THE CARBON STITCH

Assessing Carbon Lock-In in the RMG Sector of Bangladesh

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Centre for Policy Dialogue (CPD)

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EXECUTIVE SUMMARY

Bangladesh's Readymade Garments (RMG) sector plays a central role in the country's economy, driving export earnings, industrialisation, and employment, while also accounting for a significant share of industrial energy consumption and carbon emissions. As global climate commitments intensify and international buyers increasingly prioritise sustainability in sourcing decisions, the sector faces mounting pressure to transition towards lower-carbon production systems. This study examines the persistence of carbon-intensive practices through a demand-side framework that conceptualises carbon lock-in as a multidimensional outcome shaped by institutional, infrastructural, financial, and behavioural factors.

The analysis is based on plant-level survey data from 350 registered RMG enterprises in Bangladesh, selected through stratified random sampling across key districts (Dhaka, Chattogram, Gazipur, and Narayanganj), factory types (knit, woven, and sweater), and firm sizes. Data were collected through interviews with technical, executive, and production personnel. The study constructs composite indices and applies econometric techniques alongside qualitative insights to assess firm-level decision-making and constraints.

The findings reveal a partial and path-dependent transition. While many firms have adopted low-cost, incremental energy efficiency measures such as improved lighting, motor upgrades, and operational adjustments, these interventions remain limited and have not translated into deeper structural transformation. Investments in renewable energy systems, advanced machinery, and process innovation remain relatively scarce.

This outcome is driven by interrelated constraints. Financial and technological barriers, including high upfront costs, long payback periods, and limited access to affordable financing, discourage large-scale investments, particularly among smaller firms. Infrastructural limitations further restrict renewable energy adoption, as many factories lack adequate rooftop space or structural capacity. Institutional and regulatory factors also contribute, with limited incentives for deep decarbonisation and fragmented policy frameworks increasing uncertainty. At the same time, firm-level behavioural dynamics, including risk aversion and short-term cost minimisation, reinforce reliance on existing systems.

Overall, incremental improvements alone will be insufficient; without a coordinated policy push addressing these barriers, the sector risks remaining locked into a carbon-intensive trajectory, undermining both its competitiveness and Bangladesh's climate commitments.

LIST OF ACRONYMS

ADB	–	Asian Development Bank
BDT	–	Bangladeshi Taka
BLI	–	Behavioural Lock-in Index
CO_2	–	Carbon dioxide
CPD	–	Centre for Policy Dialogue
GHG	–	Greenhouse Gas
ILI	–	Institutional Lock-in Index
KPI	–	Key Performance Indicator
LASSO	–	Least Absolute Shrinkage and Selection Operator
OLS	–	Ordinary Least Squares
PCA	–	Principal Component Analysis
RMG	–	Readymade Garments
SEC	–	Specific Energy Consumption
SHS	–	Solar Home System
TLI	–	Technological Lock-in Index
USD	–	United States Dollar

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1 Introduction

The Readymade Garments (RMG) sector stands as the backbone of Bangladesh's industrial economy, contributing over 80 per cent of national export earnings and employing millions of workers, predominantly women. Over the decades, this sector has transformed Bangladesh into a global manufacturing hub for apparel. Yet, behind this economic success lies a growing environmental and energy challenge. The RMG industry is one of the most energy-intensive manufacturing sectors in the country, relying predominantly on fossil fuel-based electricity and thermal energy (Biswas et al., 2024). The RMG sector had GHG emissions of 1946 Gg CO_2eq in 2024 (Biswas et al., 2024). With increasing production capacity, rising global demand, and limited access to renewable or energy-efficient technologies, the sector's carbon footprint continues to expand, posing a structural challenge to Bangladesh's low-carbon transition ambitions. Since Bangladesh's RMG sector is part of global buyer driven value chain, it needs to comply with climate and environment related international deals which buyers of developed countries need to comply with. In this connection, RMG exporters have to meet the decarbonisation related compliance requirement followed under the European Green Deal. 'Carbon-lock-in' an attitude towards overtly dependent on fossil-fuel operated technologies and operations and fossil-fuel based energy use in the production process, would be a major constraint for RMG exporters to meet the target of phase-wise carbon reduction in the RMG supply chain linked with Bangladesh.

Being one of the most energy-intensive industries in Bangladesh, the RMG industry faces mounting pressure in reducing its carbon footprint and move towards sustainable energy consumption. It is estimated that the RMG industry's annual electricity consumption is 6,251 GWh, accounting for about 8.2 per cent of the total electricity consumption nationally (Khatun & Bari, 2024). Notably, the energy consumption pattern varies with factory size; as highlighted in Khatun et al. (2024), tier 3 (76.94 per cent) and tier 2 (57.05 per cent) RMG factories tend to rely more on grid electricity for their electricity consumption in comparison to tier 1 (40.83 per cent) factories. Further disaggregated data on the amount of electricity demand in Bangladesh's RMG industry suggests that factories with less than 650 workers have a total annual electricity demand of 722.5 GWh, while factories with more than 650 but less than or equal to 1,650 workers demand 1,489.2 GWh of electricity per annum and factories with greater than 1,650 workers demand 4,040 GWh of electricity annually (Khatun & Bari, 2024).

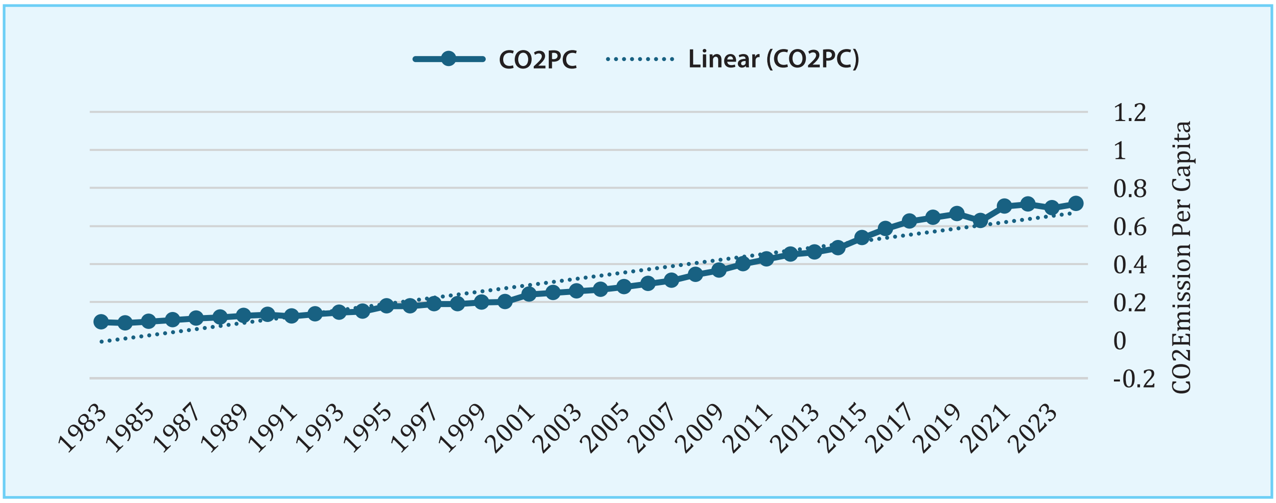
The energy mix in Bangladesh's power sector has evolved over the years. The natural gas supply, which once comprised of over 66 per cent of total power, declined to 59 per cent. At the same time, coal usage increased steeply, by accounting for over 20 per cent of power generation in 2025; renewable energy usage remained below 4 per cent but is expected to increase in the future (ORDNUR, n.d.). Nonetheless, the dominance of fossil fuels in the production of national grid electricity still remains, comprising more than 80 per cent. Therefore, many small and medium sized factories depend on grid electricity rather than on rooftop solar systems given the high investment cost and technical capacity, which the smaller-sized factories lack (Khatun et al., 2024).

Within the garment production process, sewing accounts for the most electricity-intensive step at 29 per cent of the total electricity consumption in garment production, followed by cutting (23 per cent) and pressing (21 per cent) (Uddin et al., 2023). Besides electricity, production processes such as dyeing and finishing units heavily rely on thermal energy, which are generated from natural gas or steam boilers. Due to grid instability, factories maintain their own captive power plants or diesel generators as backup systems. However, factories nowadays are installing rooftop solar systems, LED retrofits and energy efficient motors in an effort to reduce their energy consumption (ORDNUR, n.d.).

Factory-level empirical studies and energy audits provide detailed evidence of technological dependence and inefficiencies within RMG production. Khan et al. (2022) show that boilers, water pumps, gas generators, electrical motors, and lighting systems could be modified in certain ways to enhance energy efficiency and simultaneously reduce carbon emissions. Energy efficiency measures are increasingly pursued by factories in comparison with rooftop solar due to the energy demand exceeding the capacity of solar energy installed and many old factories with roofs not strong enough to bear the weight of the solar system (Alam, 2023).

It is to be noted that the per capita Green House Gas (GHG) emissions of Bangladesh have a consistent upward trend up to recent years as illustrated in Figure 1. In this context, the concept of carbon lock-in becomes highly relevant. Carbon lock-in refers to a state of path dependency in which existing technological systems, institutional arrangements, and behavioural patterns reinforce the use of carbon-intensive energy and inhibit the adoption of cleaner alternatives. These self-reinforcing mechanisms make it difficult for industries to shift towards sustainable, low-emission practices, even when low-carbon options become economically viable or technologically feasible. The lock-in effect operates through three interrelated dimensions: (a) Infrastructure and technological lock-in, driven by long-lived capital assets, outdated machinery, and energy systems dependent on fossil fuels; (b) Institutional lock-in, perpetuated by entrenched policy frameworks, regulatory inertia, and financial and supply-chain incentives favouring conventional practices; and (c) Behavioural lock-in, reflected in the attitudes, perceptions, and decision-making patterns of individuals and organisations that sustain carbon-intensive operations.

Figure 1 **GHG Emissions in Bangladesh**



Source: World Development Indicators (World Bank).

Understanding these dimensions within Bangladesh's RMG sector is critical for several reasons. First, the sector's competitiveness in global markets is increasingly tied to sustainability performance, as international buyers impose stricter environmental and energy-efficiency requirements. Second, national commitments under the Paris Agreement and the Mujib Climate Prosperity Plan call for rapid decarbonisation of industrial sectors. Third, energy security concerns, stemming from high import dependency and rising costs of fossil fuels, underscore the urgency of improving energy efficiency and diversifying towards renewable energy within industrial production.

Despite a growing body of research on Bangladesh's energy and industrial emissions, most studies focus on the supply side of the power and energy system examining generation mix, infrastructure investment, or energy policy.

There is a notable gap in understanding the demand-side dynamics, particularly the structural and behavioural factors that constrain energy users, such as RMG factories from adopting low-carbon solutions. This study aims to fill that gap by assessing carbon lock-in from the demand perspective exploring how the RMG sector, as a major consumer of energy, remains 'locked in' to carbon-intensive modes of production due to technological, institutional, and behavioural constraints.

This approach reframes carbon dependency not merely as a function of supply inadequacies but as a systemic outcome shaped by the interaction between industrial practices, regulatory design, and organisational behaviour. Even factors that appear to be supply-side limitations such as inadequate renewable supply or limited grid access, will be examined through the lens of demand-side lock-in, revealing how consumption patterns, investment decisions, and risk perceptions contribute to sustained carbon intensity.

Through this perspective, present study aims to provide a comprehensive understanding of the mechanisms that reinforce carbon dependency in Bangladesh's RMG sector. The study's insights will contribute to the national discourse on industrial decarbonisation, offering pathways to unlock these structural barriers through targeted policy, technological innovation, and behavioural transformation.

2 Study Objectives

The overarching aim of this study is to investigate the determinants of carbon lock-in in Bangladesh's RMG sector from a demand-side perspective, examining how technological, institutional, and behavioural dynamics interact to sustain high levels of carbon intensity. The specific objectives are:

i. To assess infrastructural and technological lock-in by evaluating existing energy consumption patterns, equipment age and efficiency, retrofit feasibility, and technological dependencies in RMG factories.

ii. To identify institutional lock-in by examining the influence of policies, regulatory frameworks, financial systems, and supply-chain incentives or disincentives that reinforce carbon-intensive practices.

iii. To understand behavioural lock-in by analysing the perceptions, attitudes, and decision-making processes of factory owners, managers, and workers towards adopting low-carbon technologies and energy-efficient practices.

iv. To explore cross-dimensional interactions among technological, institutional, and behavioural lock-ins to identify feedback mechanisms that perpetuate or can potentially reverse carbon dependency.

v. To develop evidence-based recommendations for targeted intervention policy reforms, financial incentives, technological upgrading, and capacity-building strategies to support decarbonisation pathways in the RMG sector.

3 Literature Review on Carbon Lock-in

3.1 Conceptual Foundations

The earliest literature shedding light on the concept of carbon lock-in can be traced back to Unruh (2000), in an attempt to explain the persistent dominance of fossil fuel–based energy systems despite the availability of cost-effective, cleaner alternatives. Carbon lock-in is defined as a systemic condition arising from the co-evolution of technologies and institutions generating increasing returns to scale, whereby industrial economies become entrenched in carbon-intensive pathways that are difficult to reverse. Carbon lock-in is explained through a concept of Techno-Institutional Complex (TIC), in which energy technologies, industrial infrastructures, regulatory frameworks, and market structures mutually reinforce one another, producing increasing returns to existing carbon-based systems (Unruh, 2000). As a result, once fossil fuel–based systems become dominant, they shape future choices by influencing cost structures, regulatory priorities, and organisational behaviour, thereby constraining the adoption of low-carbon alternatives and limiting the effectiveness of policy interventions (Unruh, 2000); Unruh, 2002).

Path dependence: Path dependence is central to the existence of carbon lock-in, where early and contingent decisions shape long-run outcomes. Unruh (2000) and Erikson et al. (2015) emphasise that early investment decisions, policy or infrastructural design choices generate positive feedback or increasing returns to scale, in the form of network effects and economies of scale, which entrenches carbon-intensive technological systems and deters adoption of low-carbon options even when they are available and superior on environmental or economic grounds. The path dependence is particularly strong given that the infrastructures involve long lifetimes and large capital expenditure, coupled with interdependent socio-technical systems (Seto et al.,2016). As a result, firms and policymakers rationally continue to invest in established carbon-intensive systems, even when cleaner technologies become technically feasible.

Process dynamism: Seto et al. (2016) and Erikson et al. (2015) further conceptualise carbon lock-in as a dynamic process operating across multiple scales, from individual facilities to national economies. They reinforce that path dependence arises because past investments constrain present and future options, particularly given that physical infrastructures are not replaced frequently. In carbon-intensive sectors, this leads to emission trajectories that are difficult to alter without deliberate and coordinated interventions.

Interconnections between different types of carbon lock-in: Carbon lock-in is sustained through reinforcing mechanisms operating across three interlinked dimensions. Infrastructural and technological lock-in is characterised by the long-lived physical infrastructure and technological investments that anchor societies to carbon-intensive pathways, making it costly and difficult to shift to low-carbon alternatives. This lock-in is generally reinforced by high sunk costs and long payback periods (Seto et al., 2016).

Institutional lock-in arises through policies, regulations, and organisational routines. Regulatory frameworks, financial systems, and industry standards tend to be designed around existing infrastructures, which stabilises the existing techno-institutional systems and raises barriers to alternative pathways (Unruh, 2000; Unruh, 2002). Unlike technological lock-in, which tends to be an unintended consequence of past investments, institutional lock-in is often intentional, shaped by powerful economic and political actors to maintain their interests. Powerful actors, such as fossil fuel companies and industry lobbyists, seek to shape institutional rules, policies, and economic systems in ways that protect their vested interests (Seto et al., 2016).

Lastly, behavioural lock-in arises from normalised carbon-intensive practices and social norms that reduce individual's responsiveness to new changes. Therefore, as carbon-intensive technologies and institutions stablise over time, carbon-intensive behaviours become cognitively easy and low-effort to maintain. Moreover, psychological factors, including risk aversion, ideological beliefs, and limited sense of individual agency in climate change preventive actions, further lead to inaction. As a result, combining all these factors builds a self-reinforcing behavioural lock-in into carbon-intensive practices even when new information on cleaner alternatives is available (Seto et al., 2016).

3.2 Review of Global and Regional Studies Examining Lock-in in Industrial and Energy Systems, with Emphasis on Developing Economies

Carbon lock-in has emerged as a relatively recent but rapidly expanding area of research within the broader climate and sustainability literature. While early work mostly provided the theoretical reasoning of the theory, empirical studies examining its mechanisms and measurement have gained momentum only in recent years. Table 1 presents the summary of carbon lock-in situation in industrial and energy systems in selected developed and developing countries.

Global and region-based literature also identify carbon lock-in as a multidimensional and self-reinforcing phenomenon rooted in the interaction of technology, infrastructure, institutions, and economic incentives. In energy and industry-heavy systems, long-lived assets, high sunk costs, and system integration (as seen in Japan's coal power system and the Netherlands' chemical industry) strongly constrain the adoption of low-carbon alternatives. In China, quantitative studies reveal that carbon lock-in varies significantly across sectors and regions, with higher lock-in concentrated in carbon-intensive manufacturing, transport infrastructure, and resource-rich or economically advanced regions, while technological progress and structural upgrading tend to weaken lock-in over time. Institutional and political–economic factors, such as policy inconsistency, lobbying, energy security concerns, and weak environmental regulations, recurrently emerge as critical drivers sustaining high-carbon pathways. At the firm level, carbon lock-in generally undermines long-term performance, although in mature markets it may provide short-term competitiveness. Overall, the findings suggest that while carbon lock-in is gradually weakening in some contexts due to technological and structural changes, entrenched institutions, infrastructure, and behaviour continue to pose significant barriers to rapid decarbonisation, especially in sectors with large, long-lived capital investments.

Table 1 Carbon Lock-in in Industrial and Energy Systems in Selected Developed and Developing Countries

Country/ Region	Sector	Method	Key Findings	Author(s), Year
Japan	Energy system (coal power)	Qualitative approach using institutional and policy analysis to study the socio-technical aspects of lock-in.	**Technological-Infrastructural lock-in:** Japan's CFPP fleet has a long technical lifetime ahead, thus operations must continue to recover the sunk investments. Moreover, the existing electricity grid structure still favours the use of coal. Investments made in R&D programmes on advanced coal power technologies further deepen the lock-in **Political–economic interests:** Strong alignment between coal companies, plant equipment	Trencher et al. (2020)

(Table 1 contd.)

(Table 1 contd.)

Country/ Region	Sector	Method	Key Findings	Author(s), Year
			manufacturers, and policymakers sustain coal through lobbying, employment concerns, and industrial competitiveness narratives. **Energy security concerns:** Post-Fukushima energy security concerns towards viewing coal as a 'reliable' option given natural gas and coal were used as short-term alternatives and the construction of new CFPP.	
China	Manufacturing Industry	Quantitative approach to measuring the degree of carbon lock-at the industrial and regional level. The carbon emissions coefficient method is used to measure the level of carbon emissions across different provinces. The Geographical Weighted Regression (GTWR) model is used to determine the influencing factors of high-carbon manufacturing industries.	High carbon emitting manufacturing industry mainly consists of ferrous metal manufacturing industry, non-metallic mineral manufacturing industry petroleum smelting industry, chemical raw material product industry and non-ferrous metal metallurgic processing industry. As per region-wise, these industries are mostly located in Bohai Bay and the North China Plain. Main reasons behind the region lock-in of high carbon manufacturing industry are attributed to industrial structure and economic scale, with the degree of lock-in increasing continuously. Resource endowment and foreign direct investments also contribute to enhancing lock-in, while technological progress reduces it.	Wang et al. (2020)
Netherlands	Chemical Manufacturing Industry	Qualitative approach to identify carbon lock-in in the Dutch chemical manufacturing industry through roadmap and policy documents analysis and semi-structured interviews with individuals from NGOs, industry	The contributing factors to carbon lock-in in the chemical manufacturing industry identified are technological incompatibility, system integration, sunk costs, policy inconsistency, and safety routines. Additional factors, such as cost competitive fossil fuel and feedstock, turnaround and payback period, low risk acceptance by investors and customer behaviour and choice are identified as barriers to reducing emissions, but lack the self-reinforcing trait of lock-in.	Janipour et al. (2019)

(Table 1 contd.)

(Table 1 contd.)

Country/ Region	Sector	Method	Key Findings	Author(s), Year
		association, government, industry, public limited company and research institute/consultancy	The chemical industry involves large scale infrastructure with long lifetime assets, which create difficulty in adopting cleaner technologies given the high sunk cost and risk of asset stranding. The adoption of cleaner technologies may be obstructed within industrial clusters due to network effects and system integration, but in case transition is decided on, industrial clusters can ensure faster adoption., but in case transition is decided on.	
China	Not based on a specific sector	Measuring carbon-lock in based on fixed investment, technique, institution and social behaviour using the Real-coded Accelerating Genetic Algorithm (RAGA-PP model)	At the national level, the overall level of carbon lock-in in fixed investment, technique and institution show a declining trend, while the social behavioural lock-in has increased. The levels of industrial carbon intensity of the top 13 carbon-intensive industries have decreased over the years, contributing to the weaking of carbon lock-in. Institutional factors strongly influence lock-in levels at the national level. Three factors that influence the evaluation of carbon at the national level are: carbon emission intensity, local government expenditure on science and technology, and market value in the technical market. Even though coal consumption in China has been declining, it remains as a dominant energy source (57.7 per cent in 2019) due to its established, stable characteristics and relatively less powerful growth of renewable alternatives. At the regional level, the extent of carbon lock-in varies, with the lock-in being weakest in the eastern region and strongest in the west and intermediate in the central and northeastern areas.	Niu & Liu (2021)

(Table 1 contd.)

(Table 1 contd.)

Country/ Region	Sector	Method	Key Findings	Author(s), Year
China	Transport Infrastructure	Carbon locked path dependence in the transport sector is quantified by constructing a composite indicator. A quantile regression model is used to assess whether the factors influencing carbon lock-in vary with its extent.	The carbon-based path dependence of transport infrastructure is measured by the composite path dependent index (PDI), with the carbon lock-in being more prominent in economically developed and resource-rich regions. Among the regions, the east and north regions show increased path dependence, while west and south show low path dependence. Therefore, carbon lock-in in the east and north are more intense given the large scale, long-established transport infrastructure. The determinants of carbon path dependence vary among the quantiles.	Zhang et al. (2025)
China	Industrial enterprises	Quantitative approach to measuring the impact of carbon lock-in on the performance of businesses. This paper constructs composite indicators of the 4 types of carbon lock in: 1. fixed input, 2. institutional, 3. technological and 4. social behaviour and attached weights to the indicators using the entropy weight method. The carbon lock-in indices are treated as independent variables with return on net assets being the dependent variable.	Results indicate that carbon lock-in in general harms have adverse effects on business performance. However, this effect varies depending on different market conditions. Particularly in more mature markets with integrated supply chains, carbon intensive firms may maintain competitiveness in the short term by using their existing knowledge and capabilities while gradually adopting low-carbon technologies. However, within dynamic and innovation driven markets, carbon lock-in is likely to hurt carbon-intensive firms more given their weak ability to respond to technological changes. Regulatory environments play a crucial role since weak environmental regulations tend to lower the pressure to decarbonise and make carbon-intensive practices economically more viable and attractive.	Tan & Chen (2025)

Source: Authors' compilation.

4 Overview of Energy Use in the RMG Sector

4.1 Evolution of Energy Use and Production Processes in the RMG Sector

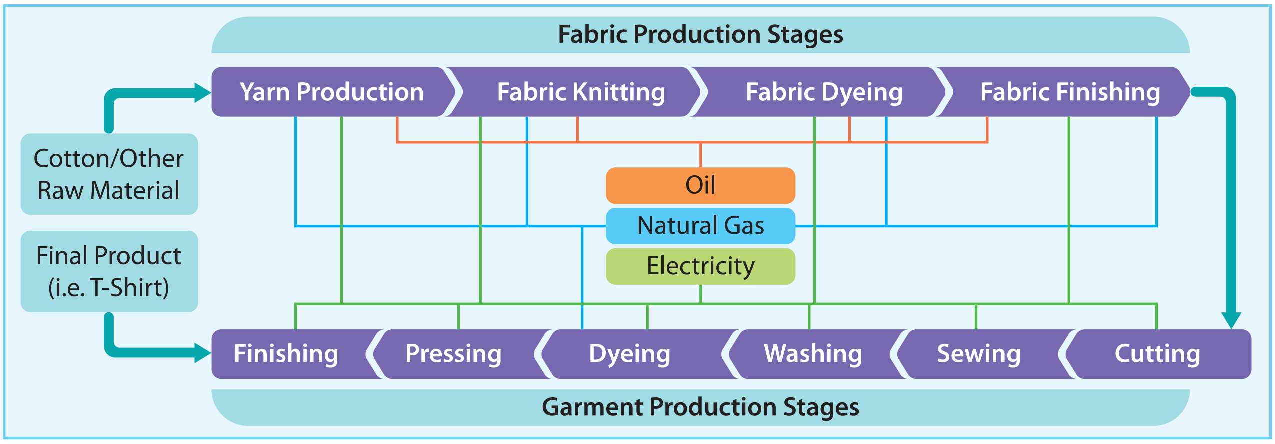
The evolution of energy use in Bangladesh's RMG sector has closely followed the trajectory of rapid industrial expansion, export orientation, and increasing production complexity. Electricity and thermal energy constitute the two dominant forms of energy consumption across the sector, with their relative importance varying by production stage. Electricity is primarily used in spinning, knitting, sewing, cutting, and finishing operations, while thermal energy is essential for wet processing activities such as dyeing, washing, bleaching, and drying. Empirical studies consistently indicate that wet processing units account for the highest share of total energy consumption due to intensive heat and steam requirements (Ordnur, 2023; CPD, 2024).

Historically, unreliable grid electricity and frequent load shedding incentivised widespread adoption of captive power generation systems, particularly gas-fired generators and diesel-based backup units. While captive generation enhanced production reliability and reduced downtime, it also reinforced dependence on fossil fuels and contributed to higher carbon emissions at the factory level. Recent improvements in grid stability have reduced reliance on captive systems in some regions, although many factories continue to operate hybrid arrangements combining grid electricity with backup generation to mitigate supply risks (Ordnur, 2023).

The sector's fuel mix remains heavily skewed towards natural gas and diesel, reflecting broader national energy trends. Although renewable energy adoption, particularly rooftop solar photovoltaic systems under net metering arrangements, has increased in recent years, its contribution to total energy demand remains marginal. Adoption is concentrated among large export-oriented factories, often driven by buyer compliance requirements and corporate sustainability commitments rather than domestic policy incentives alone (LightCastle Partners, 2024; CPD, 2024). As a result, the overall production structure of the RMG sector continues to exhibit strong carbon lock-in, with limited diversification towards low-carbon energy sources.

Figure 2 describes the production processes involved in the Readymade Garments sector. The carbon intensity of the RMG section of textile and garments industry is lower compared to the textile part as it involves relatively low energy processes such as cutting, sewing and finishing. The production processes were mapped in detail by conducting field visits and interviews.

Figure 2 Production Process of Readymade Garments Industry



Source: Authors' illustration based on collected data (Uddin et al., 2024).

4.2 Energy Infrastructure and Efficiency Patterns

Energy infrastructure and efficiency performance within the RMG sector vary significantly across factory sizes, production types, and technological vintages. Many factories operate with legacy machinery and utility systems that are characterised by low efficiency, limited automation, and inadequate energy management practices. Studies of factory-level energy audits demonstrate that specific energy consumption is highest in dyeing and finishing processes, followed by knitting and weaving, with sewing operations exhibiting the lowest energy intensity (Hasan et al., 2016; Rahman et al., 2022).

Energy efficiency interventions, such as high-efficiency boilers, waste heat recovery systems, variable frequency drives, and efficient lighting, have demonstrated substantial potential for reducing energy consumption and operational costs. However, adoption remains uneven. Larger factories are more likely to invest in advanced technologies and energy monitoring systems due to greater access to capital and technical expertise. In contrast, small and medium enterprises often rely on incremental or low-cost efficiency measures and face significant barriers to undertaking comprehensive retrofits (ADB, 2020; LightCastle Partners, 2024).

Infrastructure constraints also limit the scalability of renewable energy integration. Rooftop solar deployment is restricted by roof space availability, structural limitations, and grid interconnection challenges. Moreover, the absence of advanced energy management systems reduces the ability of factories to optimise energy use across production lines. The persistence of fragmented infrastructure planning and limited technical capacity contributes to technological inertia and slows the diffusion of high-performance energy systems across the sector (Rahman et al., 2022; CPD, 2024).

4.3 Policy and Financial Environment Affecting Energy Use and Decarbonisation

The policy and financial environment shaping energy use and decarbonisation in the RMG sector reflects growing recognition of sustainability imperatives alongside persistent structural constraints. National policy frameworks increasingly emphasise renewable energy deployment, energy efficiency, and circular economy principles, particularly within export-oriented manufacturing sectors. Policy documents highlight the role of the RMG industry in achieving national climate commitments and improving industrial energy performance (Switch2CE, 2025; CPD, 2025).

Despite these policy signals, implementation challenges remain substantial. Import duties and taxes on renewable energy equipment and energy-efficient machinery raise upfront investment costs and weaken financial incentives for factory-level adoption. Regulatory processes for net metering, power purchase agreements, and grid integration also impose administrative burdens that disproportionately affect smaller firms. As a result, policy effectiveness is uneven and often contingent on external buyer pressure rather than domestic enforcement mechanisms (Alam, 2023; Ordnur, 2023).

Access to finance constitutes a critical constraint on decarbonisation investments. While green financing initiatives, concessional loans, and donor-supported programmes have expanded in recent years, their scale remains insufficient relative to sectoral needs. Many factories face high borrowing costs, short loan tenors, and limited availability of performance-based financing instruments. Blended finance mechanisms and public-private partnerships have been identified as promising pathways to reduce investment risks and crowd in private capital, but institutional coordination and implementation capacity remain limited (Green Climate Fund, 2023; Green Policy Platform, 2024).

4.4 Comparative Energy Intensity Across Sub-Sectors

Energy intensity varies markedly across sub-sectors within the RMG industry, reflecting differences in production processes, technology use, and energy requirements. Dyeing, washing, and finishing units consistently exhibit the highest energy and carbon intensity due to their reliance on thermal energy and continuous heating processes. In contrast, knitting and garment assembly operations are predominantly electricity-driven and demonstrate lower specific energy consumption per unit of output (CPD, 2024).

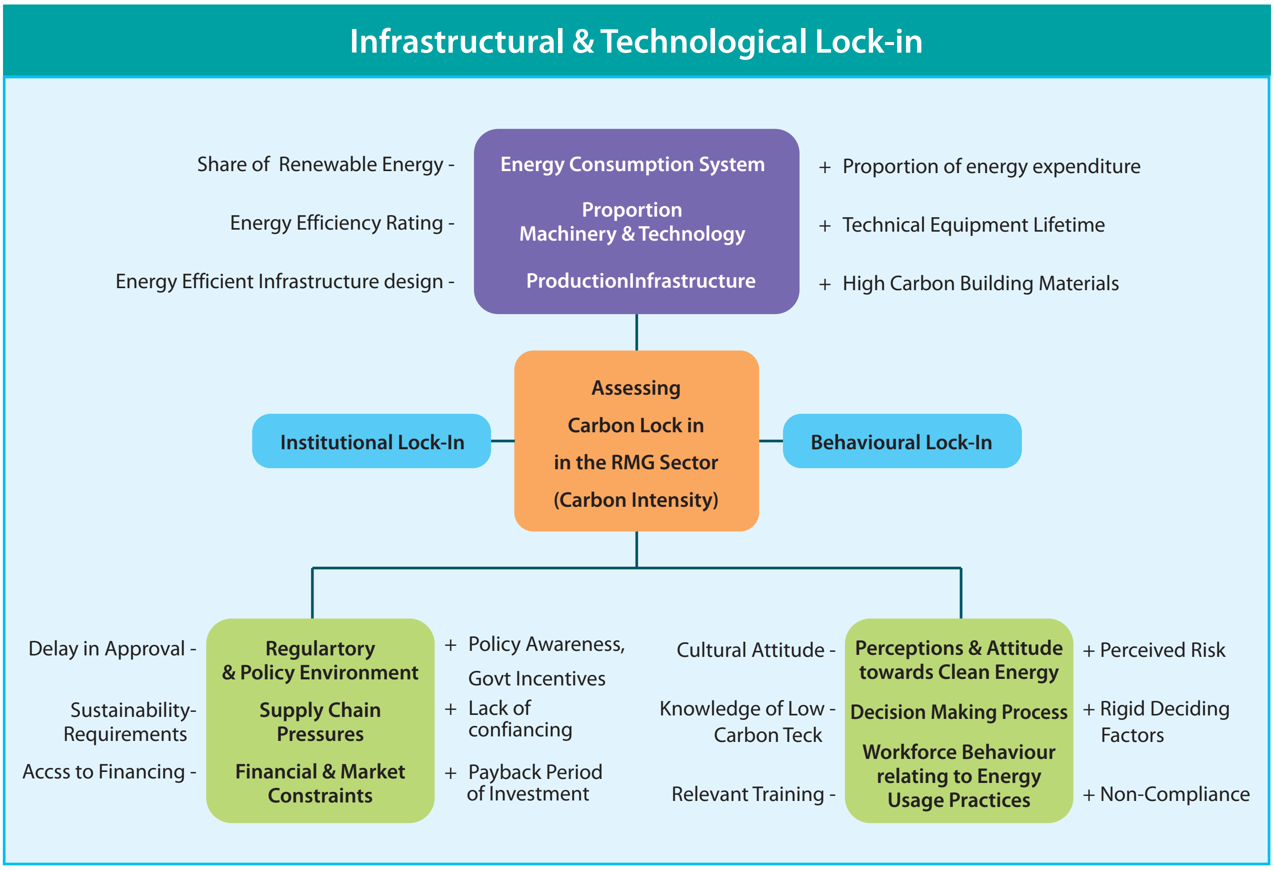
Comparative evidence indicates that woven and knit composite factories tend to have higher overall energy intensity than standalone knit or sweater units, as composite operations integrate multiple energy-intensive stages within a single facility. Factory size further amplifies these differences. Large factories typically report higher absolute energy consumption and emissions, although their energy intensity per unit of output may be lower due to economies of scale and more efficient equipment. Small and medium enterprises, while lower in absolute emissions, often operate with inefficient technologies, resulting in higher relative energy intensity (Primary Survey; CPD, 2024).

These variations underscore the importance of differentiated policies and technological strategies. Targeted interventions in wet processing sub-sectors, combined with size-specific financial and technical support, are essential for reducing energy intensity and avoiding uniform policy approaches that fail to account for structural heterogeneity within the sector.

5 Analytical Framework

Carbon lock-in is a self-reinforcing process in which initial conditions, scale economies, learning effects, and social expectations slow or prevent the adoption of low-carbon alternatives (Seto et al., 2016). Building on this premise, and recognising the role of rules and incentives in shaping organisational behaviour (North, 2012), the framework distinguishes three mutually reinforcing subsystems in Bangladesh's RMG sector: infrastructural & technological, institutional, and behavioural lock-in. These subsystems interact to reproduce carbon intensity at the firm and sectoral levels (Figure 3).

Figure 3 Analytical Framework for Carbon Lock-in in the RMG Sector



Source: Authors' illustration.

5.1 Infrastructural and Technological Lock-in

Long-lived capital with sunk costs, long payback periods, and compatibility constraints create path dependence in equipment selection and process design.

Hypothesis H1: *Firms with older capital vintages, longer remaining equipment lifetimes, and higher retrofit incompatibilities exhibit higher carbon intensity, controlling for product mix and scale.*

Mechanisms include learning-by-using on incumbent technologies and vendor lock-in in maintenance ecosystems (Table 2).

Table 2 Operational Indicators for Infrastructural & Technological Lock-in

Dimension	Indicators
Equipment and Technology	Age and efficiency classes of machinery; retrofit feasibility indices
Energy Profile	Specific energy consumption (SEC) by process; share of renewable energy in on-site supply
Infrastructure	Thermal integrity scores; reliance on high-carbon building materials
Economics	Realised payback periods

Source: Prepared by authors.

5.2 Institutional lock-in

Formal rules (permits, standards, tariffs), informal norms in supply chains, and financing architecture can intentionally or inadvertently entrench carbon-intensive choices (North, 2012; Erickson et al., 2015; Pierson, 2000). Table 3 presents the operational indicators related to institutional lock-in.

Hypothesis H2: *Delays, uncertainty, and misaligned incentives in the regulatory, supply-chain, and financial environment increase firms' discount rates and shorten investment horizons, biasing choices towards carbon-intensive options.*

Table 3 Operational Indicators for Institutional Lock-in

Dimension	Indicators
Regulation	Approval timelines for energy projects; predictability of sustainability requirements
Supply Chains	Buyer audit stringency; enforcement of environmental standards
Finance	Access to concessional/green finance; co-financing constraints
Incentives	Uptake of public support schemes; effective energy and carbon pricing

Source: Prepared by authors.

5.3 Behavioural lock-in

Cognitive heuristics, risk perceptions, and entrenched routines shape energy practices independent of technical feasibility. Table 4 presents the operational indicators related to behavioural lock-in.

Hypothesis H3: *Where perceived risk of low-carbon options is high, decision processes are rigid, and compliance cultures are weak, adoption of efficient technologies and practices is lower—even when economically viable.*

Hypothesis H4: *Targeted training and salient performance feedback reduce perceived risks and increase adoption.*

Table 4 Operational Indicators for Behavioural Lock-in

Dimension	Indicators
Attitudes	Managerial perceptions of clean energy; salience of energy costs in KPIs
Decision-Making	Rigidity of capital expenditure processes; escalation paths for approvals
Workforce Practices	Worker routines on machine operation/shutdown; compliance with energy protocols
Capacity & Learning	Frequency and quality of energy management training; records of compliance

Source: Prepared by authors.

5.4 Interactions and Feedback

The framework posits feedback:

I **Institutional → Technological:** Standards, incentives, and finance reshape feasible technology sets and payback profiles.

ii. **Technological→Institutional:** Demonstrations of profitable low-carbon upgrades shift buyer requirements and policy stances.

iii. **Behavioural ↔ Both:** Routines and perceptions condition how policies and technologies are interpreted and used; visible performance gains from pilots recalibrate risk perceptions and norms.

These feedback generate increasing returns that stabilise either a high-carbon or low-carbon path.

6 Methodology of the Study

6.1 Data and Variables

The analysis relies on plant-level data from RMG factories. The principal outcome variable is carbon intensity, defined as the amount of carbon dioxide equivalent emissions per unit of physical or value-added output. Three sets of explanatory variables are constructed to reflect the analytical framework: technological, institutional, and behavioural elements.

Technological elements include measures of equipment age and efficiency, retrofit feasibility, specific energy consumption by process, renewable energy share, and infrastructure characteristics. Institutional elements capture regulatory approval delays, predictability of sustainability requirements, buyer audit practices, access to green or concessional finance, and uptake of policy incentives. Behavioural elements measure managerial risk perceptions, rigidity in decision-making processes, compliance culture, worker practices relating to energy use, and the intensity of training and awareness-building activities. Table 5 presents dimension-wise variables used in the study.

Table 5 Dimension-wise Variables Used in the Study

Dimension	Variable	Indicators	Measure
Infrastructure and Technological Lock-In	Energy Consumption Patterns	Monthly/Annual Energy Consumption	Numeric
		Energy Source Mix	Categorical
		Energy Expenditure	Numeric
	Machinery and Technology Use	Inventory of Production Machinery	Categorical
		Technological Dependency	Numeric
		Energy-Efficient Technologies	Categorical
	Production Infrastructure	Building Design and Materials	Categorical
		Renewable Energy Generation	Categorical
Institutional Lock-In	Regulatory and Policy Environment	Regulatory and Policy Environment	Categorical
		Access to Government Incentives	Categorical
		Regulatory Barriers	Categorical
	Supply Chain Pressures	Sustainability Requirements from Buyers	Categorical
		Role of Global Brands and Retailers	Categorical
	Financial and Market Constraints	Access to Financing	Categorical
		Perceived Risks and Returns	Categorical
Behavioural Lock-In	Perceptions and Attitudes	Beliefs about Cost-Effectiveness	Categorical
		Risk Perception	Categorical
		Cultural Attitudes	Categorical

(Table 5 contd.)

(Table 5 contd.)

Dimension	Variable	Indicators	Measure
	Decision-Making Processes	Roles and Responsibilities	Categorical
		Knowledge and Awareness	Categorical
		Decision Criteria	Categorical
	Workforce Behaviour	Training and Skill Development	Categorical
		Operational Practices	Categorical
		Behavioural Challenges	Categorical

Source: Authors' compilation.

For each dimension, indices are constructed to summarise the overall degree of lock-in. Standardised variables are combined using principal component analysis or factor scoring as the primary method. Equal-weighted averages of standardised scores are used as robustness checks. Formally, for firm i and indicator j:

$$z_{ij} = \frac{x_{ij} - \bar{x}_{ij}}{s_j}, \qquad DLI_i = \sum_{j \in D} w_j z_{ij}, \qquad \sum_j w_j^2 = 1$$

where DLI_i represents the lock-in index for dimension DΣ {T, I, B}. Control variables include product mix, firm size and age, capacity utilisation, export share, buyer segment, location, and prevailing energy prices.

6.2 Sampling Methodology for the Survey

6.2.1 Identification of Target Population

The target population comprised operational Readymade Garments (RMG) factories in Bangladesh with a minimum of 10 workers. This threshold ensured inclusion of factories with a basic level of formal structure relevant for assessing carbon lock-in dynamics.

Factory identification was based on the Mapped in Bangladesh (MiB) database, which provides comprehensive and up-to-date information on factory locations, types, and operational statuses. The MiB database served as the primary sampling frame. The survey firm extracted contact details from the database and verified eligibility through phone calls or visits, as necessary, to confirm both operational status and workforce size. Only factories meeting the defined criteria were included in the final sampling pool.

6.2.2 Sample Size

With a population of 3,320 operational RMG factories in Bangladesh, according to the Mapped in Bangladesh project, a sample size of 350 factories was determined, with a 5 per cent margin of error and a 95 per cent confidence level.

6.2.3 Sampling Method

The survey followed a stratified random sampling approach, using the MiB database as the sampling frame. In this method, the population of establishments was first divided into distinct, non-overlapping strata, and samples were then drawn randomly from each stratum.

The survey used the following stratification categories:

- **Factory type:** 5 categories which were Knit Garment, Woven Garment, Both Knit and Woven Garment, Sweater, and Knit Composite.
- **Size: 3 categories:** Small (up to 500 workers), Medium (500 to 2,500 workers), and Large (more than 2,500 workers).
- **Region:** 4 categories which were Dhaka, Gazipur, Narayanganj, and Chattogram.

Table 6 below shows the sampling distribution of RMG factories across different stratification categories.

Table 6 Sampling Distribution Across Different Stratification Categories

Location	Size	Knit Garment	Woven Garment	Knit x Woven	Sweater	Knit Composite	Location
Dhaka	Small	27	31	12	16	0	86
	Medium	8	22	4	5	1	40
	Large	1	5	1	0	1	8
Gazipur	Small	20	8	4	19	1	52
	Medium	15	21	5	11	4	56
	Large	3	6	1	2	4	16
Narayanganj	Small	29	1	2	2	1	35
	Medium	9	2	1	1	3	16
	Large	0	0	0	2	0	2
Chattogram	Small	4	6	11	3	0	24
	Medium	4	3	6	0	0	13
	Large	1	1	0	0	0	2
Total		**121**	**106**	**47**	**61**	**15**	**350**

Source: Authors' calculation.

6.2.4 Respondents Within Firm

Multiple respondents within each firm were engaged to capture different dimensions of carbon lock-in:

1. Technical and Maintenance Team or TDS provided information on energy consumption and machinery, including access to electricity, fuel oil, and gas purchase invoices.
2. Board of Directors members or Managing Directors provided insights on regulatory and institutional dimensions of lock-in.
3. Sustainability, EMS, or Compliance teams provided information on buyer-related obligations and requirements.
4. Production teams provided insights on training and worker attitudes.
5. Civil teams provided information on building materials and design-related energy efficiency aspects.

6.3 Empirical Strategy

The study employs quantile regression in order to capture heterogeneity across the distribution of carbon intensity. This approach is suitable for understanding whether lock-in factors exert different effects on low-intensity and high-intensity firms. Quantile regressions are estimated at the 25th, 50th, and 75th percentiles, with additional quantiles examined in robustness checks. Standard errors are obtained using bootstrapping with clustering at the buyer-group level.

Element-wise Quantile Models

For each dimension, individual elements are regressed on carbon intensity, conditioning on the indices of the other two dimensions.

1. **Technological elements with Institutional and Behavioural indices:**

$$Q\tau\,(y_i \mid T_i\,, ILI_i\,, BLI_i\,, X_i\,) = \alpha_\tau^{\,T} + T_i^T\beta_\tau^{\,T} + \gamma_\tau^{\,T}\, ILI_i + \delta_\tau^{\,T}\, BLI_i + X_i^T\, \theta_\tau^{\,T}$$

2. **Institutional elements with Technological and Behavioural indices:**

$$Q_\tau\,(y_i \mid I_i, TLI_i, BLI_i, X_i\,) = \alpha_\tau^{\,I} + I_i^T\, \pi_\tau^{\,I} + \gamma_\tau^{\,I}\, TLI_i + \delta_\tau^{\,I}\, BLI_i + X_i^T \theta_\tau^{\,I}$$

3. **Behavioural elements with Technological and Institutional indices:**

$$Q_\tau\,(y_i \mid B_i, TLI_i, ILI_i, X_i) = \alpha_\tau^{\,B} + B_i^T\, k_t^{\,B} + \gamma_\tau^{\,B} TLI_i + \delta_\tau^{\,B}\, ILI_i + X_i^T\, \theta_\tau^{\,B}$$

These models identify the marginal association of each set of elements while controlling for broader system-level lock-in effects.

Combined Quantile Model

A comprehensive model includes all elements across technological, institutional, and behavioural dimensions simultaneously:

$$Q_\tau\,(y_i \,|\, T_i, I_i, B_i, X_i) = \alpha_\tau^{\,ALL} + T_i^T\, \beta_\tau^{\,ALL} + I_i^T\, \pi_\tau^{\,ALL} + B_i^T\, \kappa_\tau^{\,ALL} + X_i^T\, \theta_\tau^{\,ALL}$$

In supplementary analysis, interaction terms such as $TLI_i \times ILI_i$, $TLI_i \times BLI_i$, and $ILI_i \times BLI_i$ are included to examine complementarities across dimensions.

6.4 Identification and Inference

The empirical design addresses concerns of reverse causality, as low-carbon investments may be targeted at high-intensity firms. To mitigate this risk, the study employs extensive controls, fixed effects, and where feasible lagged indicators. In addition, instrumental variable quantile regressions are explored using exogenous shocks such as eligibility for particular buyer sustainability programmes or policy incentives as instruments.

Multicollinearity is assessed using variance inflation factors, and variable selection methods such as LASSO-based quantile regression are employed as robustness checks. Results are reported in standardised coefficients to facilitate comparison across variables, and statistical inference accounts for multiple testing using false discovery rate adjustments.

6.5 Estimation Outputs

The analysis produces three sets of results:

1. Quantile regression estimates of element-level effects for each dimension, conditioning on indices of the other two dimensions.
2. A combined specification including all elements across the three dimensions.
3. Post-estimation variance decomposition to assess the contribution of each dimension to explaining the distribution of carbon intensity.

Counterfactual simulations are also presented, estimating the predicted change in carbon intensity at different quantiles if a one-standard-deviation improvement is achieved in selected elements or in combined policy bundles.

6.6 Robustness and Sensitivity

The robustness of the findings is assessed through several strategies. These include alternative definitions of carbon intensity (per unit of output versus per unit of value added), alternative methods of index construction (equal weights versus principal components), and estimations at additional quantiles. Results are also compared to those obtained from unconditional quantile regression and conventional OLS and median regression.

7 Quantitative Analysis: Descriptive Statistics

7.1 Distribution of Sample Factories by District, Size, and Factory Type

Table 7 presents the distribution of sampled factories across districts, factory sizes, and production types. The sample is geographically concentrated in major industrial hubs, particularly Dhaka and Gazipur, which together account for the majority of observations. Small and medium-sized factories dominate across all districts, reflecting the structure of Bangladesh's RMG sector, where large firms are relatively fewer in number.

In terms of factory type, knit and woven units are the most prevalent across districts, while sweater and knit composite factories appear in smaller numbers. Dhaka and Gazipur exhibit greater diversification in factory types compared to Chattogram and Narayanganj, indicating more complex production structures in the former locations. Overall, the table highlights substantial heterogeneity in factory characteristics across space and size, providing a strong basis for examining variations in emissions and energy-related outcomes.

Table 7 Distribution of the Surveyed Factories

District	Factory Size	Knit	Woven	Knit x Woven	Sweater	Knit Composite	Total
Chattogram	Small	5	6	11	3	-	25
	Medium	4	3	6	0	-	13
	Big	1	1	0	0	-	2
	Total	10	10	17	3	-	40
Dhaka	Small	27	31	14	16	0	88
	Medium	8	25	7	8	1	49
	Big	2	5	2	0	1	10
	Total	37	61	23	24	2	147
Gazipur	Small	20	13	6	19	1	59
	Medium	16	22	5	13	4	60
	Big	3	6	1	2	4	16
	Total	39	41	12	34	9	135
Narayanganj	Small	31	4	2	3	2	42
	Medium	10	3	1	4	3	21
	Big	0	0	0	1	0	1
	Total	41	7	3	8	5	64

Source: CPD RMG Carbon Lock-in Survey (2025).

7.2 Summary Statistics of Carbon Emissions by Factory Type

Table 8 reports summary statistics of carbon emissions disaggregated by factory type. The results indicate considerable variation in both average emission levels and dispersion across different production categories. Knit composite factories exhibit the highest mean emission levels, followed by woven factories, while sweater and knit factories show comparatively lower averages.

The large standard deviations across all factory types suggest significant within-category heterogeneity, pointing to differences in scale, technology, and energy practices even among factories with similar production orientations. The wide range between minimum and maximum values further underscores the uneven distribution of emissions in the sector, justifying the need for multivariate analysis to account for structural and behavioural differences.

Table 8 Emissions by Factory Type (tonne CO_2 equivalent)

Summary Statistics: N mean sd min max by (factory type)					
factorytype	N	Mean	SD	Min	Max
Knit	121	29.697	46.423	1.24	268.566
Knit Composite	15	105.703	105.703	2.065	308.848
Knit x Woven	47	31.284	31.284	1.804	238.214
Sweater	61	25.681	25.681	.805	244.578
Woven	106	50.334	50.334	1.083	256.868
Total	**350**	**38.89**	**38.89**	**.805**	**308.85**

Source: CPD RMG Carbon Lock-in Survey (2025).

7.3 Summary Statistics of Carbon Emissions by Factory Size

Table 9 summarises carbon emissions by factory size. A clear gradient emerges, with large factories exhibiting substantially higher average emissions than medium and small factories. While small factories account for the largest number of observations, their mean emission levels remain relatively low compared to larger firms.

The results suggest that scale effects play a critical role in determining emission intensity, likely reflecting higher production volumes, more energy-intensive machinery, and greater reliance on fossil fuel-based energy in larger establishments. At the same time, the presence of high maximum values among small factories indicates that size alone does not fully explain emission outcomes.

Table 9 Emissions by Factory Size (tonne CO_2 equivalent)

factorytype	N	Mean	SD	Min	Max
Big	199.75	52.261	52.261	81.669	308.848
Medium	46.076	23.592	23.592	16.405	122.219
Total	**38.89**	**56.87**	**56.87**	**.805**	**308.85**

Source: CPD RMG Carbon Lock-in Survey (2025).

The empirical results indicate that factory size is strongly associated with absolute carbon emissions, reflecting the interplay of production scale, machinery intensity, and energy sourcing practices. Large factories exhibit the highest mean emissions at approximately 200 tonnes of CO_2 equivalent, with relatively moderate variation, suggesting consistently high energy use across core production sections. Medium-sized factories report substantially lower mean emissions of 46 tonnes, while small factories have the lowest average emissions at approximately 12 tonnes. However, the maximum emission values observed among small factories reach as high as 248 tonnes, indicating that some smaller establishments can be highly energy-intensive depending on production volume, machinery efficiency, and operational practices. These patterns suggest that size alone does not fully account for emissions outcomes.

8 Empirics of Machinery-wise in Different Sections of RMG Factories

8.1 RMG Machinery Profile

The machinery data across process sections in RMG factories reveal a sector characterised by highly standardised production equipment, limited diversification in certain sections, and selective adoption of energy-efficient machines, all of which contribute to infrastructural carbon lock-in (Table 10).

Table 10 Machine Type Profile by Factory Type

Type	knitting	weaving	dyeing	washing	cutting	sewing	embroi-dery	printing	finish-ing	packlbl	oth
Knit	.058	.025	0.008	.041	.992	.975	.083	.083	.736	.298	0
Knit Composite	.8	.067	0.400	.467	.933	.933	.133	.133	.867	.467	0
Knit x Woven	.106	.043	0.000	.021	1	1	0	.064	.851	.34	0
Sweater	.705	.59	0.131	.459	.377	.902	.016	.033	.672	.262	.098
Woven	0	0	0.009	.057	.991	.991	.038	.028	.896	.481	0
Total	**.19143**	**.1229**	**.0486**	**.1457**	**.883**	**.966**	**.0543**	**.06**	**.783**	**.363**	**.017**

Source: CPD RMG Carbon Lock-in Survey (2025).

8.2 Cutting Section

Cutting machines are dominated by traditional knife types, including straight, round, and band knives, with adoption rates above 80 per cent across most factory types (Table 11). Computerised and laser cutting systems are adopted sporadically, with mean adoption rarely exceeding 15 per cent. The reliance on conventional cutting machines indicates that capital-intensive, high-efficiency technologies have not diffused widely, reflecting both high upfront costs and operational inertia. This contributes to carbon lock-in, as cutting processes remain energy-intensive and tied to legacy machinery.

Table 11 Cutting Section Machines

Type	straight knife	round knife	band knife	computerised knife	laser cutting	end cutter	notching machine	die cutting	drill macine	cutting oth
Knit	.917	.567	0.525	.142	.058	.225	.008	.008	.133	.042
Knit Composite	.929	.714	0.643	.5	.143	.357	0	0	0	.143
Knit x Woven	.979	.426	0.340	.064	.128	.128	.021	.021	.106	.021
Sweater	.826	.522	0.261	0	0	.13	.087	.043	0	0
Woven	.943	.543	0.571	.076	.067	.21	.01	.019	.114	.019
Total	**.922**	**.55**	**.508**	**.107**	**.065**	**.204**	**.019**	**.016**	**.104**	**.032**

Source: CPD RMG Carbon Lock-in Survey (2025).

8.3 Sewing Section

The sewing section exhibits the highest machine saturation across all factory types, particularly for single needle and overlock machines (Table 12). Adoption rates for single needle lockstitch machines exceed 95 per cent in most factory types, while overlock and flatlock machines are similarly widespread. Specialised machines such as auto pocket setters, seam sealing machines, and elastic inserters are adopted only by a minority of factories. This pattern indicates that production-critical, low-disruption machines dominate the sewing floor, reinforcing a path-dependent infrastructure. Even in composite or knit-woven factories, adoption of advanced or automation-heavy machines remains limited, suggesting that investments are focused on incremental productivity gains rather than transformative energy-efficient systems.

Table 12 Sewing Section Machines

Type	single needle lock-stitch	double needle lock-stitch	over-lock	flatlock	chain stitch	button-hole	button sewing	bartack sewing	zigzag sewing	blind stitch	feed off arm	cover stitch	elastic insert-ing	auto pocket setter	auto belt loop setter	seam sealing	placket attach-ing	sewing other
Knit	.966	.712	0.94	.941	.339	.881	.746	.746	.28	.076	.475	.068	.119	.008	.008	.017	.025	.008
Knit Composite	1	.643	1.00	1	.071	1	1	1	.429	0	.786	0	0	0	0	0	0	0
Knit x Woven	1	.936	0.97	.936	.447	1	1	.851	.426	.213	.617	.128	.021	.021	.021	.021	0	0
Sweater	.836	.291	0.90	.636	.073	.655	.691	.618	.036	.055	.109	.055	.018	0	.018	0	.018	.109
Woven	.981	.962	0.91	.657	.61	.952	.905	.886	.276	.19	.876	.114	.076	.105	.124	.048	.057	.019
Total	**.95**	**.751**	**.935**	**.805**	**.376**	**.891**	**.828**	**.787**	**.263**	**.118**	**.577**	**.086**	**.068**	**.044**	**.05**	**.027**	**.036**	**.024**

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 13 Embroidery Section Machines

Type	single head embroidery	multi head embroidery	computerised embroidery	sequin embroidery	chenille embroidery	cap embroidery	laser embroidery	embroidery oth
Knit	.4	.4	0.500	.2	.1	0	.1	0
Knit Composite	0	1	0.000	0	0	0	0	0
Sweater	0	0	0.000	0	0	0	0	0
Woven	0	.5	0.750	0	0	0	0	0
Total	**.263**	**.421**	**.474**	**.105**	**.053**	**.053**	**.105**	**0**

Source: CPD RMG Carbon Lock-in Survey (2025).

8.4 Finishing and Embroidery Sections

In the finishing section, steam irons, fusing machines, and heat-sealing machines are widely used, whereas specialised finishing equipment (thread trimmers, needle detectors, label cutters) show lower penetration (Table 13 and 14). Embroidery machines are less common overall, concentrated in multi-head or computerised types in knit composite and woven factories. Limited adoption of advanced embroidery and finishing technologies suggests that energy-intensive secondary processes have not been systematically modernised, further reinforcing partial infrastructural rigidity.

Table 14 Finishing Section Machines

Type	iron	steam iron	heat sealing	fusing	thread trimmer	needle detector	emb back trimmer	label cutter	finishing oth
Knit	.494	.809	0.472	.438	.067	.281	.011	.247	0
Knit Composite	.615	.846	0.462	.692	.077	.462	0	.231	.077
Knit x Woven	.725	.8	0.600	.5	.125	.5	0	.3	0
Sweater	.268	.829	0.268	.22	.049	.122	0	.073	.024
Woven	.547	.863	0.442	.611	.095	.326	0	.232	.011
Total	**.526**	**.832**	**.442**	**.474**	**.077**	**.307**	**.007**	**.226**	**.011**

Source: CPD RMG Carbon Lock-in Survey (2025).

8.5 Washing, Dyeing, and Printing Sections

Washing and dyeing machines demonstrate moderate adoption of industrial washing and drying technologies, with significant variation by factory type (Table 15-19). Sweater and knit factories show the highest adoption of industrial washing systems, whereas woven factories lag. Printing equipment remains highly concentrated in screen printing, roller printing, and digital printing for knit and composite factories, with minimal adoption of advanced printing technologies. The low diffusion of modern washing, dyeing, and printing equipment indicates that resource-intensive finishing processes continue to rely on conventional, high-emission machinery, sustaining carbon-intensive practices.

Table 15 Printing Section Machines

Type	screen print	roller print	digital print	sublime print	heat trans print	pad print	print oth
Knit	.5	.2	0.200	.2	.1	0	0
Knit Composite	1	0	0.000	0	0	0	0
Knit x Woven	.333	0	0.000	0	.333	0	0
Sweater	0	0	0.000	0	0	0	0
Woven	0	0	0.000	0	.333	0	0
Total	**.333**	**.048**	**.095**	**.048**	**.048**	**0**	**0**

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 16 Washing and Dyeing Section Machines

Type	ind Wash	hydro wash	drying	dyeing	stone wash	enzyme wash	ozone wash	wash oth
Knit	.6	0	0.200	.2	.2	0	0	0
Knit Composite	.286	.143	0.286	0	0	0	0	.143
Knit x Woven	1	1	1.000	0	0	0	0	0
Sweater	.929	.929	0.786	.036	0	0	0	.036
Woven	.167	.167	0.167	0	.167	0	.167	0
Total	**.686**	**.569**	**.529**	**.059**	**.059**	**0**	**0.02**	**0.059**

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 17 Packing and Labeling Section Machines

Type	packing	label print	barcode print	shrink wrap	tagging	packing oth
Knit	.472	.278	0.389	0	.083	0
Knit Composite	.857	.857	0.857	0	0	0
Knit x Woven	.188	.188	0.188	.063	0	0
Sweater	.438	.375	0.000	0	.063	0
Woven	.431	.333	0.314	.039	.078	0
Total	**.433**	**.323**	**.299**	**.031**	**.063**	**0**

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 18 Specialised Section Machines

Type	pleat	snap button	laser marking	velcro attach	belt loop cutter	riveting	special oth
Knit	.008	.149	0.000	.017	.025	0	0
Knit Composite	.333	.4	0.133	0	0	0	0
Knit x Woven	.021	.383	0.021	0	.021	0	0
Sweater	.033	.082	0.000	.049	.016	.033	.066
Woven	.019	.264	0.019	.085	.047	.009	.019
Total	**.031**	**.214**	**.014**	**.043**	**.031**	**.009**	**.017**

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 19 Effective Section Machines

Type	fabric spread	pattern plot	fabric inspect	roller heat	effect oth
Knit	.074	.041	0.107	.008	.008
Knit Composite	.533	.333	0.667	0	.067
Knit x Woven	.021	.043	0.170	.043	.021
Sweater	.016	.016	0.016	.016	0
Woven	.019	.057	0.151	.019	.009
Total	**.06**	**.051**	**.134**	**.011**	**.011**

Source: CPD RMG Carbon Lock-in Survey (2025).

Across all production sections, the data indicate that RMG factories exhibit limited diversity in machine types, with a small set of standardised machines accounting for the majority of operational activity. Core production processes such as sewing, cutting, and finishing continue to rely heavily on high-throughput, conventional equipment that has been in use for many years. In contrast, advanced, capital-intensive, or specialised machines, which have the potential to substantially reduce energy consumption, are adopted only by a minority of factories. Peripheral or modular energy-efficient technologies, including automatic sewing machines, LED lighting, and minor upgrades in finishing operations, are more widely used, but their impact on overall energy intensity is modest. From a carbon lock-in perspective, this machinery profile demonstrates two key dynamics. First, there is a structural dependence on existing energy-intensive equipment, which forms the backbone of factory operations and reinforces the persistence of fossil-fuel-based production systems. Second, the selective adoption of energy-efficient machines occurs primarily in areas where integration with existing processes is straightforward and low risk, rather than in core energy-intensive sections. Together, these dynamics produce strong infrastructural inertia, constrain the scope for comprehensive modernisation, and limit the capacity of RMG factories to undertake deep decarbonisation, even when incremental energy-saving measures are implemented.

9 Replacement Cost and Investment Need for Infrastructural Energy Efficiency

The distribution of average replacement costs reveals a clear pattern of size-dependent infrastructural lock-in within the RMG sector in Bangladesh. Replacement costs increase sharply with factory size across all production categories, indicating that larger factories face substantially higher capital requirements to transition to energy-efficient machinery. For instance, average replacement costs for large factories are several times higher than those for small factories, particularly in Knit Composite, Knit, and Woven segments. This suggests that capital intensity and accumulated investment in existing machinery create significant structural barriers to technological upgrading.

Across factory types, Knit Composite and Woven factories exhibit the highest replacement costs, while Sweater factories show comparatively lower costs (Table 20). This indicates heterogeneous levels of technological lock-in across subsectors, with more complex and integrated production processes associated with higher transition costs. Such variation reflects differences in production structure, energy use intensity, and machinery specialisation, which shape the difficulty of adopting low-carbon technologies.

These patterns point to several diagnostic gaps in the sector's decarbonisation pathway. First, the high replacement costs for medium and large factories suggest that current decarbonisation efforts may underestimate the scale of capital mobilisation required for technological transition. Second, the steep cost gradient by factory size implies unequal transition capacity, where smaller factories may upgrade more easily while larger producers remain locked into carbon-intensive capital stock. Third, the substantial costs observed in energy-intensive subsectors highlight the absence of targeted financial mechanisms and technological support for high-impact segments.

Table 20 Average Replacement Cost by Factory Type and Size

Factory Type	Factory Size	Average Replacement Cost (Crore BDT)
Knit	Small	9.76
	Medium	35.4
	Big	106
Knit Composite	Small	11.7
	Medium	34
	Big	128
Knit x Woven	Small	9.55
	Medium	28.7
	Big	73.6
Sweater	Small	2.04
	Medium	16.7
	Big	38
Woven	Small	10.2
	Medium	41.1
	Big	102

Source: CPD RMG Carbon Lock-in Survey (2025).

Overall, the evidence indicates that infrastructural lock-in in the sector is primarily driven by accumulated capital in existing machinery and the high financial burden of replacement. This lock-in represents a critical structural constraint on emissions reduction and underscores the need for policy interventions focused on financial access.

9.1 Sector-wide Replacement Cost Calculation

For assessing infrastructural lock-in, the cost of replacing the less efficient technology with energy efficient ones for RMG factories was calculated. From the survey, it was obtained the number of machines according to different functions along with their energy consumption, cost at purchase, hourly production and average age. The efficiency of the machinery was determined using Specific Energy Consumption (SEC) of a certain type of machine available at a factory, which refers to the ratio of power specification of the machine and the hourly processing amount it handles. This SEC is a measure of how energy efficient the machine is. The machines with the least SEC were identified across the sample for each functional category and their costs were marked as the unit replacement cost for that category. For calculating the replacement cost for an individual factory in the sample, the product of the unit replacement cost and the number of less efficient machines was taken for each category and aggregated. This provides us with gross replacement cost value for each factory. Moreover, the net replacement cost was also calculated where the annually depreciated current value of all less efficient machinery was subtracted from the replacement cost. The depreciation rate was considered to be 10 per cent across all calculations.

Given the self-weighting sample representing approximately 10 per cent of the RMG factory population, industry-level replacement investment was estimated using an expansion estimator by inflating sample totals by the inverse sampling fraction.

Sampling expansion estimator

$$\hat{T} = \sum_i w_i \, y_i$$

where:

- $w_i = 1/f$ (inverse sampling fraction)
- $f = 0.10$

The above-mentioned analysis finds that in gross terms, around BDT 83.36 thousand crore or USD 6.82 billion (BDT 122.24 to USD exchange rate) is required for the machinery of the RMG sector to replace the less energy-efficient machinery with the highest efficiency standard in the current industry.

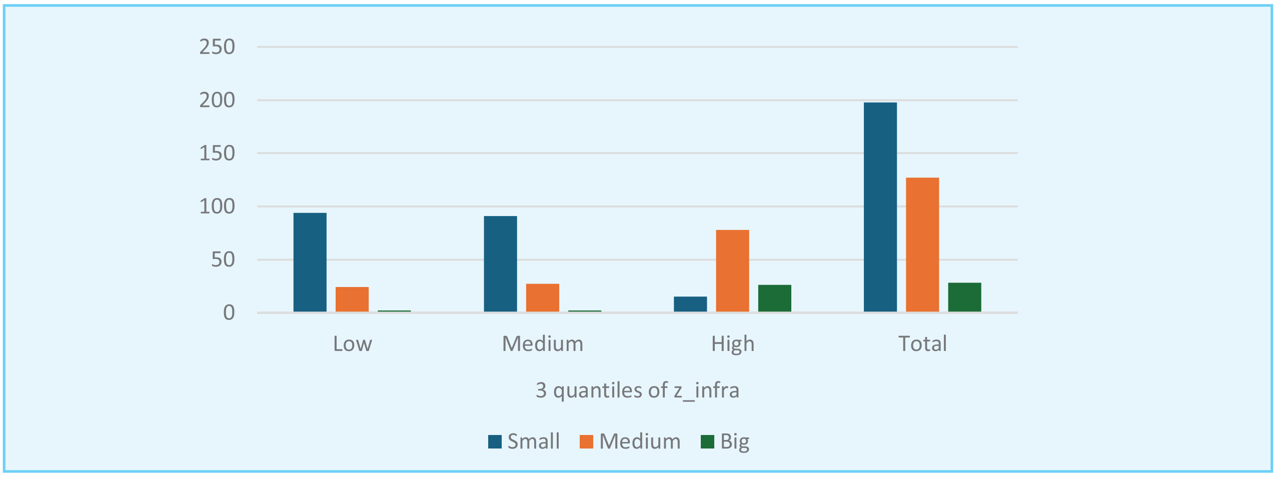
When we calculate the net amount of investment necessary subtracting the depreciated (at 10 per cent annual rate) value of the current less-efficient machinery, then the amount required is BDT 76.02 thousand crore or USD 6.22 billion.

10 Empirics of Carbon Lock-in Indices and Components

10.1 Infrastructural Lock-in by Factory Size

Figure 4 shows the distribution of infrastructural lock-in across factory sizes, categorised into low, medium, and high quantiles. Small factories are predominantly concentrated in the low and medium lock-in categories, while medium and large factories are disproportionately represented in the high lock-in group. This pattern suggests that larger firms are more likely to be tied to existing energy and production infrastructure, potentially limiting their flexibility to adopt cleaner technologies in the short run. The near-universal presence of large factories in the high lock-in category highlights the structural nature of infrastructural constraints within capital-intensive operations.

Figure 4 Infrastructural Lock-in Index According to Factory Size



Source: CPD RMG Carbon Lock-in Survey (2025).

The descriptive statistics reveal a complex pattern of infrastructural adjustment in the RMG sector, characterised by widespread adoption of incremental energy efficiency measures alongside persistent constraints on deeper structural transformation (Table 21). Together, these patterns point to a strong and enduring state of infrastructural lock-in.

Table 21 Renewable Energy Use by Factory Size in Percentage

factory size	N	Mean	SD	Min	Max
Big	29	1.069	1.889	0	7
Medium	143	1.175	2.549	0	10
Small	214	.687	1.747	0	10
Total	**350**	**.9**	**2.104**	**0**	**10**

Source: CPD RMG Carbon Lock-in Survey (2025).

Renewable energy use remains limited across all factory sizes. Average renewable energy utilisation is low, with small factories exhibiting the lowest mean levels and medium and large factories showing only marginally higher adoption (Table 21). The large standard deviations and wide ranges indicate that while a small number of factories have adopted renewable solutions at scale, the majority remain fully dependent on conventional energy sources. This uneven and generally low penetration of renewable energy suggests that existing production infrastructure continues to be anchored in fossil-fuel-based systems, limiting the scope for sector-wide decarbonisation.

Table 22 Monthly Energy Expenditure by Firm Size

factory size	N	Mean	SD	Min	Max
Big	29	4847490.3	1250827.742	2510602	7269618
Medium	143	1185904.3	625731.671	399790	3271820
Small	214	316564.51	851430.440	18470	8800000
Total	**350**	**998189.98**	**1468759.4**	**18470**	**8800000**

Source: CPD RMG Carbon Lock-in Survey (2025).

Energy expenditure varies sharply by factory size, reflecting differences in production scale and energy intensity (Table 22). Large factories incur substantially higher monthly energy costs than medium and small factories. However, higher energy expenditure does not correspond proportionately to higher renewable energy adoption. This disconnect suggests that even energy-intensive factories with greater potential cost savings face infrastructural and financial barriers that constrain transitions toward alternative energy systems. Instead, firms continue to absorb rising energy costs within existing infrastructural configurations.

Table 23 Type of Energy Efficient Machine Adopted

ee_machine_type 32. What was the type of Machines that were adopted as energy e	Freq.	Per cent	Cum.
Automatic sewing Machines	210	78.65	78.65
Boiler/steam system upgrades	16	5.99	84.64
Computerised embroidery Machines	1	0.37	85.02
Cutting Machines with low power consumption	26	9.74	94.76
Energy-efficient knitting Machines	7	2.62	97.38
Finishing/pressing Machines with energy-saving mode	7	2.62	100
Total	**267**	**100**	

Source: CPD RMG Carbon Lock-in Survey (2025).

Adoption of energy efficient machinery is relatively widespread, particularly among medium and large factories (Table 23). More than two thirds of surveyed factories report having adopted some form of energy efficient machinery, with adoption rates increasing by factory size. However, the composition of adopted machinery reveals an emphasis on low-disruption upgrades. Automatic sewing machines account for the vast majority of energy efficient machinery adopted, while investments in energy-intensive core systems such as boilers, steam systems, or knitting machines remain limited. This pattern indicates that factories prioritise efficiency improvements that can be integrated into existing production lines without requiring major infrastructural reconfiguration.

Table 24 below shows the use of energy efficient machines by size of factories

Table 24 Use of Energy Efficient Machine by Factory Size

factory size	ee_machine_use 31. Have you adopted any energy-efficient Machinery in the past f		
	No	Yes	Total
Small	85	129	214
	39.72	60.28	100.00
Medium	32	111	143
	22.38	77.62	100.00
Big	2	27	29
	6.90	93.10	100.00
Total	**119**	**267**	**386**
	30.83	69.17	100

Source: CPD RMG Carbon Lock-in Survey (2025).
Note: First row has frequencies and second row has row percentages.

The use of energy efficient practices is similarly widespread, with nearly four fifths of factories reporting the adoption of at least one energy-saving practice (Table 25-27). The most commonly reported practices include LED lighting, energy efficient compressors and HVAC systems, servo motors, and improved insulation. These measures are generally modular, low-risk, and compatible with existing factory layouts. More capital-intensive practices such as heat recovery systems and energy efficient boilers are less prevalent, particularly among smaller factories. This distribution reinforces the interpretation that infrastructural change is occurring at the margins rather than at the level of core energy systems.

Table 25 Percentage of Firms Using Energy Efficient Practices by Size

ee_practice 35. Do you use any energy-saving technologies?	Freq.	Per cent	Cum.
No	78	20.21	20.21
Yes	308	79.79	100
Total	**386**	**100**	

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 26 Energy Efficient Practices Used in Factories by Size

Type	LED lighting	Solar water heating	EE compres-sors and HVAC	Servo Motors	EE boilers	Heat recovery systems	Insulation improvem ents	BLDC Fan	Others
Big	.987	.173	0.380	.527	.307	.233	.22	.16	.007
Medium	.977	.323	0.554	.662	.454	.485	.446	.177	0
Small	1	.357	0.750	.607	.821	.536	.25	.214	0
Total	**0.986**	**0.256**	**0.491**	**0.598**	**0.42**	**0.363**	**0.313**	**0.174**	**0.004**

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 27 Overall Average Machine Age by factory size

factory size	N	Mean	SD	Min	Max
Big	27	3.557	2.788	0.600	13.787
Medium	126	3.104	2.336	0.222	17.292
Small	197	1.885	1.518	0.000	12
Total	**350**	**2.453**	**2.063**	**0.000**	**17.292**

Source: CPD RMG Carbon Lock-in Survey (2025).

Average machine age provides further insight into infrastructural rigidity (Table 27). Small and large factories report relatively low average machine ages, suggesting recent equipment upgrades. However, the exceptionally high variance in machine age among medium factories points to a coexistence of modern equipment and very old machinery within the same size category. This heterogeneity indicates uneven modernisation processes and highlights how legacy equipment continues to coexist with newer technologies, complicating coordinated transitions toward low-carbon production.

Table 28 Total Replacement Cost for Transition to Energy Efficient Machinery by Factory

factory size	N	Mean	SD	Min	Max
Big	27	983800000	635039254.083	287300000	3343000000
Medium	126	339900000	295091026.897	25980000	2377000000
Small	197	82798848	94247489.333	0	570900000
Total	**350**	**235800000**	**344700000**	**0.000**	**3340000000**

Source: CPD RMG Carbon Lock-in Survey (2025).

Replacement cost estimates underscore the scale of infrastructural barriers to transformation (Table 28). The total cost of replacing existing machinery with energy efficient alternatives increases sharply with factory size, reaching particularly high levels for large factories. Even for small factories, replacement costs represent a substantial capital burden relative to financial capacity. These high sunk costs create strong disincentives for premature replacement of existing equipment, reinforcing dependence on incumbent technologies and delaying transitions to cleaner systems.

Table 29 Whether the Factory Uses Natural Lighting

factory size	nat_lighting 38. Do you use natural lighting systems to reduce energy consumption		
	No	Yes	Total
Small	33	181	214
Medium	10	133	143
Big	1	28	29
Total	**44**	**342**	**386**

Source: CPD RMG Carbon Lock-in Survey (2025).

The widespread use of natural lighting and ventilation across factories of all sizes indicates that passive energy-saving design features are well integrated into production facilities (Table 29). While these measures contribute to reducing marginal energy demand, they do not alter the fundamental structure of energy supply or production technology. As such, they function as supplementary efficiency measures rather than drivers of infrastructural transformation. The table 30 below shows if the factories use natural ventilation to reduce their energy consumption.

Table 30 Whether the Factory Uses Natural Ventilation

factory size	nat_venti 39. Do you use natural ventilation systems to reduce energy consumption		
	No	**Yes**	**Total**
Small	25	189	214
Medium	8	135	143
Big	1	28	29
Total	**34**	**352**	**386**

Source: CPD RMG Carbon Lock-in Survey (2025).

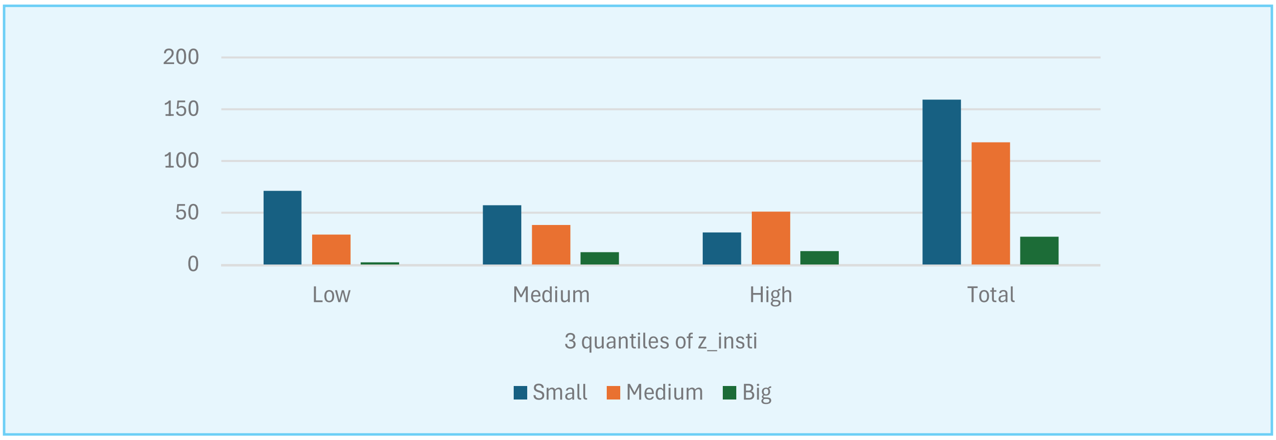
Taken together, the findings indicate that infrastructural lock-in in the RMG sector is maintained through a combination of low renewable energy penetration, selective adoption of low-disruption efficiency measures, high replacement costs, and continued reliance on legacy production systems. Factories have demonstrated a willingness to adopt incremental improvements that align with existing infrastructure but face significant constraints in undertaking capital-intensive changes that would fundamentally alter energy sourcing or production architecture. As a result, infrastructural adaptation remains partial and path-dependent, reinforcing the persistence of carbon-intensive production pathways despite growing awareness of energy efficiency and sustainability objectives.

10.2 Institutional Lock-in by Factory Size

Figure 5 presents institutional lock-in across factory sizes. Small factories are more evenly distributed across the three lock-in categories, though a plurality remains in the low and medium groups. In contrast, medium and large factories show a higher concentration in the high institutional lock-in category.

These findings indicate that larger firms may face more complex regulatory, contractual, or compliance-related constraints, which can shape their energy and environmental decision-making. The distribution suggests that institutional factors may interact with firm size to influence transition dynamics (Figure 5).

Figure 5 Institutional Lock-in Index According to Factory Size



Source: CPD RMG Carbon Lock-in Survey.

The descriptive evidence indicates a governance environment in the RMG sector in which relatively high levels of reported policy compliance coexist with limited structural change in energy infrastructure (Table 31). This combination suggests the persistence of infrastructural lock-in rather than a transition towards low-carbon production systems.

Table 31 Extent of Compliance With Policy

factory_size	policy_compliance 47. To what extent does your factory comply with these policie			
	Fully	Not at all	Partially	Total
Small	83	5	86	174
Medium	89	1	43	133
Big	22	0	7	29
Total	**194**	**6**	**136**	**336**

Source: CPD RMG Carbon Lock-in Survey (2025).

Across factory sizes, most respondents report either full or partial compliance with existing energy and environmental policies (Table 31). Medium and large factories, in particular, exhibit higher levels of full compliance. However, this compliance appears to be largely procedural in nature. The continued reliance on fossil-fuel-based energy systems alongside reported compliance indicates that policy adherence has not translated into substantive modifications in production infrastructure or energy sourcing. As a result, institutional interventions have had limited effectiveness in reducing emissions or altering underlying energy configurations.

Table 32 Factories Which Received Government Incentive for Renewable Energy Use by Size

factory size	govt_incentive_received 49. Have you received any government-provided financial		
	No	Yes	Total
Small	147	67	214
	68.69	31.31	100.00
Medium	83	60	143
	58.04	41.96	100.00
Big	13	16	29
	44.83	55.17	100.00
Total	**243**	**143**	**386**
	62.95	37.05	100

Source: CPD RMG Carbon Lock-in Survey (2025).
Note: First row has frequencies and second row has row percentages.

Access to government incentives for renewable energy adoption varies significantly by factory size (Table 32). Large factories report the highest incidence of receiving incentives, while a substantial majority of small factories report no access to such support. Given that small factories account for a large share of total production units, this uneven distribution of incentives reinforces infrastructural lock-in among smaller firms. Limited financial capacity and restricted access to concessional support constrain their ability to invest in new energy technologies, leading to continued dependence on existing gas-based and grid-connected systems.

Table 33 Whether Factories Faced Regulatory Delay Seeking Approvals for Renewable Energy Projects

factory_size	reg_delay 51. Have you experienced regulatory delays when seeking approvals for		
	No	Yes	Total
Small	174	40	214
Medium	117	26	143
Big	24	5	29
Total	**315**	**71**	**386**

Source: CPD RMG Carbon Lock-in Survey (2025).

Regulatory delays further weaken the effectiveness of institutional frameworks (Table 33). Although only a minority of factories report experiencing regulatory delays, the nature of these delays highlights important institutional constraints. Most reported delays arise from complex bureaucratic procedures and limited communication with regulatory agencies. In a sector characterised by narrow profit margins and tight delivery timelines, such procedural uncertainty increases the perceived cost of renewable energy investments. Consequently, firms are more likely to maintain existing energy systems rather than undertake investments that involve prolonged approval processes.

Table 34 Nature of Regulatory Delays Faced

reg_delay_nature 52. If yes, please specify the nature of these delays	Freq.	Per cent	Cum.
Bribery-Related Reasons for Delays	8	11.27	11.27
Complex Bureaucratic Procedures	44	61.97	73.24
Delays in Utility Connection or Licensing	3	4.23	77.46
Financial Approval Bottlenecks	1	1.41	78.87
Lake of Policy and Directions	1	1.41	80.28
Limited Outreach and Poor Communication	11	15.49	95.77
Shortage of Skilled Personnel in Agencies	1	1.41	97.18
Stringent Compliance and Documentation Requirements	1	1.41	98.59
bribery-Related Reasons for Delays	1	1.41	100
Total	**71**	**100**	

Source: CPD RMG Carbon Lock-in Survey (2025).

Buyer-imposed sustainability requirements are more prevalent among medium and large factories, reflecting their closer integration into international supply chains (Table 34). These requirements influence firm behaviour primarily through reputational considerations, long-term order security, and the avoidance of buyer exit. However, buyer engagement rarely includes direct financial or technical support. The limited incidence of buyer co-financing or technical assistance suggests that buyer-driven governance encourages incremental compliance rather than fundamental changes in energy infrastructure. As a result, factories tend to prioritise visible efficiency measures over more capital-intensive energy transitions.

Table 35 Summarises if the buyers impose any specific sustainability related requirements to the factory owners.

Table 35 Whether Buyer Imposes Specific Sustainability Related Requirements

factory size	buyer_req 53. Do your buyers impose specific sustainability requirements related		
	No	Yes	Total
Small	131	83	214
Medium	46	97	143
Big	3	26	29
Total	**180**	**206**	**386**

Source: CPD RMG Carbon Lock-in Survey (2025).

Financing behaviour further illustrates the persistence of infrastructural lock-in (Table 36-39). A considerable proportion of factories report seeking financing for energy efficiency or low-carbon technologies, yet acceptable payback periods differ markedly by factory size. Small factories exhibit strong preferences for short payback horizons, while large factories are more willing to accept longer recovery periods. These differences reflect variations in risk tolerance and access to capital, which in turn shape technology adoption decisions. Energy technologies with longer payback periods remain unattractive to smaller firms, reinforcing reliance on existing infrastructure.

Table 36 Influence of Buyer Requirement on Decisions

buyer_req_influence 55. How do these buyer requirements influence your decisions	Freq.	Per cent	Cum.
Attract Long Term Orders, Brand Reputation	1	0.49	0.49
Attract Long-Term Orders	126	61.46	61.95
Attract Long-Term Orders, No Risk Losing Key Export Clients	1	0.49	62.44
Brand Reputation	1	0.49	62.93
Brand reputation	31	15.12	78.05
Cost efficiency, No Harm on Environment	2	0.98	79.02
No Risk Losing Key Export Clients	39	19.02	98.05
No Risk Losing Key Export Clients, Attract Long-Terms Orders	4	1.95	100
Total	**205**	**100**	

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 37 Tabulation of Factory_size buy_sup

factory_size	buyer_support 56. Have any buyers offered support (e.g., co-financing, technical		
	No	Yes	Total
Small	209	5	214
Medium	133	10	143
Big	29	0	29
Total	**371**	**15**	**386**

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 38 Whether Factories Sought EE or Low Carbon Tech Financing

factory_size	financing_sought 59. Have you sought financing for energy efficiency or low-carb		
	No	Yes	Total
Small	138	76	214
Medium	65	78	143
Big	15	14	29
Total	**218**	**168**	**386**

Source: CPD RMG Carbon Lock-in Survey (2025).

Table 39 Acceptable Payback Period of Adopting Energy Efficient Technology by Size

factory size	N	Mean	SD	Min	Max
Big	29	5.379	0.622	5	7
Medium	143	4.259	1.019	2	10
Small	214	2.318	0.614	1	5
Total	**350**	**3.266**	**1.346**	**1**	**10**

Source: CPD RMG Carbon Lock-in Survey (2025).

The distribution of acceptable payback periods for energy efficient technology adoption reveals pronounced heterogeneity across factory sizes, reflecting structural differences in financial capacity and risk tolerance (Table 39). Large factories report the longest acceptable payback periods, with a mean of 5.38 years and a narrow dispersion, indicating a relatively stable willingness to engage in longer-term investment planning. Medium-sized factories exhibit a moderate mean acceptable payback period of 4.26 years, alongside greater variability, suggesting mixed investment horizons within this group. In contrast, small factories display markedly shorter acceptable payback periods, with a mean of 2.32 years and limited variation. This pattern indicates strong short-termism among smaller firms, where liquidity constraints and limited access to long-term financing restrict the feasibility of investments with delayed returns.

Table 40 Greatest Financial Risk of Investing in Sustainable Technology

invest_risk 62. What do you perceive as the greatest financial risk of investing	Freq.	Per cent	Cum.
Exchange rate fluctuations for imported equipment	5	1.30	1.30
High upfront costs compared to expected savings	62	16.06	17.36
Lack of stable buyer commitments for green products	22	5.70	23.06
Limited resale value of technology if project fails	8	2.07	25.13
Uncertain return on investment (ROI)	232	60.10	85.23
Unclear or changing government policy/regulations	17	4.40	89.64
Volatility in global apparel demand affecting cost recovery	40	10.36	100
Total	**386**	**100**	

Source: CPD RMG Carbon Lock-in Survey (2025).

Perceptions of financial risk further reinforce these investment preferences (Table 40). A dominant majority of respondents identify uncertainty regarding return on investment as the greatest financial risk associated with sustainable technology investments. This concern substantially outweighs other risks, including high upfront costs, volatility in global apparel demand, or policy uncertainty. The prominence of return uncertainty suggests that firms are less constrained by awareness of potential long-term benefits and more by doubts regarding the reliability and timing of financial returns in a volatile market environment. Risks associated with unstable buyer commitments and demand fluctuations further highlight the exposure of factories to external market dynamics, which complicates cost recovery for capital-intensive investments.

Table 41 Views on Profitability of Adopting Energy Efficient Technology

ee_profitability 63. What are your views on the profitability of adopting energy	Freq.	Per cent	Cum.
Break-even, neither profitable nor unprofitable	70	18.13	18.13
Highly profitable, with strong long-term savings	179	46.37	64.51
Moderately profitable, but savings are gradual	104	26.94	91.45
Uncertain/depends on external factors (buyer demand, incentives, etc.)	16	4.15	95.60
Unprofitable, costs outweigh savings	17	4.40	100
Total	**386**	**100.00**	

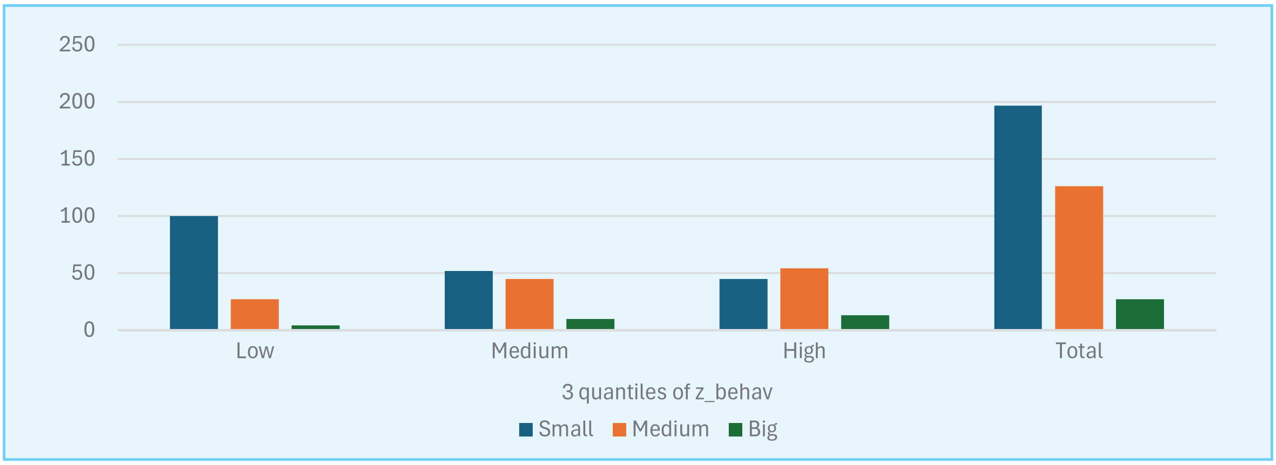
Source: CPD RMG Carbon Lock-in Survey (2025).

Despite these risk perceptions, views on the profitability of adopting energy efficient technologies are largely positive (Table 41). Nearly three quarters of respondents consider such investments to be either highly or moderately profitable, indicating broad recognition of their long-term economic potential. However, a substantial share of respondents also emphasises gradual savings or break-even outcomes, reflecting a cautious interpretation of profitability that is sensitive to time horizons and external conditions. Only a small minority view energy efficiency investment as unprofitable, suggesting that negative assessments of economic viability are not the primary barrier to adoption.

10.3 Behavioural Lock-in by Factory Size

Figure 6 reports behavioural lock-in across factory sizes. Small factories are more likely to fall into the low behavioral lock-in category, whereas medium and large factories are increasingly represented in the high lock-in group. This pattern implies that entrenched management practices, organisational routines, and risk perceptions may be stronger among larger firms, potentially slowing the adoption of energy-efficient or low-carbon practices. The gradual shift from low to high behavioural lock-in with increasing factory size highlights the importance of firm-level decision-making structures in shaping environmental outcomes.

Figure 6 Behavioural Lock-in Index According to Factory Size



Source: CPD RMG Carbon Lock-in Survey (2025).

The descriptive evidence suggests that behavioural lock-in in the RMG sector is comparatively weaker than infrastructural lock-in, although it remains present in specific organisational and operational practices (Table 42). Overall, factories exhibit relatively high levels of awareness, training provision, and stated openness toward energy efficiency and low-carbon technologies. However, these favourable behavioural indicators have not consistently translated into sustained changes in production routines or energy outcomes.

Table 42 Energy Efficiency Related Training Provided to Factories by Size

factory size	training_provided 72. Do you provide formal training to workers on energy-effici		
	No	Yes	Total
Small	53	161	214
	24.77	75.23	100
Medium	13	130	143
	9.09	90.91	100
Big	1	28	29
	3.45	96.55	100
Total	**67**	**319**	**386**
	17.36	82.64	100

Source: CPD RMG Carbon Lock-in Survey (2025).
Note: First row has frequencies and second row has row percentages.

Across all factory sizes, a substantial majority report providing formal energy efficiency related training to workers. Training provision increases with factory size, with nearly all large factories and over 90 per cent of medium factories reporting such initiatives. Even among small factories, more than three quarters report offering training. This widespread provision of training suggests that basic awareness of energy efficiency practices is well established within the sector, and that lack of training alone does not constitute a primary constraint on behavioural change.

Despite the prevalence of training, self-reported knowledge of low-carbon technologies remains concentrated at moderate levels. Most respondents across factory sizes classify their knowledge as moderate, while relatively few report high or very high levels of familiarity with relevant technologies (Table 43). Small factories display a higher concentration of low and very low knowledge compared to medium and large factories, indicating uneven diffusion of technical understanding within the sector. This pattern suggests that training may focus on operational efficiency rather than deeper technological or strategic aspects of low-carbon transition.

Table 43 Level of Knowledge Regarding Low-carbon Technologies Relevant to the RMG Sector

factory size	knowledge					
	Very Low	Low	Moderate	High	Very High	Total
Big	43	30	111	10	3	197
Medium	45	16	55	7	3	126
Small	12	1	11	1	2	27
Total	**100**	**47**	**177**	**18**	**8**	**350**

Source: CPD RMG Carbon Lock-in Survey (2025).

Organisational openness towards adopting new energy efficient technologies further reflects a mixed behavioural environment (Table 44). While a significant share of respondents describes their organisations as very open or somewhat open, a similarly large proportion report a neutral stance. Neutrality, rather than resistance, appears to be the dominant behavioural posture. This indicates that while outright opposition to new technologies is rare, proactive internal momentum for change is also limited. In such a context, adoption decisions are likely to be triggered by external pressures rather than internal initiative.

Table 44 Openness of Organisation Towards Adopting EE Technology

cultural_openness 67. How open is your organisation to adopting new technologies	Freq.	Per cent	Cum.
Neutral	143	37.05	37.05
Somewhat Open	86	22.28	59.33
Somewhat Resistant	13	3.37	62.69
Very Open	143	37.05	99.74
Very Resistant	1	0.26	100
Total	**386**	**100**	

Source: CPD RMG Carbon Lock-in Survey (2025).

Behavioural challenges related to implementation practices provide additional insight into the persistence of behavioural lock-in (Table 45). More than half of the respondents report challenges associated with inconsistent monitoring or enforcement of energy-saving rules within factories. This finding points to a gap between formal policies or stated commitments and day-to-day operational discipline. Energy efficiency measures may be introduced, but their sustained application is weakened by limited managerial follow-through and competing production priorities.

Table 45 What Behavioural Challenges Do You Face When Implementing Energy-saving Behavioural Challenge

Type	worker reluct	workers unaware	low incentive	inconsis mon rules	middle manage resist	trad method reliance	ee less prod
Big	.71	.76	0.62	.54	.35	.39	.16
Medium	.74	.76	0.61	.67	.46	.41	.33
Small	.74	.85	0.74	.59	.48	.44	.33
Total	**0.72**	**0.76**	**0.63**	**0.59**	**0.41**	**0.41**	**0.24**

Source: CPD RMG Carbon Lock-in Survey (2025).

Concerns that energy-saving measures could reduce productivity are reported by a smaller but non-negligible share of respondents. Although the majority do not perceive productivity losses as a major barrier, the presence of such beliefs among more than one fifth of factories indicates lingering skepticism regarding the compatibility of energy efficiency and production performance. In a sector driven by tight delivery deadlines and output targets, even minority perceptions of productivity risk can discourage consistent implementation of energy-saving practices.

11 Econometric Estimation on Results on Emission by Different Carbon Lock-in Indices and Components

11.1 Econometric Analysis

The results from multiple regression specifications examining the determinants of carbon emissions at the factory level is presented in the following analysis (Table 46). The models sequentially incorporate technological, financial, infrastructural, institutional, and behavioural factors to assess their association with emissions.

Across specifications, the inclusion of different lock-in indices and control variables allows for a comprehensive assessment of how structural and behavioral constraints relate to emission outcomes. While coefficient magnitudes and statistical significance vary across models, Table 46 as a whole illustrates the multifaceted nature of emission determination in the industrial sector. A detailed interpretation of individual coefficients and mechanisms is provided in a subsequent section.

Table 46 Quartile Regression Results on Emission by Different Carbon Lock-in Indices and Components

	(1) emission	(2) emission	(3) emission	(4) emission
Renewable Energy Use	1.350 (1.333)			
Energy Expenditure	0.000*** (122.327)			
Use of Energy-Efficient Machinery	0.595 (0.539)			
Number of Energy-Efficiency Practices Adopted	-0.104 (-0.328)			
Average Age of Machinery	-0.624*** (-3.140)			
Total Machine Replacement Cost	0.000*** (6.151)			
Use of Natural Lighting	0.498 (0.252)			
Use of Natural Ventilation	1.704 (0.723)			
Institutional Lock-in Index	0.215 (0.364)		-2.310 (-0.623)	-4.591 (-1.425)
Behavioural Lock-in Index	-0.238 (-0.430)	-0.478 (-0.138)		2.451 (0.763)
Infrastructural Lock-in Index		13.425*** (4.555)	21.219*** (6.951)	20.692*** (7.743)
Policy Compliance		2.124 (1.039)		
Government Incentives		0.934 (0.177)		

(Table 46 contd.)

(Table 46 contd.)

	(1) emission	(2) emission	(3) emission	(4) emission
Regulatory Delays		1.588 (0.270)		
Buyer Requirements		3.456 (0.605)		
Buyer Support		-7.178 (-0.611)		
Sought Financial Support		-5.901 (-0.931)		
Perceived Energy-Efficiency Payback Period		13.347*** (7.651)		
Perceived Risk of Energy-Efficiency Investment		0.463 (0.160)		
Perceived Profitability of Energy-Efficiency Investment		-0.146 (-0.100)		
Energy-Efficiency Training			2.522 (0.301)	
Knowledge of Energy-Efficiency Practices			4.133 (1.326)	
Organisational Openness to Change			4.264 (1.154)	
Inconsistent Monitoring and Regulatory Rules			0.177 (0.035)	
Perception that Energy Efficiency Reduces Productivity			-1.077 (-0.178)	
Constant	-1.626 (-0.946)	-20.033 (-1.642)	-4.824 (-0.249)	21.715*** (9.827)
N	308	308	308	308

Source: Authors' Analysis.

11.2 Robustness Tests: Brusch-Pagan Test for Heteroscedasticity

The Breusch–Pagan/Cook–Weisberg test for heteroskedasticity was conducted (Table 47). The test strongly rejects the null hypothesis of constant variance, indicating the presence of heteroskedasticity in the regression residuals.

This finding suggests that the variability of emission outcomes differs systematically across observations, likely reflecting heterogeneity in factory size, technology, and operational characteristics. Accordingly, robust inference methods are necessary to ensure the reliability of the estimated results presented in the econometric analysis. This heterogeneity provides support for the use of quantile regression approaches utilised in this study.

Table 47 Breusch-Pagan Test for Heteroscedasticity

Breusch–Pagan/Cook–Weisberg test for heteroskedasticity
Assumption: Normal error terms
Variable: Fitted values of emission
H0: Constant variance
chi2(1) = 830.88
Prob > chi2 = 0.0000

Source: Authors' Analysis.

11.3 Determinants of Carbon Lock-In

Infrastructural and Technological Determinants: Model (1) shows that renewable energy use has no statistically significant association with emissions. Energy expenditure is strongly and positively associated with emissions at the 1 per cent level, indicating that higher levels of energy use are directly linked to higher emissions. Among the technological variables, average machine age is negatively associated with emissions at the 1 per cent level, which suggests that older machines may operate at lower output or lower energy intensity. Total replacement cost is positive and highly significant, meaning firms with higher cost to replace existing infrastructure tend to report higher emissions. Other factors, such as the use of energy-efficient machinery, the number of energy-efficient practices, natural lighting, and natural ventilation, show no significant effects. In Models (2) through (4), the infrastructural lock-in index becomes consistently positive and highly significant. This indicates that higher emissions emerge from greater infrastructural rigidity.

Institutional Determinants: Model (2) introduces institutional variables. None of the institutional factors, including political competition, government incentives, regulatory delays, buyer requirements, buyer support, or access to finance, show statistically significant effects on emissions. The institutional lock-in index also remains statistically insignificant across all models, suggesting that institutional constraints do not have a consistent association with emission levels. One institutional variable that does matter is the energy-efficiency payback period. This variable is strongly positive and significant at the 1 per cent level, indicating that firms perceiving longer payback periods for energy-efficient investments tend to have higher emissions.

Behavioural Determinants: Model (4) incorporates behavioural indicators. Training, knowledge, cultural openness, perceptions of inconsistent monitoring, and beliefs about reduced productivity from energy efficiency all show no significant associations with emissions. The behavioural lock-in index is also insignificant in all models. These results indicate that behavioural factors do not have a measurable influence on emission outcomes within the sample.

12 Governance and Institutional Context

Although the empirical analysis finds limited direct institutional and behavioural effects on firm-level emissions, governance structures remain critical for interpreting these results. The absence of statistically significant institutional impacts should not be read as institutional irrelevance; rather, it reflects a governance environment in which policies, incentives, and enforcement mechanisms are either weakly operationalised or insufficiently aligned to influence production-level energy decisions. This section examines how the configuration of actors, coordination mechanisms, and policy frameworks contributes to persistent carbon-intensive outcomes in the RMG sector.

12.1 Mapping of Regulatory, Financial, and Policy Stakeholders

Decarbonisation outcomes in Bangladesh's RMG sector are shaped by a fragmented ecosystem of regulatory, financial, and market-based actors, each exerting partial and often uncoordinated influence over energy-related decisions. At the national level, energy policy is governed primarily by the Ministry of Power, Energy and Mineral Resources and its associated agencies, including the Power Division and SREDA. These institutions are responsible for electricity pricing, supply planning, renewable energy targets, and energy efficiency initiatives. However, their mandates are largely supply-oriented and macro-focused, with limited tailoring to the specific technological and operational realities of export-oriented manufacturing sectors such as RMG. Under the SREDA Act, energy-intensive industries, including RMG sector have been assigned as 'designated' consumers. But a national level programme to implement energy efficiency-related improvements does not exist. Only a limited number of industries have full energy audit reports that are available. ESCO-based energy efficiency measures are also nonexistent. There is limited capacity for these industries to implement recommendations from energy audits (I. Hossain et al., 2017).

Environmental regulation falls under the Department of Environment, which is tasked with monitoring emissions and enforcing compliance with environmental standards. In practice, regulatory oversight of energy use and carbon emissions within industrial facilities remains limited, with enforcement focused more on localised pollution and compliance documentation rather than systemic reductions in energy-related emissions (Tang et al., 1998). In the RMG sector, this is reflected in the continued operation of captive gas-based generators and diesel-powered backup systems in many knit, woven, and washing units, despite their significant contribution to carbon emissions.

Financial stakeholders add another layer of influence. Commercial banks, public financial institutions, and development partners provide financing for industrial investment, including occasional support for energy efficiency and renewable energy projects. Yet access to such financing is uneven and often constrained by high collateral requirements, limited familiarity with clean energy technologies, and perceived project risks (Islam, 2014). As a result, energy investments are frequently guided by short-term cost considerations rather than long-term emissions performance. In the RMG industry, smaller and mid-sized factories frequently face difficulties in securing loans for rooftop solar installations or high-efficiency boilers, as lenders remain uncertain about technology performance and repayment timelines. As a result, energy investments are frequently guided by short-term cost considerations rather than long-term emissions performance.

International buyers and brands constitute a distinctive governance actor in the RMG sector. Through compliance audits, sustainability reporting requirements, and buyer codes of conduct, they exert considerable influence over factory practices. However, buyer-driven governance tends to prioritise visible compliance outcomes, such as certifications or efficiency benchmarks, rather than deep structural changes in energy sourcing or capital stock replacement (Md Miraj Hossen & Md Faisal Islam, 2025). Industry associations, including the BGMEA and BKMEA, act as intermediaries between firms, buyers, and the state, but their role in coordinating sector-wide decarbonisation strategies remains largely advisory rather than directive. In practice, RMG factories often undertake incremental measures such as LED lighting upgrades or limited machinery retrofits, while postponing more fundamental transitions such as replacing gas-fired boilers with electrified systems or renewable energy–based alternatives. Industry associations, including BGMEA and BKMEA, act as intermediaries between firms, buyers, and the state, but their role in coordinating sector-wide decarbonisation strategies remains largely advisory rather than directive.

12.2 Institutional Coherence, Enforcement Capacity, and Incentive Alignment

The econometric insignificance of most institutional variables reflects a broader lack of institutional coherence across energy, industrial, and environmental governance domains (Moazzem & Shazeed, 2025). Policy objectives related to export competitiveness, employment generation, and energy affordability often take precedence over emissions reduction. As a result, decarbonisation goals are weakly embedded within industrial policy, limiting their influence on firm-level decision-making.

Coordination mechanisms between key institutions remain underdeveloped. Energy policy institutions, environmental regulators, and industrial authorities operate within largely siloed frameworks, reducing the scope for integrated planning or joint accountability (M. Hossain, 2018). This fragmentation weakens the transmission of policy signals to firms, contributing to a situation in which institutional interventions fail to translate into measurable emission outcomes. In the RMG sector, this is evident in the absence of coordinated mandates linking factory energy audits, environmental clearance renewals, and access to green financing, resulting in limited reductions in sector-wide carbon emissions despite multiple policy initiatives. As a result, many garment manufacturers continue to favour captive gas generation, or older boiler technologies based primarily on fuel cost considerations rather than regulatory requirements.

Enforcement capacity further constrains institutional effectiveness. Monitoring energy efficiency measures and emissions is sporadic, penalties for non-compliance are limited, and regulatory follow-up is often weak. Consequently, firms face minimal regulatory pressure to internalise the environmental costs of carbon-intensive production. In such a context, institutional rules function more as background conditions than as binding constraints on operational choices.

Incentive alignment represents a critical weakness. Existing incentive schemes for renewable energy or energy efficiency are often characterised by administrative complexity, limited scale, and short planning horizons. The strong and positive association between perceived energy-efficiency payback periods and emissions underscores the dominance of financial calculus in firm behaviour. Within the RMG sector, factory owners frequently defer investments in rooftop solar systems or high-efficiency process equipment when expected payback periods exceed three to five years, even when such investments could deliver substantial emissions reductions. Without credible mechanisms to reduce upfront investment costs, mitigate risk, or shorten payback horizons, institutional incentives fail to alter firms' reliance on carbon-intensive energy systems.

12.3 Policy Barriers and Institutional Inertia

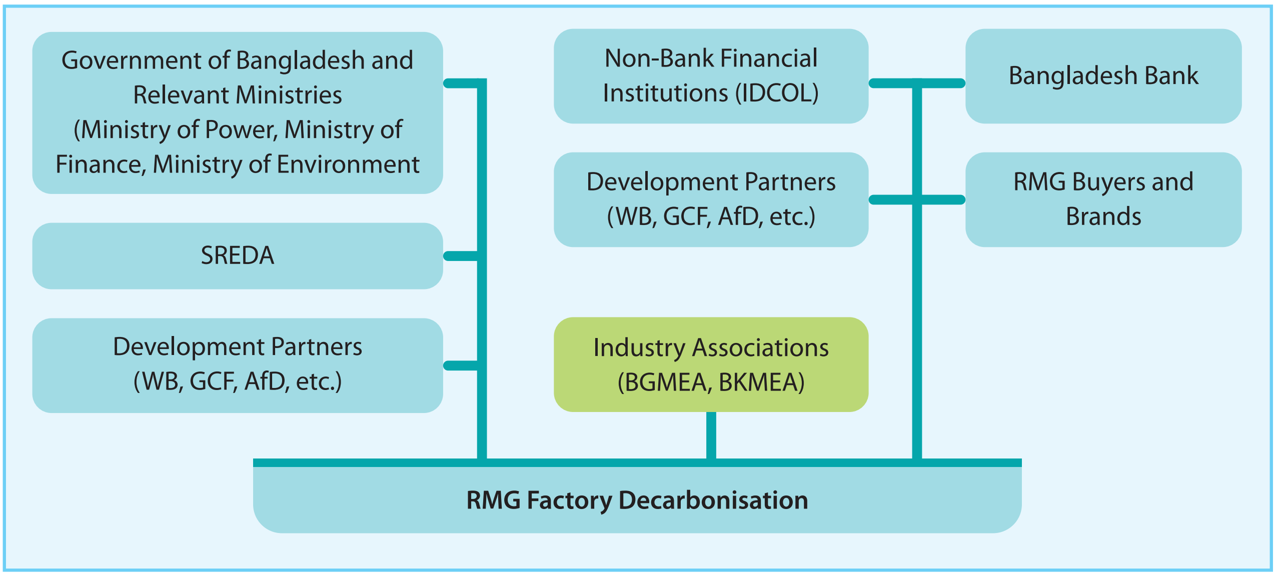
Policy barriers in the RMG sector are less about explicit resistance to decarbonisation and more about institutional inertia embedded in existing governance arrangements (Figure 5). In Bangladesh's garment industry, fragmented oversight among SREDA, the Department of Environment, utilities, and industrial authorities have resulted in parallel approval processes for energy audits, environmental clearances, and grid interconnection, with limited coordination across agencies (M. Hossain, 2018;). Frequent policy revisions, unclear eligibility criteria for incentives, and delays in approvals create uncertainty that discourages firms from undertaking long-term investments in low-carbon technologies. This uncertainty is particularly consequential in a sector characterised by thin margins, tight delivery schedules, and high sensitivity to cost fluctuations. For RMG exporters operating on buyer-negotiated prices, even modest increases in energy-related capital expenditure can erode competitiveness, reinforcing preferences for low upfront-cost energy solutions (Ahmed & Nathan, 2014).

Institutional inertia is also reinforced by the continued normalisation of fossil-fuel-based energy as the default option for industrial production. In practice, most RMG factories continue to rely on grid electricity backed by captive gas generators and gas-fired boilers for dyeing and washing operations, reflecting long-standing infrastructure investments and fuel supply arrangements (Rahman et al., 2022). Electricity tariffs, captive generation arrangements, and infrastructure planning implicitly favor conventional energy sources, while renewable and advanced efficiency solutions are treated as supplementary or optional. For instance, rooftop solar installations in garment factories are commonly pursued only when supported by donor-funded pilots or buyer-led initiatives, rather than as a core component of factory energy planning (SREDA, 2021; GIZ, 2022). This reinforces infrastructural lock-in, which the empirical results identify as a significant driver of higher emissions.

Moreover, policy frameworks in the RMG sector tend to emphasise voluntary adoption and market-led transitions, assuming that firms will respond to economic and buyer-driven signals. In practice, environmental upgrading and decarbonisation-related investments are undertaken largely at the discretion of individual firms, often in response to buyer environmental requirements rather than binding sector-wide mandates (Shumon et al., 2019).The empirical insignificance of behavioural and institutional lock-in indices suggests that, in the absence of strong regulatory or financial drivers, individual attitudes or institutional perceptions are insufficient to overcome entrenched production practices. This is evident in the persistence of energy-intensive dyeing, washing, and finishing processes that prioritise throughput and delivery speed over energy optimisation, even in factories with sustainability certifications (Md Miraj Hossen & Md Faisal Islam, 2025).

Overall, the governance context reveals that carbon lock-in in the RMG sector is sustained not by overt policy failures but by weak institutional traction (Figure 7). Decarbonisation remains peripheral to core industrial governance, resulting in a system where infrastructural rigidity dominates, while institutional and behavioural factors lack the force needed to reshape emission trajectories. Addressing this inertia requires a shift towards more coherent policy design, stronger enforcement capacity, and incentive structures that align short-term firm-level decision-making with long-term low-carbon objectives.

Figure 7 **Actors in RMG Financing and Regulation Environment of Bangladesh**



Source: Authors' Illustration.

13 Cross-Country Analysis of Carbon Lock-in Determinants

This section discusses cross-country comparisons of carbon lock-in in different developed and developing countries of Asia (Table 48).

13.1 China

As the world's largest textile and apparel producer, China's energy consumption patterns hold great importance for competing countries, such as Bangladesh, to understand the ways how Bangladesh fares in terms of energy consumption and carbon emission. China's textile and apparel factories predominantly draw electricity from the national grid, which remains highly coal driven (Cascale, 2025a). In 2024, 62 per cent of electricity was generated from fossil fuels and 38 per cent from low-carbon sources (Ember, 2025a). However, the energy landscape of China has been rapidly evolving with the increased deployment of solar power. As a result, the factories drawing electricity from the grid are essentially sourcing less from coal, thereby resulting in a reduction in carbon emissions.

Overall, China's textile and apparel sector emits around 230 million metric tonnes of carbon each year, accounting for roughly 2.8 per cent of national industrial emissions (Cascale, 2025a). At the product level, emissions vary widely; for example, a typical cotton T-shirt made in China produces about 9.18 kg CO2eq, while heavier garments such as fatigues or workwear can emit 20–40 kg CO2eq (Wang et al., 2025). Many older mill establishments still use coal-fired boilers to generate heat or steam, which contributes to poorer energy efficiency and more carbon emissions (Cascale, 2025a).

Various national and industrial initiatives are set in place to accelerate green energy adoption and energy efficiency. For example, China's national 'dual carbon' strategy sets the precedent for the textile industry to peak carbon emissions by 2030 and enhance energy efficiency (Hong et al., 2025). To further support the transition to green and efficient energy measures in industries, the Chinese government provides financial incentives and tax holidays to companies that adopt green technologies. Local governments have also stepped up to provide grants to factories willing to install solar panels, which have a greater impact on reducing the financial burden of upgradation (Cascale, 2025a). Moreover, industry bodies such as the China National Textile and Apparel Council (CNTAC) launched a Life Cycle Assessment (LCA) plus platform to enable factories to measure and disclose the carbon emissions relating to the entirety of the textiles and apparel supply chain. China's Ministry of Industry and Information Technology (MIIT), on the other hand, encourages the upgradation to new, energy-efficient machinery from old, energy-intensive machinery (Cascale, 2025a).

13.2 Vietnam

Vietnam's textile and garment sector is one of the most energy-intensive industries in the economy, consuming around 8 per cent of industrial energy demand. Furthermore, the industry remains majorly dependent on coal and grid electricity, with 94 per cent of its electricity powered by coal-based grid and 6 per cent from (Cascale, 2025b). In 2024, Vietnamese grids sourced 56 per cent of its electricity from fossil fuels and 44 per cent from low-carbon sources (Ember, 2025b). The industry overall spends an estimated USD 3 billion annually on energy, with electricity accounting for around 8-10 per cent of total production costs and rising to approximately 20-25 per cent in energy-intensive dyeing and washing operations (Energy efficiency and sustainable development in textile sector, 2025). Moreover, thermal energy accounts for more than half of the textile industry's energy demand, and heat and steam generated by thermal energy are used in the dyeing, washing, bleaching, rinsing stages, etc. (Major milestone in Viet Nam's textile sector decarbonisation, 2025). In terms of the carbon footprint, the apparel and footwear industry emits a carbon footprint of about five million tons annually (Cascale, 2025b).

Specifically, in the garment sector, substantive efforts have been made to make the energy industry efficient in terms of using LED lighting, energy-efficient sewing machines, and smart energy management systems. Moreover, many garment factories are now shifting towards rooftop solar systems to fulfil their energy requirements and reduce dependence on grid electricity. However, many challenges plague the industry's effort to decarbonise. For example, the garment sector is mostly comprised of small and medium sized enterprises (SMEs), which tend to use outdated, inefficient technologies primarily because moving to efficient machinery involves substantial cost and knowledge barriers (Asian Productivity Organization, 2025).

Vietnam's textile and apparel decarbonisation efforts are anchored in a tightening national policy framework and reinforced by sector-specific initiatives and buyer pressure. At the national level, the Vietnam National Green Growth Strategy 2021– 2030 requires reductions in the textile industry's energy use and carbon emissions, aligning with the country's goal to achieve zero carbon emissions by 2050 (Asian Productivity Organization, 2025).

Under the collaborative initiative between the Ministry of Industry and Trade (MoIT) and Vietnam Textile and Apparel Association (VITAS), industrial facilities are encouraged to adopt energy saving solutions, which is aimed to reduce energy consumption by minimum 10 per cent (Vietnam's Textile and Footwear Industries Join Forces for Sustainable Future: MoU Signed to Drive Circular Economy and Energy Efficiency, 2024). Renewable energy adoption with the textile sector has gained substantial importance as well, since it aims to increase the share of renewable sources to generate electricity to 10 per cent by 2025, and an overall reduction in annual energy-intensity of roughly 0.4 to 0.7 per cent over 2021–2030. Regulatory oversight has strengthened further with Decision No. 13/2024/QD-TTg, which obliges large textile and footwear enterprises to measure and report greenhouse gas emissions in line with Vietnam's national net-zero objective (Cascale, 2025b). On the supply side, the introduction of Direct Power Purchase Agreements in July 2024 has created a new pathway for large electricity consumers to source renewable power directly instead of purchasing through the state-owned utility, Vietnam Electricity (EVN) (Cascale, 2025b).

At the industry level, firms are actively investing in energy-efficiency measures and on-site solar generation (Energy efficiency and sustainable development in textile sector, 2025. Major buyers sourcing from Vietnam have also reinforced these trends by setting supplier decarbonisation requirements and withdrawing from coal-dependent factories (Asian Productivity Organization, 2025). Brands and international organisations also extend their support to the industry in reducing its carbon footprint, such as WWF, H&M Group, Apparel Impact Institute, enabling the leading supplier, Bangjie, to install a fully electrified heat pump, effectively replacing coal-powered boilers in dyeing facilities (Major milestone in Viet Nam's textile sector decarbonization, 2025).

13.3 India

India's textile and apparel industry is the fifth-largest energy-consuming sector in the country, accounting for over 4 per cent of total industrial energy consumption, with the textile sector's electricity consumption being recorded at 16.68TWh (Domestic Textile Industry Actively Moving Over To Renewable Energy, 2025; Sharma et al., 2024). Additionally, energy costs make up an estimated 15 to 20 per cent of total production costs, highlighting the sector's structural exposure to energy price volatility. Energy consumption in the industry is distributed in the following manner: chemical processing (including dyeing and finishing) accounts for around 38 per cent of total consumption, followed by spinning (34 per cent), weaving (23 per cent), and miscellaneous uses (5 per cent) (Domestic Textile Industry Actively Moving Over To Renewable Energy, 2025).

The textile industry's greenhouse gas emissions account for 5 to 8 per cent of the industrial emissions, resulting in about 42-67 $MtCO_2$ of emissions (Sharma et al., 2024). Dyeing and wet processing stages are highly energy-intensive, with 72 per cent of this energy coming from thermal sources. It is important to note that there is a high carbon dependency, particularly in thermal process given that it is mostly generated from coal-based boilers. As a result, thermal energy generation alone accounts for 43 per cent of the total carbon emissions (Sharma et al., 2024). Aside from thermal energy, electricity remains a dominant source of energy (Sharma et al., 2024). The carbon footprint of the industry remains high as India's grid is mostly tied to fossil fuel, with 78 per cent of electricity being powered by fossils and only 22 per cent from low-carbon sources (Ember, 2025c). However, recent trends among textile factories show that overall energy intensity has increased, along with renewable energy adoption share has increased from 26 to 28 per cent, mainly via rooftop solar (Indian textile sector ramps up renewable energy use; faces rising energy intensity, 2025).

India's decarbonisation pathway for the textile industry is shaped by a combination of energy efficiency regulation, renewable energy usage mandates and long-term national climate commitments. A key policy instrument has been the Perform, Achieve and Trade (PAT) scheme, covering 13 energy-intensive sectors, including textiles. Under the first three PAT cycles, the textile industry was successful in exceeding their energy efficiency goals by 97 per cent in Cycle I (2013-15), 69 per cent in Cycle II (2016-19) and 20 per cent in Cycle III (2017-20), with a total reduction of 1.54 $MtCO_2e$ emissions (Sharma et al., 2024). Under another initiative named Sustainable and Accelerated Adoption of efficient Textile technologies (SAATHI), the Ministry of Textiles and Ministry of Power work collaboratively to assist factories in shifting away from outdated machinery in weaving processes with more energy efficient alternatives without any upfront cost. Similarly, the Integrated and Sustainable Textile Policy allows factories to access a capital subsidy in setting up solar power plants (Sharma et al., 2024). Moreover, through the amendment of the 2001 Energy Conservation Act in 2022, the Indian government mandated the use of non-fossil fuel sources for industries, while also enabling direct procurement of renewable electricity from producers, improving price certainty for both generators and industrial consumers (Climate Tracker, 2025). These measures align with India's broader energy transition roadmap, which targets 500 GW of renewable energy capacity by 2030, equivalent to 50 per cent of cumulative installed capacity, and net-zero emissions by 2070. As of June 2025, renewable sources already account for about 49 per cent of installed capacity (476 GW), including roughly 227 GW of renewables (Domestic Textile Industry Actively Moving Over To Renewable Energy, 2025).

Currently, industry-wide, both large firms and MSMEs are increasingly investing in rooftop solar and captive open-access renewable power, driven by cost considerations and buyer-imposed sustainability requirements. Adoption of renewable energy has been especially strong in southern India, where Tamil Nadu hosts around 45 per cent of the country's spinning capacity, nearly 70 per cent of spinning units reportedly source between 40 per cent and 90 per cent of their energy from renewables, primarily wind and solar, with many export-oriented units having fully transitioned to cleaner energy (Domestic Textile Industry Actively Moving Over To Renewable Energy, 2025). Cluster-level transformation is most evident in Tirupur, India's leading knitwear hub, which has fully shifted to cleaner energy, with installed green capacity of around 1,950 MW, far exceeding its current consumption needs (Domestic Textile Industry Actively Moving Over To Renewable Energy, 2025). India's Tirupur stands out as an example of how factories within a cluster can potentially benefit from each other in transitioning to renewable energy.

International brands operating in India, just like in other countries, are reinforcing transitions through supplier decarbonisation requirements, renewable electricity targets etc. (Sharma et al., 2024). Financial and technical support from international actors has also played a role. For example, IFC and H&M's partnership with factories has supported Indian garment suppliers in providing rooftop solar and energy-efficiency assessment and solutions, aiming to improve both emissions performance and operational profitability (Tailoring Energy Solutions that Fit India's Garment Suppliers, 2019).

Table 48 Cross-country Summary

Indicator	China	Vietnam	India
Carbon emission (annual)	230 $MtCO_2$	5 million tons of CO_2	42-67 $MtCO_2$
Dependence on Grid Electricity	Predominantly grid-based; grid remains coal-driven, but the share of coal usage is declining.	Heavy dependence on grid electricity; high coal reliance.	Electricity is a dominant energy source, sourced mainly from the grid; the grid is largely fossil-fuel-based.
Grid Energy Mix (in 2024)	62% fossil fuels; 38% low-carbon	56% fossil fuels; 44% low-carbon	78% fossil fuels; 22% low-carbon
National decarbonisation framework	'Dual carbon' Strategy states the goals to achieve carbon emissions peak before 2030 and reaching carbon neutrality by 2050.	National Green Growth Strategy 2021– 2030 for restructuring the economy to achieve net-zero emissions by 2050.	Panchamrit Strategies targets the 500 GW of renewable energy capacity by 2030.
Industrial decarbonisation initiatives	Financial incentives, tax holidays, and machinery upgrading support. China National Textile Apparel Council's Life Cycle Assessment plus platform for supply-chain emissions disclosure	Mandatory GHG reporting for large firms (under Decision No. 13/2024/QD-TTg). Direct Power Purchase Agreements in July 2024 allow large electricity consumers to source renewable power directly instead of purchasing through the state-owned utility, Vietnam Electricity (EVN) Brands and international organisations' collective support in reducing textile industry's carbon footprint.	Energy efficiency targets and reporting under PAT and the Energy Conservation Act encourage factories to shift from outdated machinery to energy-efficient ones and mandate energy generation from non-fossil sources.

Source: Compiled by authors based on web-based information.

For Bangladesh, these cross-country experiences indicate that reducing carbon lock-in in the RMG sector requires moving beyond isolated energy-efficiency or decarbonisation projects and towards an integrated policy package. Adaptable best practices include introducing mandatory energy and emissions reporting for large and export-oriented factories, enabling direct renewable power procurement for industrial consumers, and promoting cluster-level renewable and thermal decarbonisation solutions. Equally important is institutional coordination between energy regulators, industrial ministries, and export-oriented association bodies to ensure policy coherence. By integrating such instruments within Bangladesh's existing industrial governance structure, the RMG sector can progressively unlock entrenched technological, institutional, and behavioural barriers, while maintaining competitiveness in increasingly carbon-conscious global value chains.

14 Recommendations to Address Carbon Lock-in in the RMG Sector

14.1 Structural and Technological Transformation of Industrial Infrastructure

14.1.1 Transition From Incremental Efficiency to Deep Decarbonisation

The findings reveal that most factories have adopted low-disruption energy efficiency measures, such as automatic sewing machines, LED lighting, and passive energy-saving features, while investments in core energy systems and production technologies remain limited. This pattern indicates that technological change has largely occurred at the margins of production rather than at the level of fundamental energy sourcing and industrial processes.

Policy interventions should therefore prioritise structural transformation through the replacement or retrofitting of energy-intensive infrastructure, including boilers, thermal systems, and production machinery. Sectoral transition roadmaps should provide clear technological pathways for decarbonisation, while technology demonstration programmes and pilot projects can reduce uncertainty regarding new energy systems. Targeted incentives should encourage firms to adopt technologies that fundamentally alter production architecture rather than incremental efficiency upgrades.

14.1.2 Expansion of Renewable Energy Access and Industrial Energy Reform

The limited penetration of renewable energy across factory sizes reflects structural barriers related to infrastructure, market access, and energy reliability. Continued dependence on fossil-fuel-based energy systems reinforces long-term emissions and limits the scope for sector-wide decarbonisation.

Policy reforms should facilitate direct renewable energy procurement for industrial users, promote distributed generation systems, and support cluster-level renewable energy solutions in industrial zones. Improvements in grid infrastructure, energy storage capacity, and hybrid energy systems would enhance reliability and reduce operational risks associated with renewable adoption. Such measures would enable firms to diversify energy sources and reduce dependence on conventional energy systems.

14.1.3 Industrial Upgrading and Technology Diffusion

Technological progress and structural upgrading play a critical role in weakening carbon lock-in by reducing dependence on legacy production systems. The coexistence of modern and outdated machinery within factories indicates uneven technological diffusion and fragmented modernisation processes.

Industrial policy should promote the adoption of best available technologies, support process innovation, and facilitate technology transfer within the sector. Knowledge-sharing platforms and technical advisory services can improve access to advanced production methods and reduce informational barriers to technological upgrading. These measures would enhance productivity while supporting environmental sustainability.

14.1.4 Management of Legacy Assets and Replacement Costs

High sunk costs and long-lived capital assets create strong disincentives for early replacement of existing machinery, reinforcing dependence on incumbent technologies. Replacement cost estimates indicate that transitioning to energy-efficient equipment represents a significant financial burden across factory sizes.

Policy should support asset replacement through targeted financing instruments, retrofitting programmes, and phased transition timelines that reduce financial pressure on firms. Mechanisms such as depreciation incentives, equipment buy-back schemes, and structured transition plans can facilitate gradual technological replacement while maintaining production continuity.

14.2 Institutional and Regulatory Reform for Policy Effectiveness

14.2.1 Outcome-Based Regulatory and Compliance Frameworks

The coexistence of high reported policy compliance and continued reliance on carbon-intensive production systems suggests that existing regulatory frameworks emphasise procedural adherence rather than measurable environmental outcomes. This limits the effectiveness of institutional interventions in driving structural change.

Regulatory reforms should shift towards outcome-based compliance systems that link policy adherence to verified energy performance and emissions reduction targets. Energy performance standards, emissions benchmarks, and periodic technology audits would strengthen accountability and ensure that regulatory compliance translates into tangible environmental improvements.

14.2.2 Mandatory Energy and Emissions Reporting

The absence of systematic monitoring and disclosure mechanisms reduces transparency and weakens incentives for technological transition. Without reliable information on energy consumption and emissions, policymakers face limitations in designing targeted interventions.

Mandatory reporting requirements for large and export-oriented factories should be introduced to monitor energy use, emissions intensity, and technological adoption. Standardised reporting and verification mechanisms would enhance transparency, facilitate benchmarking, and strengthen regulatory oversight.

14.2.3 Institutional Coordination and Policy Coherence

Fragmented governance structures and overlapping institutional mandates create inconsistent policy signals and reduce implementation effectiveness. Weak coordination between energy regulators, industrial authorities, and environmental agencies constrains policy coherence.

Formal coordination mechanisms should be established to align industrial development strategies with energy transition objectives. Integrated policy planning and inter-agency collaboration would ensure consistent regulatory frameworks and reduce institutional fragmentation.

14.2.4 Streamlined Regulatory Procedures and Administrative Efficiency

Complex bureaucratic procedures and regulatory delays increase transaction costs and discourage firms from investing in renewable energy and low-carbon technologies. Procedural uncertainty can raise perceived investment risks, particularly in a sector characterised by tight production schedules and narrow profit margins.

Administrative reforms should simplify approval processes, introduce single-window clearance mechanisms, and strengthen communication between regulatory agencies and industrial firms. Digitalisation of regulatory procedures and capacity-building within public institutions would improve implementation efficiency and reduce delays.

14.3 Financing and Market Mechanisms for Low-Carbon Investment

14.3.1 Inclusive Access to Green Finance

Liquidity constraints and unequal access to financial incentives, particularly among small factories, limit investment in capital-intensive technologies. Short acceptable payback periods and limited access to long-term financing further constrain technological adoption.

Financial support mechanisms should expand access to concessional credit, risk-sharing facilities, and long-term financing instruments. Technology leasing arrangements and blended finance models can reduce upfront investment costs and support wider adoption of energy-efficient and renewable technologies.

14.3.2 Risk Mitigation and Investment Certainty

Uncertainty regarding return on investment represents a major barrier to sustainable technology adoption. Firms remain cautious about long-term investments due to market volatility, uncertain demand conditions, and fluctuating energy prices.

Policy measures should reduce investment risk through stable incentive structures, guaranteed energy savings contracts, and performance-based financing mechanisms. Predictable policy environments and long-term regulatory commitments would strengthen investor confidence and encourage long-term planning.

14.3.3 Market-based Incentives for Low-Carbon Transition

Market signals play a critical role in shaping firm behaviour and investment decisions. The absence of strong incentives for low-carbon production allows continued reliance on inefficient technologies.

Policy instruments should encourage low-carbon investment through emissions performance standards, compliance-linked incentives, and targeted subsidies for clean technologies. Such measures would align economic incentives with environmental objectives and promote efficient resource allocation.

14.3.4 Alignment With Global Value Chain Competitiveness

The RMG sector operates within global value chains where sustainability standards increasingly influence market access. Domestic decarbonisation strategies must therefore be aligned with evolving international requirements.

Policy should support firms in meeting international sustainability standards through certification programmes, technical assistance, and export-oriented transition strategies. This alignment would strengthen long-term competitiveness while promoting environmental performance.

14.3.5 Buyer Engagement and International Partnerships

Buyer-driven sustainability requirements currently emphasise reputational compliance and rarely provide financial or technical support for structural transformation. This limits the potential of global value chain pressures to drive deep decarbonisation.

Policy should facilitate structured partnerships between manufacturers, international buyers, and financial institutions to promote co-financing arrangements, technology transfer, and technical cooperation. Enhanced collaboration can strengthen investment capacity and accelerate technological upgrading.

14.4 Organisational and Behavioural Transformation

14.4.1 Strengthening Energy Management and Implementation Systems

Behavioural lock-in is reflected in inconsistent monitoring of energy-saving practices, limited managerial enforcement, and weak implementation of existing policies. The gap between formal commitments and operational practice reduces the effectiveness of energy efficiency initiatives.

Institutional support should promote standardised energy management systems, performance monitoring frameworks, and managerial accountability mechanisms. Certification schemes and performance-based incentives can improve operational discipline and ensure sustained implementation of energy-saving practices.

14.4.2 Enhancing Technical Knowledge and Strategic Capability

Although training initiatives are widespread, knowledge of low-carbon technologies remains moderate and uneven across factory sizes. Limited technical expertise constrains firms' capacity to evaluate and implement complex technological solutions.

Capacity-building programmes should extend beyond operational training to include technology assessment, transition planning, and strategic decision-making. Technical advisory services and industry-wide knowledge platforms can strengthen firms' ability to undertake structural transformation.

14.4.3 Promoting Long-Term Investment Orientation

Short investment horizons and strong risk aversion, particularly among smaller firms, limit the adoption of technologies with longer payback periods. These behavioural tendencies reinforce reliance on existing infrastructure.

Policy interventions should encourage long-term investment planning through financial incentives, planning frameworks, and institutional support mechanisms that extend feasible investment horizons and reduce perceived risks.

14.4.4 Supporting Organisational Culture and Behavioural Change

Neutral organisational attitudes towards technological change and concerns regarding productivity impacts slow the adoption of energy-efficient practices. Even when awareness is high, internal momentum for change remains limited.

Awareness programmes, demonstration projects, and evidence on productivity benefits of energy-efficient technologies should be disseminated to strengthen organisational commitment. Behavioural interventions that align environmental performance with productivity goals can promote sustained adoption of low-carbon practices.

14.5 Policy Integration and Transition Strategy

The effectiveness of this policy framework depends on coordinated implementation across technological, institutional, financial, and behavioural domains. Structural technological change requires supportive financing mechanisms, effective regulatory governance, and strengthened organisational capacity. Similarly, institutional reforms and financial incentives must be complemented by technological infrastructure and behavioural transformation to achieve sustained decarbonisation.

A phased transition strategy should prioritise immediate institutional and financial reforms, followed by infrastructure transformation and long-term industrial upgrading. Through integrated governance, market alignment, and technological innovation, the RMG sector can progressively reduce carbon lock-in while maintaining industrial competitiveness and supporting national energy transition objectives.

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This study examines the structural determinants of carbon lock-in in Bangladesh's RMG sector from a demand-side perspective. Despite rising decarbonisation pressures, the sector remains dependent on carbon-intensive production. Using plant-level survey data and a mixed-methods approach, the study investigates how technological, institutional, and behavioural factors sustain carbon dependency. Findings show that factories mainly adopt low-cost energy efficiency measures, while deeper transitions are hindered by high capital costs, limited financing, and regulatory and supply-chain rigidities. Renewable energy adoption remains low and uneven, particularly across factory sizes, while compliance is largely procedural with limited structural impact. Behavioural barriers, including risk aversion and decision-making inertia, further reinforce carbon lock-in. The study recommends concessional financing, regulatory simplification, and coordinated incentives to enable sustainable industrial transition.

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