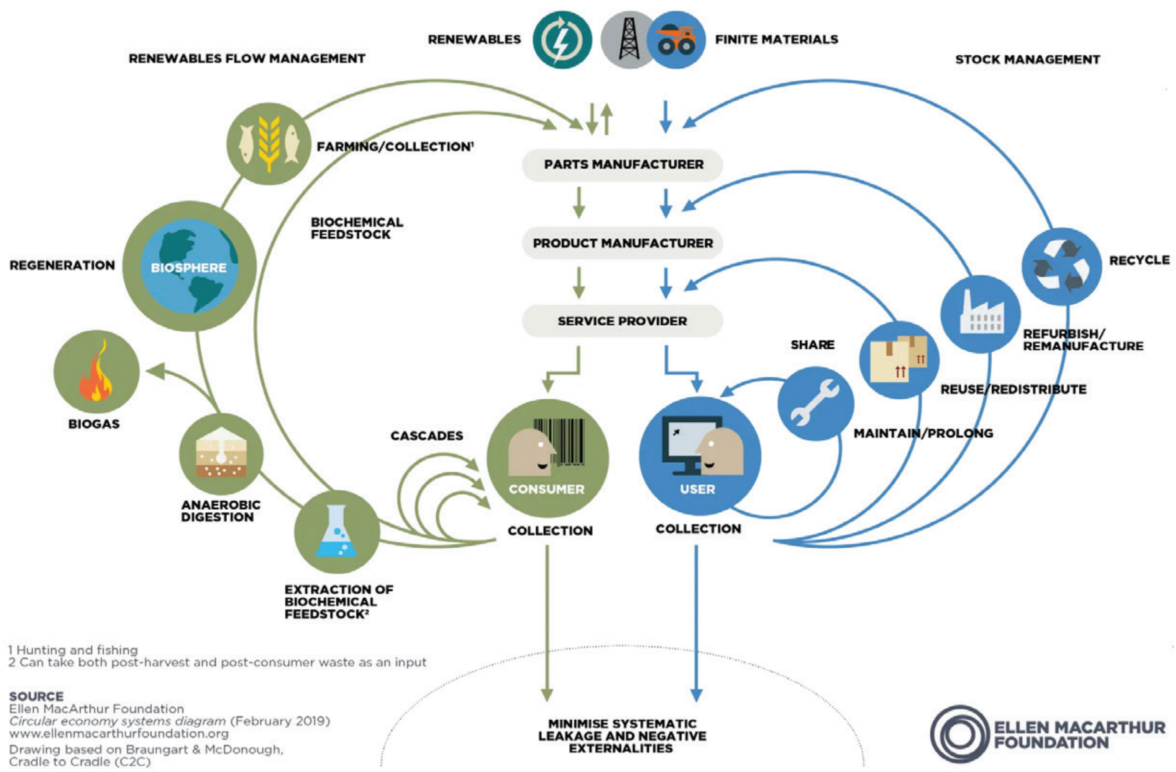


Figure 24. Material efficiency circular economy (Ellen MacArthur Foundation, 2019)

In the textile industry, demand management and material efficiency could focus on sustainable sourcing of raw materials, incorporating recycled fibers, and adopting manufacturing processes that reduce waste. Techniques such as digital printing can minimize fabric waste. The concept of a circular economy is particularly relevant here, where end-of-life garments are recycled back into the production cycle, thus reducing the demand for virgin materials and the overall carbon footprint of the products (Hasanbeigi 2013). Embracing these practices not only aids in decarbonization but also positions Sri Lankan textiles in a competitive spot in the global market, which increasingly values sustainability.

In Sri Lanka's cement and concrete industry, material efficiency is also a crucial decarbonization pillar. The industry can significantly reduce its carbon footprint by optimizing concrete recipes and recycling cement and concrete. This approach not only lessens the demand for raw materials but also decreases energy consumption in the cement manufacturing process. Techniques like concrete recycling, which reprocesses waste concrete into aggregate for new construction, are technologically mature and offer a practical solution to reduce reliance on virgin materials (US DOE 2022). While these practices are gaining traction globally, their adoption in Sri Lanka could be influenced by factors like regional availability, economic feasibility, and the increasing demand driven by urbanization and infrastructure development.

Energy efficiency

The application of energy efficiency measures and technologies reduces fuel and electricity use and their associated CO2 emissions in industry. The technologies and measures are often well-known and cost-effective, providing immediate actions that can be taken in near-term to reduce overall demand for energy from industry. Substantial CO2 emissions reduction can be achieved through application of commercialized energy efficiency technologies and measures in industry in Sri Lanka. The previous section showed the energy efficiency and associated CO2 emissions reduction for industrial motor systems in Sri Lanka.

Cross-cutting energy systems such as electric motor systems and boiler/steam systems present substantial opportunities for energy efficiency across various industries in Sri Lanka. Electric motor systems, which are ubiquitous in industrial processes, can be made more efficient through the use of high-efficiency motors, variable speed drives, and various other measures (McKane and Hasanbeigi 2010). In the previous section we showed a substantial energy saving and CO2 emissions reduction potential for industrial motor systems in Sri Lanka.

In boiler and steam systems, energy efficiency can be achieved through improved insulation, the implementation of economizers to recover waste heat, the use of advanced boiler control systems for better temperature and pressure management, and other measures. A UNIDO study in China showed that around 30% energy saving potential exist through adoption of energy efficiency and systems optimization measures (Table 10) in industrial boilers and steam systems in China. Over 80% of the saving potential was found cost-effective (Hasanbeigi et al. 2014).

Table 10. Examples of energy efficiency measures for industrial steam systems (Hasanbeigi et al. 2014).

	Energy efficiency measure
1	Excess air management: tune existing positioning control (or simple control)
2	Sootblower optimization (for coal boilers)
3	Optimization of insulation of steam piping, valves, fittings, and vessels
4	Optimization of boiler blowdown and recovery of heat from boiler blowdown
5	Implementation of an effective steam trap maintenance program
6	Optimization of condensate recovery
7	Flue gas thermal energy recovery (Economizer and/or air heater)
8	Flash-steam recovery
9	Loss On Ignition (LOI) optimization (for coal boilers)

Sector-specific energy efficiency technologies and measures are also important, which are applicable based on specific context of each sector. For example, Hasanbeigi (2010) lists 180 energy efficiency technologies and measures for the textile industry, which is a key sector in Sri Lanka. In addition, U.S. EPA provides several energy efficiency technology guidebooks for the food and beverage sector which is another important industry in Sri Lanka (U.S. EPA, various years).

Electrification

Industrial process heating operations include drying, heat treating, curing and forming, calcining, smelting, and other operations. Process heating technologies can be grouped into four general categories based on the type of energy consumed: direct fuel-firing, steam-based, electric-based, and hybrid systems (which use a combination of energy types). In process heating, material is heated by heat transfer from a heat source such as a flame, steam, hot gas, or an electrical heating element by conduction, convection, or radiation—or some combination of these. In practice, lower-temperature processes tend to use conduction or convection, whereas high-temperature processes rely primarily on radiative heat transfer. Energy use and heat losses from the system depend on process heating process parameters, system design, operating practices, and other factors (ORNL, 2017). In the food and beverage and textile industries, which are two major sector in Sri Lanka, over 90% of the the heat demand is for processes below 200 degree Celsius (Rightor et al. 2020; McMillan, 2019; Hasanbeigi 2022). With a few exceptions, it is generally easier to electrify low-temperature processes than high-temperature processes. Therefore, there is significant potential for electrification of industrial processes for low or medium heating applications. Figure 25 shows the share of industrial head demand by temperature in selected industries.

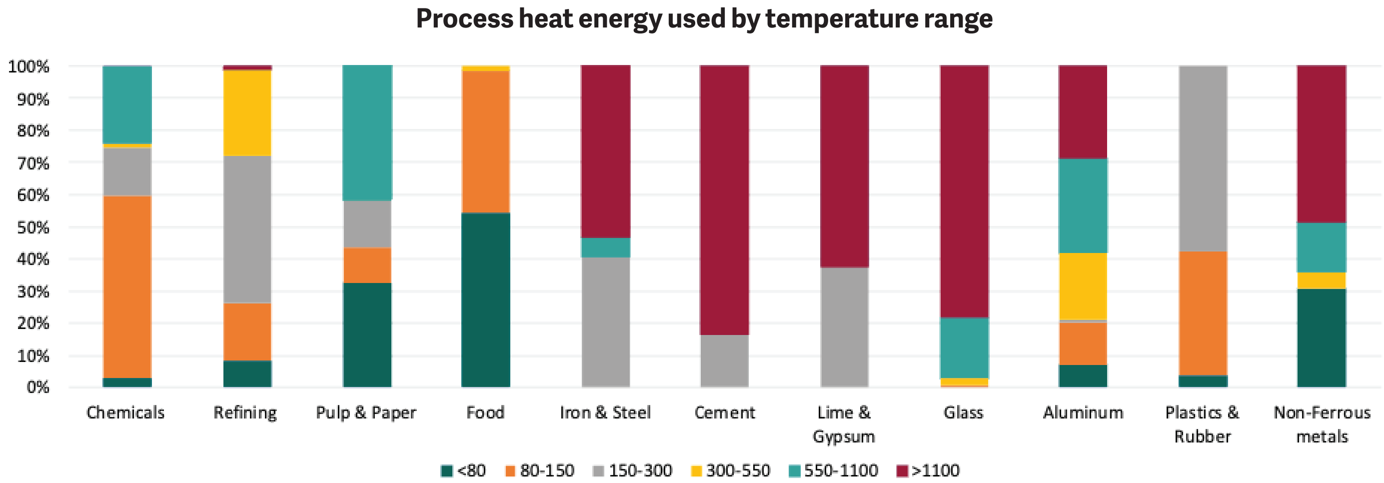


Figure 25. Share of industrial head demand by temperature in selected industries (Our analysis based on Rightor et al. 2020; McMillan, 2019)

There is a significant opportunity to decarbonize the industrial sector in Sri Lanka by shifting heat production away from carbon-intensive fossil fuels to clean sources such as electrification where low- or zero-carbon electricity is used.

Three technological pathways to industrial electrification in Sri Lanka are:

- Electric boilers
- Industrial heat pumps
- Alternative processes with electrified heating.

Electric boilers

Steam boilers are an important technology for delivering energy in industrial settings, primarily responsible for converting water into steam. This steam carries substantial energy, widely used to regulate temperatures and pressures in industrial processes, dry products, separate contaminants, and more. Boilers can consume a significant amount of energy in the industrial and manufacturing sectors. In Sri Lanka with many light industries that reply heavily in steam, boilers account for the majority of fuel use in those sectors.

Contrastingly, electric boilers, which are more efficient (achieving up to 99% efficiency), still hold a small market share, despite being a mature technology. These electric boilers function either as electric resistance boilers, where an electrically heated element transfers heat to water, or as electrode boilers, where electric current directly heats the water. Electric boilers offer advantages like reduced air pollution, quicker ramp-up times, and overall efficiency gains.

The primary challenge for wider electric boiler adoption has been economic. As renewable electricity prices drop and the push for decarbonization intensifies in Sri Lanka, electrification of boilers may become more attractive. Transitioning to electric boilers can significantly reduce CO_2 emissions, especially when the electricity is sourced from renewables, making it a crucial step towards meeting climate goals. Several recent studies have shown large potential for GHg emissions reduction in industry sector in various countries through the adoption of electric boilers (Hasanbeigi et al. 2021, 2023)

Industrial heat pumps

Heat pumps drive heat from one or more heat sources (Qin) at low temperatures (Tsource) to one or more heat sinks (Qout) at high temperatures (Tsink) with the assistance of an external energy source (electricity; Win). The thermodynamic working principle of an electric heat pump is illustrated in Figure 1a. In other words, heat pumps are designed to transfer thermal energy opposite to the direction of natural heat flow by absorbing heat from a cold reservoir and discharging it to a hot one. The external energy or work required to drive a heat pump depends on how much the temperature of the low-quality heat is to be raised.

Heat pumps employ refrigerants as transitional fluids to absorb heat and vaporize in an evaporator. Refrigerants have low boiling points and evaporate even at sub-zero temperatures. Despite the evaporation, the refrigerant is not hot enough to warm the process fluid. Hence a compressor is used to further raise the temperature and pressure of the refrigerant through volume reduction and forces the high temperature and pressure gas to a condenser. The absorbed heat is released where the refrigerant condenses in a condenser. Finally, the temperature and pressure of the refrigerant are further reduced after passing through an expansion valve (Zuberi et al. 2022). Figure 1b presents the heat pump cycle. The most common examples of heat pumps are refrigerators and air conditioners.

Heat pumps are very efficient because they only transfer heat instead of combusting fuels to create it, ultimately reducing GHG emissions from heating applications such as in the manufacturing industry. The performance of a heat pump is defined by the coefficient of performance (COP) which is the ratio of heat output to energy input (Zuberi et al. 2022).

In the current industrial landscape, the advent of commercial industrial heat pumps capable of delivering heat and steam up to 170 degrees Celsius marks a significant technological advancement. This development is particularly relevant for key industries in Sri Lanka, such as the food and beverage, textile, and rubber industries, which predominantly require low-temperature heat. Heat pumps are an ideal solution for these sectors, offering an energy-efficient method to provide the necessary heating for various processes. In the food and beverage industry, for instance, heat pumps can be used for applications like drying, where controlled, low-temperature heat is essential. Similarly, in the textile industry, processes such as washing, dyeing and drying often require heat at low temperatures (below 150 C), which can be efficiently supplied by steam generating heat pumps (Zuberi et al. 2022, Hasanbeigi et al. 2023).

Furthermore, industries that require both heating and cooling stand to gain from the versatility of heat pumps. In dairy processing, for example, heat pumps can be used to efficiently manage the cooling required for milk storage and the heating needed for processes like cheese making or yogurt fermentation (Zuberi et al. 2022). This dual functionality not only simplifies the thermal management systems but also enhances overall energy efficiency by recycling heat within the process. In the rubber industry, where vulcanization requires heating and subsequent processes may need cooling, heat pumps can provide a seamless solution for these temperature transitions. The integration of heat pumps into these industrial processes in Sri Lanka represents a great opportunity for decarbonizing the industry sector.

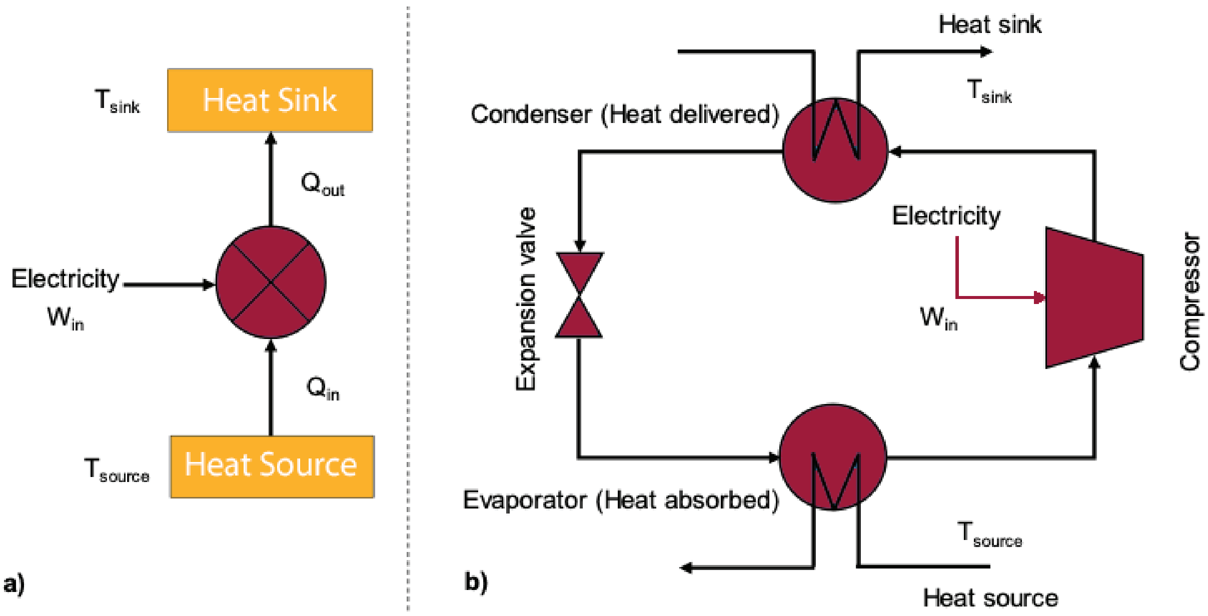


Figure 25. Thermodynamic representation and cycle of a heat pump (Zuberi et al. 2022).

Alternative processes with electrified heating

Alternative processes with electrified heating offer innovative solutions for industrial electrification. This involves redesigning traditional industrial processes to incorporate electric heating elements directly into the process. For instance, in the textile industry, processes like heat setting and drying can be re-engineered to use direct electric heating, which can be more efficient and easier to control than conventional methods. Similarly, in the food processing sector, baking and cooking processes can be adapted to use electric ovens and cookers (Hasanbeigi et al. 2021). These electrified processes not only reduce carbon emissions but also offer improved process control and quality. The key to success in this area lies in the careful integration of electric heating technologies with existing industrial processes, ensuring that they meet the specific needs of each industry while enhancing overall energy efficiency.

There are various electrification technologies used in alternative processes with electrified heating. While many of these technologies are fully commercialized, some, particularly those for high-temperature processes, are still in development or pilot stages. This is especially true for industries like cement, glass, and certain chemical productions, where high-temperature heating processes are prevalent.

Electric arc furnaces, used predominantly in steel recycling, melt metals through direct and radiant heating from high voltage electric arcs, offering lower energy consumption compared to primary steel production methods. Induction heating, which heats materials within an electromagnetic field, is used for various applications like metal hardening and soldering, offering uniform heating and no on-site emissions. Radio-frequency heating, efficient for materials that are poor heat and electricity conductors, and electric infrared heaters, which directly heat objects rather than the surrounding air, are other notable technologies. UV heating, primarily used for curing coatings, offers advantages like faster production speeds and low energy intensity. Microwave heating, effective for materials with poor thermal conductivity, is utilized for applications like drying and defrosting (Hasanbeigi et al. 2021).

Electrification technologies like electric induction melting and plasma melting also play significant roles. Electric induction melting, used for metals with varying melting points, ensures homogenous output with high efficiency. Plasma melting, used across various industries, offers benefits like reduced impurities and ease of temperature adjustment. Electrolytic reduction, another important technology, is used in processes like smelting of alumina and iron ore, offering the potential for substantial CO2 emission reductions when powered by low-carbon electricity. These technologies collectively represent a diverse and suite of tools for industrial electrification, each contributing uniquely to the reduction of carbon emissions and enhancement of energy efficiency in various industrial processes (Hasanbeigi et al. 2021).

Frequency	50Hz-500kHz	10-100 MHz	200-3000 MHz	30-400 THz		1-30 PHz
Wavelength						
	Induction	Radio	Microwave	Infared	Visable Light	Ultra-violet
Max temp ^{0}C	3000	2000	2000	220		N/A
Power density (kW/m^2)	50,000	100	500	300		100
Efficiency	50-90%	80%	80%	60-90%		
Application	Rapid internal heating of metals	Rapid internal heating of large volumes	Rapid internal heating of large volumes	Very rapid heating of surfaces and thin material		Non-thermal curing of paints and coatings

Figure 26. Electromagnetic heating technologies (Beyond Zero Emissions, 2018)

Low-carbon fuels, feedstocks, and energy sources (LCFFES)

The Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES) pillar is a critical component of industrial decarbonization in Sri Lanka. LCFFES encompasses a range of fuels that have lower carbon emissions compared to traditional fossil fuels or a range of feedstock that have lower carbon content compared to the traditional ones. This includes renewable electricity sources like solar and wind, concentrating solar power, and geothermal energy. The transition to these cleaner energy sources is essential for industries in Sri Lanka looking to reduce their carbon footprint. While some LCFFES technologies are ready for immediate deployment, others, for example, those involving clean hydrogen as feedstock and synthetic fuels, are still under development and require further research to enhance their cost-effectiveness and efficiency.

In Sri Lanka's food and beverage industry, the adoption of LCFFES can play a pivotal role in reducing emissions and energy costs. For instance, using biogas generated from organic waste in food processing or adopting solar thermal systems for heating purposes are viable options. These renewable sources can replace conventional fossil fuels used in various processes like drying, pasteurization, and refrigeration. Additionally, the integration of renewable electricity, either from the grid or through on-site installations like solar PV panels, can significantly reduce the carbon footprint of this sector. The key challenge lies in integrating these technologies into existing production lines and ensuring their reliability and cost-effectiveness.

For the textile industry in Sri Lanka, LCFFES offers opportunities to reduce reliance on conventional energy sources and move towards a more low-carbon production. The use of renewable energy sources, such as solar or wind power, for electricity needs should be considered. Additionally, the adoption of sustainable bio-based feedstocks in textile processing could reduce the industry's carbon footprint. For example, employing sustainable biomass as a fuel for steam generation is practical application of LCFFES.

The rubber industry in Sri Lanka can also benefit from the integration of LCFFES technologies. Transitioning to renewable energy sources for electricity and heat generation in rubber processing can significantly reduce GHG emissions. For instance, solar thermal systems can be used for the vulcanization process, and biomass boilers can provide the necessary steam for rubber processing. Implementing these technologies requires careful planning to ensure they meet the specific energy demands of the rubber industry while being economically viable.

In Sri Lanka's cement industry, the use of alternative, low-carbon fuels like biofuels or waste-derived fuels can reduce the reliance on coal and other fossil fuels. All the fuel use and over 50% of the electricity used in a cement plant is consumed for clinker2 production. Also all process-related CO2 emissions from calcination process is for clinker production. A higher clinker-to-cement ratio results in higher CO2 emissions per tonne of cement produced. Therefore, replacing clinker with supplementary cementitious materials (SCMs) such as fly ash, blast furnace slag, natural pozzolans, ground limestone, and calcined clay is a key element of the LCFFES decarbonization pillar (U.S. DOE 2022) and can help to significantly reduce energy and CO2 intensity per tonne of cement produced in Sri Lanka.

2 Clinker is a solid material produced in the manufacture of portland cement as an intermediary product.

Carbon capture, utilization and storage (CCUS)

In the context of Sri Lanka, Carbon Capture, Utilization, and Storage (CCUS) is mostly applicable to the cement industry, which is a heavy carbon-intensive industry. In Sri Lanka's cement sector, CCUS technologies emerge as a key strategy to mitigate CO2 emissions, especially considering that over 50% of CO2 emissions results from the calcination of limestone in the kiln, and are not related to energy use. Unlike pre-combustion CO2 capture, which is less effective due to the specific emission characteristics of the cement industry, post-combustion CO2 capture technologies are more suitable for this sector (Figure 27). These can be integrated into existing cement manufacturing processes, making them suitable for both the construction of new kilns and the retrofitting of existing ones (CEMBUREAU 2023).

Oxy-fuel combustion technology, which replaces air with oxygen in cement kilns, shows particular promise in the cement industry. This approach leads to a more concentrated stream of CO2 emissions, thereby streamlining the capture process. Additionally, the cement plant in Sri Lanka typically produce substantial amounts of waste heat at low and medium temperatures, which can be effectively harnessed in the post-combustion carbon capture process. This not only boosts the energy efficiency of the cement plants but also enhances the overall practicality of implementing CCUS technologies in the sector.

The utilization aspect of CCUS holds significant potential for Sri Lanka as well. The captured CO2can be employed in various commercial applications, such as in the curing of concrete, the production of aggregates and construction materials, or even in the cultivation of algae biomass. These applications offer avenues for new economic development.

The applicability and selection of these five decarbonization pillars will vary for sectors and trade-offs in cost (energy and operational costs (e.g., cost of CO2 capture), local energy or carbon storage availability, infrastructure, etc. will influence choices. Investment and pursuit of multiple pillars in parallel will be vital for sectors to reach net/near zero CO2. The in-depth study of the decarbonization pillars and quantification of their impact on GHG emission of industry in Sri Lanka was beyond the scope of this study. This can be the topic of future studies in Sri Lanka.

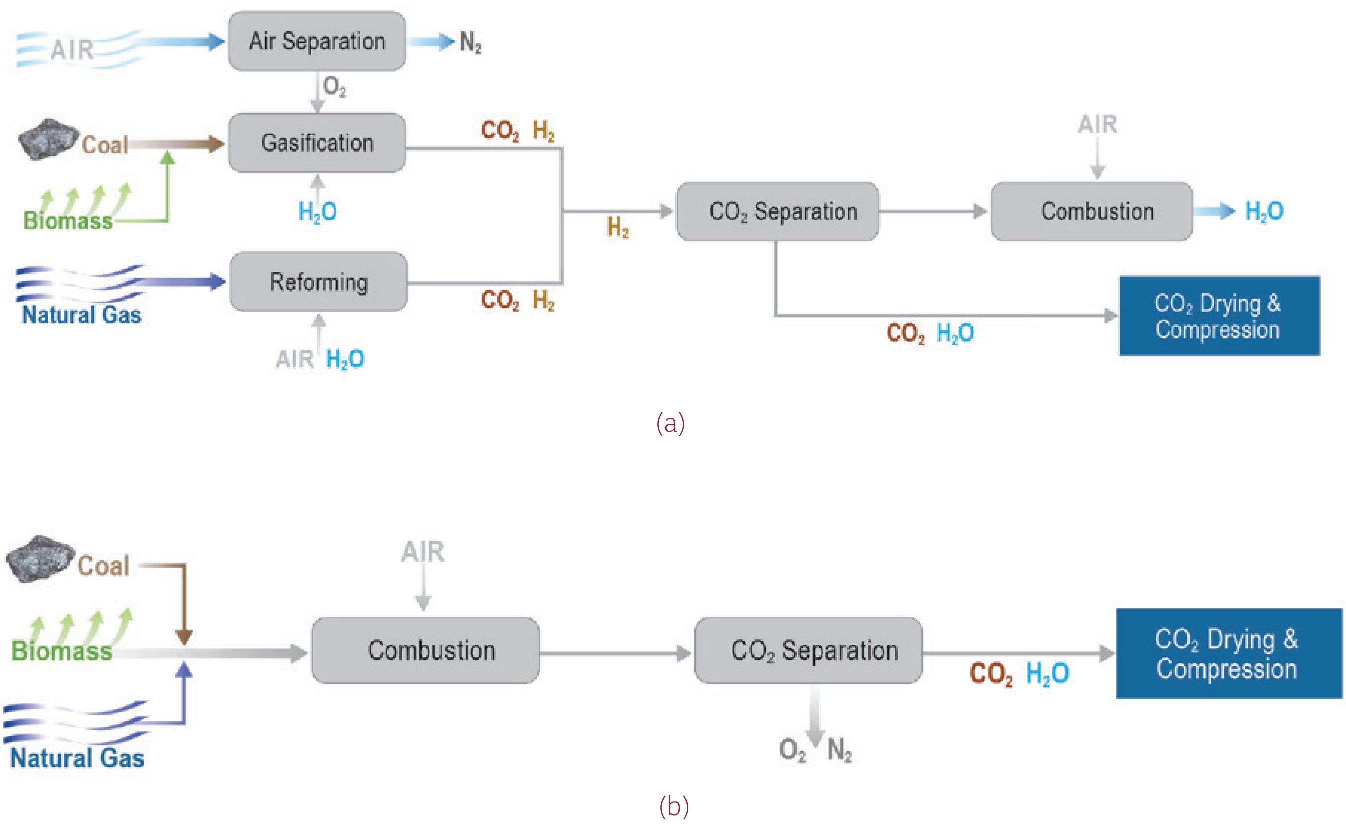


Figure 27. Typical Pre-combustion (a) and post-combustion (b) carbon capture process (Sandalow et al. 2019)

7 International best practices on industrial energy efficiency policy

In the ever-evolving landscape of energy and climate policy, it is beneficial to examine international best practices regarding industrial energy efficiency and decarbonization. This chapter will provide a comprehensive exploration of various strategies and policies that have proven successful in different parts of the world. By examining these examples, we aim to glean insights and identify innovative approaches that could be adapted and applied in Sri Lanka. From policy frameworks and regulatory measures to financial incentives and technology innovations, we will delve into a wide range of practices, detailing how they have been implemented and the impact they have had on enhancing energy efficiency and reducing carbon emissions within the industrial sector. This will help us not only to understand the global trends in this domain but also to provide tangible and practical lessons that can be utilized in Sri Lanka's context.

7.1. Overarching programs to incentivize industrial energy efficiency

7.1.1. Voluntary agreements

Agreements to meet specific energy-use or energy efficiency-targets are used in the industrial sector in many countries around the world. Such agreements can be viewed as a tool for developing a long-term strategic plan for increasing industrial energy efficiency that fully engages not only the engineers and management at industrial facilities, but also includes government, industry associations, financial institutions, and others. An agreement or target can be formulated in various ways. Two common methods are those based on specified energy-efficiency (or energy intensity) improvement targets and those based on absolute energy use or greenhouse gas emissions reduction commitments. Either an individual company or an industrial subsector, as represented by a party such as an industry association, can enter into such agreements.

Voluntary agreements on energy savings often exist with the ETS. As a result, in many countries, including Germany, Belgium, Finland, Netherland, and the UK, voluntary agreements on energy savings also apply to participating enterprises in the EU Emissions Trading System (ETS). Generally, under a voluntary agreement, participants negotiate a target with the government and by achieving the target, participants can get a variety of support and benefits from the government including technical assistance for energy efficiency, subsidies for energy audits and energy efficiency investments, tax relief or reduction, etc. There are also countries that use voluntary agreements with non-ETS participants and the mechanism and benefits are similar.

The key elements of voluntary agreement programs are the assessment of the energy-efficiency potential of the participants as well as target-setting through a negotiated process with all parties. The targeting setting process enables enterprises to better understand their energy efficiency opportunities. In addition, voluntary agreement programs often include supporting programs and policies, such as audits, assessments, benchmarking, monitoring, information dissemination, and financial incentives, which provide information, technical assistance and financial incentives to participants.

For example, the Netherlands has implemented the third generation of the Long-Term Agreements (LTAs) since 2007. This program covers small and medium size energy users (energy consumption < 0.017 Mtce/yr)[3] and includes energy savings throughout the entire product chain. All participants are required to develop energy efficiency Plans and implement all profitable measures. The government provides technology list with payback periods developed at the sector level to assist participants in choosing appropriate energy efficiency measures. Benefits of participating in the program and achieving the targets include regulatory benefits and financial benefits:

1. participating and compliance companies will no longer be subject to supplementary national policy governing CO_2 reduction or energy conservation
2. participating and compliance companies will no longer be subject to specific national energy tax;
3. participating and compliance companies will no longer pay the costs of buying carbon credits in the field of the Joint Implementation, the Clean Development Mechanism (CDM) or emissions trading (IIP, 2015c).

7.1.2. China's Top 10,000 Program

The Top 10,000 Program in China represents a significant step in the country's efforts to enhance industrial energy efficiency and reduce industrial GHG emissions. Launched following the success of the Top 1,000 Enterprises Program, the Top 10,000 Program covered approximately 66% of China's overall energy usage, which equates to 15,000 industrial establishments consuming over 10,000 tonnes of coal equivalent (tce) annually. Additionally, it includes about 160 major transportation companies, such as large shipping entities, and public structures consuming more than 5,000 tce per year. In total, the program extends its coverage to around 17,000 enterprises (ESCiI2017).

The Top 10,000 Program was structured to drive large-scale energy efficiency improvements across diverse industrial sectors. It required participating enterprises to conduct comprehensive energy audits, set specific energy-saving targets, and develop detailed action plans for energy efficiency improvements. These plans often included technological upgrades, process optimizations, and enhanced energy management practices (Liu et al. 2016).

Targets were set based on the energy audit results, with enterprises committing to absolute or intensity-based energy savings. Compliance with these targets was closely monitored, with regular reporting and verification processes in place. The program not only focused on achieving short-term energy savings but also aimed to foster a long-term commitment to energy efficiency among China's industrial giants.

The Chinese government played a crucial role in facilitating the success of the Top 10,000 Program. This support came in various forms, including financial incentives like subsidies and tax breaks, technical assistance, and capacity-building initiatives. These measures significantly lowered the barriers to implementing energy-efficient technologies and practices. The Top 10,000 Program was effectively integrated with China's broader environmental, climate, and energy policies. It complemented other initiatives like the national carbon trading scheme and sector-specific regulations, creating a comprehensive framework for industrial energy efficiency and decarbonization (Liu et al. 2016).

The Top 10,000 Program has been instrumental in reducing energy intensity and carbon emissions in China's industrial sector. By targeting the largest energy consumers, it has achieved substantial aggregate energy savings and emissions reductions. The program also spurred technological innovation and promoted the adoption of best practices across industries. The experience gained from the Top 10,000 Program provides valuable insights into scaling up industrial energy efficiency initiatives and underscores the importance of government support, clear targets, and robust compliance mechanisms in achieving energy and carbon reduction goals.

7.1.3. Energy and carbon trading

Carbon emissions trading schemes have been adopted in a number of countries as a means to price carbon, reduce CO2 emissions, and save energy. Emissions trading schemes are used to incentivize enterprises to invest in energy efficiency and emissions reduction projects through raising the cost of using energy and generating CO2 emissions by charging enterprises a price per ton of CO2 emitted (Aflaki, et al. 2012; Altmann, et al. 2013). Energy trading schemes are similar, but instead of trading carbon allowances, energy trading schemes use energy savings certificates. We review the white certificate scheme, the Perform, Achieve, Trade scheme in India.

3 Large industrial energy users (companies with an energy consumption of at least 0.5 PJ per year) were covered by the 1st generation LTAs from 1992 to 2000 and then were covered by the Benchmarking Covenant until 2012, and are now covered by the LTA on energy efficiency (LEE), which is specifically designed for enterprises that participate in the EU ETS.

India's perform, achieve, trade (PAT) scheme for energy-intensive industries

India's Perform, Achieve, Trade (PAT) program is a market-based, energy efficiency trading scheme that aims to improve energy efficiency in energy-intensive industries. The PAT Scheme is being implemented in phases. The PAT scheme is the first cap-and-trade program for energy efficiency in developing countries. The scheme aims to enable industrial firms to continue expanding their activities, as long as they operate in an environmentally conscious manner. The scheme has also created an institutional structure to enable online data submission, annual audits and verification by designated auditors. It also helps enhance capacity-building in enforcing policies, collecting data, conducting monitoring and verification, and assessing compliance and levying penalties, which are all prerequisites for successfully implementing the scheme. PAT Cycle-I was designed to improve efficiency in eight energy intensive sectors: Aluminium, Cement, Chlor- Alkali, Fertilizer, Iron & Steel, Paper & Pulp, Thermal Power Plant and Textiles. The achievement in PAT Cycle-I is 8.67 Million Tonne of Oil Equivalent (Mtoe). PAT Cycle-II and III have added many more industrial plants and several new sectors and aim to achieve higher energy saving (Bureau of Energy Efficiency, n.d.).

The Ministry of Power's Bureau of energy efficiency (BEE) is responsible for setting mandatory, specific targets for energy consumption for larger, energy-intensive facilities (CDKN, 2013). BEE sets energy efficiency targets for each Designated Consumer (DC) by calculating their baseline production, baseline energy consumption, and analyzing their potential for energy efficiency improvement. The government will set stricter target (percentage of reduction relative to baseline energy consumption) for historically less-efficient DCs than more-efficient ones. DCs report their energy efficiency efforts and progress to achieve their targets during the compliance period. If DCs save more energy than their targets, they will receive energy savings certificates (1 certificate=1 Mtoe), equaling to the amount of energy they have saved minus the amount of targeted savings. These certificates can be traded on two power exchanges, and a platform developed by BEE specifically for the trading of energy saving certificates (IETA, 2015; CCAP, n.d.).

The PAT scheme is the first cap-and-trade program for energy efficiency in developing countries (IETA, 2013b). In theory, the scheme should enable industrial firms to continue expanding their activities, as long as they operate in an environmentally conscious manner. The scheme has also created an institutional structure to enable online data submission, annual audits and verification by designated auditors. It also helps enhance capacity-building in enforcing policies, collecting data, conducting monitoring and verification, and assessing compliance and levying penalties, which are all prerequisites for successfully implementing the scheme (CDKN, 2013).

7.2. Key supporting mechanisms

7.2.1 Information to Inform Decision-makers and Spur Competitiveness

High-quality information on energy efficiency potential and the benefits of investing in energy efficiency can give decision-makers the knowledge needed to undertake energy efficiency investments. Such information can be provided to decision-makers through studies, guidebooks, networks, and industrial associations as well as through high-quality energy audits.

A. High-quality information on energy efficiency potential including technology performance, costs, Savings

High-quality information on energy efficient technologies, as well as high-quality information regarding the overall potential for energy savings and emissions reductions in industrial facilities or industrial sectors, is essential for setting realistic energy efficiency targets, establishing energy efficiency investment plans, and spurring meaningful action. High-quality information on energy efficient technologies include information on technology performance (e.g. quality, lifetime), upfront capital and installation costs, energy savings compared to conventional efficient technologies, and other benefits such as reduced labor costs for maintenance, reduced product waste, and reduced emissions of pollutants. The information is usually supported by guidebooks, criteria and other supplemental materials to help enterprises understand and utilize the information. It can be provided or managed directly by the government, by independent entities designated by the government, or networks or organizations established by enterprises.

Sources of high-quality energy efficiency information

Industrial energy accelerator:

The Industrial Energy Accelerator is a UNIDO-led network of international initiatives working to inspire global action on industrial energy efficiency. It showcases the vast opportunities that industrial energy efficiency and related efforts can provide for people, businesses, economies. In emerging and developing economies, their local teams of experts help drive momentum for energy efficiency with tailored training for industries, improved access to finance for entrepreneurs and policy advice for governments. The Industrial Energy Accelerator is a rich source of information for industrial energy efficiency.

The Industrial Energy Accelerator works to increase the uptake of measures and technology to boost efficient energy use. This involves designing solutions tailored to specific country needs and taking what we learn to inspire global action on industrial energy efficiency. Its network operates programs in over 10 countries which are home to large and growing industrial sectors with huge energy efficiency potential. Working in-country allows the Accelerator to forge critical relationships with local governments and industry players. These partnerships enable the Accelerator network to convene and build on existing work undertaken by various local and international organizations. Collaboration across sectors, stakeholders and countries is encouraged to improve knowledge sharing and collective impact. At a global level we share our collective experience with the world, showcasing best practice through stories of impact and knowledge resources, with the aim of inspiring greater global action on industrial energy efficiency (Industrial Energy Accelerator 2021).

U.S. Department of Energy's technology guidebooks[1]:

The U.S. Department of Energy's Advanced Manufacturing Office (AMO) partners with industry, small business, universities, regional entities, and other stakeholders to identify and invest in emerging clean energy technologies. AMO has published series of guidebooks on energy efficiency technologies and measures in different industry subsectors and energy systems (e.g., motor systems, steam systems, process heating systems, etc.). Also, AMO has supported the development and publication of several energy assessment tools for industrial plants and energy systems.

U.S. Environmental Protection Agency's Energy Star Program:

The U.S. Environmental Protection Agency (EPA) Energy Star Program has an Industrial Energy Management information center2 designed to be a useful resource for industrial energy managers, and contains energy management information tailored to industries or focused on specific plant utility and process improvements. This center provides information on energy efficiency technologies through various guidebooks for each industry subsector. It also provides tools and information for energy intensity benchmarking of industrial plants (EPA, 2015).

UK's Carbon trust

The UK's Carbon Trust is an independent entity that assists businesses and the public sector to reduce carbon emissions. The Carbon Trust identifies carbon emissions reduction opportunities and provides resources and tools to help enterprises improve energy efficiency (Carbon Trust, 2016). Carbon Trust also help the UK government manage its Energy Technology List, which provides eligible technologies and products that are qualified for tax relief based on the ECA scheme (UK Gov. 2015c).

European learning energy efficiency networks:

Recently, the concept of energy efficiency Networks has had a significant success and interest in Europe. Learning Energy Efficiency Networks (LEEN) is a concept developed in Switzerland back in the 1990s. Since then, the approach has been successfully transferred to Germany, France and Austria. With these networks, 10 to 15 regionally based companies from different sectors share their energy efficiency experiences in moderated meetings. After the companies have formed the network, the process starts with an energy review and the identification of profitable energy efficiency measures in each company. Afterwards, the participants decide upon a joint target, which is allocated to the partners according to their efficiency potential. The subsequent networking process enables a continuous exchange on energy efficient solutions provided by the experiences of the network partners as well as external experts. The performance of each company is continuously monitored and controlled on a yearly basis. The network's operating period is typically from three to four years.

LEEN provides services such as initial energy diagnosis, survey and on-site evaluation. LEEN also provides suggestions on energy efficiency and carbon reduction measures and their economics. LEEN works with enterprises to help them set energy efficiency goals and organizes workshops and experience exchange activities. LEEN also helps to evaluate energy saving performance in the end. LEEN facilitates the communication between enterprises and provides expertise and knowledge to enterprises, which not only saves information searching and decision-making costs, but also improves energy efficiency awareness in enterprises and provides a healthy environment for enterprises to compete with and learn from each other on energy efficiency efforts. In addition, as a network and group, enterprises benefit from a louder and better voice to the government and the public, and could obtain better service from ESCOs more easily. Government has a vital role in supporting the LEEN concept and encouraging enterprises to participate.

1 Link to tools published by AMO: http://www.energy.gov/eere/amo/software-tools
2 Link to the Industrial Energy Management Information Center: https://www.energystar.gov/buildings/facility-owners-and-managers/industrial-plants/industrial-energy-management-information-center

For example, Swiss established "Carbon Emissions Law" and "Electricity Law" to either encourage or require enterprises to participate in the network to get tax relief. In Germany, after the initial establishment of the LEEN, the government improved its training and certification system for LEEN and set up energy efficiency network standard, which was later certified by ISO 50001. After these efforts, Germany included energy efficiency network into its National Energy Efficiency Action Plan. The German government could provide up to 80% of consultancy fee and financial support for some energy efficiency measures (OFWeek, 2016).

B. High-quality energy audits

An industrial energy audit is a necessary first step for understanding a facility's energy consumption by end-use and identifying key areas for energy saving in industrial operations. An industrial energy audit can also provide important impetus for industrial facilities to implement energy-efficiency measures and technologies.

High-quality energy audits can provide detailed cost-effective analyses of all identified measures and technologies, based on a plant's specific operating conditions and can provide packages of customized recommendations for plants to consider. Energy audits are sometimes funded by the government or public utilities and are usually partially subsidized or provided entirely free of charge to industry. Energy audits could be performed through a stand-alone energy auditing program, or implemented as a supporting policy tool for policies such as voluntary agreements or emissions trading programs.

A stand-alone energy auditing program largely focuses on the energy audit itself, and asks participants to perform energy audits. An integrated energy audit program combines energy audits with other policy measures to better motivate participants, to help decision-makers set reasonable yet ambitious energy-saving targets, and to achieve the broader goals of the program. Since energy-efficient technologies and measures improve over time, energy audits should not be viewed as one-time events, but should be performed regularly and can be combined with other policies and mechanisms to continuously promote industrial energy efficiency.

To ensure that energy auditing programs are successful, they should be supported by regulations, standards, and guidelines for conducting standardized energy audits, collecting energy auditing results, analyzing and evaluating energy audits, as well as incentives and supporting measures for participants. Quality control and monitoring of energy audits, as well as information dissemination are also important to robust energy auditing programs. Energy audit programs should also provide training and certification of energy auditors, since they will have a significant impact on the quality and output of the energy audits. Some countries provide a directory or network of accredited auditors or consultants to perform the audits, such as Australia's (former) EEAP and Norway's IEEN and Enova (MURE II, 2005; WEC, 2003). The U.S. Office of Industrial Technologies (OIT) Best Practices Program works with the selected facility to identify potential candidates to help with the audits (U.S. DOE OIT, 2005). For large energy consumers with advanced energy efficiency programs, the UK's Carbon Trust works directly with clients to address specific needs (Price, et al. 2005).

Stand-alone energy auditing programs

Stand-alone energy auditing programs were identified in six countries. These programs were established by the national governments to stimulate demand for industrial energy audits, especially for small-and-medium enterprises (SMEs). The stand-alone energy auditing programs can be grouped into two categories

Table 11. Types of Stand-Alone Energy Auditing Programs

Category	Program examples
Free energy audits	US industrial assessment centers (US Department of Energy)
	UK carbon surveys (Carbon Trust)
	Japan industrial energy audits (Energy Conservation Center of Japan)
	Ireland energy advice to SMEs (Sustainable Energy and Authority of Ireland)
Subsidized energy audits	Swedish program of energy audits for companies (Swedish Energy Agency)
	India's perform, achieve, and trade (PAT) scheme mandates energy audits for large energy-consuming industries (BEE)
	China's top 10,000 program requires key energy-consuming enterprises to conduct energy audits.
	Indonesia promotes energy audit through Directorate General of New, Renewable Energy and Energy Conservation (EBTKE)
	Brazil's national energy conservation program (PROCEL)

(Table 11): 1) programs that offer energy audits to facilities free-of-charge, and 2) programs that provide subsidies to companies to partially cover the costs of energy audits.
There are several common features of the sta-alone energy auditing programs. First, these national programs are all voluntary and are open to all interested participants. Second, except for the Program of Energy Audits for Companies in Sweden, all other programs focus on SMEs. SMEs often do not have the resources that large enterprises possess in terms of expertise and information related to energy-efficiency (Nagesha and Balachandra, 2006; Worrell and Price, 2001). Typically, due to the pressing issues of economic survival and limited management capacity, SMEs either are not interested in energy audits or do not have the financial resources to afford a professional energy audit. Thus, a government-initiated energy auditing program can be a convenient channel for SMEs to seek expertise or financial support.

Stand-alone energy auditing programs typically focus on SMEs and are offered for free or with the costs shared between the industry and government. Stand-alone energy auditing programs often emphasize how to build an effective, standardized, and practical system and are designed to ensure that industrial participants can implement the proposed cost-effective measures. They also emphasize that energy audits be conducted in a comparable and coherent manner, and that the results be measurable, verifiable and useful to other manufacturers. Subsidies for energy audits, training and certification of energy auditors, standardized tools and guidebooks, energy audit databases, post-audit follow-ups and dissemination of case studies are critical to a robust and high-quality stand-alone energy auditing program.

Integrated energy auditing program

Many industrial energy-efficiency policies and programs include industrial energy audits as a key component which is combined with other policy measures to better motivate participants and to achieve broader goals. Sixteen programs in 14 countries and the European Union have integrated industrial energy-efficiency policy programs that include energy audits.

The integrated policy programs include voluntary agreement schemes and mandatory regulations. Voluntary agreements (agreements signed between industry and the government) have been widely used (Price, 2005) and in many cases require energy audits for participants. Mandatory requirements are regulations or legal mandates established by national governments, which often require facilities to conduct energy audits, or meet energy-efficiency improving targets, or establish a certified energy/environmental management system. Often, energy audits have been utilized as one of the effective tools to achieve broader goals of the national regulations.
Integrated industrial energy-efficiency policy programs with energy audits use an array of other policies or programs in combination with energy audits. These may include the use of certified energy or environmental management systems, requiring the establishment of energy-efficiency improvement targets or goals, requiring the establishment of energy action plans, exemptions from energy and/or CO_2 taxes, the threat of applying an energy or CO_2 tax if targets or goals are not reached, financial support for investments, subsidies for energy audits, and recognition labels and awards. Based on country-specific conditions, energy auditing program developers (e.g., policy makers) decide which program type to use (either voluntary or mandatory), and which measures to include in their country-specific programs.

C. Providing technical assistance through enterprise performance rating systems

Many enterprise performance rating programs in the U.S. help enterprises save energy and costs, through providing technical assistance or by requiring adoption of a standardized energy management system. Enterprises that participate in the program can get assistance, guidance or training on identifying and understanding energy efficiency opportunities.

Better plants and better plants challenge program

The U.S. Department of Energy (DOE)'s Better Plants Program is a national partnership initiative to drive significant improvement in energy efficiency across U.S. industry. Manufacturers sign a voluntary agreement with DOE to reduce energy intensity by 25% over ten years with DOE. DOE in turn provides technical assistance to manufacturers to help them establish key energy performance metrics, evaluate energy saving opportunities, and organize plant-level training events. About 150 industrial companies, representing about 2,300 facilities and close to 11% of the total U.S. manufacturing energy footprint have participated in the program. The Better Plants Program is a broader-based initiative, which allow companies to make long- term commitments to energy efficiency and report their progress once a year.

Besides the Better Plants Program, the U.S. DOE also offers a Better Plants Challenge Program, which require more commitment from participating companies. The Better Plants Challenge requires partners to take on additional commitments to openly share their energy performance data and market-leading energy efficiency strategies (DOE, 2015). Manufacturers can partner with DOE through either the Better Plants Challenge or the Better Plants Program.

Superior energy performance program

In 2007, DOE partnered with the U.S. Council for Energy Efficient Manufacturing (U.S. CEEM), American National Standards Institute (ANSI), and the ANSI-ASQ National Accreditation Board (ANAB) to establish the Superior Energy Performance (SEP) Program. SEP certifies industrial facilities that implement an energy management system that meets the ISO 50001 global energy management system standard and achieves improved energy performance. An independent third party audits each facility to verify achievements and qualify it for recognition at the Silver, Gold, or Platinum level, based on performance. To date, the program participants achieved annual savings of $87,000 to $984,000 using no-cost or low-cost operational measures, with an average of 10% reduction in energy costs within 18 months of SEP implementation and 6% to 25% improvement in energy performance over three years (DOE, 2015c).

The Superior Energy Performance program requires manufacturers to implement an ISO 50001 certified energy management system, which can identify current energy practices and energy improvement opportunities. With the implementation of an energy management system that provides data and analysis to inform decision-making, the plants are not only able to make better decisions on energy improvement, but also document their performance and increase their recognition and credibility (McKane 2014; DOE, 2015c). The SEP program provides guidance, tools and recognition, which is essential to the implementation of energy management.

D. Providing favorable tax treatment or incentives through technology promotion list

Many countries provide tax reduction and other financial incentives to enterprises that install targeted energy efficiency technologies that are included in a technology promotion list. The UK's Enhanced Capital Allowance Scheme is an example of such a technology promotion list. Enterprises that invest in energy-saving technologies specified in the "Energy Technology List", can deduct the capital costs of those technologies against their taxable profits for the investment year (HM Revenue & Customs, 2008).

7.2.2 Reducing energy efficiency investment risk

A. Use of green bank to reduce investment risk and provide technical assistance

Green banks are financial institutions that assist their customers with purchase of clean energy technologies. Green banks have been established to address cost concerns and administrative complexities associated with direct incentive programs such as grants and rebates (Belden, et al. 2015).

The UK Green Investment Bank (GIB) is the first green bank to provide funding for green and profitable infrastructure projects. Supported technologies in the energy efficiency area include building retrofits (e.g., lighting, insulations, glazing), on-site generation (e.g. CHP, renewable heat, heat pumps), industrial process (e.g. motors, pumps, kilns), and Infrastructure (e.g. streetlighting, heat networks). From 2014-2015, funding of $324 million (£260 million)[3] was provided to energy efficiency projects, including sheltered housing boiler replacement, street-lighting project, data center retrofit, and a SME energy efficiency platform. The total investment in energy efficiency projects accounted for 14% of the bank's total investment (GIB, 2015).

The Union of Concerned Scientists evaluated six state governments (Connecticut, New York, Pennsylvania, Kentucky, Iowa, and Massachusetts) in the US and one national government (Germany) that have developed green banks (Belden, et al. 2015). The study shows that green banks have helped promote investments in clean energy and these clean energy financing programs have successfully engaged diverse stakeholders to help mobilize capital. The study provides some important insights on the role of government administrators and collaborative efforts (Belden, et al. 2015): "Government administrators have: 1) made use of in-house energy expertise to reduce the financial risks of private-sector loans for clean energy projects; 2) educated, and were educated by, the financial sector; 3) enabled a broad array of individuals, businesses, and institutions to achieve savings from clean energy investments."

1. And collaborative efforts have also been included to "make use of existing contractor networks to help roll out financing programs"
2. to "consult with the financial community to build trust and identify sustainable funding sources"
3. and to "draw on local utilities" experience in delivering programs to their customers to avoid duplication and maximize effectiveness.

3- 1 British Pound=1.245 US Dollar as of November 3, 2016.

B. Loans and grants to provide financing

The DOE Loan Guarantee Program was created in 2005 under Section 1703 of Title XVII of the Energy Policy Act of 2005 to support innovative clean energy technologies that are typically unable to obtain conventional private financing due to high technology risks. These technologies include: biomass, hydrogen, solar, wind/hydropower, nuclear, advanced fossil energy coal, carbon sequestration practices/technologies, electricity delivery and energy reliability, alternative fuel vehicles, industrial energy efficiency projects, and pollution control equipment (DOE, 2015e).

The UK's Carbon Trust provided interest-free loans to small- and medium-sized enterprises (SMEs) (Carbon Trust, 2008). Interest-free loans were available to eligible SMEs in Wales and Northern Ireland that wish to upgrade to more energy efficient equipment and renewable technologies. Carbon Trust provided $1,246 of loan for every 1.5 tCO_2 energy efficiency project is expected to save per annum within the range from $2,729 to $249,290[4] (Carbon Trust, 2015).

Australia implemented a Clean Technology Investment Program in 2012. It provided $615 million (800 million AUD)[5] grants for over 7 years for capital investment in energy efficient equipment and low emissions technologies, processes and products. Manufacturers that meet a minimum energy or emissions threshold can apply (IEA, 2015).

C. Public Private Partnerships to mobilize energy efficiency Investment

Public-private partnerships (PPPs) for energy efficiency finance are "mechanisms that use public policies, regulations, or financing to leverage private-sector financing for energy efficiency projects" (IEA, 2011). There are three main forms of PPPs in the energy efficiency area: 1) dedicated credit lines; 2) risk-sharing facilities; and 3) energy performance contracting (EPC).

Dedicated Credit Lines

Dedicated credit lines are mechanisms to encourage local financial institutions (LFIs) to offer sub-loans to implementers of energy efficiency projects. Public entities, such as government, international financial institutions, and donor organizations, provide funds to private-sector organizations such as banks and LFIs, at a low interest rate to encourage them to provide and lend more funds for energy efficiency projects, which usually have higher interest rates. Local financial institutions earn profits from these loan transactions (IEA, 2011).

Dedicated credit lines help LFIs improve their awareness of the benefits and characteristics of energy efficiency financing. Public entities leverage dedicated credit lines to encourage LFIs to provide funds to expand the scale of the fund available for financing from public entities. Governments also provide technical assistance to LFIs to build and enhance the capacity of LFIs (IEA, 2011).

For example, Thailand initiated the Energy Efficiency Revolving Fund (EERF) in 2003 to incentivize financial institutions in Thailand to lend for energy efficiency measures (Grüning et al. 2012). For industry, eligible projects included "improvement in combustion efficiency of fuels; prevention of energy loss; recycling of energy wastes; substitution of one type of energy by another; more efficient use of electricity through improvements in power factors, reduction of maximum power demand during peak demand, use of appropriate equipment and other approaches; and use of energy efficiency machinery or equipment as well as use of operation control systems and materials that contribute to energy conservation" (IEA 2011). The source of funding for the EERF was the government budget collected from a tax on petroleum products.

The EERF was successful in stimulating financial institutions in Thailand to finance energy efficiency, and also represented a shift in the role of government from "enforcer and regulator to facilitator and supporter" (Grüning et al. 2012; USAID, 2009). Success factors included: 1) simplified procedures for project application, appraisal, reporting, and loan processing; 2) offering loans with interest rates lower than the market rate to attract commercial banks; and 3) technical assistance and education from the Department of Alternative Energy Development and Efficiency (DEDE) (IEA 2011, Grüning et al. 2012, USAID 2009). To obtain EERF financing, the owner of an industrial or commercial facility or ESCOs conducted energy audits to identify energy efficiency projects. Then commercial banks conducted financial analysis of the project if they have the technical staff, and if not, DEDE helped them conduct the technical assessment (USAID, 2009). A DEDE official also paid a visit to all banks in Thailand to promote the EERF and explain the application process and the eligibility criteria (Grüning et al. 2012).

Streitferdt and Chirarattananon (2015) explain, however, that an external financial mechanism such as EERF can damage the market and impede it from becoming mature since the mechanism couldn't "induce banks to experiment with different credit provision models" and the technical support was superficial and failed to sufficiently "transfer the technical and credit lending advice to the banks". They also pointed out the there is a lack of demand for energy efficiency projects and finance from customers, which may result from a lack of mandatory regulation on energy efficiency improvement or a lack of implementation and enforcement of these regulations (Streitferdt and Chirarattananon, 2015).

4- 1 British Pound=1.245 US Dollar as of November 3, 2016. Carbon Trust provides £1,000 of loan for every 1.5 tCO2 energy efficiency project is expected to save per annum within the range from £3,000 - £200,000. 5- 1 Australian Dollar=0.77 US Dollar as of November 3, 2016.

Risk-sharing facilities

Risk-sharing facilities are mechanisms where a public entity offers guaranteed product to reduce energy efficiency project financing risks to private sector. Government, multilateral banks, or donor organizations absorb some energy efficiency project financing risks by providing a partial guarantee that covers a percentage of the loss due to loan defaults. Risk-sharing facilities also include some technical assistance and capacity building, as in the case of dedicated credit lines (IEA, 2011).

Two examples of risk-sharing facilities are the Commercializing Energy Efficiency Finance (CEEF) Program in Europe that operated from 2003 to 2008 and the Partial Risk Sharing Facility for energy efficiency (PRSF) in India since 2015. The CEEF was launched by the International Finance Corporation (IFC) and the Global Environment Facility (GEF). The PRSF was an agreement between the World Bank and the Indian government with funding from GEF and the Clean Technology Fund (CTF) under the Climate Investment Fund (CIF). Both programs have a risk sharing component where IFC or the Small Industries Development Bank of India (SIDBI) guaranteed a certain amount of project risk to the participating financial institutions. The CEEF offers 50% of the project risk and PRSF guarantees the partial credit to 40-75% of the energy efficiency loan (IEA, 2011; WB, 2015).

The two programs also have technical assistance and capacity building components, which help financial institutions market and develop their energy efficiency financial services, prepare projects for investment, improve capacities for energy efficiency project financing, and help ESCOs to develop energy efficiency projects and their business capacities. Technical assistance is considered very important and participants appreciated the trainings and seminars provided (IEA, 2011). It is also very important to have a local presence from the granting agency in the countries where the program is implemented, as local staff of the agency can help participants to continue their work and ensure take-off of the projects (IEA, 2011).

The market maturity of energy efficiency and general acceptance of the guarantee product is also very important. The IEA points out that the CEEF has been more successful in the countries with more developed energy efficiency markets than in the countries where financial institutions are less interested in energy efficiency financing and there are fewer ESCOs (IEA, 2011).

Energy performance contracting and ESCOs

Energy Performance Contracting (EPC) is a mechanism that uses private sector investment and expertise to deploy energy efficiency retrofits in buildings, industries, and other types of facilities (Shen, et al. 2015). ESCOs and public agencies will make performance-based agreement and ESCOs will get payments contingent on demonstrated performance (IEA, 2018).

1. About 40 countries around the world have ESCO activities. ESCOs started in the US, Canada, Sweden and the UK in the 1970s and early 1980s, and were then established in many other countries in the late 1980s, 1990s and even today (Vine, 2005; Goldman, et al. 2005). Studies on the experiences of these countries have identified the following success factors and actions to further promote ESCOs (Vine 2005; Bertoldi, et al. 2006):
2. Provide training to energy managers and financial institutions to increase their awareness of ESCO services and projects. To disseminate ESCO information, a third-party financing network can also be established to include all key players in the market, including ESCOs and their associations, energy efficiency agencies at the national and local level, financial institutions, equipment manufacturers, and other stakeholders.
3. Establish accreditation systems for ESCOs, such as the US ESCO accreditation system implemented by the National Association of Energy Service Companies (NAESCO), to ensure that they provide qualified and reliable service.
4. Develop funding and financing sources for ESCOs to market, prepare, and develop their projects. Funding sources could be traditional, such as private financial institutions, multi-lateral funders such as the World Bank and IFC, and could also be innovative, such as revolving funds.
5. Standardize energy performance contracts, and measurement and verification (M&V) so that facilities and financial institutions can better understand and develop EPCs. For example, NAESCO worked with industry to develop the International Performance Measurement and Verification Protocol (IPMVP), which is used to measure and evaluate energy-efficiency projects.

These three approaches - dedicated credit lines, risk-sharing facilities and EPC - can be applied in different market environments. Dedicated credit lines are most suitable in financial markets that are less mature and LFIs are in need to provide better understanding of the benefits and characteristics of energy efficiency projects. Dedicated credit lines also require greater funding from public sectors as they have to finance LFIs (IEA, 2011). Risk-sharing programs are applicable to markets that are somewhat mature and LFIs want to finance energy efficiency but are worried about the high risks associated with those projects (IEA, 2011). EPCs are most useful in mature financing markets with enough liquidity of LFIs and enough awareness and capability to provide energy efficiency financing. EPCs have the potential to scale up LFI financing, which is difficult to achieve through dedicated credit lines and risk-sharing programs (IEA, 2018, Zhu 2020).

D. Tax incentives to incentivize energy efficiency investment

As mentioned above in the technology promotion list with tax incentives, many countries have utilized tax incentives and tax relief to boost investment in energy efficient products, equipment, and technologies. IEA (2015, 2012) identified 13 IEA countries that have implemented tax relief programs for industrial equipment: Belgium, Canada, France, Germany, Ireland, Italy, Japan, the Republic of Korea, Netherlands, Norway, Portugal, the United Kingdom, and the United States.

Tax rebates are programs in which companies deduct the cost of energy-efficient equipment from their annual profits and are found in Japan, Korea (Republic of), the Netherlands, and the UK. In the Republic of Korea, a 5% income tax credit is available for energy-efficiency investments such as replacement of old industrial kilns, boilers, and furnaces; installation of energy-saving facilities, co-generation facilities, heat supply facilities, or energy-saving equipment; alternative fuel using-facilities; and other facilities that reduce energy use by 10% (UNESCAP, 2000). In Japan, there is a "Green Investment Tax Reduction" program to provide small and medium enterprises business operators that purchase eligible energy savings or CO_2 emissions reduction equipment with a special depreciation of 30% against the standard purchase prices or a 7% tax deduction (IEA, 2016).

In the Netherlands, under the Energy Investment Deduction (Energie Investeringsaftrek, EIA) program, originally 40% and now 55% of the annual investment costs of energy saving equipment can be deducted from the fiscal profit of the calendar year in which the equipment was procured, up to a maximum of US $116 M (€107M). Qualifying equipment is provided on an "Energy List" and the costs associated with obtaining advice for purchased equipment can also be included. Approval is granted by SenterNovem, an agency under the Dutch Ministry of Economic Affairs. The UK's Enhanced Capital Allowance Scheme discussed above is also an example of tax relief, which provides 100% write-off in the first year of purchase (Price, et al. 2005). Germany has implemented a Tax Cap ("Spitzenausgleich") since 2013, which provides tax relief for industrial companies that take energy efficiency measures such as implementation of energy management systems and achieving energy efficiency targets that are required for receiving the exemption (IEA, 2015).

However, the real effectiveness of tax relief is difficult to measure because of limited data and free-rider issues[6] (Ryan, et al., 2012; Price, et al. 2005b). Programs should be designed such that they avoid providing tax relief for technologies that are already profitable (de Beer et al., 2000).

7.2.3 Green public procurement to increase demand for low-carbon products

The products that governments procure for large infrastructure projects such as roads, buildings, and railways account for a large percentage of CO_2 emissions. These projects heavily use construction materials such as steel and cement. When governments leverage their large-scale purchasing power by buying goods and services with lower environmental impact, they help drive markets towards sustainability, reduce the emissions footprint of their operations, and create new markets for innovative low-carbon products. Green public procurement (GPP) is a policy mechanism that can facilitate this change.

Many governments around the world have already recognized the value of green public procurement as a policy instrument and are leveraging the money they invest in large contracts to achieve environmental goals. Hasanbeigi et al. (2019) studied 30 such programs, 22 of which were in countries in Asia, Europe, North and South America, Africa, and Oceania, five case studies at the city and regional level, and three GPP programs at multi-lateral banks and the UN. Based on this study, they identified the GPP program in The Netherlands as one of the world's best for the reduction of emissions from construction materials (cement, steel, etc). Below is a summary of international best practices in the GPP programs studied:

- **Netherlands:** The Dutch GPP program has two kinds of environmental criteria: minimum requirements, quality criteria, and preference-based, or performance criteria. Tenders that do not meet quality criteria are disqualified from consideration. Performance criteria do not disqualify bids. Rather, they give preference to green materials during the Most Economically Advantageous Tender (MEAT) evaluation.

  The Dutch GPP program uses software called DuboCalc. DuboCalc is a life-cycle analysis-based

6 -The free rider issue "is a market failure that occurs when people take advantage of being able to use a common resource, or collective good, without paying for it, as is the case when citizens of a country utilize public goods without paying their fair share in taxes". (Investopedia, n.d.)

tool that calculates the environmental impact of proposed designs based on the materials to be used. It calculates 11 environmental impact parameters and combines them into a single value, the Environmental Cost Indicator (ECI). Bids must meet a maximum allowable ECI and additional reductions in emissions are monetized as a discount applied to the quoted price. The tool is publicly available and can be used by governmental and non-governmental entities. This type of whole-project assessment allows for cross-industry comparison: rather than prescribing technical details, it places the onus on the bidder to consider trade-offs between cost, embodied emissions, and durability of materials.

The Dutch public procurement expertise center, PIANOo, supports procurement officials in adopting green procurement practices. It maintains a website with information about current GPP targets set by Rijkswaterstaat. It also maintains an online tool for building tender documents with environmental criteria. This simplifies the process for procurement officials and bidders alike.

- **European Union:** The European Commission has created a set of common GPP criteria which is the basis for GPP in member states. The criteria are divided into selection criteria, technical specifications, award criteria, and contract performance clauses. For each set of criteria, there are two levels: core criteria, which are designed for ease of use while reducing key environmental concerns, and comprehensive criteria, which are more ambitious requirements for agencies that want to go further in supporting environmental and innovation goals.

  The European Union supports the use of project-level analysis in GPP criteria based on a point system. Points can be awarded based on the improvement of life cycle assessment (LCA) performance in comparison with business as usual or competing designs. A weighting system is applied to combine various LCA indicators including global warming potential (GWP), depletion potential of the stratospheric ozone layer (ODP), and acidification potential of soil and water (AP) into an overall score. In the absence of an LCA, the GWP from a carbon footprint (CF) assessment can be used. In the absence of both, points can be calculated from proxy data such as the reduction of CO_2 equivalent emissions from the transportation of materials and recycling of demolition waste (European Commission 2022).

- **California, United States:** The State of California was the first state to pass the Buy Clean policy in the United States. The Buy Clean California Act requires state-funded projects to consider the global warming potential (GWP) of a set of construction materials during procurement. Covered materials include structural steel, concrete reinforcing steel, flat glass, and mineral wool insulation. An amendment to include concrete in this list is underway.

  These laws were introduced in two stages. In the first stage, which lasted three years, manufacturers of eligible materials were required to submit facility-specific EPDs in their bids. Using these EPDs, the Department of General Services determined maximum acceptable GWP limits for each product category. These were set at the industry average for each material. In the second stage, beginning July 1, 2022, compliance with GWP limits will be required to be awarded a state-funded project. The department must review the maximum threshold for each material every three years. They may adjust the number downward to reflect industry improvements. However, the threshold should not be adjusted upward for any materials (California Department of General Services 2022).

8 Policy recommendations and roadmap

The policy recommendations and action plans outlined in this chapter are to address the significant challenges and barriers identified in both Chapter 4 and the survey results of policymakers and industry in Sri Lanka. These challenges, including inadequate data collection, insufficient financing mechanisms, and a lack of technical expertise and information, are substantial impediments to improving industrial energy efficiency and decarbonization in Sri Lanka. This chapter's recommendations, such as the development of energy standards, innovative funding mechanisms, and capacity building programs, are not only responses to these identified gaps but also proactive measures to harness the substantial potential for energy savings and emissions reduction in Sri Lanka's industrial sector. This recommendations are based on an understanding of the current landscape, as detailed in Chapter 4, and is further informed by insights gathered from policymakers and stakeholders through surveys and in-person meetings.

8.1. Policy options for industrial energy efficiency and decarbonization in Sri Lanka

Energy standards and labels for industrial equipment

One of the ways of accelerating the deployment of energy-efficient technologies and encouraging industry to invest in energy-efficient technologies could be to develop and mandate the standards and labels for the industrial equipment (United Nations Industrial Development Organization (UNIDO), 2018). The standards and energy efficiency labels can then be used to adopt minimum energy performance standards (MEPS) in the industry (for example, many countries have adopted MEPS for electric motors). The standards and labeling programs was among the top ranked policies in the survey we conducted in Sri Lanka.

Innovative funding mechanisms, grants and subsidies

Investment in industrial energy efficiency can be encouraged by subsidizing the loans for industrial energy efficiency projects using public funding i.e., soft loans which are offered at an interest rate lower than the market interest rate. Innovative funds can be a combination of funds from ESCOs, guarantee funds, revolving funds or venture capitalists and grants from the public sector to encourage investments in industrial energy efficiency measures typically until they achieve the market acceptance level and then be funded on their own. This policy tool can be of particular interest to developing economies such as Sri Lanka since it is usually more difficult to raise finances for industrial energy efficiency investment in high-risk market conditions (United Nations Industrial Development Organization (UNIDO), 2007). Similar funding scheme used in Sri Lanka in 2012-2013 for domestic refrigerators – "Refrigerator Rebate Scheme" that rolled out national program encouraging users through subsidies to go for energy efficient refrigerators and deep-freezers could be adopted for industrial equipment in Sri Lanka.

Along with grants and innovative funding policies, the Government of Sri Lanka can encourage the investment in industrial energy efficiency by providing other fiscal incentives like tax exemptions on the purchase of equipment for energy conservation projects or by providing an exemption on import duties on energy-efficient technologies as well as fiscal penalizations like application of fines for non-compliance with energy efficiency laws/regulations. These fines can then be used to set up some sort of energy efficiency fund. The fund can be used to provide financial support for other aspects of industrial energy efficiency program (United Nations Industrial Development Organization (UNIDO), 2018)).

An overarching financing strategy for industrial decarbonisation can ensure coordination and complementariness between the aforementioned financial mechanisms, grants and subsidies.

Target agreements with financial incentives

Large energy-intensive industries from the manufacturing sector can enter into a voluntary target agreement with the Government of Sri Lanka to improve industrial energy efficiency and reduce GHG emissions. The target agreements can be set up with or without financial incentives (Fernando Castro-Alvarez, 2018). As part of the target agreements, the participating companies undergo an energy audit by the government or a third-party auditing agency and a list of cost-effective energy efficiency measures is suggested. The cost-effectiveness of investments in energy-saving projects can be enhanced through market-based mechanisms like tradable excess energy savings certificates (ESCert or white certificates). These white certificates are issued to the company for surpassing the saving targets set in a voluntary agreement and the companies that do not meet the targets set in the agreements are obligated to buy those certificates (e.g., PAT scheme from India). Financial incentives can also be provided in the form of future threats of regulation/CO_2 tax or currently existing CO_2 tax can also be used to incentivize the companies to commit to voluntary target agreements (Price, 2005).

The data from the implementation of industrial energy efficiency measures from the voluntary target agreements can also be used to create a database of industrial energy efficiency measures under the technology/knowledge sharing programs. Regional clusters can also be created to encourage knowledge and technology sharing within the clusters.

Energy management standards

Energy management systems like ISO 50001, a system of voluntary standards provide a set of protocols and procedures for the management of energy consumption. Such energy management systems can be used to identify the opportunities, set and track internal goals for industrial energy efficiency improvement and GHG emission abatement. Certifications like ISO 50001 can be used voluntarily, or compliance can be mandated for selected large consumers by the government. Facilitation/encouragement of energy management systems can be an attractive tool for industrial energy efficiency improvement in developing countries like Sri Lanka since it is one of the effective ways for private sector actors to systematically improve energy efficiency and reduce GHG emissions. Moreover, the governments can also provide technical support directly to the staff to implement monitoring systems and to identify energy-saving measures (USAID, 2020). Data obtained from our field survey shows that only 6% of industrial plants surveyed have ISO 50001 certification. This shows a great potential for capacity building and support to increase Energy management systems certification in industry in Sri Lanka.

Incentivizing adoption of electric boilers and heat pumps in key industries

Recognizing the pivotal role of electrification in reducing carbon emissions from industrial heating, we recommend the formulation and implementation of policies that incentivize the adoption of electric boilers and industrial heat pumps in key industries within Sri Lanka. This could be achieved through a combination of financial incentives, such as tax credits or subsidies, designed to alleviate the initial capital costs associated with transitioning to electric heating technologies. Additionally, the government could establish preferential tariff structures for industries adopting electric heating systems, ensuring that the cost of electricity for heating purposes becomes competitive with traditional fossil fuel alternatives. Collaborative initiatives with financial institutions could be explored to facilitate access to affordable financing for the purchase and installation of electric boilers and industrial heat pumps.

Promoting renewable energy use in industries

This policy recommendation focuses on fostering the widespread integration of various renewable energy sources across industries in Sri Lanka. The government should introduce a comprehensive set of financial incentives, such as tax credits, subsidies, and concessional financing, to encourage industrial establishments to invest in renewable energy solutions such as solar thermal, renewable natural gas, sustainable biomass, etc. Simplifying approval processes for renewable energy projects and ensuring seamless grid integration would enhance the attractiveness of these technologies. An essential component of this policy involves initiating awareness campaigns and capacity-building programs to educate industries about the advantages of transitioning to renewable energy.

Promoting the use of low carbon feedstock in industries

In aligning with the LCFFES pillar, we recommend the formulation of policies aimed at promoting the utilization of low carbon feedstock in industrial processes throughout Sri Lanka. The government can incentivize industries to transition from conventional high-carbon feedstocks to low-carbon alternatives by introducing tax breaks, grants, or other financial incentives tied to the adoption of low-carbon feedstock sourcing practices. To ensure effective implementation, the government could collaborate with industry associations and research institutions to establish clear guidelines and standards for the identification and utilization of low carbon feedstock. By showcasing successful case studies and providing technical support, the government can support industries in this space.

Supporting carbon capture in the cement industry

A mid-to long-term policy recommendation related to the CCUS pillar is the adoption of carbon capture technologies specifically tailored for the cement industry in Sri Lanka. The government should establish a regulatory framework that support cement plants to integrate carbon capture, utilization, and storage (CCUS) technologies into their operations. To facilitate compliance, financial incentives such as tax credits, subsidies, or low-interest loans can be introduced. Moreover, initiating a collaborative platform involving government bodies, industry stakeholders, and research institutions will help with knowledge sharing, addressing technological barriers and promoting best practices in carbon capture for cement manufacturing. By implementing such a policy, Sri Lanka can significantly reduce the carbon footprint of its cement sector, which is a large contributor to its national CO_2 emissions. The government should also incentivize the cement industry to explore and implement innovative ways of utilizing captured carbon.

Enabling energy service companies (ESCOs) market

ESCOs are private or public companies that can provide technical, commercial and financial services needed for industrial energy efficiency projects. ESCOs can take project performance risks, arrange financing and may also take customer credit risks in some cases. ESCOs can operate through shared saving contracts (where performance and credit risks are assumed by ESCOs) or through the guaranteed saving contract (where the finance is arranged by ESCO, but the loan contract is between the bank and the customer) (USAID, 2020).

8.2. Skills and capacity building programs for industry in Sri Lanka

The successful execution of an industrial energy efficiency and decarbonization program demands a cohort of proficient experts capable of identifying opportunities, implementing measures, and rigorously evaluating and monitoring programs across various stages and levels. To bridge the existing gaps in skills and knowledge related to energy efficiency improvement and decarbonization, targeted capacity building programs must be developed to cultivate a group of experts within the country. These programs should encompass a blend of theoretical insights and hands-on intensive training workshops, specifically tailored for key stakeholders in both private and public sectors, including industry engineers and managers, equipment manufacturers, government agencies, and consulting companies. Recognition of competency through certification enhances the effectiveness of these training programs.

Our survey results reveal a considerable number of Sri Lankan companies lacking dedicated personnel or units responsible for energy efficiency initiatives. Many companies exhibit insufficient knowledge in energy management practices, lack awareness regarding the application of financial models to evaluate the feasibility of potential energy-saving and decarbonization projects, and face an overall deficit in capacity, education, and training. To address these challenges, comprehensive capacity-building programs are imperative for both companies and policymakers in Sri Lanka.

International organizations such as UNIDO can play a pivotal role in supporting technical capacity building in developing countries like Sri Lanka. An example of one such program is UNIDO's China Motor System Energy Conservation Program through which many engineers were trained in motor system optimization techniques which resulted in the identification of nearly 40 million kWh in energy savings through the assessment of 38 plants (United Nations Industrial Development Organization (UNIDO), 2007).

In tandem with technical workshops, the Sri Lankan government should incentivize educational institutions to integrate energy efficiency and decarbonization training into their curricula. This approach ensures that the next generation of engineers, economists, and technical professionals graduating from these institutions possess competencies in areas such as system optimization and energy auditing. The government's emphasis on building research capacities ensures that local manufacturers can leverage expertise to upgrade and innovate their products, aligning with the high standards of energy efficiency.

Some examples of the training and capacity building programs related to each of industrial decarbonization pillars are briefly explained below:

1. **Demand management and material efficiency:**

   Capacity building initiatives focused on demand management and material efficiency in Sri Lanka should encompass training programs designed to enhance skills in optimizing material consumption throughout the life cycle of industrial processes. This involves imparting knowledge on light-weighting techniques, reduced over-design, and improved product quality. Workshops should look into specific applications for industries such as food and beverage, textile, rubber, and building materials. Training should address the intricacies of resource availability in Sri Lanka to effectively lower the carbon footprint of final products.

2. **Energy efficiency:**

   Training programs for energy efficiency should equip participants with the technical know-how of implementing measures to reduce fuel and electricity consumption and associated CO2 emissions. Sri Lankan industries, such as food and beverage, textile, and rubber, can benefit from workshops on commercialized energy efficiency technologies. Training on energy efficiency and systems optimization for cross-cutting energy systems such as electric motor systems (pump, fan, compressed air) and boiler and steam systems would be very critical to improve energy efficiency in industry sector in Sri Lanka.

3. **Electrification:**

   To advance electrification in industries, training programs in Sri Lanka should cover various electrification technologies, such as electric boilers and industrial heat pumps. Technical workshops should look into the specifics of these technologies, focusing on their applications in different industrial processes. Industries like food and beverage, textile, and rubber can benefit from practical training in adopting electrified heating processes, enhancing efficiency and reducing carbon intensity. Moreover, the training should highlight the importance of integrating these electrification technologies into existing industrial setups for a seamless transition.

4. **Low-carbon fuels, feedstocks, and energy sources (LCFFES):**

   Capacity building for LCFFES technologies requires detailed training on clean energy solutions like renewable electricity, solar thermal, and sustainable biomass. Workshops should explore applications relevant to industries in Sri Lanka, such as solar thermal application in industries like food and textile.

5. **Carbon capture, utilization, and storage (CCUS):**

   Training programs on CCUS technologies should focus on the cement industry in Sri Lanka, emphasizing post-combustion CO_2 capture technologies suitable for the existing plant. Additionally, participants should gain insights into utilizing low and medium-temperature waste heat from cement plants in the post-combustion carbon capture process. Training should extend to exploring commercial applications of captured CO_2.

In promoting skills and capacity building for industrial decarbonization, it is crucial to address gender balance within the workforce. Efforts should be made to ensure equal participation and representation of women in training programs, workshops, and decision-making roles related to energy efficiency and decarbonization initiatives. By actively encouraging women's involvement, the industrial sector can benefit from diverse perspectives and skills, contributing to more holistic and innovative solutions for decarbonization in Sri Lanka.

8.3. Data collection framework for industrial data in Sri Lanka

Sri Lanka lacks proper data collection framework for industrial energy use and emissions. While conducting this study, we face severe challenges regarding data and information related to energy use in industry sector in Sri Lanka. Even basic information on how much energy use by industry subsector and energy type is not available in Sri Lanka. This highlights an immediate need in Sri Lanka to establish a proper data collection framework for collecting industrial data.

Having an effective data collection framework is necessary to track industrial energy efficiency progress and disentangle the different drivers of energy demand and GHG emissions. Data collection framework for industrial energy efficiency improvement and decarbonization should include energy demand side data as well as data related to the assessment of industrial energy efficiency improvement. Along with sub-sectoral energy demand data, it's necessary to include the activity data (value-added or physical output) representing similar boundaries in the data collection framework in order to track the energy intensities at the level of industry sector and sub-sectors.

The first step in the data collection framework that could be suggested for the government of Sri Lanka is taking inventory of already available data required to track the industrial energy efficiency. This data may already have been collected by the subsector related trade organizations. This step is followed by identifying the data gaps, deciding the methods of data collection, frequency of data collection and sample sizes. There are various ways of collecting the bottom-up data required for the implementation of a successful industrial energy efficiency program. Data collection for both energy demand and energy efficiency at the subsector level could be performed with the combination of surveys, modeling and metering. Surveys can be conducted either by industry census (applicable to more homogenous subsectors with bulk products such as iron and steel, cement, pulp and paper etc.) or by a stratified sample approach (practical for heterogenous subsectors). In order to effectively capture the development of energy efficiency trends, the surveys should be carried out annually.

The Government can either mandate the responses or provide financial or non-financial incentives to the respondents. Metering is typically done in the context of holistic energy audits of individual establishments. Metering can be an important method for tracking energy efficiency at the level of industry processes and benchmarking exercises. Collection and publication of metered data however can be inhibited by confidentiality issues. Which can be overcome by anonymizing the data wherever possible. Modeling can be used to complement the surveys and measured data. Models are useful in developing more detailed indicators such as process efficiencies and technology diffusion as well as for generating future scenarios. Detailed energy benchmarking exercises as well as the energy efficiency measures already implemented within the industry sector can also be made part of data collection framework to evaluate the energy performance of industrial processes in relation to industry best practices (International Energy Agency (IEA), 2014).

8.4. Development of detailed sector-specific net-zero roadmaps for key industrial sectors in Sri Lanka

The imperative for Sri Lanka to transition towards a low-carbon industrial future necessitates the development of detailed sector-specific net-zero roadmaps, particularly for key industrial sectors in Sri Lanka such as textiles, food and beverage, and rubber. These roadmaps should take into account the unique characteristics and challenges of each sector. By quantifying the impact of five key decarbonization pillars – material efficiency, energy efficiency, electrification, low-carbon fuels, feedstocks and energy sources (LCFFES), and carbon capture, utilization, and storage (CCUS) – these roadmaps will provide a comprehensive view of the pathways to reduce energy use and emissions. The roadmap for each sector must include a granular, techno-economic assessment that evaluates the feasibility, costs, and benefits of adopting key technologies under these five pillars for each sector. This assessment should be forward-looking, extending up to the year 2050, to align with global climate goals and Sri Lanka's own NDC targets. It will not only highlight the immediate steps needed but also provide a long-term view of the transition, enabling policymakers, industry and other stakeholders to plan and allocate resources effectively.

In developing these roadmaps, a multi-faceted approach is essential. This involves engaging with industry experts, policymakers, and financial institutions to ensure that the strategies are realistic and actionable. Each roadmap should also include a detailed analysis of the potential barriers and enablers for the adoption of these technologies, supported by a robust analysis on savings, GHG impact, and funding mechanisms.

8.5. Awareness strategy to engage industrial companies in Sri Lanka

Information campaigns to raise awareness and engage industrial companies should be at the core of energy efficiency program (United Nations Industrial Development Organization (UNIDO), 2007). Industry engagement strategies are typically set with the goal of addressing the communication gaps, lack of collaboration between the government and the private sector and reducing asymmetric information related to industrial energy efficiency programs. The outreach to the private sector right from the initial stages of the industrial energy efficiency policies and programs will result in the private sector being active partners in the process of setting up the programs and governments will benefit from developing a strong understanding of drivers and barriers for the industrial energy efficiency within the private sector. For an effective industrial energy efficiency program, the government needs to form partnerships with companies from the private sector.

The first step for the Government of Sri Lanka in order to engage the private sector could be to analyze the context of engagement. This can be done by setting up a committee composed of government officials responsible for industrial energy efficiency programs and key market enablers from the private sector.

Once the contexts are analyzed, the government can then set up an outreach program to communicate the energy efficiency program with the private sector, identify the vulnerabilities and revise and appraise the program if necessary. During the implementation stages, the government can provide support for the implementation of energy efficiency measures within the companies. Development of reporting and monitoring mechanisms should also be part of the private sector engagement strategy.

The private sector engagement can be further enhanced by sharing knowledge and success stories (Crawford, 2020).

These partnerships can result in changing existing practices and behaviors in favor of greater industrial energy efficiency, dissemination of energy efficiency messages further down the supply chain or to trade associations, developing credibility within the industry sector, ensuring the proposed policies are practical, identifying the right talent pool for further building capacity programs and dissemination of financial benefits of industrial energy efficiency (UNIDO,2018).

8.6. Monitoring and evaluation framework

Having clear goals and clear metrics can greatly help the effectiveness of industrial energy efficiency program. Monitoring and evaluation of energy efficiency programs can help ensure the accountability and effectiveness of the program. Establishing the goals and metrics at the beginning of the program can help to identify which data should be collected, and the process of data collection. Monitoring is a process of collecting the data related to effects of energy efficiency measures and evaluation entails analysis of collected data. The government of Sri Lanka can set up the monitoring task using several different ways (USAID):

- Computer-based modelling to predict energy performance.
- Measurement of the energy use on the whole before and after implementation of the industrial energy efficiency program.
- Conducting field measurements for the energy savings by individual upgrades.
- Monitoring the market compliance through product testing based on prescribed protocols, accreditation of testing facilities and proper reporting.
- Top-down monitoring of energy efficiency gains at sectoral and sub-sectoral levels.
- Monitoring of market trends of energy efficient technologies.

The evaluation of the energy efficiency program helps governments gauge the success or a failure of the program. In case of failure the monitoring and evaluation framework can help identify the pitfalls of the program. Evaluation of the energy efficiency program typically takes place at three levels. Process level evaluation addresses the stages like design and implementation of the program, capacity building activities to support the program and financial mechanisms. Impact evaluation focuses on the energy savings achieved through the program whereas market evaluation assesses the market growth and energy efficient technology penetration.

8.7. Recommendations for institutional arrangements and responsibilities

Based on the recommendations of the different policy options for industrial energy efficiency and decarbonization in Sri Lanka, it is suggested that a "**National Industrial Energy Efficiency and Decarbonization Committee (NIEDC)**" be constituted to undertake activities related to policy formulation, monitoring, reporting and verification for industrial energy efficiency. It is suggested that the chairman of the NIEDC or taskforce should be from the Ministry of Power and Energy. Members of the NIEDC from other ministries and agencies will be the Ministry of Finance, Energy Commission, Ministry of Industries, Environmental Protection Agency and Council for Scientific & Industrial Research. Additionally, other members of the NIEDC shall be from academia, industry, professional bodies, private sector, research and energy consultancies, etc. These entities should have coordinated responsibilities to play across the whole spectrum for industrial energy efficiency in Sri Lanka, bringing on board local knowledge and international best practices as may be relevant. The table below suggests some of the proposed entities and their respective responsibilities under the NIEDC.

Table 12. Roles and responsibilities of members of the National Industrial Energy Efficiency and Decarbonization Committee (NIEDC)

Institution	Recommended roles and responsibilities
Ministry of power and energy (MoEn)	Be the sector lead in preparing industrial energy efficiency policies and Legislative Instruments. In collaboration with Energy Commission (EC) and other agencies to prepare proposals to secure grants to undertake national industrial energy efficiency projects.
Ministry of finance (MoF)	Support in subsidizing loans for industrial energy efficiency projects using public funding (i.e., soft loans which are offered at an interest rate lower than the market interest rate). Provide other fiscal incentives like tax exemptions on the purchase of equipment for industrial energy efficiency projects.
Ministry of industries (MoI)	Lead in the preparation and enforcement of standards and labels (S&L) for high energy consuming industrial equipment. Lead in the preparation of national industrial energy efficiency programs and timelines. Prepare national communications (NCs) and reports on industrial energy savings from industrial energy efficiency projects. Lead awareness creation and information sharing on industrial energy efficiency. Provide registration and licensing of energy auditors for industrial energy efficiency projects. Develop and implement a system for Measurement, Reporting and Verification (MRV) of industrial energy efficiency in Sri Lanka.
Ministry of environment	Ensure cohesive implementation of energy efficiency policies and standards across ministries, aligning them with broader environmental goals. Assess the environmental impacts of industrial energy efficiency projects to ensure compliance with protection standards and sustainable development. Lead initiatives to increase public and industrial awareness of the benefits of energy efficiency and decarbonization. Advocate for robust industrial energy efficiency policies, providing expert advice to centralize environmental considerations in energy planning.
Sustainable energy authority	Policy formulation for industrial energy efficiency and decarbonization in Sri Lanka. Monitoring activities related to industrial energy efficiency and decarbonization. Verification of industrial energy efficiency and decarbonization initiatives.

Institution	Recommended roles and responsibilities
Climate change secretariate	Prepare national inventory of GHG emissions from large industrial faculties. Prepare reports on GHG emissions reduction potential from industrial energy efficiency programs.
National cleaner production centre Sri Lanka	Support research on industrial energy efficiency opportunities across different industries in Sri Lanka. Develop guidebooks and tools for industrial energy efficiency.
Academia	Through their certified centers for Sustainable Energy Services, deliver training and certification for energy auditors and energy management professionals. Support Energy Commission to conduct industrial energy audit. Support research on industrial energy efficiency.
Sri Lanka energy managers association (SLEMA), energy consultants and ESCOs	Advice on policy development of industrial energy efficiency based on international best practices. Conduct market research, capacity building and training on industrial energy efficiency based on international expertise and best practices. Advice on development of policy on data collection and analysis framework for industrial energy efficiency. Advice on policy aimed at financial & investment evaluations for industrial energy efficiency based on local and international expertise. Advice on policy development and incentives to leverage private sector investors' support for industrial energy efficiency.
Association of Sri Lanka industries	Support in collecting energy consumption data collection from the member industries. In collaboration with EC and ESCOs, implement mandatory energy management systems (ISO 50001 & ISO 50002) in member organizations/industries. To lead in signing target agreements between large energy-intensive industries and the Government of Sri Lanka to improve industrial energy efficiency and reduce GHG emissions.
Sri Lanka banks	Support in preparing loans "special interest rates" that are lower than market rates for industrial energy efficiency projects.

9 Policy proposal: Top-100 energy consuming enterprise program in Sri Lanka

The suggested Top-100 Energy-Consuming Enterprise Initiative in Sri Lanka draws inspiration from global target-setting initiatives, sometimes referred to as voluntary or negotiated agreement programs. Since the 1990s, these programs, aimed at enhancing energy efficiency and minimizing GHG emissions in the industrial sector, have been adopted in both advanced and emerging economies. Notably, the Netherlands rolled out a commendable voluntary agreement scheme focused on industrial energy efficiency, while China's Top-1,000 and Top-10,000 initiatives rank among their most effective energy conservation strategies.

These initiatives essentially represent an agreement between the government and the industrial sector, outlining mutually agreed upon targets, commitments, and timelines. They generally span five to ten years, facilitating strategic planning and execution of energy-efficiency measures. A primary goal is to ensure all stakeholders prioritize energy efficiency and emission reduction. Key aspects of these programs encompass evaluating the energy efficiency potential of industrial entities and determining targets through collaborative discussions. Both rewards and penalties encourage industries to participate. Ancillary measures, such as facility evaluations, benchmarking, continuous monitoring, knowledge sharing, and fiscal incentives, support participants in optimizing their energy consumption and GHG emissions to achieve set objectives. Some of the most impactful voluntary agreement initiatives incorporate mechanisms to lessen environmental regulations or tax burdens for involved parties (Price et al. 2008). We aim to introduce a similar initiative in Sri Lanka, initially targeting the Top-100 energy-intensive enterprises.

Characterization of the Top-100 industries in Sri Lanka

The industrial plants to be included in Sri Lanka's Top-100 Energy-Consuming Enterprise program are large-scale enterprises that are ranked as the top 100 in terms of total energy consumption.

Target-setting for the Top-100 energy-consuming enterprises in Sri Lanka

The primary objectives of the Top-100 Energy-Consuming Enterprise initiative are to notably enhance the energy efficiency and decarbonization of the Top-100 enterprises; bring unit energy consumption in line with national best practice standards for all major products; and ensure certain enterprises achieve either global best practice benchmarks or industry-specific best standards. All enrolled enterprises will enter into agreements with the government, committing to achieve the energy savings and/or CO_2 emissions reduction goals within five years from the agreement's inception. These targets will be revised every five years to promote sustained progress.

Expectations of the Top-100 energy-consuming enterprises in Sri Lanka

The Top-100 enterprises will be expected to do the followings:

- establishment of energy conservation working groups in enterprises,
- implementation of the target responsibility and accounting system,
- conducting detailed energy audits and developing energy efficiency plans, based on the guidelines provided by the government,
- conducting energy efficiency benchmarking,
- establishment of energy management systems (EnMS) either based on the national standards or international ISO 50001 standard for energy management systems,
- have dedicated energy manager in each facility and conduct trainings for energy managers,
- implementation of energy utilization reporting system and report their energy consumption by fuel quarterly to government,
- continuation of phasing-out of backward technologies,
- acceleration of energy efficiency retrofits,
- improvement of energy measurement and measuring instruments.

Energy managers and energy management system requirement in Top-100 program

Under the Top-100 initiative, industrial establishments are required to appoint a dedicated energy manager or assemble an energy management team. The government ought to offer complimentary training sessions and furnish guidelines for these energy managers. Moreover, entities within the Top-100 initiative should adopt energy management systems (EnMS), such as ISO 50001. The EnMS establishes a framework of standards, outlining protocols and procedures for overseeing energy usage. These systems facilitate the identification of opportunities, setting, and monitoring of internal objectives for enhancing industrial energy efficiency and curbing GHG emissions.

Role of the national, regional, and local governments in Top-100 program

Various national governmental departments and institutions will participate in the Top-100 Initiative in Sri Lanka. This includes the Ministry of Power and Energy, Ministry of Finance, Ministry of Industry, Sustainable Energy Authority, Climate Change Secretariate among others.

It's crucial for the national government to set out and promote the program's fundamental principles and objectives, as well as to disclose a list of the Top-100 enterprises. Energy efficiency and decarbonization bodies at regional, district, or city levels should be tasked with partnering with corresponding organizations to spearhead and execute the Top-100 initiative. This encompasses overseeing, managing, and monitoring the energy efficiency efforts of the involved enterprises. Local governing bodies should assist enterprises in their energy management, audits, and reporting responsibilities.

The Ministry of Power and Energy is expected to organize a range of training workshops tailored for the staff of Top-100 enterprises, covering an array of subjects pertinent to industrial energy efficiency under this initiative. The government needs to introduce a set of supportive policies, specifically crafted for the Top-100 initiative, ensuring that enterprises receive the necessary incentives and backing to reach their goals.

Furthermore, the government should contemplate instituting an award system for enterprises that fulfill their objectives. They should also consider potential penalties for those lagging behind, while examining how the funds for these awards could be sourced and if they would effectively motivate enterprises.

Lastly, it's vital for the government to liaise with international entities that can offer support to vital elements of the Top-100 initiative, such as UNIDO, the United Nations Development Program/Global Environmental Facility (GEF), USAID, The World Bank, among others.

Energy efficiency funding and financial incentives for Top-100 program

As previously mentioned in this report, various financing mechanisms can support energy efficiency enhancements within the Top-100 initiative. Incentives for industrial energy efficiency and decarbonization investments, like grants, loans, tax breaks, subsidies, and more, should target projects with substantial energy savings potential that might be overlooked by enterprises due to high upfront costs. Alongside these local funding avenues, international sources of energy efficiency finance, such as grants from the United Nations Development Program/Global Environment Facility (GEF), ought to be explored to bolster the Top-100 initiative.

Information dissemination and capacity building for Top-100 program

Promoting awareness and building capacity are crucial aspects of target-based and other industrial energy efficiency and decarbonization strategies. Numerous countries produce resources such as energy efficiency and decarbonization technologies handbooks, software tools, databases, and specialized energy efficiency analyses. Sri Lanka can leverage these resources and share them with its industrial sector.

The Sri Lankan government can also undertake the following measures to share information and enhance capabilities for industrial energy efficiency as part of the Top-100 initiative:

- Engage industry associations or other specialized professionals to craft energy efficiency and decarbonization esource materials tailored to the needs of the Top-100 enterprise sectors.
- In collaboration with sector associations or specialists, create benchmarking tools to aid in assessing each enterprise's energy efficiency and decarbonization prospects, offer a streamlined energy auditing instrument, and support in drafting each enterprise's energy strategy.
- Generate comprehensive energy management guidance based on global best practices, which includes a framework to standardize, assess, and acknowledge industrial system enhancement initiatives.
- Examine a selection of enterprise audit reports to gauge their thoroughness and quality, pinpointing areas where added training on certain facets of energy auditing might elevate audit standards.
- Curate a database or directory spotlighting energy audit organizations and ESCOs, highlighting their specializations.

- Evaluate a subset of enterprise energy strategies to assess their depth and quality, identifying areas where additional training on certain elements of crafting and utilizing energy strategies might raise their standards.

- Collaborate with primary industry-centric associations and research bodies to formulate and distribute sector-specific insights for energy assessments, energy benchmarking, and pinpointing energy-efficient and decarbonization technologies and strategies. Partner with regional entities and technical institutions to enhance their industry-specific proficiencies.

- Prioritize establishing the National Energy Conservation Center or another central energy information sharing and training hub to orchestrate numerous facets of the Top-100 initiative.

- Organize select study tours to the U.S., EU, and Asia, regions with robust target-based strategies, for delegates from pioneering enterprises in the Top-100 initiative.

Monitoring and evaluation of Top-100 program

Setting up robust monitoring protocols at the onset of an energy-efficiency or target-based initiative is crucial. Enterprises should be provided with well-defined and transparent guidelines detailing what should be reported, the timeline for reporting, the method of reporting, and the recipient of the information. Comprehensive clarity on how the initiative's savings will be recorded and the desired precision level should be shared from the project's commencement. Preferably, an independent third party should conduct verification to confirm the data provided and supervise the monitoring practices. It's vital to explicitly articulate the monitoring workflow, specify the structure and essentials of monitoring documents, and offer distinct explanations concerning energy consumption and energy conservation strategies.

The Top-100 initiative should craft enterprise-specific monitoring and reporting protocols, encompassing not just yearly energy consumption and CO_2 emissions but also data on annual production figures, alterations within the enterprise's organization, and updates on the energy-saving measures highlighted in the enterprise's action plan.

Top-100 Program timeline and expansion

Figure 26 illustrates the proposed timeline for the design, rollout, and expansion of the Top-100 initiative in Sri Lanka. Following its first phase, the program should progress to encompass Top-200 and eventually Top-300 in 2030. As both the government and industry accumulate expertise and fine-tune the initiative during its early stages, broadening its scope should be the logical progression. Furthermore, energy efficiency and decarbonization goals should be reassessed every three years, with the establishment of new objectives.

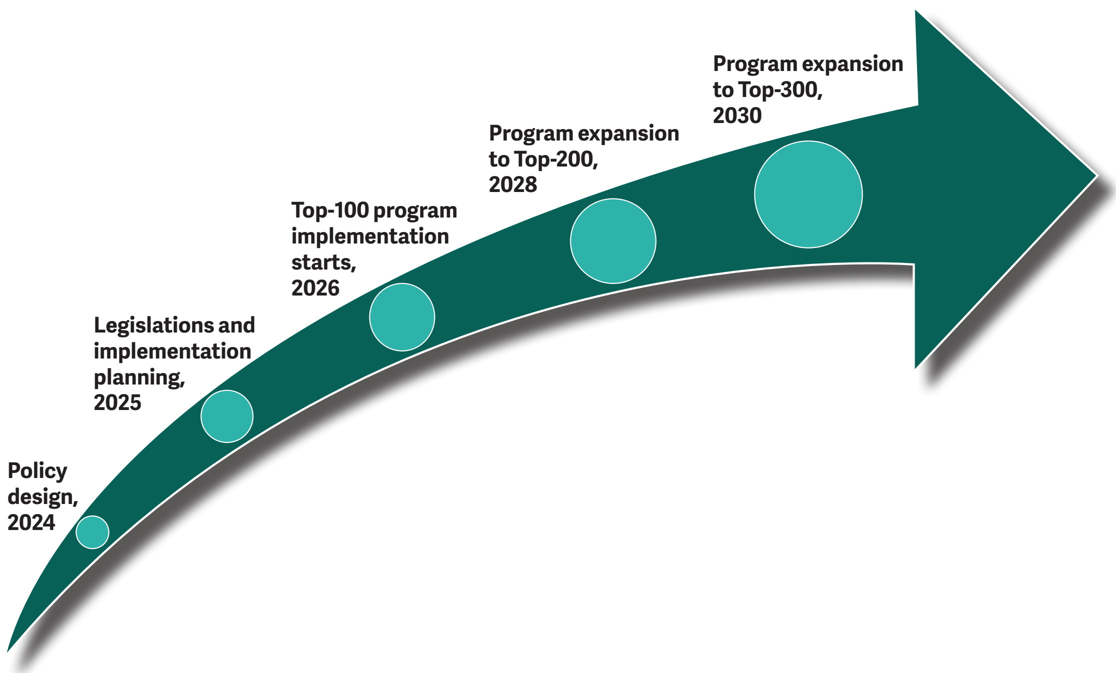


Figure 26. The suggested timeline for design, implementation, and expansion of Top-100 Energy-Consuming Enterprise Program in Sri Lanka

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Appendices

Appendix 1. Methodology for motor systems energy efficiency cost curve

We analyzed the industrial motor systems energy-efficiency potential in Sri Lanka.
The base year for our analysis is 2021, the latest year for which energy-use data were available at the time of the study.

Country-specific data were collected from various sources. Electricity use for industrial subsectors in Sri Lanka was from IEA's World Energy Statistics (IEA 2021). For this study, we built on the information collected and the method developed during our study for the United Nations Industrial Development Organization (McKane and Hasanbeigi 2010). We refined the methodology from that study and used more recent data, applying it to Sri Lanka.

To conduct these studies, we also developed a framework to obtain expert input to supplement existing data. We consulted 13 motor system experts during our previous UNIDO study on the percentage of system energy use by industrial sector, energy efficiency of systems in a market with a defined set of characteristics, creation of a list of common energy-efficiency measures, and the energy savings and implementation costs associated with these measures. A Delphi-type approach was taken in which several cycles of input, analysis, and review were performed to refine the expert input.

Estimation of electricity use by industrial motor systems in sri Lanka, by manufacturing subsector

Because no database reports manufacturing subsector electricity use in Sri Lanka, we estimated these values. The international energy agency (IEA) publishes national data on energy consumption for different countries including Sri Lanka. In these data set, they report electricity use by different economy subsector (residential, commercial, industrial, and transport) and fuel (IEA 2021). This source does not report electricity use by manufacturing subsector for Sri Lanka. Once we estimated the electricity use for industry in Sri Lanka, we used the 70% ratio from IEA (2016) and U.S. DOE (2022) to estimate industrial motor systems electricity use in Sri Lanka.

Base-case system efficiency scenario definition

We established three base-case efficiency scenarios (LOW-MEDIUM-HIGH) for industrial motor systems based on previous research and expert input. There was a remarkable degree of agreement among the experts concerning the range of efficiency for each system type that could be expected in these base-case scenarios. After defining the base cases, we assigned base case values to Sri Lanka, to establish a reference point for current motor system performance in the country.

The first step in establishing a base case was to create a unique list of system energy-efficiency practices representative of each of the three efficiency scenarios for motor systems. Tables A.1-A.3 in Appendix lists the practices assigned to each base-case efficiency level for industrial pump systems, fan systems, and compressed air systems, respectively.

Table A.1. Characteristics of LOW-MEDIUM-HIGH efficiency base-case scenarios for pump systems

No.	LOW efficiency base-case scenario
1	Less than 10% of pump systems have been assessed for system energy efficiency.
2	Maintenance is limited to what is required to support operations.
3	Flow is typically controlled by throttling or bypass.
4	Flow regularly exceeds actual system needs.
5	Variable-speed drives are not commonly used
6	Motors of all sizes are routinely rewound multiple times instead of replaced.
7	~10% of the installed motors are high efficiency--either EPAct or EFF1 equivalent.
No.	**MEDIUM efficiency base-case scenario**
1	~20% of pump systems have been assessed for system energy efficiency.
2	Maintenance is a routine part of operations and includes some preventative actions.
3	System operators take steps to avoid controlling flow via throttling or bypass.
4	Efforts are made to efficiently match supply with demand.
5	Variable-speed drives are frequently proposed as a solution for flow control.
6	Motors ≥ 37 kW are typically rewound multiple times, and smaller motors may be replaced.
7	~25% of the installed motors are high efficiency--either EPAct or EFF1 equivalent.
No.	**HIGH efficiency base-case scenario**
1	30% or more of pump systems have been assessed for system energy efficiency.
2	Both routine and predictive maintenance are commonly practiced.
3	Flow is not controlled by throttling or bypass except in emergencies.
4	Fluid is only pumped where and when needed to meet demand.
5	Variable-speed drives are one of several flow-control strategies commonly applied to increase system efficiency.
6	Most facilities have a written rewind/replace policy that prohibits rewinding smaller motors (typ <37 kW).
7	50% or more of the installed motors are high efficiency--either EPAct or EFF1 equivalent.

Table A.2. Characteristics of LOW-MEDIUM-HIGH efficiency base-case scenarios for fan systems

No.	LOW efficiency base case scenario
1	Less than 10% fan systems representing 40% of the connected fan load have been assessed for system energy efficiency
2	Maintenance is limited to what is required to support operations
3	Flow is usually controlled by dampers or bypass
4	Low cost fans types, like radial, are often used even in clean air applications
5	Fans are sometimes located on the dirty side of the process
6	Fans are sometimes oversized for the present load
7	Variable speed drives or variable inlet vanes are sometimes proposed as a solution for flow control
8	Motors of all sizes are routinely rewound multiple times instead of replaced
9	10% or less of the installed motors are high efficiency--either EPAct or EFF1 equivalent
No.	**MEDIUM efficiency base case scenario**
1	~30% fan systems representing 60% of the connected fan load have been assessed for system energy efficiency
2	Maintenance is a routine part of operations and includes some preventative actions
3	System operators take steps to avoid controlling flow via dampers or bypass
4	Airfoil or backward curved impellers are used in clean air handling applications
5	Fans are located on the clean side of the process whenever possible
6	Fans are chosen to efficiently serve a given condition
7	Variable speed drives or variable inlet vanes are frequently proposed as a solution for flow control
8	Motors ≥ 37 kW are typically rewound multiple times, while smaller motors may be replaced
9	~25% of the installed motors are high efficiency--either EPAct or EFF1 equivalent
No.	**HIGH efficiency base case scenario**
1	~50% fan systems representing 80% of the connected fan load have been assessed for system efficiency
2	Both routine and predictive maintenance are commonly practiced
3	Flow is not controlled by dampers or bypass except in emergencies
4	Fans are located on the clean side of the process whenever possible
5	Variable speed drives are one of several flow control strategies commonly applied to increase efficiency
6	Fans types are chosen based on the highest efficient type to serve a given condition
7	Fans are selected and procured so that typical process flow and pressure requirements are at or near Best Efficiency Point
8	Most facilities have a written rewind/replace policy that prohibits rewinding smaller motors (typ <45 kW)
9	50% or more of the installed motors are high efficiency--either EPAct or EFF1 equivalent

Table A.3. Characteristics of LOW-MEDIUM-HIGH efficiency base-case scenarios for compressed air systems

No.	LOW efficiency base case scenario
1	Less than 10% of compressed air systems have been assessed for system energy efficiency (both supply and demand side assessment)
2	Maintenance is limited to what is required to support operations
3	Compressor control is coordinated but poorly and a single trim compressor operates inefficiently
4	System pressure profile, supply / demand balance, and storage partially optimized
5	Leaks are ≥ 25%, but < 35% and are fixed irregularly
6	There is widespread inappropriate use of compressed air
7	Motors of all sizes are routinely rewound multiple times instead of replaced
No.	**MEDIUM efficiency base case scenario**
1	~20% of compressed air systems have been assessed for system energy efficiency (both supply and demand side assessment)
2	Maintenance is a routine part of operations and includes some preventative actions
3	Compressor control is coordinated and a single trim compressor operates efficiently
4	Variable speed drives are frequently proposed as a solution for flow control
5	Leaks are ≥ 15%, but < 25% and are fixed periodically
6	Inappropriate end use of compressed air has been reduced
7	Motors ≥ 37 kW are typically rewound multiple times, while smaller motors may be replaced
No.	**HIGH efficiency base case scenario**
1	~30% or more of compressed air systems have been assessed for system energy efficiency (both supply and demand side assessment)
2	Both routine and predictive maintenance are commonly practiced
3	Compressor controls and storage are used to efficiently match supply to demand
4	System pressure profile from supply to end use has been optimized
5	Leaks < 15%; Leaks management is ongoing
6	Inappropriate end use of compressed air has been minimized
7	Most facilities have a written rewind/replace policy that prohibits rewinding smaller motors (typ <37 kW)

We asked motor systems experts to estimate the range of system energy efficiency they would expect to see when auditing a system in an industrial facility with the characteristics given for each efficiency base-case scenario (LOW-MEDIUM-HIGH).

Table A.4-A.6 in Appendix shows the consolidated results, including the base-case values used in calculating the efficiency cost curves. There was a high degree of agreement among experts regarding the range of system energy efficiency that would be expected based on the list of characteristics assigned to the base cases. We used the average of low and high values for the LOW-MED-HIGH efficiency base cases in our analysis.

Table A.4. Consolidated system efficiency for LOW-MED-HIGH efficiency baselines

	Pump system efficiency		
	low end (%)	high end (%)	Average (%) - used in the analyses
Low level of efficiency	20%	40%	30%
Medium level of efficiency	40%	60%	50%
High level of efficiency	60%	75%	68%

Table A.5. Consolidated system efficiency for LOW-MED-HIGH efficiency baselines

	Fan system efficiency		
	low end (%)	high end (%)	Average (%) - used in the analyses
Low level of efficiency	15%	30%	23%
Medium level of efficiency	30%	50%	40%
High level of efficiency	50%	65%	58%

Table A.6. Consolidated system efficiency for LOW-MED-HIGH efficiency baselines

	Compressed air system efficiency		
	low end (%)	high end (%)	Average (%) - used in the analyses
Low level of efficiency	2.0%	5.0%	3.5%
Medium level of efficiency	4.8%	8.0%	6.4%
High level of efficiency	8.0%	13.0%	10.5%

After defining the base-case efficiencies for each motor system, we assigned a base case to Sri Lanka as a reference point for current industrial motor system performance in Sri Lanka based on available information. Table A.7 shows the base-case efficiencies assigned for each industrial motor systems in Sri Lanka

Table A.7. Base-case motor systems efficiencies assigned to Sri Lanka

Motor system	Base case efficiency level
Pump systems	LOW
Fan systems	LOW
Compressed air systems	LOW

Energy-efficiency measures and their savings and costs

We developed a list of motor system energy-efficiency measures and asked motor system experts their opinion on energy savings likely to result from each measure implemented independent of the others, expressed as a percentage improvement over each of our base cases (LOW-MED-HIGH).

The experts were also asked to provide cost information for each measure, disaggregated by motor size range. The size ranges were selected based on categories developed for the most detailed motor system study available. In this study, "motor system size" refers to a motor system's aggregate hp or kW. The costs provided are for when efficiency measures are implemented in systems with LOW base case efficiency level. However, for systems that have Medium or High efficiency base case, the cost of efficiency measures where reduced using an adjustment factor.
In addition to the energy-efficiency improvement cost, we asked experts to provide the useful lifetime of the measures, disaggregated into two categories of operating hours (1,000 - 4,500 hours per year and more than 4,500 hours per year). In some instances, the initial list of measures included several measures that would be unlikely to be implemented together (i.e., it is more likely that one would be selected). In those cases, we chose the most common measure based on experts' judgment.

Tables A.8, A.9 show example of typical percentage improvements in efficiency over each base case as well as an estimated typical capital cost of one motor system energy-efficiency measure, differentiated by system size. The actual installed cost of some system measures can be highly variable and dependent on-site conditions, including the number and types of end uses. The need to add or modify physical space to accommodate new equipment can also be a factor in installed cost.

Table A.8. Example energy-efficiency measure and typical % efficiency improvement impact on pump systems in Sri Lanka

Energy-efficiency measure	Typical % improvement in energy efficiency practice		
	% Improvement over LOW eff. base case	% Improvement over MED eff. base case	% Improvement over HIGH eff. base case
Replace pump with more energy efficient type	16%	10%	5%

Table A.9. Example of installed cost of a typical pump system energy-efficiency measure in Sri Lanka

Energy-efficiency measure	Typical installed cost (US$)				
	≤50 hp	>50 hp ≤100 hp	>100 hp ≤200 hp	>200 hp ≤500 hp	>500 hp≤1000 hp
	≤37 kW	>37kW ≤75kW	>75kW ≤150kW	>150kW ≤375kW	>375kW ≤745kW
Replace pump with more energy efficient type	$ 6,000	$ 10,000	$ 18,000	$ 22,000	$ 50,000

Systems larger than 1,000 hp (745kW) are usually custom designed, and their cost is highly variable. The cost data from experts for this size system varied so much that it injected significant uncertainty into the final results, so we excluded systems larger than 1,000 hp (745kW) from the final analysis. Excluding these systems from the analysis resulted in a proportional decrease in total system energy use and a corresponding decrease in the energy savings resulting from the energy-efficiency measures analyzed. This limitation should be considered when reviewing the results presented in this report.

This report uses the estimated full cost of the energy-efficiency measures analyzed rather than the incremental cost. This choice was based on the goal of our analysis, which was to assess the total potential for energy efficiency in industrial motor systems in the base year (2021) assuming a 100% adoption rate. Therefore, we assumed that all the measures are installed in the base year, so the full cost of the measures should be used because the existing systems are not all at the end of their lifetimes.

Development of energy-efficiency cost curves

The energy-efficiency cost curve (also known as the energy conservation supply curve) is an analytical tool that captures both the engineering and economic perspectives of energy efficiency. The curve shows energy-efficiency potential as a function of the marginal cost of conserved energy (CCE). CCE can be calculated from Equation A.1.

$$\text{Cost of Conserved Energy (CCE)} = \frac{\text{(Annualized capital cost + Annual change in O\&M costs)}}{\text{Annual energy savings}} \quad \text{(Eq. A.1)}$$

The annualized capital cost can be calculated from Equation A.2.

$$\text{Annualized capital cost} = \text{Capital Cost}*(d/ (1-(1+d)-n) \quad \text{(Eq. A.2)}$$

d: discount rate, n: lifetime of the energy efficiency measure

In this study, because only one type of cost (capital cost) was available for each measure, the capital cost was used to calculate the CCE without regard for any change in operations and maintenance cost (given in Eq. A.1). Some of the measures themselves are improvements in maintenance practices.

After calculating the CCE for all energy-efficiency measures, the measures are ranked in ascending order of CCE. Also, on an efficiency cost curve, an energy price line is determined. All measures that fall below the energy price line are identified as "cost-effective." That is, saving a unit of energy by means of the cost-effective measures is cheaper than buying a unit of energy. On the curves, the width of each measure (plotted on the x-axis) represents the annual energy saved by that measure. The height (plotted on the y-axis) shows the measure's CCE. Figure A.1 shows an illustrative example of an energy-efficiency cost curve for measures A and B.

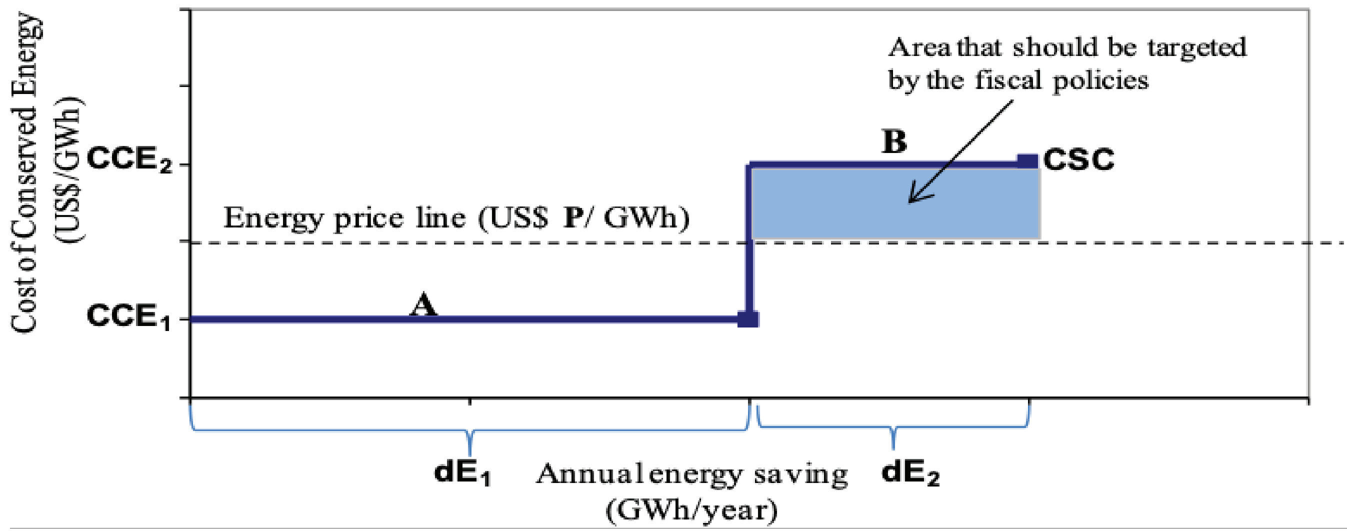

Figure A.1. Illustrative example of an energy-efficiency cost curve

In our analysis, a real discount rate of 15% was assumed. This choice seems to be reasonable since the commercial banks interest rates in Sri Lanka are quite high and it was over 15% in 2021. The choice of the discount rate also depends on the purpose of the analyses and the approach (prescriptive versus descriptive) used. A prescriptive approach (also called social perspective) uses lower discount rates (4% to 10%), especially for long-term issues like climate change or public-sector projects. Low discount rates have the advantage of treating future generations equal to our own, but they also may cause relatively certain, near-term effects to be ignored in favor of more uncertain, long-term effects.

Figure A.2 is a schematic of the process of calculating motor system energy-efficiency cost curves. The details of each step are explained in the following sections.

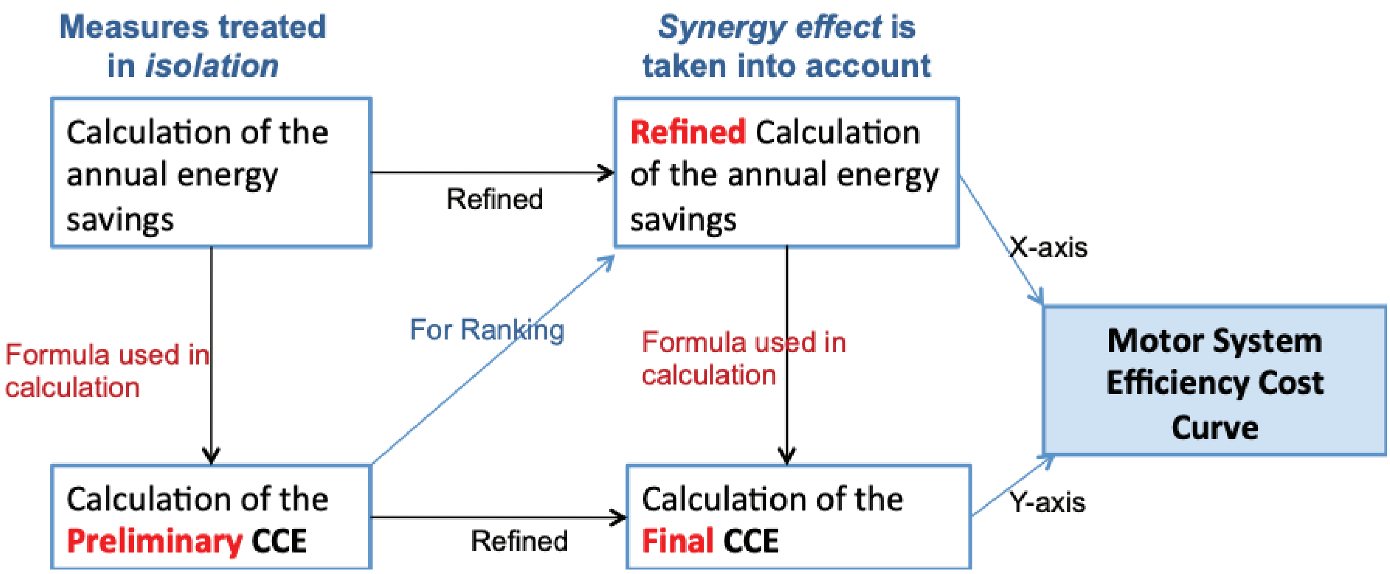

Figure A.2. Calculation process for constructing motor system energy-efficiency cost curves

For calculating energy savings from each motor system efficiency measure, the following inputs were available:

- The efficiency base-case scenarios for motor systems (low, medium, high), developed as described above. As explained earlier, Sri Lanka was assigned a LOW base-case motor system efficiency.
- For each motor system efficiency measure, experts provided a typical percentage improvement in energy efficiency over each base-case efficiency.
- Electricity use in the industry in Sri Lanka.
- From the above information, the annual electricity savings can be calculated for each individual industrial motor system efficiency measure when measures are treated individually and can be implemented regardless of the implementation of other measures.

However, implementation of one measure can influence the efficiency gain from the next efficiency measure implemented. When the first measure is implemented, the base-case efficiency is improved. Therefore, the efficiency improvement of the second measure will be less than if the second measure was implemented first or considered alone. Because of this, in our analysis, the measures were treated in relation to each other (as a group). In other words, the efficiency improvement from implementation of one measure depends on the efficiency improvement achieved by the previous measures implemented. We call this the **synergy effect.**

In this method, the **cumulative** electricity savings are calculated by taking into account the synergy effect of the measures rather than by treating the measures in isolation from one another. For instance, the cumulative annual electricity savings from measure #3 include the efficiency gains from the previous measures implemented (measures #1 and #2).

Calculation of the cumulative savings rather than individual savings is also desirable because the cumulative electricity savings will be used to construct the motor system efficiency supply curves. At the same time, the ranking of the measures significantly influences the energy savings attributed to each measure. That is, given a fixed percentage improvement of efficiency from each individual measure, the higher the rank of the measure, the larger the contribution of that measure to the cumulative savings. To define the ranking of the efficiency measures before calculating the cumulative energy savings using the method described above, we calculated a preliminary CCE for each measure, treating each in isolation from the others, i.e., without taking any synergy effect into account. The measures were ranked based on their preliminary CCEs, and this ranking was used to calculate the final cumulative annual energy savings as well as the final CCE. Table A.10 shows some of the assumptions used in the analyses.

Table A.10. Average unit price of electricity for industry and emissions factor for grid electricity in Sri Lanka in 2021

	Sri Lanka
Average unit price of electricity for industry in 2021 (US$/MWh)	80
Emission factor for grid electricity in 2021 (kgCO_2/MWh)	520

It should also be noted that the purpose of our analysis is to determine the cost-effectiveness of efficiency measures and estimate the total electricity savings potential for industrial motor systems. This study does not analyzed scenarios based on the assumption of different penetration rates of the measures in the future; instead, we aimed to identify the magnitude of the total savings potential in 2021 and associated costs.

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ACCELERATING INDUSTRIES' CLIMATE RESPONSE SRI LANKA

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