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Technical Report

Sustainable Energy Practices in Cambodia's Garment Industry

An Energy Audit Study

SWITCH GARMENT
PROMOTION OF SUSTAINABLE ENERGY PRACTICES IN THE GARMENT SECTOR IN CAMBODIA

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TAFTAC Textile, Apparel, Footwear & Travel Goods Association in Cambodia

About Switch Garment

The "Promoting Sustainable Energy Practices in the Garment Sector in Cambodia", called Switch Garment, is a four-year project started in May 2020 and funded by the European Union SWITCH-Asia Programme. Switch Garment is jointly implemented by the Global Green Growth Institute (GGGI), Geres, and Textile, Apparel, Footwear & Travel Goods Association in Cambodia (TAFTAC). The objective of this project is to increase competitiveness of the Cambodian garment industry through investment in sustainable energy technologies and practices. Ministry of Environment (MOE) and Ministry of Industry Science Technology & Innovation (MISTI) are two government counterparts of the Project.

Technical Report

Sustainable Energy Practices in Cambodia's Garment Industry: An Energy Audit Study

Developed by Global Green Growth Institute (GGGI) and The Energy and Resources Institute (TERI) with the inputs and extensive review provided by Geres, Textile Apparel, Footwear & Travel Goods Association in Cambodia (TAFTAC) and Cambodian Garment Training Institute (CGTI). Thanks to the strategic guidance and technical inputs provided by Ministry of Environment (MOE) and Ministry of Industry Science Technology & Innovation (MISTI).

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The graphic design and layout of this report is made by GGGI Cambodia.

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Abbreviations

ADB	Asian Development Bank
BAU	Business as Usual
BLDC	Brushless Direct Current
CMT	Cut-Make-Trim
DG	Diesel Generator
EDC	Electricite du Cambodge
EE	Energy Efficiency
EEM	Energy Efficiency Measures
EMI	Electromagnet Interference
EU	European Union
FTL	Fluorescent Tube Light
GDP	Gross Domestic Product
GFT	Garment, Footwear & Travel Goods
GGGI	Global Green Growth Institute
GHG	Greenhouse Gas
IGV	Inlet Guide Vane
kL	Kilo litres
kW	Kilo Watt
kWh	Kilo Watt Hours
LED	Light Emitting Diode
LTS4CN	Long-Term Strategy for Carbon Neutrality
MEA	Multi Fibre Agreement
MISTI	Ministry of Industry, Science, Technology & Innovation
MME	Ministry of Mines and Energy
MT	Metric Tonnes
MOE	Ministry of Environment
NCSD	National Council for Sustainable Development
NDC	Nationally Determined Contribution
NEEP	National Energy Efficiency Policy
NESAP	National Environment Strategy & Action Plan
No.	Numbers
NSDP	National Strategic Development Plan
NSPGG	National Strategic Plan on Green Growth
PDP	Power Development Plan
PF	Power Factor
PV	Photo Voltaic
REDD	Reducing Emissions for Deforestation & Forest Degradation
RE	Renewable Energy
RGC	Royal Government of Cambodia
RPM	Revolutions per Minute
SME	Small & Medium Sized enterprises
TAFTAC	Textile, Apparel, Footwear & Travel Goods Association in Cambodia
TPH	Tons per Hour
tCO2	Tonnes of Carbon dioxide
toe	Tonnes of Oil Equivalent
V	Voltage
VSD	Variable Speed Drive

Executive Summary

This technical report analyzes the energy efficiency and renewable energy potential within Cambodia's garment, footwear, and travel goods (GFT) sector. Based on 50 energy audits conducted between August 2021 and August 2022, the report identifies key opportunities for cost reduction and environmental improvement, and it also examines the relevant Cambodian policy framework.

Based on the primary data collected through energy audits, the following findings were identified:

Energy Profile

Energy audit data showed that the total energy consumption across 49[1] audited factories amounted to approximately 20,009 toe/year. This energy consumption resulted in a total GHG emission of around 77,172 tCO2/year, with 55% attributed to electricity usage. Notably, energy costs were reported to constitute less than 5% of the overall production costs in the GFT industry.

Energy Saving Potential

Several energy conservation measures were identified during the energy audits. As expected, significant scope for improvement was reported in boiler systems, air compressor systems, lighting systems as well as in ventilation systems. The potential for installing solar rooftop systems was also identified. The total identified energy-saving potential from audited industries is 2,550 toe/year, representing 12.74% of the total energy consumption. By implementing such energy-saving measures, GHG emissions of 13,141 tCO2/year can be reduced. The estimated integration of solar PV systems in the audited factories could generate 12.6 million kWh per year, reducing GHG emissions by 8,184 tCO2 annually. The proposed energy conservation measures are categorized into low-cost, medium-cost, and high-cost measures, with low- and medium-cost interventions accounting for 56% of the total energy savings. To date, 25 factories out of 50 have already invested USD 3.69 million in implementing energy-saving measures, including installation of solar rooftop systems.

Required investment

Energy audit data indicates that a total of USD 20 million would be required to implement all the energy conservation measures recommended in the energy audit reports for 50 factories. In Cambodia, there are more than 1,000 garment industries, and at least USD 200 million would be needed to implement energy conservation measures across the entire GFT sector. However, the project team suggests that an initial investment of USD 20 million would be required to address the short- and medium-term sustainability needs of GFT industries.

Policy Landscape

Implementation of sustainable energy measures requires an enabling policy landscape. The Royal Government of Cambodia (RGC) has recently adopted the National Energy Efficiency Policy (NEEP) led by the Ministry of Mines and Energy in September 2022. The NEEP aims to reduce 20% of energy consumption in the industrial sector. It clearly outlines an action plan that includes the implementation of an energy management program for industries, developing regulations to enforce industry compliance, and establishing Standards and Labelling (S&L) frameworks. The recently adopted Power Development Plan (PDP) 2040 also emphasizes implementation of energy efficiency actions in line with NEEP.

1 One factory relies solely on wood as fuel for its cogeneration facility, resulting in a distinct energy profile that is discussed in the relevant sections of this report.

Lessons Learned

Several valuable lessons were learned during overall energy audits activities, which can be summarized as follows:

1. Early market challenges: At the project's inception, the sustainable energy market in Cambodia was underdeveloped, making factory recruitment difficult. The Key stakeholders, including factory owners, required substantial awareness-building. The pandemic caused factory shutdowns and delays, impacting international audit teams' work. Efforts to hire local energy auditors were challenging due to a lack of certified professionals, highlighting the need to build a more competent pool of national auditors.
2. Contract and ownership issues in making energy efficiency investment decisions: During the presentation of energy audit results to the factories, the project team identified that the sustainability of a garment business is significantly influenced by the terms of the supply contract between the industry and the buyer. This directly impacts long-term sustainable energy investment decisions. Another critical factor affecting investment decisions is the ownership structure of the industrial buildings; when factory buildings are leased, it becomes challenging to make long-term investment commitments.
3. Efforts by the garment industries and international Buyers: Since the share of energy costs is not that high in the overall mix of production costs, it is not economically compelling for industries to implement energy conservation measures. On top of this, the political context also does not help motivate industries to implement such energy measures. However, several buyers and factories have undertaken proactive targets in reducing their carbon footprint as part of their environmental commitment.

Recommendations

Based on the lessons learned during implementation of energy audit activities the project team recommends following actions:

1. Introduce industrial sustainable energy program: A public-led energy management program will facilitate a centralized, well-coordinated energy management approach. As mentioned in the NEEP, the government will soon launch an energy management program. However, an association-led initiative, such as one by TAFTAC, could support factories in implementing energy conservation measures. The implementation of the TAFTAC Model Green Factory Program in garment industries, along with its replication in other sectors, will play a crucial role in this effort.
2. Capacity building of the factory staffs: Technology-focused training programs should be delivered to the technical staff of the factories to address the low-hanging but most impactful energy-saving measures. Detailed training on boiler systems and air compressor systems will enhance energy management practices and provide immediate results in terms of significant energy savings. Factory management and development partners, in collaboration with relevant ministries, may introduce these training programs.
3. Technology demonstration: Technology-specific pilot projects might be implemented to demonstrate energy-saving potential to other industries. Some industries have installed BLDC fans and rooftop solar systems, which can be presented to other factories by arranging factory visits. TAFTAC can play a vital role in promoting such demonstration projects across its member factories.

4. Enabling policy context: Energy audits have identified significant opportunities for implementing solar rooftop systems. However, factories are eagerly awaiting a conducive policy environment to make the installation of solar systems economically viable. While awaiting greater clarity on compensation tariffs, the government could consider intermediate actions, such as allowing GFT factories to install solar systems without incurring additional fees. This would allow the industries to respond to the sustainability requirements asked by their buyers.

This technical report was produced as part of the EU-Switch Garment project, a collaborative effort to advance sustainable energy practices in Cambodia's garment industry. Supported by the European Union's SWITCH-Asia Grants Programme, the project brings together the Global Green Growth Institute (GGGI) Cambodia, TAFTAC (Textile, Apparel, Footwear & Travel Goods Association in Cambodia), and Geres, in partnership with the Ministries of Environment (MOE) and the Ministry of Industry, Science, Technology & Innovation (MISTI).

1. Introduction

1.1. Background

The garment industry is one of the key pillars of the Cambodian economy and a major source of employment for the people. However, its growth has resulted in significant natural resource consumption and has negatively impacted the environment. To make the garment sector more sustainable, fundamental changes are needed by mainstreaming resource efficiency and circular economy principles in garment manufacturing and processing. These changes aim to minimize or mitigate the detrimental environmental impacts of the garment industry and ensure long term sustainability. Identifying energy efficiency measures to reduce energy consumption is critical, as energy is the largest contributor to emissions in the garment industry. Reducing energy use and integrating renewable energy at the individual garment industry level can contribute to achieving net-zero emissions. The EU-Switch Garment project focuses on understanding the key barriers inhibiting the sustainable growth of the garment sector and identifying opportunities to reduce energy and resource consumption, supporting the sector's sustainable development in Cambodia. Against this backdrop, 50 energy audits in the garment sector in Cambodia were conducted between August 2021 and August 2022.

1.2. Objectives

The overall objective of the energy audit is to identify techno-economically feasible energy and resource-efficient options for garment manufacturing units in Cambodia. The identified options will also address the related environmental and social impacts relevant to these units. Energy audit activities were planned, comprising the following sub-activities:

- Conducting energy audits in the selected 50 garment manufacturing units;
- Identifying suitable energy conservation measures/options to enhance the performance of the units, addressing aspects related to energy, environment, and resources.
- Preparing energy audit reports that outline techno-commercially viable options for further detailed investigation and investment targeting.
- Supporting factories in implementing the recommended energy audit measures.

This report communicates the results achieved through 50 energy audits conducted under EU Switch Garment project.

1.3. Energy Audit Procedure

Energy audit activities began with the recruitment of factories. The original plan was to start recruiting factories in the second quarter of 2021; however, the pandemic struck hard in Cambodia during that time. Reaching out to factories to conduct audit activities and recruit candidates proved to be quite challenging. Despite these obstacles, the project team successfully recruited and conducted audits in 50 factories. The energy audit activities were conducted in three stages: the pre-audit stage, the audit stage, and finally, the post-audit stage.

Stage I: Pre-audit stage

The scope of the energy audit, the procedure, and the support required from factories were explained to each factory during the recruitment process. Once agreed, factories signed a commitment letter outlining the audit's terms of reference. Factory employees then received training on gathering pre-audit data on energy consumption and production metrics, including electricity usage, diesel consumption, wood/biomass consumption, and water consumption over a minimum of one year. An inventory list detailing major energy systems and equipment, such as boilers, lighting fixtures, air-conditioning units, air compressors, and furnaces, was prepared by the project team to be completed and submitted by the factories. To ensure the confidentiality of factory information and data, a non-disclosure agreement was signed between the project consortium partners and each factory.

Stage II: Audit stage

The project team, along with energy auditors, visited the factories in person to conduct the energy audit, beginning with an orientation meeting. Depending on the size and production volume of the factory, energy audit data collection took one or two days. The energy auditors toured the facility to identify factors contributing to energy consumption for each piece of equipment. An energy consumption profile for all equipment was recorded, and the operating conditions were analyzed to assess their effectiveness.

The pattern of energy consumption was identified as a key component in optimizing system performance, in conjunction with the technology currently in use, operating hours, fuel sources, and environmental factors like maintenance schedules. The system's performance and potential savings were evaluated by comparing pre-audit data with actual energy consumption. After completing the audit, a brief summary was presented to the factory staff, along with general findings from the energy audit and cost-free energy-saving tips that could be implemented afterward.

Stage III: Post-audit stage

In this stage of the audit activity, the project team conducted a detailed assessment of the collected data, followed by the development of an energy audit report. The report addressed all on-site utility usage and energy tariffs, estimated the site's energy balance, and included resource efficiency and economic analysis. Recommendations for investments in sustainable energy were categorized into three cost categories: low/no, medium, and high. The first draft of the energy audit report was shared with the project lead and the factory to develop a detailed strategy for retrofits, conservation measures, and modified energy supply options. The selection of sustainable energy measures was based on technical feasibility and alignment with the factory's strategic business goals. Following the selection of actions and agreement with the factory, the final energy audit report included a detailed description of the business and facility, a condition assessment of targeted energy systems, utility use and tariff analysis, energy balance, resource efficiency savings, and energy supply measures, as well as recommendations for economic analysis and implementation. The final energy audit report was delivered to the factory, along with a presentation explaining the potential for savings and suggested sustainable actions that could be put into practice. A factory feedback form was also shared to collect data on the factory's interest in implementing audit recommendations. The project team continued to follow up with the factories to track the implementation of energy conservation measures, including solar energy. To date, 25 factories have reported implementing some interventions, resulting in an investment mobilization of USD 3.69 million.

1.4. Structure of the Technical Report

This technical report communicates the collective results gathered through energy audits in 50 garment factories. Chapter 1 provides an overview of the project, including the energy audit activity and its defined scope of work. Chapter 2 outlines the Sustainable Energy Policy Landscape in Cambodia, specific to garment industries. Chapter 3 presents information about the garment industry in Cambodia and its energy intensity. It also covers the garment industry's economic importance and its impact on the environment, emphasizing how much of the impact comes from consumption patterns. Chapter 4 highlights energy conservation opportunities in garment industries, categorizing cost-saving measures into low/no-cost, medium-cost, and high-cost energy consumption measures and investments. It also estimates the GHG emissions and the potential for emission reduction from energy and resource-saving measures. Chapter 5 emphasizes the lessons learned from the energy audit exercise conducted across 50 garment factories. Chapter 6 lists recommendations for the implementation of energy audit measures.

2. Sustainable Energy Policy Landscape in Cambodia

Policy and regulation are the foremost prerequisite to create an enabling environment for any sector. Policy instruments facilitate a basis and motivation for the stakeholders to undertake sustainable energy measures by creating a win-win situation for all. Therefore, in Cambodia where sustainable energy specifically energy efficiency is not a common practice despite high electricity cost, policy measures would play a vital role by reducing the cost of energy for the end uses and helping government to accelerate access to energy.

2.1. Cross Cutting Policy

Existing cross cutting policy initiatives, and policy instruments around energy sector are highlighted in Table 2.1.

Table 2.1. Cross cutting policies, policy instruments, and policy initatives.

Instrument/Policy/Initative	Description	Relevance to Energy, Industry, and Finance
Rectangular Strategy IV	The Rectangular Strategy sets out to guide the implementation of the agenda of the Royal Government and selects key elements from the Millennium Development Goals (MDGs), the Cambodia Socio-Economic Development Program, the Cambodia National Poverty Reduction Strategy, and the various policies, strategies, plans and other important reform programs.	Electricity is mentioned as one of the four priority areas. • Rectangle 2- includes improvement of energy, Fourth Industrial Revolution and financial sector. This identifies high electricity costs, limited reliability, and low renewable energy as challenges. • Rectangle 3- recognizes the contribution of SME sector to country's economy. It suggests development and implementation of Small and Medium Enterprises Development Policy, SME Bank, "National Entrepreneurship Fund" and "Entrepreneurship Development Center". • Rectangle 4- mentions about achieving development goals, addressing climate change and formulation of "National Strategic Plan on Green Growth 2013-2030".

Instrument/Policy/Initative	Description	Relevance to Energy, Industry, and Finance
Pentagonal Strategy - Phase I	The Royal Government of Cambodia (RGC) of the 7th Legislature of the National Assembly has launched the Pentagonal Strategy-Phase I. The Strategy is founded on 5 strategic objectives including Growth, Employment, Equity, Efficiency and Sustainability. This was adopted in August 2023.	One of the key strategic objectives is ensuing sustainable socio-economic development and building resilience to climate change. This also emphasizes green financing, including climate-resilient and low-carbon public investment to respond to climate change challenges.
Cambodian Sustainable Developmen Goals (CSDGs) Framework (2016-2030)	The CSDG framework (2016-2030) is localized to the national context of the global SDGs 2016-2030. The CSDGs, along with socioeconomic platform of the Government, provides national goals, targets and indicators based on Cambodia's priorities for policymakers across different sectors and for cross-sectoral collaboration.	In the CSDG framework 2016-2030, the government's target is to ensure access to affordable, reliable, sustainable, and modern energy for all, including increasing the proportion of renewable energy in total final energy consumption to 5,066.2 Mtoe by 2030—more than double the baseline from 2015. Also, increasing the access to the primary reliance on clean fuels and technology for 40,000 people by 2030 in addition to the current 6.16 million people, increase number of population access to electricity 13.16 million people. Promote inclusive and sustainable industrialization and, by 2030, raise industry's share of employment from the current 10% (baseline in 2016) to 25% (the proportion of employment in the manufacturing sector) of the total employment.

Instrument/Policy/Initative	Description	Relevance to Energy, Industry, and Finance
National Strategic Development Plan (2019-2023)	National Strategic Development Plan ("NSDP 2019-2023") is the roadmap for the implementation of the Political Platforms of the Royal Government as well as the Rectangular Strategy. The NSDP provides identification of the priorities, indicators and timeframe for the implementation and with the identification of mechanism for monitoring and evaluation of the Result Framework, especially setting responsibility of the line ministries and agencies within each angle to achieve the Cambodia Visions 2030 and 2050. The NSDP attempts to transform Cambodia to become a higher-middle income country by 2030.	NSDP (2019-2023) discusses economic diversification covering reduction of electricity tariff, preparedness for the industrial revolution, the private sector development and employment; and inclusive and sustainable development.
National Policy on Green Growth (2013) & National Strategic Plan on Green Growth 2013-2030 (2013a)	Balance economic development with environment, society, culture, and sustainable use of national resources through integration, matching and adaption.	The Strategic Plan provides action plans including: • Attracting green investors • Promotion of renewable energy • Energy saving and efficiency • Mainstreaming of green growth into the financial banking and economic systems • Green certification program for the private sector.
Resource Efficiency and Cleaner Production Strategy (RECP) and Action Plan for Industry and SME Sectors 2021-2030	MISTI adopted the strategy in 2021. The objective is to depict the strategic direction and set the roadmap of actions for implementing RECP in the industrial sector of Cambodia. This includes following three strategic objectives:	Out of 12 RECP actions 5 are directly related to Sustainable Energy: • Develop regulations for voluntary self-reporting of industrial data

Instrument/Policy/Initative	Description	Relevance to Energy, Industry, and Finance
	1. Strengthen regulations, standards, and data reporting 2. Support scalable RECP program delivery models 3. Promote innovation, entrepreneurship, and enhanced capacity to undertake RECP implementation	• Establish S&L guidelines and MEPS for industrial equipment, followed by regulations to support the planning, development, and implementation of Eco -labelling • Program based support for transformation of Industrial Zones (located in SEZ's) into eco - industrial parks • Develop an ESCO incubation facility • Develop Green Industry Awards for Industry and SME in Cambodia
Environment and Natural Resources Code	The Royal Kram (Royal Code) on Environment and Natural Resources (code) have been adopted in 2023 to modernize, strengthen and improve the management of environmental protection, conservation and restoration of the natural resources, biodiversity and ecosystem functions for Cambodia's sustainability. The code aims to implement all activities related environment and natural resources in well managed and sustainable way in the Kingdom of Cambodia.	This covers energy, financial condition and mobilization related the implementations to reduce GHG by: • Promoting and enhance energy efficiency • Promoting and developing renewable energy usage • Mobilizing climate financing and related fund • Strengthening capacity building of technical skill and organization management to respond to the climate change • Awareness rising in public for the climate change • Completing the financial demand by using mobilizing local or international sources related to the climate change adaptation and mitigation

2.2. Sustainable Energy Policy Tools

Various Cambodian policies are in place to deal with Sustainable Energy, particularly in the Garment (Industrial) sector, highlighted in Table 2.2.

Table 2.2. EE related policies, policy instruments, and policy initiatives.

Instrument or Policy	Description	Relevance to Energy and Industrial Sector
National Energy Efficiency Policy	The Royal Government of Cambodia (RGC) has recently adopted the National Energy Efficiency Policy (NEEP) led by Ministry of Mines and Energy in September 2022. The NEEP has a target to reduce 20% of energy consumption by the industrial sector. The NEEP also provides an action plan to achieve energy efficiency targets and the Switch Garment project aligns closely with the actions designed for the industrial sector. The successful implementation of NEEP is now critical, and requires the issuance of respective sub-decrees. The MME is already working on standards and labelling as well as certification of energy auditors. Other development partners are also looking for possible cooperation with the MME in implementation of other key action points as stipulated in the NEEP. The EU-Switch Garment energy audits will help implementation of the NEEP action plan, primarily with baseline data for rolling out energy management program.	The following NEEP actions will impact Cambodian garment industries directly in going green: • Establishing an energy management program for industries and buildings • Developing regulations to enforce compliance by industries and buildings with mandatory provisions of the energy management program • Establishing a system for the empanelment and rating of ESCOs • Developing MRV systems for industrial and building energy efficiency technologies with high energy saving potential • Standards and Labelling (S&L) for household appliances and cookstoves, building and industrial equipment and regulations to enforce "Minimum Energy Performance Standards" (MEPS) • Implementing training program with Certification for energy auditors.
Power Development Plan (PDP) 2040	The Royal Government of Cambodia aims to enhance energy security at reasonable costs. Along with the NEEP the government has also launched the Power Development Plan (PDP) 2040.	The PDP was prepared based on the analysis of different scenarios. Finally, PDP decides to have an energy mix comprising of conventional energy sources as well as renewable energy generation topped up with implementation of energy saving under NEEP. PDP expects an energy mix of 40.4% coal, 27.7% hydro, 8.7% of fuel Oil, 17.9% of solar, 3.6% of battery storage and 1.7% of biomass in 2030.

<table>
<tr><th>Instrument or Policy</th><th colspan="3">Description</th></tr>
<tr><td rowspan="8">Guidelines on Solar Rooftop</td><td colspan="3">The RGC published a regulation in January 2018 stipulating the general conditions for connecting solar PV generation sources to grid, which included some limitations on installation of solar PV. This created some barriers in scaling up solar installations, particularly in the garment industries. In April 2023, the MME revised the solar policy, addressing some of the pre-existing barriers. However, as this report is being drafted, few of the terms and conditions of the new solar policies are waiting for further clarification. Below is a comparative analysis of previous and existing solar guidelines:</td></tr>
<tr><th>Category</th><th>Guideline 2018</th><th>Guideline 2023</th></tr>
<tr><td>Prakas</td><td>General Conditions for connecting Solar PV Generation Sources to the Electricity Supply System of National Grid or to The Electrical System of a Consumer connected to the Electricity Supply System of National Grid</td><td>Principles for Permitting the Use of Rooftop Solar Power in Cambodia</td></tr>
<tr><td>Off-grid systems</td><td>Not subject to any regulation</td><td>Requires approval</td></tr>
<tr><td>Grid-connected systems</td><td>Requires approval</td><td>Requires approval</td></tr>
<tr><td>Installed capacity</td><td>The solar capacity of a grid-connected system cannot exceed 50% of EDC contract capacity of the facility</td><td>No limitation</td></tr>
<tr><td>Consumer level</td><td>Low-voltage facilities i.e. residential sector are not allowed to have a grid-connected system</td><td>No restrictions</td></tr>
<tr><td>Capacity Charge (Grid connected solar roof-top systems are subject to a fee i.e. USD 5/kW/month of factory contracted capacity)</td><td>All medium voltage and high voltage connected consumers will be subject to the capacity charge</td><td>A consumer with PV system will have to pay a compensation tariff which will compensate the economic benefit expected from the solar system. Extent of compensation will depend on two factors i.e. cost of solar generation per kWh and line loss, both to be decided by EAC in every 6 months or 1 year.</td></tr>
</table>

	Category	Guideline 2018	Guideline 2023
	Third-Party Ownership Models (PPAs)	Not allowed	Not allowed
	Leasing Model	Not forbidden	Long-term contracts/ arrangements not allowed
	Quota System	Not mentioned	Newly introduced. There will be national, zonal and provincial limit of solar installation.
	Solar PV installer license	Not required	License required
	The new solar policy provides more clarity and addresses the barrier associated with the installation limit of 50% of total sanctioned load i.e. a factory could only install solar with AC capacity not more than 50% of total sanctioned load. It also removes the capacity charge while introducing a compensation tariff. The lower the compensation tariff, the greater the benefit for consumers. The MME is expected to clarify the compensation tariff in detail in the near future. Therefore, garment factories will be more interested in installing solar systems if the compensation tariff is on the lower side.		

Instrument or Policy	Description	Relevance to Energy and Industrial Sector
Basic Energy Plan for Cambodia (BEPC)	The BEPC states numerical and achievable targets. It covers six energy fields: (i) oil, (ii) electricity supply, (iii) renewable energy, (iv) energy efficiency, (v) energy security, and (vi) the energy outlook. Basic principles: • Affordability • Accessibility • Security (sustainable security) • Safety • Transparency of the market	The projected total demand for the industry sector by 2030 under various scenarios: • Business as Usual (BAU) - 1.45 Mtoe at 2.3% • Alternative Policy Scenario (APS) - 1.29 Mtoe at 1.5% • Energy Efficiency Framework (EEF) - 1.24 Mtoe at 1.2%. The BEPC also suggests short term, medium term and long term strategies and measures to enhance energy efficiency across sectors.
Industrial Development Policy 2015-2025	The IDP provides guidance to enhance industrial sector development, which will contribute to maintaining sustainable and inclusive economic growth through economic diversification, strengthening competitiveness and increasing productivity. The IDP intends to promote, transform, and modernize Cambodia industrial structure from labor-intensive industry to a skill-based industry by 2025.	IDP sets a target to increase GDP by 30% by 2025 from industrial sector. Developing and modernizing SMEs by strengthening of the management mechanism and by promoting their official registration.

Instrument or Policy	Description	Relevance to Energy and Industrial Sector
The updated NDC (2020)	The updated NDC for Cambodia presents the government's commitments and needs for the next decade (2020 to 2030), in order to realize the vision of a low carbon and resilient society. The estimated GHG emission reduction target by 2030 under the NDC scenario is approximately 64.6 MtCO2e/year (41.7% reduction compared to BAU scenario, of which 59.1% is from the Forest and Other Land Use (FOLU) sector. The share of distribution of the planned emission reductions under the NDC scenario among different sectors: 59.1% from FOLU, 21.3% from Energy, 9.6% from Agriculture, 9.1% from Industry (IPPU), 0.9% from Waste.	The contribution of the Industrial sector (IPPU) for GHG emission reduction is 5.9 MtCO2e (9.1%) of the overall 64.6 MtCO2e, under the 2030 NDC scenario. Mitigation measures from MISTI focuses on - Promote sustainable energy practices in manufacturing, Develop centralized recycling facility for industrial waste from the garment sector, Better management of industrial wastewater in the food and beverage sector. Adaptation measure from MISTI: Heat stress adaptation for industrial production. The energy sector's contribution of 13.7 MtCO2e (21.3%) to the GHG emission reduction target is also significant and closely related to the industrial sector.
Garment Sector Development Strategy	The garment sector is one of the biggest economic pillars of the Royal Government of Cambodia. Therefore, growth, modernization and expansion are vital for the country's economic growth. The Ministry of Economy and Finance has thus launched the Cambodia garment, footwear and travel goods sector development strategy for 2022-2027 (1). The plan targets to enhance and diversify high-value products while also improving the skills of factory workers. Hence, exports have risen by 10%, i.e. $ 8.83 billion for these goods according to the Textile, Apparel, Footwear & Travel Goods Association in Cambodia (TAFTAC). This six years development strategy is essential to cater to changing global and domestic scenarios. Efforts to enhance local and foreign investments in this sector will be followed aggressively to expand and improve the quality of the goods.	This strategy envisions to further developing the garment, footwear and travel goods to the next level by focusing on energy and environment sustainability while maintaining quality and competitiveness. The plan aims to encourage and promote the use of renewable energy with energy efficiency.

2.3. Ban on Burning Garment Waste in Boilers

The Cambodian textile, garment, and footwear industry produces 140,000 tonnes of textile waste per year, most of which is burned or disposed of in landfills [2]. In some cases, it has been used as fuel in factories or brick kilns [3]. The smoke from burning waste releases toxic fumes, negatively impacting both human health and the environment. The waste includes labels, footwear, and textile scraps, which are used as fuel. Furthermore, an increase in wood costs has led to the use of garment waste alongside wood. An estimate of these costs suggested that a truckload of garment waste for fuel costs only $100, while a similar truckload of wood is more expensive, costing around $1,000 to $1,500 [4].

The Cambodia Environment and Natural Resources Code was promulgated and signed by His Majesty King Norodom Sihamoni on 29 June 2023. The code aims to strengthen and improve the management, protection, conservation, and restoration of the country's natural resources, in line with the development context of Cambodian society. It includes legislation to impose fines for the violation of dumping waste in landfills and burning solid waste, with penalties of up to five years of imprisonment and a $24,000 fine [5].

Measures to mitigate this problem have been implemented by imposing a 'digital product passport,' which involves sharing the product life cycle through the Extended Producer Responsibility (EPR) scheme [6]. In addition, a circular economy has been planned to promote centralized waste-to-energy systems to generate electricity for the grid and develop Refuse Derived Fuel (RDF) to convert waste into heat-generating steam for production [7].

Tracing suppliers of garment waste is a challenge, although ethical teams continuously monitor and conduct awareness campaigns. In this context, the circular fashion system in Cambodia's fashion industry needs to foster collaboration between manufacturers, brands, recyclers, collectors, and the government to promote circularity [8]. Waste generated from the garment sector is converted into alternative fuel (e.g., in making pallets) or value-added products. These alternative fuels can substitute wood, which will help reduce deforestation.

3. Garment Industry in Cambodia and Energy Profile

3.1. The Cambodian Garment Industry

The GFT industry plays a critical role in Cambodia's economy. The sector constituted 1.4% of global GFT product exports and USD 11 billion of the total Cambodian GFT products exported in 2023 [9]. In 2024, the sector supports roughly 925,000 jobs, mostly for women, and the livelihoods of over 2.5 to 3 million people in the country. In 2020, the garment sector was hit hard by the COVID-19 pandemic; with supply disruptions and a drop in demand led the sector to contract by 6.7%. The garment export value also dropped by 10% compared to 2019. Approximately 110 garment factories were closed, leaving 55,174 workers unemployed [10].

The EU and the USA are the largest markets for Cambodian garment exports, followed by Canada and Japan. These markets mainly cater to global international brands like Adidas, Tommy Hilfiger, and Marks & Spencer, among others. The high demand for finished garment products, Cambodia's geographical location in the center of the East-West Corridor of the Greater Mekong Sub-region, low-cost manufacturing, proximity to major world markets, and supportive government policies have boosted the garment industry in Cambodia [11]. The energy component is a major factor (after the workforce) in operational costs to enhance profitability and ensure the smooth functioning of the manufacturing units. Thus, sustainable energy-saving practices play a key role in the growth and functioning of the garment industry.

Globally, the major garment suppliers are China and India. Both countries reached their quotas under the Multi-Fiber Agreement (MFA), creating an opportunity for Cambodia's garment and wearing apparel exports. As the vast majority of Cambodia's garment factories are subcontractors and vendors, the products have low added value. Approximately three-quarters of garment exports are relatively simple, and commodities such as sweaters/pullovers, men's trousers, women's trousers, and t-shirts/singlets have fundamentally remained unchanged. Cambodia's garment production mainly depends on imported inputs, including fabric and other raw materials, mostly from China, because Cambodia's local supply chain and supporting sector for garment manufacturing are inadequate. It was observed that most garment units are in long-term leased properties, while fewer units are established as greenfield factories.

3.1.1. Cost Structure

The cost structure of the garment industry in Cambodia includes: Material 45-50%, Labor 32-38%, Energy 3%, Other Costs 10-14%, and Profit 0-12% (14). The median of these is shown in

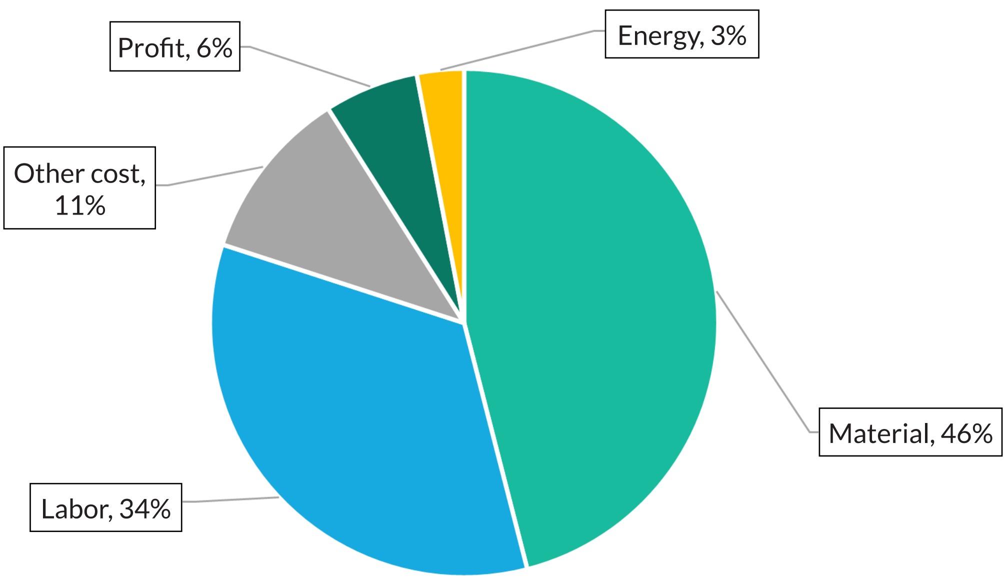


Figure 3.1. Cost structure of the garment industry in Cambodia.

Figure 3.1 below [12]. Although the share of energy costs (3%) in the overall cost structure is small, compared to other countries in the region, energy costs are higher in Cambodia. With moderate infrastructure, the production costs of Cambodian factories remain high, along with longer production lead times.

3.1.2. The Values Chain

The garment value chain in Cambodia consists mainly of five stages as follows:

- The first stage involves the supply of raw materials, which includes both natural and synthetic fibers.

- In the second stage, these raw materials are converted into yarns and fabrics, which become the main components for garment production.

- In the third stage, garment production takes place. It mainly involves two types of production: CMT (cut-make-trim) and full-package. CMT production units are primarily assemblers, while full-package units are highly developed with advanced technology, research, and design capabilities.

- In the fourth stage, the products from these units are sent to branded apparel companies via export link channels.

- In the fifth stage, distribution is carried out to retail and factory outlets, exporters, importers, and traders within the garment value chain, focusing on ensuring final quality and delivering the products to global buyers.

3.2. Profile of Switch Garment Member Factories

The EU-Switch Garment member factories encompass various categories within the garment sector, featuring either single or multiple product lines, as depicted in Figure 3.2.

The garment sector workforce is predominantly female, as shown in Figure 3.3. According to the statistics for the audited garment units, approximately 82% of the workforce is female, while male employees account for only 18%.

Figure 3.2. Number of factories based on their production type.

Note: some factories may produce more than one product.

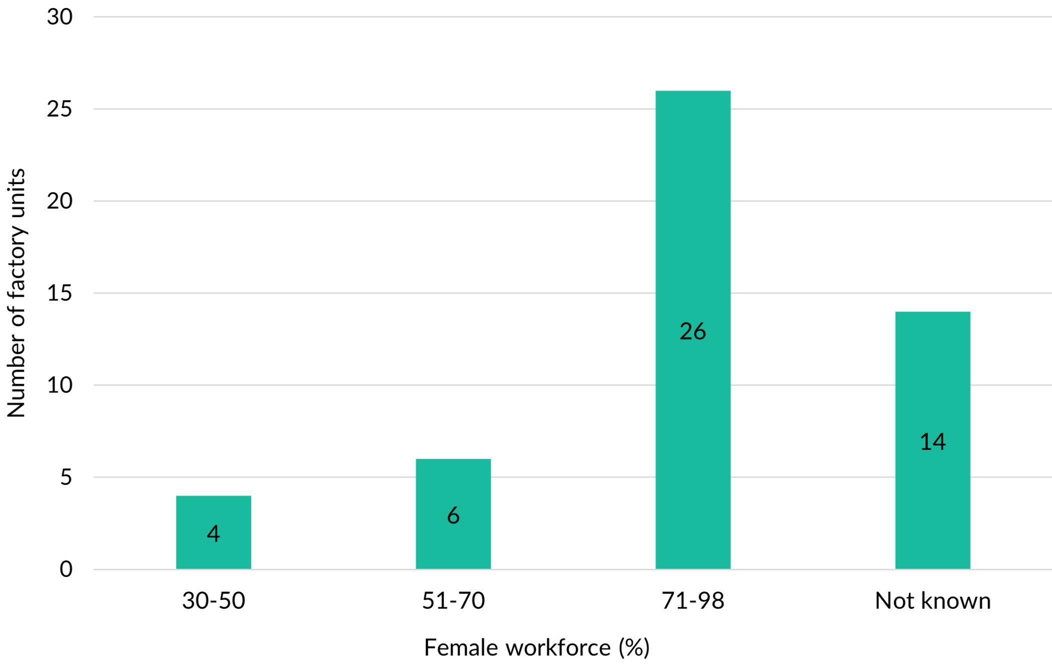


Figure 3.3. Female workforce in audited garment manufacturing units.

3.3. Need for Sustainable Energy

The garment sector is often reluctant to embrace technical innovations, as the business model still primarily depends on cheap labor. However, automated sewing and cutting machines are being utilized in Cambodia's garment manufacturing. These machines are capable of continuously sewing garments with minimal human intervention. Several factories connected to the global value chain and serving large international retailers have upgraded their technology by incorporating new automated machinery into their manufacturing units. For the remaining factories, upgrading technology is crucial to remain competitive within the sector, although this will result in higher energy demand. Therefore, adopting sustainable energy interventions, such as solar PV and energy efficiency measures, is essential.

The age of the factory is an important factor that also indicates the need for sustainable energy interventions. Table 3.1 presents the classification of Switch Garment factories based on their year of establishment:

Table 3.1. Segregation of audited units based on the year of establishment.

SN	Year	Number garment factories
1	Before 2000	2
2	From 2001 to 2009	9
3	From 2010 to 2022	39

Garment units that have been established for more than twenty years have grown into larger operations. However, these units experience significant distribution losses, which can be minimized by implementing various energy efficiency measures, such as replacing insulation materials.

For units older than fifteen years, compressed air leakages are common and should be addressed. Additionally, replacing motors with energy-efficient models and installing solar-powered outdoor lighting can further reduce energy costs. Regardless of the factory's age, incorporating solar PV systems can lead to substantial energy savings and a lower carbon footprint.

3.4. Energy Consumption and Emission Profile

Energy Profile: GFT industries primarily rely on electricity, diesel, and wood as their energy sources. Some industries also use LPG, mainly for dormitory cooking purposes. The number of industries using each type of energy source is shown in Figure 3.4.

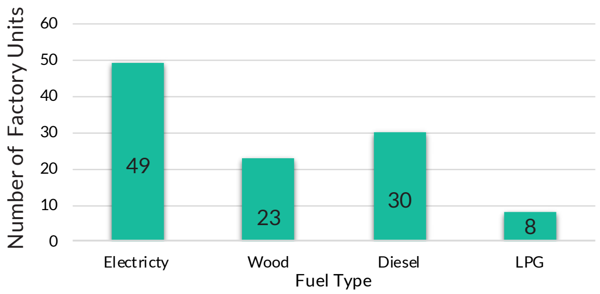


Figure 3.4. Number of industries with their energy sources.

As shown in Figure 3.4, electricity is the primary energy source for garment industries, with 49 (98%) of them relying on it, followed by wood (including pellets) at 23 (46%). Electricity is mainly used to operate process and auxiliary equipment, while wood is used in boilers to generate steam. In addition to electricity and wood, 30 (60%) of industries also use diesel, primarily to power backup generators and forklifts, although the annual diesel consumption is quite low. Around 10 industries use LPG, mainly for cooking in employee quarters. One factory has a unique energy profile compared to the others. This factory has installed a co-generation facility to meet its electricity and heat demand, with diesel generators serving as a backup. The co-generation system is biomass-based, making wood the primary energy source for this factory, which sets it apart from the other factories. Therefore, the energy profile and GHG emission reduction of this factory (referred to as #50 factory) will be analyzed separately in this report. The energy mix of the remaining 49 industries is shown in Figure 3.5.

The total energy consumption of all 49 industries is around 20,009 toe/year. The #50 factory has itself 18,889 toe/year energy consumption largely coming from wood.

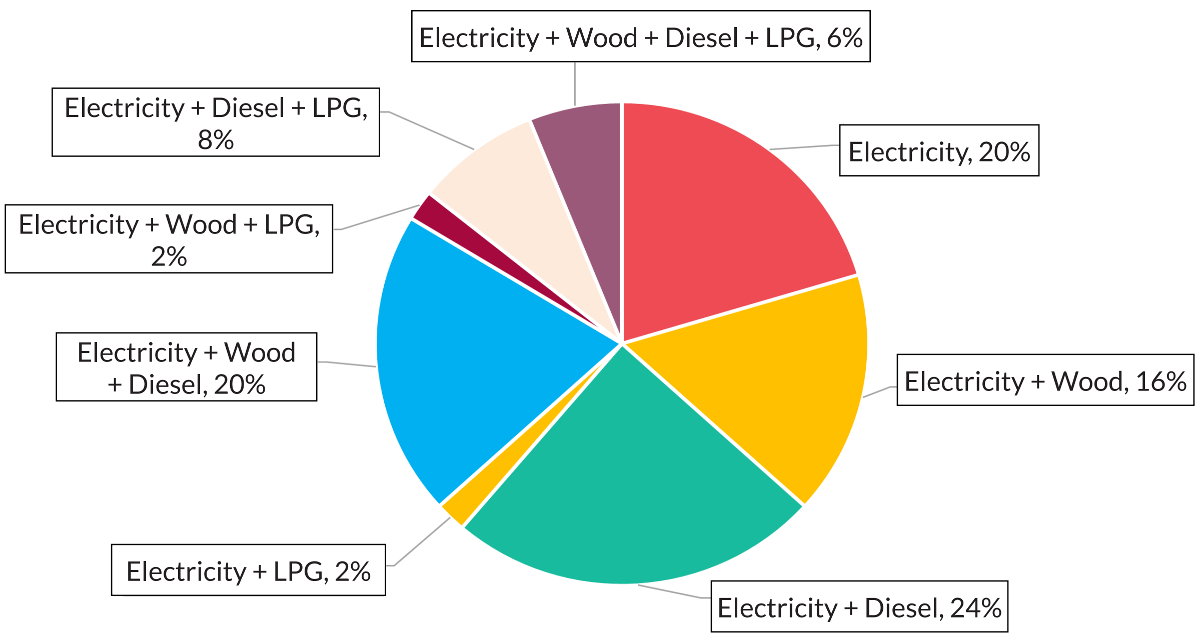


Figure 3.5. Industry-wise energy mix (49 factory units).

Energy from wood accounts for up to 68% of the total energy usage, approximately 13,609 toe/year. As shown in Figure 3.6, electricity is the second-largest source, making up 28% of the total (5,590 toe/year), followed by diesel, which constitutes 4% (719 toe/year) of the energy share.

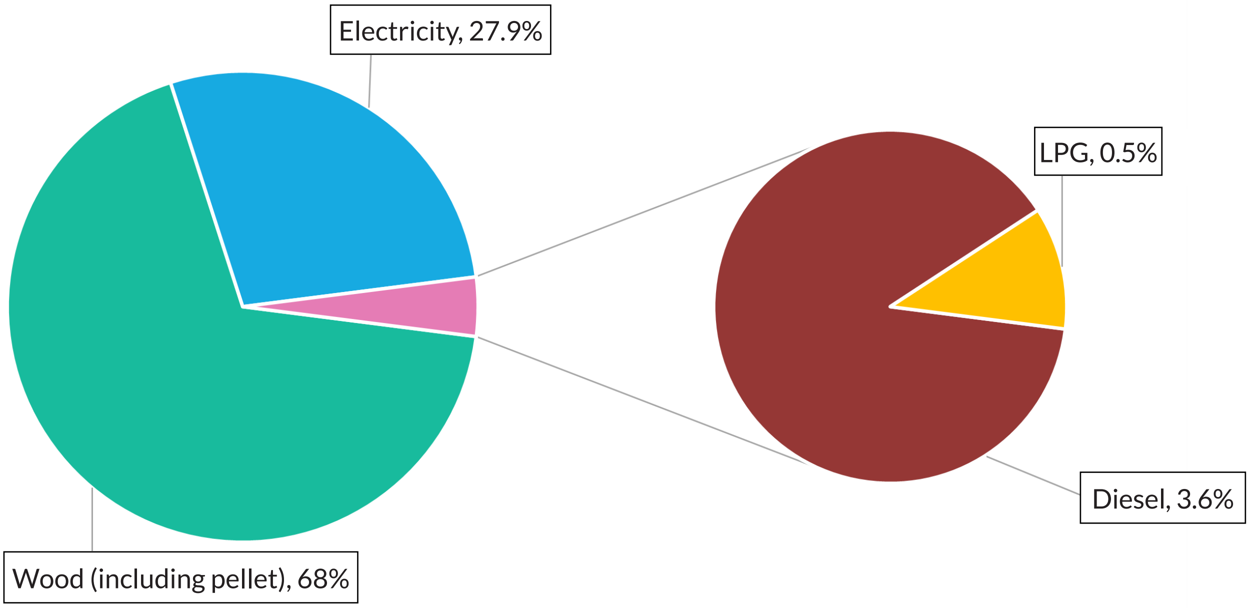


Figure 3.6. Fuel-wise energy mix.

To have a better understanding of industry-wise energy consumption, all the audited industries are divided into three categories based on annual production:

1. Low production (0 to 2 million pieces),

2. Medium production (2 to 5 million pieces) and

3. High production industries (above 5 million pieces).

Table 3.2 below shows the number of industries in each category.

Table 3.2. Categorization of industries.

	Low Production	Medium Production	High Production
No's of industries	11	10	22
Annual Production (million pieces)	0 - 2	2 - 5	Above 5

Note: Two industries reported production data in kg and five industries have not shared production data.

Annual energy consumption depends on factors such as the type of products, fuel mix, capacity utilization, and the operating efficiency of the equipment. For instance, in fabric printing industries, while annual production i.e. number of pieces may be high, the total energy consumption might be relatively low.

Emission Profile: A recent study estimates that the fibers, textiles, apparel, and garment sector contribute nearly 8% of global greenhouse gas (GHG) emissions [13]. Therefore, it is crucial to reduce GHG emissions and improve productivity while promoting environmentally friendly practices in Cambodia's garment sector. Table 3.3 summarizes the range of GHG emissions.

Table 3.3. GHG emissions range from audited factories.

Consumption in toe	No's of industries	Range of GHG emission (tCO2/year)
5 - 100	18	37 - 743
100-500	17	434.3 - 2457
500 - 1000	8	1922 - 3013.5
1000 - 5000	6	3629 - 11909
>5000	1	52131

Eighteen of the audited garment industries reported lower energy consumption (ranging from 5 to 100 toe), which corresponded to lower GHG emissions. As energy consumption exceeded 100 toe, annual GHG emissions increased to over 2,000 tCO2/year. Therefore, reducing energy consumption can help lower GHG emissions. This can be achieved by adopting a hybrid energy mix that includes renewable energy alternatives, which will not only enhance energy savings but also contribute to mitigating the effects of climate change.

The total GHG emissions for the 49 factory units amount to approximately 77,172 tCO2/year. As given in Figure 3.7, emissions from electricity account for 55% of the total GHG emissions, approximately 42,221 tCO2/year. Emissions from wood come second, constituting 42% of the total (32,637 tCO2/year), followed by diesel, which contributes less than 3% (2,073 tCO2/year). The emission coming from #50 factory is 43,441 tCO2/year which is mainly contributed by the consumption of wood for their co-generation facility.

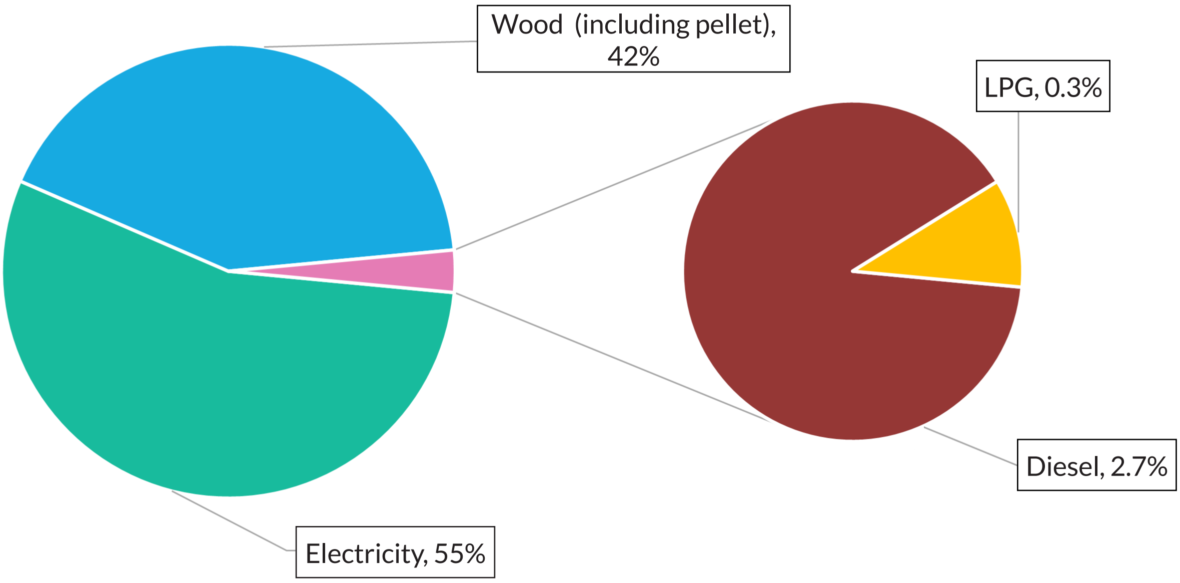


Figure 3.7. Fuel wise share of GHG emissions (49 factory units).

It has been observed that the fuel mix significantly impacts GHG emissions. Industries that consume more wood tend to produce higher emissions. GHG emissions from electricity can be notably reduced by installing rooftop solar PV systems. GHG emissions based on industry category are given in Table 3.4.

Table 3.4. Category-wise annual GHG emissions.

	Low Production		Medium Production		High Production	
GHG Emission (tCO_2/year)	Min	Max	Min	Max	Min	Max
	37	3,014	269	4,662	277	2,066

4. Energy Saving Potential in Garment Industry

This section discusses the overall findings of the energy audits.

4.1. Summary of Energy Efficiency and Emission Reduction Potential

Energy Efficiency Measures (EEMs) are recommended following a thorough assessment that includes site visit observations, operating parameters, technical specifications of equipment, energy-saving potential, and applicability, all determined through a cost-benefit analysis. The EEMs are categorized into three groups based on the investment required to implement such measures (estimated equipment cost):

1. Low cost (up to 5,000 USD),
2. Medium cost (5,000 – 20,000 USD) and
3. High cost (above 20,000 USD).

During the field visit, information regarding the connected load of the industry, the type and annual consumption of fuels, the list of installed equipment, technical details of the equipment, running hours, operating parameters, and annual production were collected. In order to monitor any seasonal or monthly variations in electricity consumption, monthly electricity bills for three years were also collected.

Annual energy-saving potential is calculated based on the operating conditions observed during the field visit. Accordingly, the investment required to implement the proposed measures, and the payback period are also calculated. The total identified energy-saving potential in Switch Garment member industries is 2,550 toe/year, which represents 12.74% of the total energy used in the audited industries. By implementing the identified energy efficiency measures, GHG emissions will be reduced by 17%, or 13,141 tCO2/year. The fuel-wise energy-saving potential is provided in Table 4.1.

Table 4.1. Fuel-wise energy saving potential.

Electricity Saving*		Wood Saving#		Total Energy Saving Potential
kWh/year	toe/year	MT/year	toe/year	toe/year
15,646,196	1,346	2,708	1,204	2,550

*Including electricity generation from rooftop solar PV. #Including Pellets.

Categorization of energy-saving potential based on investment (equipment cost) required to implement the measure is given in Table 4.2.

Table 4.2. Categorization of energy saving potential based on investment required.

	Unit	Low-Cost Measures	Medium-Cost Measures	High-Cost Measures*	Total
Electricity Saving Potential	kWh/year	1,629,065	1,376,020	12,641,111	15,646,196
	toe/year	140	118	1,087	1,346
Wood Saving Potential	MT/year	1,761	748	97	2,708
	toe/year	829	333	43	1,204
Total Energy Saving Potential	toe/year	969	451	1,130	2,550
Total GHG Reduction Potential	tCO2/year	3,077	1,653	8,410	13,141

*Including electricity generation from rooftop solar PV plant.

Approximately 38% of the identified energy savings can be achieved by implementing low-cost measures, which either have an immediate payback period or a payback within 2 years. The implementation of medium-cost measures, with a payback period between 2 to 5 years, can save around 18% of energy. The remaining 44% of the identified energy savings can be achieved by implementing high-cost measures, with a payback period of around 8 years.

High-cost measures account for 63% of the total GHG reduction potential, followed by low-cost measures and medium-cost measures. The pie chart showing GHG reduction potential based on the required investment is shown in Figure 4.1.

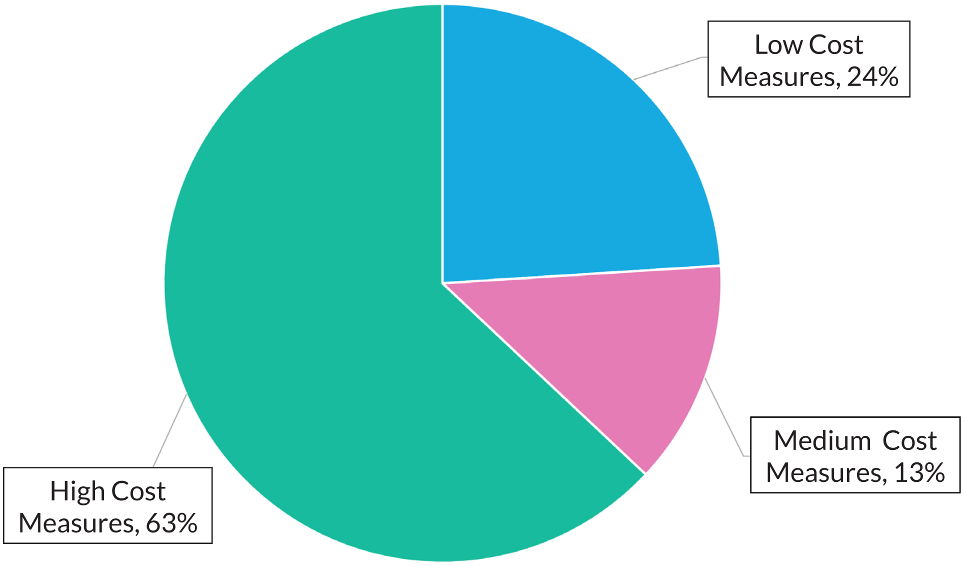


Figure 4.1 GHG reduction potential based on investment required.

Note - Since, installation of rooftop solar PV system requires high investment cost due to which GHG reduction potential is more by implementing high-cost measure.

The energy efficiency measures with the highest potential for energy savings, which can be implemented in the majority of industries, are detailed in the following subsections.

4.2. Details of Energy Efficiency and Emission Reduction Potential

4.2.1. Lighting Systems

1. Replacement of conventional lamps with energy efficient LED lamps

Observation – Few of the industries are using T5 or T8 Fluorescent Tube Lamps (FTL) in production and packaging area. The rated wattage of these FTLs varies from 14W to 36W.

Recommendation – It is recommended to replace the existing FTLs with energy efficient LED tube lights.

Energy Saving Potential – Replacing FTL with energy-efficient LED lights can reduce lighting energy consumption by approximately 30-35%.

FTL Rated Wattage	Equivalent LED Wattage
14W	9W
28W	18W
36W	22W

In addition to the energy savings, LED lights also offer longer operational lifespans, and a higher color rendering index compared to FTL.

Cost Benefit Analysis – The cost of the LED tube lights varies from 3 to 8 USD per lamp depending on the rated wattage. The payback period depends on the daily operating hours, ranging from 6 months to 1.5 years.

Energy efficiency measure		Replace conventional fluorescent tube lights with energy efficient LED tube light
Number of times recommended		15
Total electricty saving potential	kWh/year	512,916
	toe/year	44.1
Total GHG emisison reduction potential (tCO2/year)		333.3

2. Installation of tubular skylights

Observation – During the field visit, it was observed that in most factories, roof-hanging lights were kept 'ON' continuously during the daytime, especially in the warehouses and packing areas. The lighting requirement in these sections is minimal due to the nature of the work and location. Therefore, there is a significant potential to save energy during the daytime by utilizing natural light and reducing the use of the current artificial lighting.

Recommendation – It is recommended to install tubular skylights in these areas to reduce the use of artificial lighting during the daytime. The advantage of tubular skylights is that they allow daylight without causing glare or heat. This will help utilize daylight without increasing the room temperature. Additionally, tubular skylights can be installed alongside a solar rooftop system with necessary modifications.

Energy Saving Potential – Energy savings depend on the number of lights switched off during the daytime after installing the tubular skylights. Daily energy savings can be calculated by multiplying the total wattage of the lights switched off by the total operating hours during the daytime.

Cost Benefit Analysis – The cost of a tubular skylight is approximately 1,500 USD per piece. Multiple skylights can be installed to cover the entire area. The payback period for installing tubular skylights is generally high, ranging from 4 to 15 years.

Energy efficiency measure		Installation of tubular skylight
Number of times recommended		18
Total electricty saving potential	kWh/year	192,347
	toe/year	16.5
Total GHG emisison reduction potential (tCO2/year)		125.0

4.2.2. Compressed Air Systems

1. Arresting compressed air leakage

Observation – A compressed air leakage test was conducted in all the industries. In some industries, a large quantity of compressed air leakage was observed at different junction points, instrument regulator valves, and supply valves in the distribution network. Compressed air leakage can lead to several operational issues, including:

- Fluctuating system pressure, which can affect the functional efficiency of air tools and other air-operated equipment, potentially impacting productivity.
- Excess compressor capacity, leading to higher operating costs.
- Reduced service life and increased maintenance requirements (including for the compressor package) due to unnecessary cycling and increased operating hours.

Although leakages can occur in any part of the compressed air distribution system, the most common areas are couplings, hoses, fittings, pipe joints, quick disconnects, FRLs (filter, regulator, and lubricator), condensate traps, valves, flanges, packing, thread sealants, and points of use for pneumatic devices. The leakage rate is influenced by the supply pressure in an uncontrolled system and increases with higher system pressures. Leakage rates are also proportional to the square of the orifice diameter.

Recommendation – It is recommended to address air leakage by installing suitable application -specific nozzles, adopting appropriate periodic maintenance practices, and conducting regular inspections of the distribution network. The permissible leakage limit is about 10% of the total compressed air generated.

Energy Saving Potential – Energy savings directly depend on the percentage reduction in compressed air leakage and the specific power consumption of the compressor (kW/m^3/min).

Cost Benefit Analysis – The cost of addressing air leakage depends on the work required to repair the leaks. However, in general, the cost of fixing air leakage is rel atively low (~500 USD), and the payback period is typically less than a year.

Energy efficiency measure		Arresting compressed air leakage
Number of times recommended		30
Total electricty saving potential	kWh/year	821,755
	toe/year	70.6
Total GHG emisison reduction potential (tCO2/year)		534.1

2. Installation of variable frequency drive for air compressor

Observation – All industries have installed air compressors to meet both service and instrument air requirements. During the site visit, it was observed that in some industries, the unloading time of the air compressors is more than 40%. During unloading, the compressor does not deliver air, but the motor consumes power (~30% of the load power). The unloading power consumption of the compressor can be reduced by installing a Variable Frequency Drive (VFD).

Recommendation – It is recommended to install a VFD to reduce the unloading power consumption of the compressor. The VFD will regulate the air compressor motor based on the pressure requirement in the receiver tank, thereby minimizing unloading power by bringing the motor to a halt.

Energy Saving Potential – Energy saving by installing VFD will depends on loading and unloading time of air compressor. If the unloading time of air compressor is more, energy saving will also be more and vice-versa. It has been observed that, in general there would be a 3 to 7% energy saving by installing VFD for air compressor.

Cost Benefit Analysis – The cost of installing a VFD depends on the rated power of the air compressor motor. However, the estimated cost of the VFD is around 50 USD/kW, with a payback period of 2 to 5 years.

Energy efficiency measure		Install VFD for air compressor
Number of times recommended		6
Total electricty saving potential	kWh/year	83,718
	toe/year	7.2
Total GHG emisison reduction potential (tCO2/year)		54.4

3. Optimise the pressure setting of the air compressor

Observation – Garment industries require compressed air at 4–5 bar. However, during the field visit, it was observed that in a few factories, the set pressure of the air compressor was around 7–8 bar. This high-pressure setting is primarily due to air leakages, which cause a pressure drop across the air distribution line.

Recommendation – It is recommended to set the pressure of the air compressor at 4-5 bar.

Energy Saving Potential – Reducing the delivery pressure by 1 bar in a compressor can decrease power consumption by 6–10%.

Cost Benefit Analysis – The cost to implement the measure is zero and payback will come immediately.

Energy efficiency measure		Optimise the pressure setting of the air compressor
Number of times recommended		17
Total electricty saving potential	kWh/year	99,043
	toe/year	8.51
Total GHG emisison reduction potential (tCO2/year)		64.37

4. Installation of auto drain valve for air compressor

Observation – During the field visit, it was found that most industries did not have automatic drain valves installed for compressed air receiver tanks. In some cases, automatic drain valves were installed but were not functioning properly. As a result, factory personnel manually drained the receiver tank before starting the compressors. However, after a few hours of compressor operation, the receiver tank would fill with condensate. This reduces the available volume of the receiver tank, leading to more frequent loading cycles and increased power consumption. Additionally, the water from the receiver tank carries forward to the dryer, increasing the dryer load.

Recommendation – It is recommended to install automatic drain valves for air receiver tanks. Automatic drain valves promptly remove water condensate, reduce the load on the air dryer, and lower the energy consumption of the air compressor.

Energy Saving Potential – Installing automatic drain valves has the potential to reduce annual energy consumption by 1–2%.

Cost Benefit Analysis – The cost of an automatic drain valve is approximately 150 USD per piece, with a payback period of less than one year.

Energy efficiency measure		Installation of auto drain valve for air compressor
Number of times recommended		10
Total electricty saving potential	kWh/year	20,278
	toe/year	1.74
Total GHG emisison reduction potential (tCO2/year)		13.18

4.2.3. Boiler System

1. Insulate boiler surface and steam distribution & condensate return line

Observation – In some factories, steam distribution and condensate return pipelines, flanges, and valves were not insulated. Additionally, in certain industries, the insulation on boiler surfaces and steam main headers was observed to be old and in need of replacement.

Uninsulated steam distribution and condensate return lines are a continuous source of energy loss. Proper insulation can reduce radiation losses by up to 90% and help maintain adequate steam pressure for plant equipment. Ideally, any surface with a temperature exceeding 50°C should be insulated, including boiler surfaces, steam and condensate return piping, and associated fittings. Insulation often becomes damaged or is removed during steam system repairs and is not replaced.

Common areas where defective insulation was observed in most industries include:

a) Steam header.

b) Steam distribution pipes near user end.

c) Flanges & Valves.

d) Condensate return pipe and condensate recovery tank.

Recommendation – It is recommended to perform regular inspections (once a month) of the insulation on the entire boiler and steam system using an infrared thermometer (temperature gun). Any damaged insulation should be repaired or replaced promptly to minimize radiation losses.

Energy Saving Potential – Practical experience indicates that reducing the outer surface temperature of a boiler by 20°C can improve boiler efficiency by 1%, leading to a reduction in annual fuel consumption of 2–3%. However, the exact savings will depend on the operating parameters of the boiler.

Cost Benefit Analysis – The cost of insulating the surfaces of boilers, steam distribution systems, and condensate return pipes is relatively low, ranging from 40 to 60 USD per meter.

Energy efficiency measure		Insulate boiler surface and steam distribution and condesate return line
Number of times recommended		9
Total electricty saving potential	kWh/year	31
	toe/year	13.7
Total GHG emisison reduction potential (tCO2/year)		31.6

2. Installation of condensate recovery system

Observation – Most factories have installed proper networks to collect condensate from end-user points. However, in a few industries, condensate was observed to be drained into the effluent line instead of being recovered. These industries lack a condensate recovery system (tank and pump).

Recommendation – It is recommended to install a condensate recovery system, including a tank and pump. This system can significantly increase feedwater temperature, thereby reducing the fuel required to produce the same amount of steam. Additionally, since condensate is naturally clean, its recovery will minimize boiler blowdown and the associated energy loss.

Other benefits of a condensate recovery system include:

- Reducing feedwater quantity, resulting in water cost savings.
- Lowering water treatment costs (for both feedwater and wastewater).
- Minimizing blowdown heat loss, as the hot condensate requires less energy to convert into steam.

The recovered condensate can be directly fed into the boiler or mixed with the boiler's feedwater supply.

Energy Saving Potential – The energy-saving potential of a condensate recovery system depends on the quantity, temperature, and pressure of the recovered condensate. Increasing the feedwater temperature from 35°C to 75°C can save approximately 30 MT of wood annually.

Cost Benefit Analysis – The estimated cost of installing a condensate recovery system (tank and pump) is approximately 3,000 USD, with a payback period of less than 3 years.

Energy efficiency measure		Installation of condensate recovery system
Number of times recommended		12
Total electricty saving potential	kWh/year	217
	toe/year	96.5
Total GHG emisison reduction potential (tCO2/year)		221.3

3. Replace conventional damper with Inlet guide vane (IGV) for Boiler FD fan

Observation – The majority of factories use a damper control mechanism to regulate the airflow of the Forced Draft (FD) fan. In some factories, it was observed that the dampers were only 30% open, resulting in a significant pressure drop across the damper. This high pressure drop leads to increased energy consumption and, in some cases, overloading of the FD fan motor.

Recommendation – It is recommended to replace the damper control mechanism with an inlet guide vane (IGV) for the FD fan.

Energy Saving Potential – Replacing dampers with IGVs can potentially reduce energy consumption by up to 30%. However, the exact energy savings will depend on the existing pressure drop across the damper.

Cost Benefit Analysis – The estimated cost of implementing the measure is approximately 500 USD per IGV, with a payback period of 1–2 years.

Energy efficiency measure		Replace damper with IGV for boiler FD fan
Number of times recommended		5
Total electricty saving potential	kWh/year	9,029
	toe/year	0.77
Total GHG emisison reduction potential (tCO2/year)		5.86

4. Efficiency improvement of the boiler

Observation – The majority of garment factories have in-house wood-fired boilers to generate steam, primarily used for ironing and washing purposes. During the field visit, boiler efficiency was assessed based on operating parameters. It was observed that most boilers operate with very low efficiency. This is mainly due to inadequate operating practices such as fixed damper positions for ID/FD fans, the use of moist wood, damaged insulation, and the absence of condensate recovery systems.

Recommendation – The following energy efficiency measures are recommended to improve boiler operating efficiency:

a) Installation of air-fuel ratio controller to enhance combustion efficiency.

b) Reduction of excess air by installing VFDs for ID and FD fans.

c) Installation of economizer – to raise feedwater temperature.

d) Use of small, dried wood to minimize heat loss due to incomplete combustion.

e) Arresting air incursion across the boiler.

f) Relining and nano-coating the furnace area.

Energy Saving Potential – The energy savings will depend on the improvements in boiler operating efficiency. For every 1% reduction in excess air, boiler system efficiency can increase by approximately 0.06%. Additionally, raising feedwater temperature through an economizer can improve boiler efficiency by 2–3%.

Cost Benefit Analysis – The cost of implementing these energy efficiency measures, and the payback period will depend on the scope of work required to improve boiler efficiency. However, in most cases, the payback period is within 4–5 years.

Energy efficiency measure		Efficiency improvement of boiler
Number of times recommended		21
Total electricty saving potential	kWh/year	15,200
Total wood saving potential	MT/year	1,926
Total energy saving potential	toe/year	858
Total GHG emisison reduction potential (tCO2/year)		1,188

4.2.4. Ironing

1. Use foot operating switch or optical position sensor controller for suction blowers in steam ironing table

Observation – Most of the audited factories use steam ironing tables, each equipped with a 0.75- or 1.0-kW suction/vacuum blower to remove hot and humid air. A foot-operated switch is typically provided to control the operation of the suction blower. However, during the field visit, it was observed that in many factories, the foot-operated switch is bypassed for the convenience of operators, resulting in increased idle operating time for the suction blowers.

Recommendation – It is recommended to utilize the foot-operated switch or install an optical position sensor at each ironing table to prevent idle operation of suction blowers. An optical position sensor can continuously monitor the position of the ironing box on the table. If the ironing box is moved away from a designated location, the suction blower will activate automatically. Once the task is complete, the operator must place the ironing box within the optical position sensor's scanning area to deactivate the blower.

Energy Saving Potential – Using a foot-operated switch or an optical position sensor controller can reduce the operating hours of suction blowers by approximately 15–20%.

Cost Benefit Analysis – The cost of an optical position sensor is around 50 USD per controller, with a payback period of 1–2 years.

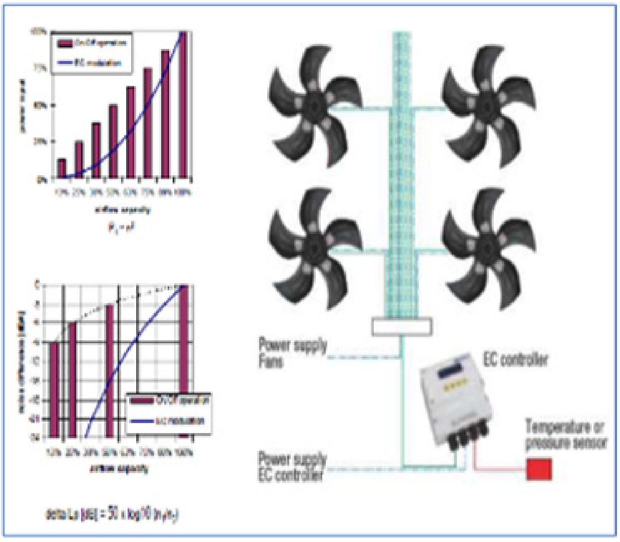
Energy efficiency measure		Use foot operating switch or optical position sensor controller for suction blowers in steam ironing table
Number of times recommended		4
Total electricty saving potential	kWh/year	61,154
	toe/year	5.25
Total GHG emisison reduction potential (tCO2/year)		39.75

4.2.5. Ventilation System

1. Replace air cooler/exhaust fans with energy efficient BLDC fan with auto-control system

Observation – The majority of factories have installed air coolers or exhaust fans for ventilation and to regulate temperature and humidity in production areas. During the audit, it was observed that exhaust fans operated without any control mechanism and ran continuously during production hours.

Recommendation – It is recommended to replace air coolers and exhaust fans with energy-efficient BLDC (Brushless DC) fans equipped with an auto-control system. The proposed auto-control system can adjust fan speed based on temperature feedback from the respective production building, ensuring optimized operation. One controller can manage up to four fans simultaneously. Additionally, BLDC fans are microprocessor-controlled, ensuring that the stator current remains in phase with the rotor's permanent magnet, resulting in lower current consumption. BLDC fans also have a significantly longer lifespan compared to conventional fans.



Energy Saving Potential – Compared to conventional exhaust fans, energy-efficient BLDC fans consume 30–40% less power while delivering the same air volume (m³/min).

Cost Benefit Analysis – The cost of a single BLDC fan is approximately 600 USD, and the associated charge controller costs around 1,000 USD. The payback period is estimated to be between 2–6 years, depending on the daily operating hours.

Energy efficiency measure		Replace air cooler/exhaust fans with energy efficient BLDC fan with auto-control system
Number of times recommended		37
Total electricty saving potential	kWh/year	1,866,362
	toe/year	160.5
Total GHG emisison reduction potential (tCO2/year)		1,213.1

2. Replace ceiling/pedestal fans with energy efficient BLDC fan

Observation – To provide comfort for employees, industries use a large number of ceiling and pedestal fans in production areas and offices. The rated capacity of ceiling fans is approximately 75W, while pedestal fans are around 300W. These fans are typically operated for 8–10 hours daily.

Recommendation – It is recommended to replace conventional fans with energy-efficient BLDC fans. Ceiling fans can be replaced with 35W BLDC fans, and pedestal fans can be replaced with 120W BLDC fans without reducing airflow.

BLDC Technology Overview

BLC stands for Brushless Direct Current. BLDC motors do not use mechanical brushes for commutation of the windings, which is managed electronically. The input voltage is 230V AC, converted to 24V DC, enabling the fan to run internally at 24V and consume only 100W at full speed.

Advantages of BLDC Fans:

- Elimination of friction & associated power loss.
- Greater flexibility in controlling motor speed.
- No spark and minimal electrical noise due to the absence of slip rings or mechanical brushes.
- Consistent performance even during low voltage and power fluctuation
- Timer feature for automatic fan switching.
- Sleep mode that gradually reduces speed after a set period, saving energy.

Energy Saving Potential – Compared to a conventional exhaust fan, energy-efficient BLDC fans consume 60% less power to deliver the same air volume (m3/min).

Cost Benefit Analysis – The cost of one BLDC fan is around 500 USD and payback will come in 2-6 years depending on daily operating hours.

Energy efficiency measure		Replace ceiling/pedestal fans with energy efficient BLDC fans
Number of times recommended		14
Total electricty saving potential	kWh/year	426,301
	toe/year	36.6
Total GHG emisison reduction potential (tCO2/year)		277.0

4.2.6. Motor

Replace old inefficient multiple time re-wounded electric motor with new energy efficient (IE3/IE4) motors

Observation – The majority of electric motors used in garment industries are of standard efficiency class (IE1 or equivalent). Additionally, in many industries, it is a common practice to use motors that have been re-wound multiple times. After each re-winding, the efficiency of the motor decreases by 2-3%. It was also observed that only a few industries maintain records of motor rewinding.

Recommendation – It is recommended to replace the old, inefficient, multiple-time re-wound motors with new energy-efficient (IE3/IE4) motors on a priority basis. In the subsequent phase, the factory can replace all standard efficiency (IE1 or equivalent) motors with high-efficiency (IE3/IE4) motors.

High-efficiency motors are typically made from materials that incur lower energy losses compared to standard motors. These motors are carefully designed with attention to the geometry and construction to optimize energy efficiency. The improvements in high-efficiency motors are as follows:

- Longer core lengths of low loss steel laminations to reduce flux densities and iron losses.
- Maximum utilization of the slots and generous conductor sizes in the stator and rotor to reduce copper losses.
- Optimized slot numbers and tooth/slot geometry to reduce stray losses.
- Less heat generation, which leads to reduced cooling fan size, lower windage losses, fewer chances of failure, and ultimately lower energy and operational & maintenance (O&M) costs.

From the motor efficiency chart, it can be observed that the energy efficiency improvement will be more significant for smaller-sized motors (i.e., motors with a rated power < 50 kW). Therefore, it is recommended to replace small-size standard efficiency motors with high-efficiency (IE3/IE4) motors in the initial phases.

Energy Saving Potential – The energy saving potential depends on the motor's rated power, rated efficiency, the number of times the motor has been re-wound, and the annual operating hours.

Cost Benefit Analysis – The cost of energy-efficient (IE3/IE4) motors is around 55-60 USD/kW, with a payback period ranging from 2 to 5 years.

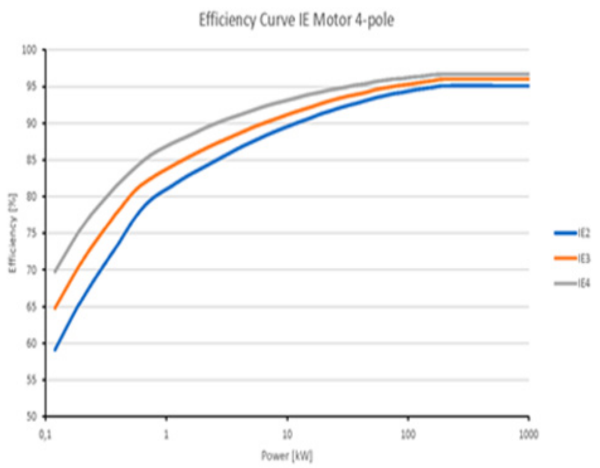


Figure 4.2. Motor efficiency chart [14].

Energy efficiency measure		Replace old inefficient multiple time re-wounded electric motor with new energy efficient (IE3/IE4) motors
Number of times recommended		4
Total electricty saving potential	kWh/year	26,109
	toe/year	2.24
Total GHG emisison reduction potential (tCO2/year)		16.97

4.2.7. Electrical Systems

1. Optimise voltage level by installing voltage stabilizer or by changing transformer tap position

Observation – It was observed that the rated voltage of the equipment in all industries is 380V (3-phase), but in some industries, the voltage at the incomer can vary significantly, ranging as high as 400–405V and as low as 360–365V.

Recommendation - To maintain a constant voltage at the motor terminals, it is proposed to install an automatic voltage stabilizer operating in auto mode. The use of an automatic voltage stabilizer in auto mode will ensure that the voltage level at the load end is maintained near 375–380V. Alternatively, wherever possible, the voltage can also be optimized by adjusting the transformer tap position.

Energy Saving Potential - Most of the three-phase motors installed in industries are designed for a 380V power supply. A low voltage supply will cause overheating, shortened equipment life, reduced starting ability, and decreased pull-up and pull-out torque. Similarly, a high voltage supply tends to push the magnetic portion of the motor into saturation, causing the motor to draw excessive current in an effort to magnetize the iron beyond the point where magnetization is practical. This results in excessive heating and shortened motor life. Therefore, providing a constant voltage supply (near the design voltage of ~380V) can reduce inherent losses, leading to a reduction of around 2 to 5% in overall energy consumption.

Cost Benefit Analysis – The cost of the voltage stabilizer will vary from USD 10,000 to 15,000. However, the exact cost of the stabilizer will depend on the connected load and transformer rating. The cost of changing the transformer tap position is almost zero. For changing the transformer tap position, the payback will be immediate. For installing the voltage stabilizer, the payback will depend on the monthly electricity consumption. For large industries with high electricity consumption, the payback will come in 3 to 5 years, but for small industries with lower electricity consumption, the payback period could extend up to 8 years.

Energy efficiency measure		Optimize voltage by installing voltage stabilizer or by changing transformer tap position
Number of times recommended		11
Total electricty saving potential	kWh/year	160,592
	toe/year	13.8
Total GHG emisison reduction potential (tCO2/year)		104.3

2. Installation of active harmonic filters at main incomer

Observation – During the field visit, a portable three-phase power analyzer was connected at the main incomer of the factory to measure the total energy demand, daily load variation, voltage fluctuations, power factor, and voltage & current total harmonic distortion. The measurements revealed that in some cases, the harmonic levels exceeded the permissible limits.

Recommendation – It is recommended to install a three-phase, four-wire active harmonic filter at the incomer. The rating of the harmonic filter will depend on the peak harmonic current.

Energy Saving Potential – The energy savings of installing an active harmonic filter will depend on the total load of the factory and the peak harmonic current. The higher the peak harmonic current, the greater the energy-saving potential.

Cost Benefit Analysis – The cost will depend on the rating of active harmonic filter but the payback will come within 2-3 year. The cost of an active harmonic filter will vary depending on its rating and specifications. However, the expected payback period is typically 2–3 years, based on the factory's energy consumption and load profile.

Energy efficiency measure		Installation of active harmonic filters at main incomers
Number of times recommended		11
Total electricty saving potential	kWh/year	149,322
	toe/year	12.84
Total GHG emisison reduction potential (tCO2/year)		97.05

4.2.8. Renewable Energy Measures

1. Install solar water heater in accommodation

Observation – A few industries have accommodation facilities within the factory boundary for employees. For hot water, these industries use electric water heaters with a rated power capacity of 3-4 kW, primarily during the morning and evening hours. The daily operating hours vary from 3-5 hours (on average).

Recommendation – It is recommended to install solar water heaters to fulfill the hot water requirements in the bathrooms. A solar hot water tank can be integrated with a thermostat and backup electric heaters (for emergencies). The average capacity of one electric water heater is 50 liters, while that of a solar water heater is 100 liters per day (LPD). Therefore, one solar water heater can replace two electric water heaters.

Energy Saving Potential – It was estimated that installing a solar water heater could enable the industry to save, on average, 1 kWh of electricity per day for each person using hot water for bathing.

Cost Benefit Analysis – The cost of a solar water heater is around 500 USD per unit. The industry can install multiple solar water heaters in parallel based on their requirements. The payback period will vary from 5 to 7 years.

Energy efficiency measure		Install solar water heater in accommodation
Number of times recommended		3
Total electricty saving potential	kWh/year	8,697
	toe/year	0.74
Total GHG emisison reduction potential (tCO2/year)		5.6

2. Install solar lamps for outdoor lighting

Observation – Currently, all the audited industries are using either conventional lamps or LED lamps for outdoor lighting. There is a potential to increase renewable energy integration in garment industries by replacing these outdoor lamps with solar LED lamps of suitable ratings and types based on the application.

Recommendation – It is recommended to replace the outdoor lamps with solar LED lamps of equivalent ratings.

Energy Saving Potential – Installing solar LED lamps can reduce the night-time outdoor lighting power consumption to zero.

Cost Benefit Analysis – The cost of outdoor solar LED lamps will vary from 100-150 USD per unit, with a payback period of 2-3 years, depending on the annual operating hours of the outdoor lamps.

Energy efficiency measure		Install solar lamps for outdoor lighting
Number of times recommended		16*
Total electricty saving potential	kWh/year	43,556
	toe/year	3.75
Total GHG emisison reduction potential (tCO2/year)		28.31

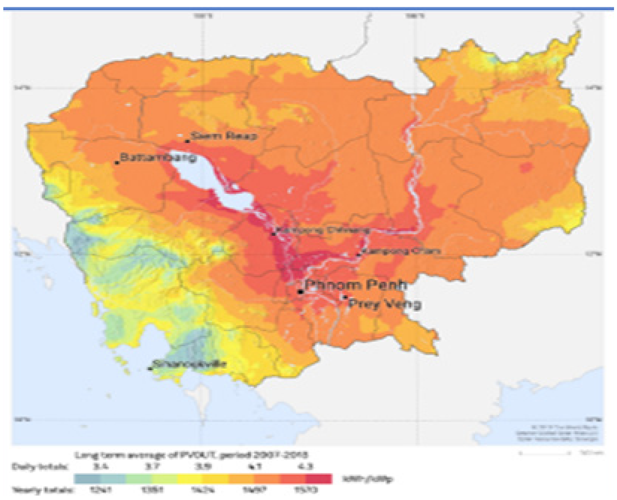
**The EEM can be implemented in all the factories. However, it is recommended only in 16 factories based on the operating hours of the outdoor lamp and payback period.*

4.3. Renewable Energy Integration Potential

Observation – The majority of industries receive electricity from the grid, while a few generate their own power through co-generation systems. During the site visit, it was observed that all the industries have large rooftop areas available for installing solar PV systems.

Recommendation – It is recommended to install solar rooftop systems, subject to a load-bearing capacity assessment of the building structure.

Energy Saving Potential – The average horizontal irradiation of the location is approximately 5.1 kWh/m^2/day. Currently, the tariff system applicable to the factories is the 'Simple Tariff' (Uniform Rate Tariff).



During the energy audits (2021-2022), according to the rules of the electricity purchase agreement in Cambodia, any party could install a solar PV system with a maximum capacity limited to 50% of the contract demand (in kW) at the inverter output, under a two-part tariff system with zero power export. Additionally, there was also a capacity charge of USD 5/kW/month for consumers with solar systems. However, as mentioned in Chapter 3, the solar regulations are being revised, which may bring positive momentum to the solar market.

There would be no direct energy saving from installing a solar rooftop PV system, as the electricity generated by the system will only reduce the electricity drawn from the grid. This, in turn, will help reduce the annual GHG emissions from the factories. The energy generated by the solar PV system is directly proportional to the size of the system installed. On average, a 1 kW rooftop solar PV system can generate 1,140 kWh per year (~3 kWh per day).

Cost Benefit Analysis – The average cost of the rooftop solar PV system is around 700 USD per kWp. Industries can install a solar PV system based on their annual electricity consumption, available rooftop area, and contract demand. The payback period is generally high, around 8-10 years, mainly due to the capacity charge.

Total Solar Electricity Generation Potential in Audited Garment Factories (49 factory units)		Total GHG Emission Reduction Potential
kWh/year	toe/year	tCO2/year
12,592,856	1,083	8,184

Considering the policy scenario in 2022, integrating renewable energy (i.e., rooftop solar PV systems) in all the audited factories has the potential to reduce total energy consumption by 5.4%, which would result in a 10.5% reduction in total GHG emissions. Additionally, electricity consumption from the grid would be reduced by 20%.

Total Electricity Consumption, kWh/year	Total Solar Electricity Generation Potential, kWh/year	% Reduction in Electricity Consumption from Grid
65,000,924	12,592,856	20%

Total Energy Consumption, toe/year	Total Energy Generation Potential, toe/year	% Reduction in Energy Consumption
20,009	1,083	5.4%

Total GHG Emissions, tCO2/year	Solar GHG Emissions Reduction Potential, tCO2/year	% Reduction in GHG Emissions
77,172	8,184	10.5%

Other renewable energy integration options: Other renewable energy integration options include solar water heaters for staff quarters, solar LED lamps for outdoor lighting, and tubular skylights for indoor lighting. The energy-saving potential of these renewable energy options is explained in detail in Section 4.2.

Cambodia has abundant solar energy, and since 2018, the Electricity Authority of Cambodia (EAC) has approved the installation of grid-connected solar systems for all electricity users with a transformer capacity of at least 250 kVA. Additionally, the solar regulation stipulates that 100% off-grid systems do not require approval.

Since the introduction of the solar regulation in 2018, many factories have successfully installed grid-tied solar systems. They have also completed the request process with EDC and received the necessary approvals. Some factories have even installed fully off-grid systems, generating all required power through solar, batteries, and some diesel backup.

Below is a comparative analysis of Grid-tied and fully off grid systems:

Type of solar system	Advantages	Disadvantage
Grid tied	• Proven concept • Lease options available • Energy and CO2 saving about 30% • Payback-time about 6-8 years	• Capacity charge/compensation tariff
Hybrid on-grid white batteries	• Energy and CO2 saving about 40-60% • Limited active zero export control, peak saving, increase stability • Payback about 8-10 years	• High-capacity charge/ compensation tariff • Payback under current regulation (capacity charge) not feasible, however this might change within next year (once compensation tariff gets more clarity)
Full off grid	• Energy and CO2 saving about 90% • High score and green image for brands on CO2 savings • No issue if kWh price increase in the near future	• Costly • Payback time over 10 years • Replacement of batteries in about 10 years

Currently, the on-grid solution is the most preferred by garment factories, offering energy savings and a reduction in CO2 emissions of about 30%. Fully off-grid systems are more expensive as they include battery backups. Off-grid systems also require backup generators, which are mostly run on diesel. However, the payback time for such systems is decreasing due to falling battery prices. The downside is that batteries need to be replaced at least twice during the project's lifespan and have negative environmental impacts, while the solar panels typically last for at least 20 years.

5. Lessons Learned

Energy audits in the sector have provided a solid baseline for evaluating GHG emissions and identifying opportunities for energy savings in GFT industries. These audits highlight actionable strategies for improving energy use, adopting cleaner energy sources, and optimizing operational and maintenance practices. While GFT industries face trade-offs in their transition to a low-carbon economy through the adoption of such practices, it is widely acknowledged that climate sustainability must remain a priority, as it presents both challenges and economic opportunities. The following lessons were learned during the energy audits:

5.1. Sectoral Perspective

Energy efficiency is an emerging concept in Cambodia's garment sector, though it is increasingly recognized as a vital tool for reducing GHG emissions, especially by international buyers. While many industry owners are convinced of the commercial viability of energy efficiency measures, several barriers exist to their implementation. These include high transaction costs, ownership structures i.e., factory buildings are mostly leased, restrictive supply contracts, policy barriers and a reluctance to share information. Overcoming these barriers is essential for broader adoption of sustainable energy measures.

5.2. Sustainable Energy Adoption Trend by Industry

Factories often begin by adopting energy efficiency measures that are considered "low-hanging fruit" due to their relatively low implementation cost and ease of integration, such as improvements in lighting or equipment efficiency. However, more capital-intensive measures, such as those related to utility systems (air compressors, space conditioning, boilers, and steam systems), tend to have a slower adoption rate, especially when their payback period exceeds three years.

5.3. Example from One Industry

One audited garment factory demonstrated substantial energy and cost savings by implementing energy efficiency upgrades. These retrofits led to reduced operating costs, lowered electricity consumption, improved utility systems, and enhanced employee comfort, while raising environmental awareness among the staff and visitors. Key lessons learned from this retrofit that are applicable across the sector include:

Commitment starts at the top: Sustainability goals were shaped by senior management's commitment to high-efficiency targets. Top-level support was essential to the project's success.

Low-hanging savings opportunities: The factory incorporated various energy-saving measures early on, maximizing energy efficiency and achieving significant cost savings with minimal effort. Upgrades to space conditioning, rooftop insulation, lighting, and building management systems improved comfort, air quality, and maintenance ease.

Factory operations and maintenance are key: Beyond installing efficient equipment, the factory upgraded its energy management system and trained staff to continually assess energy performance. This ongoing commitment to monitoring and adjusting operations led to increased energy savings.

5.4. Specific Examples of Energy Efficiency Measures

Lighting Retrofit: Many factories have successfully carried out lighting retrofits using LEDs and high-efficiency T-5 fittings. Additionally, several have integrated solar-powered perimeter lighting. One garment brand implemented energy-saving fluorescent T-5 fittings, which have a long lifespan and low mercury content, along with electronic ballasts and timers to automatically switch off office lights after pre-determined hours. These measures were designed to maintain the required lux levels and reduce energy consumption.

Use of wood pellets in the boiler: A significant energy efficiency gain was observed by switching from wood logs to wood pellets in the boiler systems. While the cost of pellets is higher, they reduce operating costs by improving boiler efficiency. Additionally, the use of pellets drastically reduces CO_2 emissions compared to wood logs.

5.5. The Government's Role in Energy Efficiency at the Factory Level

The government plays a critical role in promoting energy efficiency by creating an enabling environment. Setting appropriate energy prices, including those that account for environmental externalities, and implementing policies related to trade, competition, and privatization can incentivize industries to adopt energy-efficient technologies. The garment sector, which is primarily driven by the private sector, has been quick to adjust to these changes, showing promise for continued improvements in energy efficiency.

5.6. Private Sector Participation and Energy Efficiency

Private sector involvement has been a key driver in the success of energy efficiency programs, accelerating the pace of structural changes in the industry. Privately owned companies have been quick to close non-viable production facilities, streamline operations, and invest in new assets to remain competitive. Low-energy-intensity factories have successfully worked with garment sector representatives to implement energy-saving initiatives.

5.7. Financing Energy Efficiency Projects

Dedicated financing facilities for green financing are being developed, which can be accessed by factories as well as energy service providers. Recently, the Green Climate Fund (GCF) approved the Cambodia Climate Finance Facility (CCFF), co-managed by the Agricultural and Rural Development Bank (ARDB) and Mekong Strategic Capital (MSC). The CCFF offers a $100 million loan facility to support Cambodia's sustainable development, which can also be utilized for sustainable energy interventions. Additionally, the Asian Development Bank (ADB) is actively working to launch the Energy Efficiency Revolving Fund (EERF) to provide concessional financing for energy efficiency projects. While low-cost financing is crucial, it is not sufficient on its own to drive widespread adoption of energy efficiency measures. Building an enabling ecosystem by enhancing the capacity of key stakeholders, including financial institutions, is equally important.

5.8. The Importance of Senior Management Buy-In

The most important driver of energy efficiency implementation in the garment sector is strong senior management buy-in. This includes not only securing financial investment but also ensuring that factory staff are adequately trained on the sustainability aspects of their work. A proper energy management system, led by a trained energy manager, has a profound impact on shaping the energy culture within factories. When fully integrated and embraced by factory management, these systems can lead to significant improvements in both behavioral and organizational energy efficiency.

6. Recommendations

Based on the lessons learned during the energy audit activities, the project team has developed several recommendations. These recommendations primarily focus on promoting sustainable energy technologies by looking into low hanging opportunities and creating a conducive policy context.

6.1. Technical Recommendation

6.1.1. Efficient Operation of Boiler and Steam System

During the energy audit, it was found that most garment factories have installed boilers of small capacity (1-3 TPH), which produce low-pressure steam for ironing and washing purposes. The evaluated operating efficiency of these boilers is less than 50%, mainly due to inefficient operation and part-load conditions. Additionally, steam economy was found to be low. It is a priority for garment factories to focus on proper operation and regular routine maintenance to ensure that the boiler plant operates at peak efficiency, thereby minimizing running costs.

There is an immediate need for boiler operator training (one day) covering the following topics:

- Boiler types and components
- Combustion process and draft system for steam boilers using biomass as fuel
- Boiler control and protection systems
- Routine operation and emergency/cleaning procedures
- Problems and maintenance of the Steam distribution network

Common boiler auxiliaries and operating techniques should be covered in detail. Fuel preparation and efficiency of operation need to be emphasized. Other areas, such as modern boiler water treatment techniques, construction and repair methods, waste heat recovery, controls for steam distribution, and the benefits of condensate recovery, should also be explained.

It is recommended that boiler operators and management create awareness about efficient ways to operate the boiler and adopt best practices for boiler and steam systems.

6.1.2. Fixing Compressed Air Leaks

Air compressors are widely used in garment factories across Cambodia, accounting for around 5% of total factory electricity consumption. In general, the air compression efficiency of these compressors is less than 20% of the input energy. In many factories, compressed air leakage is notably high. Compressed air leaks not only increase energy costs but can also disrupt the system's functionality. Leaks force compressors to work harder to produce the same amount of compressed air, adding stress that could compromise equipment reliability, increase operating hours, and raise overall lifecycle costs.

Specialized equipment and skilled technicians should be deployed for reliable leak detection, particularly in noisy environments like garment factories. Ultrasonic leak detection devices are the most effective tool for identifying leaks. Regular use of these devices, along with consistent leak audits, can reduce wasted energy costs, prevent unnecessary wear on compressors, and minimize downtime.

Discussions with factory management revealed that few companies in Cambodia provide contract services for detecting and fixing compressed air leaks. Therefore, it is recommended to train more technicians in leak detection and repair, and to provide contract services to factories. The garment association can lead this initiative, while institutes can mobilize funds for hardware, ensuring that all garment factories can benefit from these services.

6.1.3. Demonstration of Brush Less DC Fan (BLDC)

Factories use a large number of conventional ceiling, wall, pedestal, and exhaust/ventilation fans in both office and production areas. These fans help ensure proper air circulation and provide comfort to employees. Power consumption by these fans accounts for a significant share of the total electricity consumption in the factory. Recently, many conventional fans have been replaced with brushless direct current (BLDC) motor fans.

A brushless DC (BLDC) motor is a synchronous electric motor powered by direct current (DC) electricity and uses an electronic commutation system instead of a mechanical commutator and brushes. The conversion of electrical parameters, such as current to torque and voltage to speed (rpm), are linear relationships in BLDC motors. A BLDC motor has an external armature called the stator, and an internal armature (permanent magnet) called the rotor, which is similar to an AC motor (permanent magnet type).

BLDC motors offer several advantages over brushed DC motors, including higher efficiency, increased reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, more power, and overall reduction in electromagnetic interference (EMI). In general, BLDC motors are more efficient at converting electricity into mechanical power than brushed DC motors, largely due to the absence of electrical and friction losses caused by brushes.

For fans, the total airflow or displacement is determined by the blade size and speed (rpm), and does not change due to other factors. BLDC motor-based ceiling fans provide the same airflow or displacement with lower energy usage and have improved power factor (PF). There is significant energy-saving potential in replacing conventional fans with energy-efficient BLDC fans. Since BLDC fan technology is relatively new in Cambodia, it is important to demonstrate its effectiveness in the factory setting. Developing a case study based on demonstration results is recommended, as it will also help increase the adoption of BLDC fans in garment factories.

6.1.4. Demonstration of Solar Water Heaters

Currently, factories with staff quarters are using electric water heaters (rated power ~ 4kW) to provide instant hot water in bathrooms. One of the most cost-effective ways to incorporate renewable technologies into a building is by installing a solar water heater. Solar water heaters capture solar radiation and use it to heat water. A typical residential solar water heating system can reduce the need for conventional water heating by about two-thirds, minimizing electricity costs and reducing the associated environmental impacts.

To promote the use of solar water heaters with a backup electric heater and pressure pump, it is recommended to demonstrate this technology at one of the factories. Based on the construction and water circulation rate from the demonstration results of solar water heaters, other factories can replicate the setup to showcase renewable energy integration.

6.2. Regulatory Recommendation

6.2.1. Programmatic Approach

Integrating energy efficiency measures into both new and existing garment factories will enable Cambodia to achieve a more reliable energy future, reduce costs, and address pressing climate issues. Successful energy efficiency management programs must be well-coordinated across the garment sector, involving relevant ministries and stakeholders to ensure wide-reaching and effective implementation. Therefore, a government-led energy management program should be initiated for the effective implementation of sustainable energy measures in the industrial sector of Cambodia. Associations like TAFTAC can also introduce private-sector-led sustainable energy programs for their member factories.

6.2.2. Energy Auditor and Manager Program

The development of local energy auditors and managers is crucial to creating an ecosystem for the successful implementation of sustainable energy interventions. During the implementation of energy audits, the project team identified a lack of domestic capacity to meet market demand. This issue will become even more critical as the government begins implementing the NEEP action plan. Therefore, a publicly led energy auditor and energy manager training and certification program should be introduced promptly.

6.2.3. Attractive Solar PV Tariff

All industries have vast unutilized rooftop areas to install grid-connected solar PV systems. But due to capacity charge, installing a rooftop solar PV system was not attractive for factories. In April 2023 a new solar guideline has been published removing capacity charge but introducing compensation tariff. TAFTAC may lead negotiations with electricity supply companies to adopt a tariff structure that attracts garment industries to install rooftop solar PV systems.

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