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Abstract

This study estimates the current state of renewable energy technology adoption amongst apparel exporters in Bangladesh. The ready-made garment (RMG) sector has played a pivotal role in the country's economic development by providing employment opportunities, especially to women, and comprising 80 per cent of Bangladesh's exports. The global policy push towards sustainable supply chains requires an energy transition towards renewable sources, which may further contribute towards meeting Nationally Determined Contribution (NDC) goals. Our findings suggest that approximately 31 per cent of factories have adopted renewable energy technology (RET), mostly rooftop solar installations. However, the average capacity of these installations is quite low and inadequate to contribute significantly to the overall energy demand of the factories. High upfront installation costs represent a major barrier to adoption. Coordinated policy interventions will be needed to move towards more sustainable energy sourcing within the sector whilst remaining competitive in an increasingly challenging global policy environment.

1 Introduction

In this study, we aimed to understand the current rate of adoption of renewable energy technology, primarily solar panels, among ready-made garment (RMG) producers and exporters. The RMG sector has played an important role in the growth and development of the country and has also contributed to employment, especially for women (Menzel & Woodruff, 2021; Rahman & Bari, 2018). The employment opportunities for women have further contributed to educational aspirations for the next generation (Heath & Mobarak, 2015).

Whilst the apparel trade with European and US markets has been beneficial for the country, consumers, brands, and policymakers in these countries are increasingly committed to lowering their carbon footprints.[1] Many companies have taken steps to green their supply chains. Whilst “greening” can encompass changing several different processes, including relying on more sustainable supply chains, energy transition, especially through adoption of solar panels as a source of electricity for factories, is a key component (Harrison et al., 2017). However, there has not been any comprehensive study on the status of renewable technology adoption, factors associated with adoption, and the perceived barriers among factories that are yet to adopt renewable technology. This study will fill the gap in knowledge and indicate possible research and policy paths forward.

Our study uses data from several different sources. Firstly, the research team uses data from Mapped in Bangladesh (MiB), which includes data for all apparel-exporting companies and is therefore the most comprehensive dataset available for the RMG sector in Bangladesh. The latest version of the census data includes a binary indicator of whether the factory has solar panels installed within the factory premises, along with factory locations and a host of other variables that we use for econometric analyses.

Whilst MiB has data for all factories, it is limited in several ways, and we intend to supplement it with a survey we carried out with the IGC's support. We further collect data on other possible renewable energy technology (RET) sources (e.g., biogas and wind turbines) and the total capacity of solar panels. We also collect information on the primary motivations behind adopting RET. Furthermore, we explore the barriers and constraints to adopting RET and facilitating energy transitions. Finally, we complement our mostly quantitative findings with qualitative information from a previous study for a more comprehensive understanding of the current landscape of energy transitions among global apparel suppliers from Bangladesh.

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[1] The fashion industry is estimated to be responsible for 2-8 percent of global GHG emission and the overwhelming part of the emission takes place within the supply chain (Sadowski et al., 2021). Global trade contribute about 6.4 billion tons CO2 or 23% of global annual emissions embodied in traded goods as of 2011 (Davis et al., 2011). Several initiatives have taken place already, including Fashion Industry Charter. Many prominent brands as well as suppliers are either a signatory or a supporter of this charter.

Our findings suggest that approximately 31–32% of factories have installed solar panels, which is the dominant technology for sourcing from renewables in the apparel-exporting sector in Bangladesh. However, the current average capacity of renewables in factories is quite low, and about half of the factories with renewables use it for production. In general, larger factories and factories with more diverse buyers are more likely to adopt solar panels.

Our findings have some important policy implications. Whilst our prior work shows that the adoption of renewables can save energy costs by up to 26%, most factories do not pursue such opportunities. The upfront financial investment appears to be the major obstacle to adopting rooftop solar installations of meaningful size, as reported by the factories. Most factories expect support from the government, along with support from other stakeholders such as industry trade bodies and buyers. The industrial sector, due to the availability of large roofs, can potentially provide scope for solar panel installations and facilitate the country's energy transition.

2 Methods

2.1 Background

The apparel sector in Bangladesh has been a pivotal sector for the economic development of Bangladesh. Currently, the sector contributes to about 80 percent of the country's export and considered the second largest apparel exporter in the world (after China, see Mostafa & Klepper, 2018; Raihan, 2024). The sector grew out of initial support from South Korean firm Daewoo which trained 124 staff of newly established company, Desh Garments in 1978 (Mostafa & Klepper, 2018). After the initial success of Desh Garments, the trainees left and established their own garment exporting companies. By mid-1980s, there were more than 600 garment producers, which increased to more than 3000 by 2020s (see Mostafa & Klepper, 2018 and MiB data). Since the early 1980s, over the next 30 years, the export values increased from being almost insignificant to 30 billion USD by late 2010s (Raihan, 2024).

The growth of RMG sector has several different implications for the country. Bangladesh has a higher female labour force participation compared to its neighbours such as India and Pakistan, the RMG sector, among other factors has played a part in it (Drèze & Sen, 2013). Higher female labour force participation has also spilled over to the children in terms of higher level of education (Heath & Mobarak, 2015). The sector has also provided scopes for line operators to move into managerial roles, albeit real and perceived constraints (Macchiavello et al., 2020).

Despite these achievements, experts and scholars have expressed concerns regarding the RMG-based growth in Bangladesh. The export base of Bangladesh is very narrow, with more than 80 percent of the total exports concentrated on RMG. Various subsidies and facilities have contributed to the growth including different international trade arrangements (Kim et al., 2006; Raihan, 2024). Bangladesh is also set for graduating out of its LDC status and in a more competitive environment without the various preferential treatments for RMG along with reciprocal tariffs imposed by the US, one of the largest buyers, the future of the country remains quite precarious (Rahman & Bari, 2018).

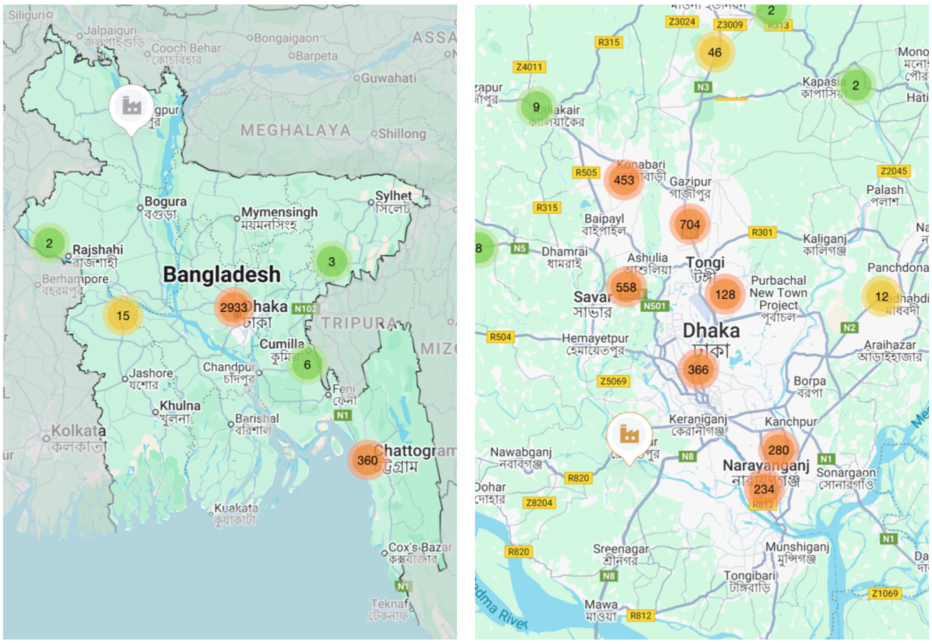
The sector has also been criticised for its unfair labour practices. Setting minimum wages has always been an issue and factories often face labour unrest leading to closure and firing of workers, losing production efficiency (Akerlof et al., 2020; Kabir et al., 2022). The labour unions are generally discouraged in the RMG factories; however, workers' committees have been formed and organized in many factories, partly at the behest of the multinational buyers, leading to positive small impacts on the workers' safety without any loss in productivity (Boudreau, 2024).

2.2 Study Site Selection

Bangladesh is home to approximately 3,320 active apparel manufacturing units, commonly referred to as factories.[2] The majority of these factories are concentrated in and around the capital city, Dhaka, forming a significant industrial cluster. For the purposes of the IGC project, the study focused on two specific locations: Savar, an upazila within the Dhaka district, and Gazipur, a neighbouring district situated directly to the north of Dhaka. Notably, more than one-third of the country's apparel factories are located within these selected study sites, underscoring their importance in the sector and relevance to the research objectives.

[2] The number of active factories certainly vary over time. The BGMEA and BKMEA directories maintain the membership lists. But typically, the directories will not update whether they are in production or not. Many factories have also changed ownership, which are not always reflected in the membership directories. According to the Mapped in Bangladesh (MiB) website, as of 4 October 2025, there are 3,320 factories active in Bangladesh.

Figure 1: The locations of the RMG factories in Bangladesh



(a) In Bangladesh (b) Around Dhaka

Source: Mapped in Bangladesh website. Accessed 4 October 2025.

2.3 Sampling

The sampling frame for the survey consisted of the 1,937 garment factories listed in the MiB database within the target regions of Gazipur and Savar. To refine this frame, the study concentrated on the primary industrial sub-districts: Gazipur City Corporation, Gazipur Sadar Upazila, and Savar Upazila. Factories located in smaller outlying areas (with fewer than 30 factories per thana) were excluded to ensure adequate representation from significant clusters. After this filtering, 1,673 factories remained in the eligible sampling frame.

A stratified random sampling approach was employed to select factories for the survey. The factories were first grouped by their local area (police thana), and a proportional random sample was drawn from each group to reflect the area's share of the total frame. In practice, approximately 39% of the factories in each major area were randomly selected, aiming for a target of about 650 factories overall. The selection was done by assigning each factory a random number and then sorting within each stratum, ensuring an even and unbiased coverage across Gazipur and Savar. The sampling was implemented in three sequential batches of 663, 334 and 102 factories respectively to reach the targeted mark of 650.

Out of a total of 1099 factories sampled, 1,090 factory visit attempts were made by the enumerator teams. Among these, 317 factories (29%) were found to be non-operational or closed at the time of visit, and 50 factories (5%) declined to participate (refusing the survey or denying entry to the survey team). Despite these challenges, 671 factories granted the survey team access for interviews. Out of those, 661 factory representatives successfully completed the full survey (10 interviews were started but not completed). An additional 52 factories agreed to be interviewed later but could not be revisited due to time constraints and thus were not surveyed. The final sample thus comprised 661 completed factory surveys, slightly exceeding the initial target and providing a robust dataset for analysis.

2.4 Data Collection Dates and Protocol

Prior to data collection, a comprehensive training program was conducted to prepare the field team. CED organized a three-day interactive training workshop for enumerators from April 15–17, 2025. During this training, the field officers were instructed on the survey questionnaire, interviewing techniques, ethical research practices, and the use of the data collection tools. They also engaged in role-playing and field-testing to ensure they understood the questions and could handle potential challenges in factory settings.

Following the training, the field survey was carried out over a period of about three weeks, from April 19 to May 6, 2025. Teams of enumerators visited the selected factories in the Savar, Ashulia and Gazipur to conduct the survey. All participants provided written informed consent before taking part in the survey. They were assured of confidentiality and anonymity and informed that they could withdraw from the study at any time without any negative consequences. Each interview was conducted in a private setting within the factory premises to maintain confidentiality. The questionnaire was designed in English and Bengali, and responses were recorded in the language preferred by the participant to ensure clarity.

For data capture, the research team utilized an Open Data Kit (ODK) platform named "ODK Collect" mobile application. Enumerators entered responses directly into handheld tablets or smartphones during the interviews. Data from the devices were periodically uploaded to a secure server whenever internet connectivity was available, ensuring that information was backed up and centrally accessible to the research team throughout the data collection period.

2.5 Data Quality Assurance

The project implemented several quality control measures to ensure the reliability and validity of the collected data. The research team monitored data, checking plausibility of responses.

Frequent feedback was provided to enumerators; for instance, if any survey appeared to have inconsistencies or missing information, the field team was promptly alerted to correct these issues in subsequent interviews or, if possible, to revisit the factory for clarification. After the fieldwork, the dataset underwent a thorough cleaning and validation process by the researchers. This involved identifying records with extreme or logically inconsistent values on key variables related to energy usage and capacity. The following criteria were used to flag unusual entries for verification:

- Unrealistically low energy consumption: Reported monthly energy usage far below typical factory requirements.
- Unusually high generator usage: Generator capacities or usage frequencies that appeared exceptionally high relative to factory size.
- Unrealistic installation area per kW: Cases where the physical area reported for solar panel installations did not align with the capacity (either too small or too large an area per kW of solar).
- Excessively large installed capacity: Factories claiming renewable energy installations with capacities much higher than industry norms for similar facilities.
- Suspicious cost per kW: Reported costs of installation per kilowatt that were extremely low or high, raising doubts about accuracy.
- Solar usage exceeding generation: Instances where the monthly energy reportedly obtained from solar panels exceeded the calculated generation capacity of those panels (indicating a likely reporting error).

Using these six checks, a total of 94 survey responses were flagged for potential data issues, affecting 74 unique factories (about 11% of the 661 surveyed factories). Each flagged case was individually reviewed. The team conducted follow-up phone calls to the factory representatives to verify the data. Through this verification process, most anomalies were resolved or explained. Out of the 94 flagged entries, 78 cases were confirmed to be unchanged and thus retained in the dataset, while 11 cases were verified as true outliers. 5 cases could not be fully resolved because the factories became unreachable for follow-up. Through these rigorous data collection protocols and quality assurance steps, the study aimed to minimize errors and biases.

2.6 Ethics Approval

This study was conducted in accordance with ethical standards for research involving human participants. Ethical approval was obtained from the Institutional Review Board (IRB) of the BRAC James P Grant School of Public Health (JPGSPH), BRAC University. The research protocol was reviewed and approved under IRB Protocol No. IRB-2024-IS-33. The approval certified that the study design, consent procedure, and data handling practices complied with the IRB's ethical guidelines. The IRB granted approval for one year from the date of issuance, valid up to November 4, 2025.

This project is a continuation of a prior research initiative on renewable energy in the garment sector funded by PEDL. The current study's protocol was approved as an amendment of a previous IRB approval (from an earlier phase of the project funded by PEDL, Protocol No. IRB-21 June'23-023). The amendment involved modifications to the study design – notably, the exclusion of a case-study work package and a planned techno-economic analysis component that were part of the earlier project. These changes were submitted to the IRB, and the revised methodology was approved under the new protocol number mentioned above. Throughout the study, the research team adhered strictly to the ethical guidelines of BRAC JPGSPH IRB. All analysis has been done on anonymized data.

3 Findings

3.1 Basic Characteristics

In Table 1, we compare the basic features of the factories by different sample types. We had 1,937 factories in total in our study site (Savar, Dhaka and Gazipur). We excluded 264 factories as they were in areas where we had too few factories and we dropped them to accommodate the survey resources we had at our disposal. As one can see from Table 1, the average number of factories within 1.5 km radius is much smaller (about 15) than a typical factory within our study site (about 58, see the "Total" column). These factories are also larger (employing about 1532 workers on average compared to 1046 for all). They are also less likely to have shared premises compared to others (11 percent compared to 22 percent in total). So, the factories we dropped for sampling are generally different compared to the ones located in the sample areas.

Our surveyed factories had an average age of 15 years (which is typical across all types). They average employed worker size was about 1040, with 29 percent of the factories being involved in producing heavy knit or sweater items.[3] About 51 percent of the factories were part of either Accord or Alliance and about 75 percent of them had a Workers' Participation Committees (WPCs). On average these suppliers export to about six brands and about 6.4 countries.

Table 1: Basic Characteristics by Sample Types

	Not in the sample areas (N = 264)	Within the sample areas (N = 574)	Sampled but not surveyed (N = 438)	Finally surveyed (N = 661)	Total (N = 1937)
Age of the factory in years	15.06 (7.35)	15.60 (9.01)	15.10 (8.22)	15.36 (8.48)	15.33 (8.44)
Total number of workers	1531.95 (1876.33)	949.74 (1158.72)	887.19 (1491.70)	1039.86 (1442.00)	1045.71 (1458.59)
= 1 if Heavy Knit/Sweater factory	0.18 (0.39)	0.29 (0.46)	0.25 (0.43)	0.29 (0.45)	0.27 (0.44)
= 1 if factory is in shared premise	0.11 (0.31)	0.22 (0.41)	0.26 (0.44)	0.23 (0.42)	0.22 (0.41)
Has solar panels according to MiB data	0.39 (0.49)	0.36 (0.48)	0.18 (0.39)	0.44 (0.50)	0.35 (0.48)
= 1 if factory is part of Accord or Alliance	0.68 (0.47)	0.49 (0.50)	0.48 (0.50)	0.51 (0.50)	0.52 (0.50)
= 1 if WPC exists	0.86 (0.34)	0.75 (0.43)	0.74 (0.44)	0.75 (0.43)	0.76 (0.43)
Number of countries factory exports to	6.85 (4.11)	6.24 (4.87)	6.41 (4.96)	6.37 (5.23)	6.40 (4.94)
Number of brand(s) factory supplies to	6.51 (4.14)	5.76 (4.42)	5.77 (4.86)	6.08 (5.29)	5.98 (4.82)
Number of MiB factories within 1.5km radius	14.84 (15.57)	64.37 (44.82)	63.46 (45.81)	66.31 (46.56)	58.07 (46.23)
Number of MiB factories with solar installations within 1.5km radius	5.44 (5.81)	20.25 (14.22)	20.02 (14.41)	20.76 (14.53)	18.36 (14.48)

Source: MiB Data.

About 44 percent of the factories reported installing solar panels according to MiB data. On average there are 66 factories within a 1.5 km radius around their premises, of which 21 (32

[3] The sweater or heavy knit factories have a few distinguishing features. They have either individual machine operators working individually paid on piece rate or increasingly moving to adopting knitting machines replacing labours (Akerlof et al., 2020). They are also part of a separate industry body, namely, BKMEA.

percent) reported adopting solar panels as a source of energy. The adoption of solar panels seems to have some clustering features which we will explore in our regression analyses.

Table 2: Regression Results from the MiB Data

	LPM		Logit (marginal effects)	
Age of the factory in years (Std.)	-0.020		-0.082	
	(0.013)		(0.059)	
Total workers (Std.)	0.071	***	0.382	***
	(0.014)		(0.095)	
= 1 if Heavy Knit/Sweater factory	0.011		0.029	
	(0.026)		(0.133)	
= 1 if factory is part of Accord or Alliance	0.137	***	0.542	***
	(0.031)		(0.143)	
= 1 if WPC exists	0.143	***	0.812	***
	(0.029)		(0.165)	
Number of countries factory exports to (Std.)	0.002		0.012	
	(0.014)		(0.065)	
Number of brands factory supplies to (Std.)	0.035	**	0.177	**
	(0.018)		(0.086)	
Factories within 1.5km (Std.)	-0.107	***	-0.673	***
	(0.019)		(0.132)	
Factories with solar within 1.5km (Std.)	0.122	***	0.739	***
	(0.019)		(0.127)	
R-squared	0.15			
Adjusted R-squared	0.15			
Number of observations	1660		1660	

Note: The standard errors are reported in the parentheses. *** p<.01, ** p<.05, * p<.1

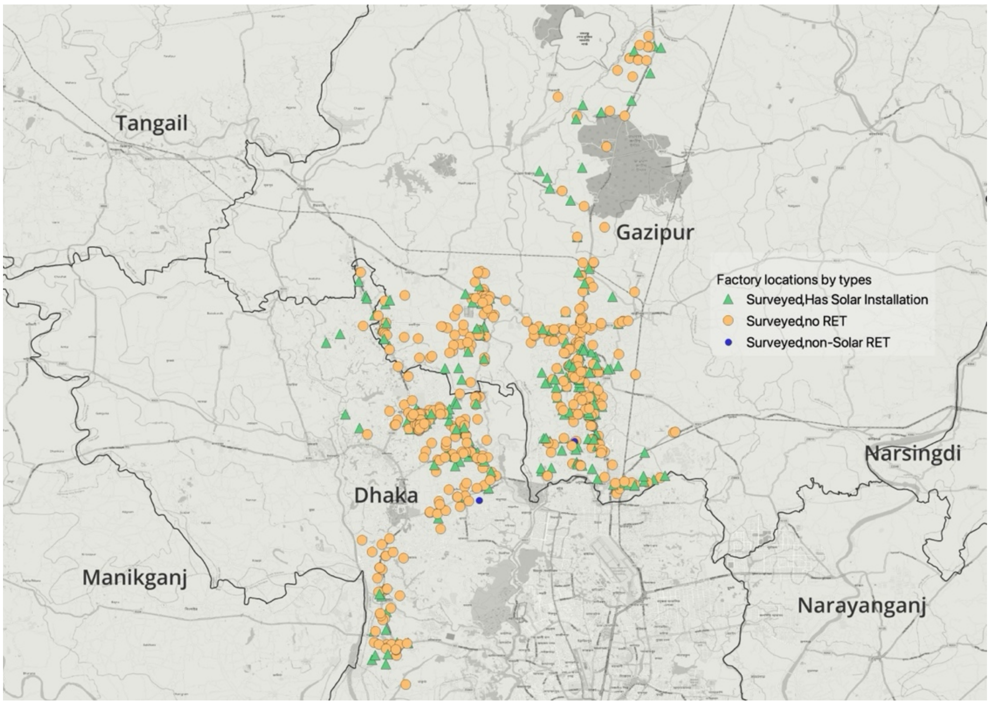
3.2 Regression analyses using MiB Data

In Table 2, we report the regression results from the MiB Data. We restrict the MiB data to our study site. The sample is based on the variables for which there were not missing values. We get a sample of 1660 factories. We use both simple OLS model (linear probability model, LPM with robust standard errors (SEs), reported in parentheses in Table 2). We also re-estimate the model using logit specification and estimate the average marginal effects.

We find the older factories are less likely to adopt solar panels, however, the relationship is not statistically significant. The size of the factories, measured by total number of employment workers, is positively associated with solar installations, suggesting the larger factories are more likely to adopt renewable energy technology. Being a heavy knit or sweater producer is not associated with solar installations. The more compliant factories are also more likely to adopt solar panels. Such factories generally are more open to adopt better and more sustainable production practices. Having a more diverse buyer portfolio is also associated with solar installations, however, number of countries that a factory exports to does not have a strong association with adoption of solar energy.

Lastly, we also explore clustering or agglomeration effects of the factories on adoption of solar panels (see Figure 2). We use two different variables, number of factories within 1.5 km radius of the factory building as well as number of factories with solar panels (without counting if the factor itself has a solar installation). We find there is a negative association between the total number of factories within 1.5 km radius and likelihood of solar adoption. It is difficult for factories to find space for itself in densely populated areas. While most of the installations are rooftops, but they still require large sheds to make the installation viable, if not profitable. Interestingly, there is a positive correlation between the number of factories with solar installation within the 1.5 km radius and adoption of solar panels. This association can be explained in several different ways. There can be demonstration effects as well as knowledge spillovers between factories that close to each other. The factories within the same areas may also better access to roads, easing transferring installation materials to the factory premise. The exact nature of spillovers will probably require further explorations in the future.

Figure 2: Location of the RMG Factories by Solar Installation



Source: MiB Dataset. The map is rendered by the research team.

Table 2 also reveals large differences in the coefficients between two specifications. LPM assumes a linear relationship between the exploratory variables and the probability of adoption, which may not be appropriate in our case. This will also require further analyses which we aim to do in the future.

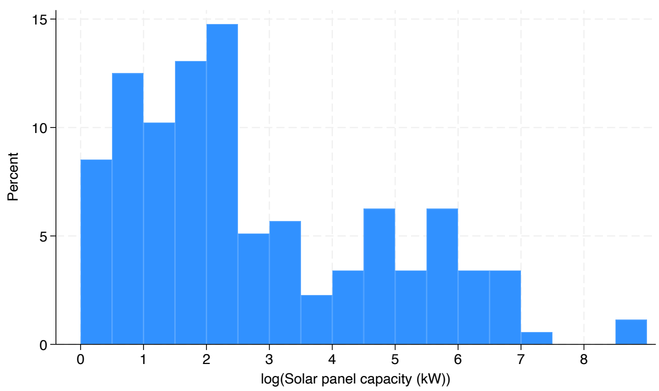
4 Adoption at the intensive margin

We implemented a survey using MiB's comprehensive database as a sample frame (details are provided in Section 2.3 above). MiB, while comprehensive in its coverage, it does not have detailed information on the renewable energy technology adoptions. In our survey we further collected the total capacity and power generation, installation year, and types of renewable energy technology being used by the factory as well as whether the installed capacity is linked with production or not. We also collected attitude towards RET adoption among factories which have adopted RET. We also assessed the barriers and constraints against adoption of RET among the factories that were yet to take up RET to meet its energy needs. We discuss this further in the next section. In this section, we focus on survey findings on RET adoption.

4.1 Basic features

Among the 661 surveyed factories, 211 have installed solar panels, with nearly all (98.5%) utilizing their existing rooftops for installation. The average age of these installations is approximately 73 months, or six years, indicating that adoption began gaining momentum around 2019. The distribution of solar panel capacity, shown on a logarithmic scale, reveals considerable variation in installation sizes across factories. The capacity distribution appears relatively spread out across the log scale, suggesting that factories have adopted solar panels at widely varying scales, from small installations of just a few kilowatts to much larger systems potentially reaching hundreds of kilowatts or more (see Figure 2). This heterogeneity in capacity likely reflects differences in factory size, available roof space, energy demand, and financial resources. The use of a logarithmic scale to display the data indicates that capacity varies by orders of magnitude across the sector, with some factories making modest investments while others have

Figure 2: Distribution of Capacity among the Adopted Factories



implemented substantially larger renewable energy systems. This wide range in adoption scale underscores the diverse circumstances and capabilities within the RMG sector.

4.2 Determinants of Solar Panel Capacity

The detailed factory survey allows us to investigate extensive as well as intensive margin. The previous analyses from Mapped in Bangladesh (MiB) data were based on a much larger sample size. However, as we mentioned able, the survey data have the advantage of collecting data on the current capacity of the installed renewable energy capacity at the factory premise (mostly, on the roof tops). We carry out simple OLS analyses only based on the adopting factories as well as a censored Heckman-corrected regression with the total sample of factories we surveyed (N = 661). The results are presented in Table 3.

Table 3: Determinants of Adoption of Solar Panel by Capacity

	OLS estimates		**Heckman two-stage model**			
			First stage		Second stage	
	Log (Solar Capacity (kW)		= 1 if the factory has installed solar panels		Log (Solar Capacity (kW)	
Age of solar panel (months)	-0.009	***			-0.010	*
	(0.002)				(0.005)	
= 1 if off-grid	-0.033	***			-0.032	
	(0.004)				(0.034)	
Age of the factory in years (Std.)	0.417	***	-0.074		0.727	
	(0.131)		(0.065)		(0.767)	
Total workers (Std.)	0.427	***	0.152	**	-0.117	
	(0.162)		(0.068)		(1.223)	
= 1 if Heavy Knit/Sweater factory	-0.398		0.004		-0.347	
	(0.249)		(0.137)		(0.916)	
= 1 if factory is part of Accord or Alliance	0.418		0.360	**	-1.429	
	(0.333)		(0.149)		(3.814)	
= 1 if WPC exists	0.235		0.704	***	-3.285	
	(0.400)		(0.183)		(7.304)	
Number of countries factory exports to (Std.)	0.132		0.084		-0.223	
	(0.088)		(0.061)		(0.802)	
Number of brands factory supplies to (Std.)	-0.045		0.071		-0.333	
	(0.100)		(0.065)		(0.698)	
Factories within 1.5km (Std.)	-0.216		0.060		-0.476	
	(0.240)		(0.114)		(0.927)	
Factories with solar within 1.5km (Std.)	-0.395	*	0.027		-0.513	
	(0.239)		(0.112)		(0.805)	
lambda					-6.499	
					(13.114)	
R-squared	0.42					
Adjusted R-squared	0.38					
Number of observations	172				602	

*** p<.01, ** p<.05, * p<.1

The analysis employs two econometric approaches to examine factors influencing solar panel capacity adoption among RMG factories. The first approach uses ordinary least squares (OLS) regression on the subsample of 172 factories that have already installed solar panels, with logtransformed solar capacity as the dependent variable. The second approach applies a Heckman two-stage selection model to address potential self-selection bias, analyzing all 602 factories. The Heckman model first estimates the probability of solar panel adoption (first stage) and then examines capacity determinants among adopters while correcting for selection bias (second stage).

4.2.1 OLS Results

The OLS estimates reveal several significant predictors of solar capacity among adopting factories. The age of solar panels shows a small but highly significant negative effect (-0.009, $p<0.01$), suggesting that older installations tend to have smaller capacities, possibly reflecting technological improvements and falling costs over time that have enabled larger installations in recent years. Off-grid status has a significant negative association (-0.033, $p<0.01$), indicating that factories not connected to the grid install smaller solar systems, likely using solar as a supplementary rather than primary or major power source when it is possible.

Factory characteristics demonstrate strong positive relationships with capacity. Factory age exhibits a substantial positive coefficient (0.417, $p<0.01$), indicating that older, more established factories install significantly larger solar systems. Similarly, total workforce size shows a highly significant positive effect (0.427, $p<0.01$), reflecting that larger factories with greater energy demands invest in correspondingly larger solar installations. These findings align with expectations that organizational maturity and scale drive greater renewable energy investment.

Interestingly, the spatial concentration of factories with solar panels shows a marginally significant negative effect (-0.395, $p<0.1$), suggesting that factories in areas with higher solar adoption by neighboring facilities tend to install smaller systems. This counterintuitive finding might reflect competitive resource constraints, such as limited availability of installation services or equipment in high-adoption areas, though this interpretation requires caution given the marginal significance level.

Other variables including heavy knit/sweater factory type, Accord/Alliance membership, Worker Participation Committee (WPC) existence, export market diversity, number of brands supplied, and overall factory density within 1.5km show no significant relationships with installed capacity in the OLS model. The model achieves an R-squared of 0.42 and adjusted R-squared of 0.38, indicating that these variables collectively explain approximately 38-42% of the variation in log solar capacity.

4.2.2 Heckman Two-Stage Model Results

The Heckman model's first stage examines adoption decisions across all 602 factories. Several variables significantly predict whether a factory installs solar panels. Total workforce size shows a positive significant effect (0.152, $p<0.05$), indicating larger factories are more likely to adopt solar technology. Accord/Alliance membership demonstrates a significant positive association (0.360, $p<0.05$), suggesting that factories participating in these international safety and compliance initiatives are more likely to adopt renewable energy, possibly reflecting greater exposure to international standards and buyer expectations. The existence of a Worker Participation Committee shows the strongest positive effect (0.704, $p<0.01$), indicating that factories with more developed worker engagement mechanisms are substantially more likely to adopt solar panels, potentially reflecting better overall management practices and organizational capacity.

Notably, factory age, which strongly predicts capacity in the OLS model, shows no significant effect on the adoption decision itself, suggesting that while older factories install larger systems when they do adopt, age does not determine whether they adopt in the first place. Similarly, other variables including heavy knit factory type, export diversification, brand relationships, and spatial factors show no significant influence on adoption decisions.

The second stage of the Heckman model, which estimates capacity among adopters while correcting for selection bias, reveals a striking pattern: only the age of solar panels remains marginally significant (-0.010, $p<0.1$), while all other variables lose statistical significance. The lambda coefficient (inverse Mills ratio) is large but statistically insignificant (-6.499, $p>0.1$), suggesting that selection bias may not be a substantial concern in this context. The dramatic loss of significance for variables like factory age and workforce size in the Heckman second stage, compared to their strong effects in the OLS model, indicates considerable uncertainty in the estimates once selection correction is applied. The very large standard errors in the Heckman second stage (for example, 0.767 for factory age compared to 0.131 in OLS, and 1.223 for workforce compared to 0.162 in OLS) suggest potential model identification issues or multicollinearity problems when attempting to separate selection from capacity decisions.

4.2.3 Comparison of Models

The comparison between OLS and Heckman models reveals important insights about the reliability of capacity estimates. The OLS model shows strong, intuitive relationships where factory age and size significantly predict installed capacity, with relatively tight standard errors and reasonable model fit. However, these relationships largely disappear in the Heckman second stage, which shows substantially inflated standard errors and loss of significance across nearly all variables. This pattern suggests either that the selection correction is creating estimation problems, or that the factors driving adoption decisions differ fundamentally from those determining capacity levels among adopters.

The insignificant lambda coefficient in the Heckman model suggests that self-selection bias may not be severe enough to warrant the additional complexity of the two-stage approach. In other words, the characteristics that lead factories to adopt solar panels may not strongly bias estimates of what determines their capacity choices. This finding somewhat validates the simpler OLS approach for this research question, though the Heckman first stage provides valuable insights into adoption determinants that the OLS model cannot address.

The first-stage results add nuanced understanding by identifying institutional factors, Accord/Alliance membership and WPC existence, as important adoption predictors, even though these don't influence capacity conditional on adoption. This suggests that while organizational governance and international engagement help factories overcome initial adoption barriers, once factories decide to install solar panels, their capacity decisions are driven more by operational factors like age, size, and technical considerations like grid connectivity.

4.2.4 Summary

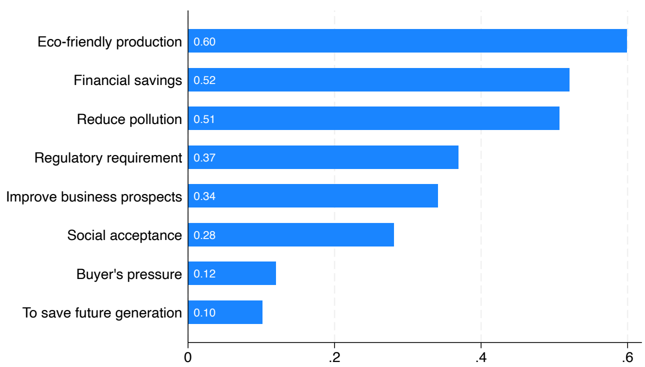
The analysis reveals that among adopting factories, older and larger establishments install significantly greater solar capacity, while off-grid factories and those with older panels have smaller installations. However, these relationships become uncertain when accounting for selection bias through the Heckman approach. The adoption decision itself is driven by factory size, international compliance program participation, and worker engagement mechanisms. Overall, the findings suggest that organizational capacity and maturity influence both adoption and scale, though estimation challenges complicate definitive conclusions about capacity determinants.

5 Perceptions regarding adoptions and barriers

In this section, we will present results from the factory surveys. Here we will primarily focus on certain perceptions regarding adoption of RET in the factory premises. We will explore perceptions and attitudes among factories that have already adopted RETs (mostly roof-top solar panels) as well as the ones that are yet to adopt RETs. For the former, we will delve into the primary motivations behind adoption. As we have seen in the previous section, only about half of the factories reported using the RET for production purposes and the average adoption capacity is quite low. Hence, we also explored whether there is an intention to increase the current capacity. Among the latter (those who are yet to adopt RET), we examined the perceived barriers and the supports the factories are expecting that can potentially facilitate further adoption of renewable energy.

5.1 Motivations behind adoption

Figure 3: Reasonle for Adopting RET



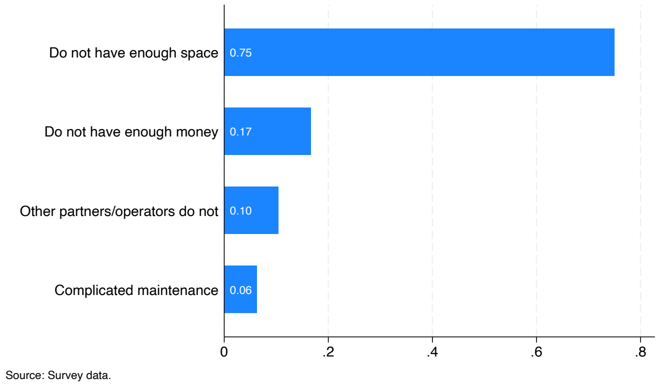
Source: Survey data.

Based on the data from 221 RMG (Ready-Made Garment) factory respondents in Bangladesh, the primary motivation for adopting renewable energy technology is eco-friendly production, with 60% citing this reason. Financial savings follows closely as the second most important factor at 52%, while reducing pollution ranks third at 51%. These top three reasons suggest that factories are driven by both environmental consciousness and economic benefits. Regulatory requirements (37%) and improving business prospects (34%) represent moderate motivations, likely reflecting compliance pressures and market competitiveness. Interestingly, external stakeholder influences appear less significant, with social acceptance at 28%, buyer's pressure at just 12%, and saving future generations at only 10% being the least cited reason despite its long-term importance. The voluntary nature of this adoption is particularly striking: 94% of respondents used their own funds for renewable energy investments, indicating strong internal commitment rather than external financing or mandates. As one researcher and factory audit regulator observed, “Solar power is now affordable while grid electricity is costly. In the RMG sector, companies are adopting solar on their own initiative.” This suggests that the convergence of improved solar economics and high conventional energy costs has created a compelling business case that drives factories to pursue renewable energy primarily for immediate environmental and financial gains rather than external pressures or altruistic concerns about future generations.

5.2 *Barriers to Expanding Renewable Energy Capacity*

Among the 48 factories that have adopted renewable energy but do not wish to expand beyond their current low-capacity levels, lack of space emerges as the overwhelmingly dominant barrier, cited by 75% of respondents. This finding is particularly significant given that only half of the factories currently use solar energy for production, and average capacity remains quite low. Financial constraints rank a distant second at 17%, while lack of interest from other partners or operators (10%) and complicated maintenance concerns (6%) play minimal roles. The prominence of space limitations suggests that many RMG factories, likely operating in densely built urban or industrial areas, face fundamental physical constraints to scaling up rooftop solar installations. This spatial barrier may be more difficult to overcome than financial or technical challenges, potentially limiting the sector's renewable energy expansion despite the strong economic incentives and voluntary adoption patterns observed earlier.

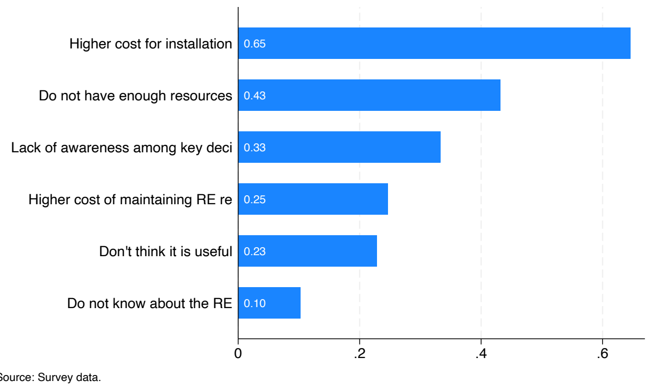
Figure 4: Factors behind not expanding the current capcity



5.3 *Financial and Knowledge Barriers to Initial Adoption*

Among the 438 factories that have not yet adopted renewable energy technology (RET), high installation costs stand out as the most significant barrier, cited by 65% of respondents. Insufficient resources follow at 43%, reinforcing that financial constraints represent the primary obstacle to initial adoption. These economic barriers are compounded by knowledge gaps: 33% report lack of awareness among key decision-makers, 25% believe RET is not useful for their operations, 23% cite high maintenance costs as a concern, and 10% simply lack information about

Figure 5: Reasons for not adopting RET

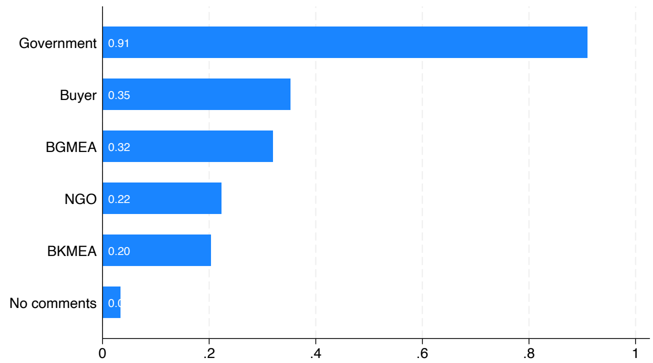


renewable energy options. This pattern contrasts sharply with the earlier finding that 94% of adopters used their own funds, suggesting a divide between factories that can self-finance and those that cannot.

The severity of these financial barriers, particularly for small and medium enterprises (SMEs), is echoed by industry stakeholders. A BGMEA representative emphasized that "implementing phased financial incentives will ease the burden on SMEs transitioning to renewable energy." Similarly, an industry expert noted that "small factories will need a complete technological solution tailored to their limited resources, something that enables them to mitigate the overwhelming initial costs of RET installation." These insights suggest that while renewable energy has become economically attractive for larger factories with available capital and space, smaller operations require targeted financial support and customized solutions to overcome the substantial upfront investment hurdle.

5.4 Expectations for Support in Renewable Energy Adoption

Figure 6: Supports expected from which institutions

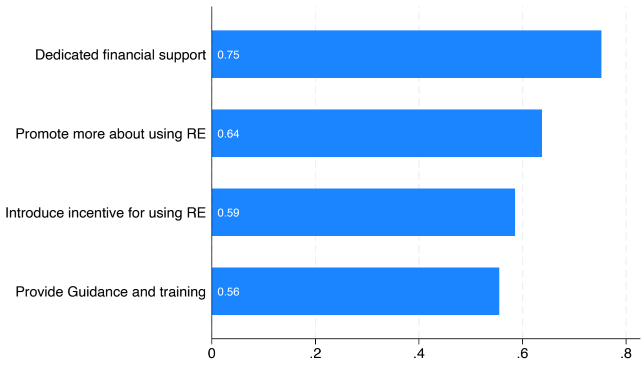


Source: Survey data.

Among all 661 respondents, expectations for support in promoting renewable energy technology adoption are overwhelmingly directed toward the government, with 91% identifying it as a key source of assistance. This strong expectation aligns with the earlier finding that high installation costs (65%) and insufficient resources (43%) are the primary barriers for non-adopters. Buyers rank second at 35%, followed closely by the Bangladesh Garment Manufacturers and Exporters Association (BGMEA) at 32%, suggesting that factories also look to their trade association and international clients for support. NGOs (22%) and the Bangladesh Knitwear Manufacturers and Exporters Association (BKMEA) (20%) are viewed as less critical support sources, while only 3% offered no comments. The dominant role of government in these expectations underscores the need for policy interventions such as the phased financial incentives mentioned by the BGMEA representative, particularly to help SMEs overcome the substantial upfront costs that currently prevent many factories from adopting renewable energy technology.

Regarding the specific types of support desired, dedicated financial support emerges as the top priority, with 75% of respondents identifying this need. This directly addresses the cost barriers that prevent adoption among non-adopters and limit expansion among current users. Promotional activities to raise awareness about renewable energy benefits follow at 64%, which is crucial given that 33% of non-adopters lack awareness among key decision-makers and 10% are simply unfamiliar with renewable energy options. Incentives for using renewable energy are sought by 59% of respondents, while 56% desire guidance and training. This comprehensive set of expectations—spanning financial assistance, awareness-building, incentive structures, and capacity development—suggests that a multi-faceted support strategy will be necessary to accelerate renewable energy adoption across the RMG sector, particularly among smaller factories that lack the resources and knowledge to adopt independently.

Figure 7: Types of support expected



Source: Survey data.

5.5 Summary

This study of Bangladeshi RMG factories reveals that renewable energy adoption is primarily driven by environmental consciousness and financial savings, with most adopters self-financing their installations. Despite favorable economics making solar power increasingly affordable compared to grid electricity, adoption rates remain constrained by significant barriers. Space limitations emerge as the dominant obstacle for factories seeking to expand their current low-capacity systems, while high installation costs and insufficient resources prevent initial adoption among non-adopters. Knowledge gaps and lack of awareness among key decision-makers further compound these challenges, particularly affecting smaller enterprises. Respondents overwhelmingly look to the government for support, specifically seeking dedicated financial assistance, promotional campaigns to raise awareness, and incentive programs. Industry stakeholders emphasize the need for phased financial mechanisms and customized technological solutions tailored to resource-constrained SMEs. The findings suggest that while larger factories with available capital have embraced renewable energy voluntarily, accelerating sector-wide adoption requires a comprehensive support strategy addressing financial, spatial, and knowledge barriers through coordinated government intervention and industry collaboration.

6 Discussion

The manufacturing sector has immense potential to contribute towards a much-needed energy transition in Bangladesh. Given the geographic location, solar energy is likely to dominate as the primary source for renewables. Large factories can provide the space, especially on their roofs, for installing solar panels. The garment sector remains the major industrial sector and is also exposed to buyers' demands for "greening" their production processes, which is likely to intensify in the future (Charter & Sanchez-Moreno, 2023; Isokangas, 2020).

In this study, we aimed to learn about the current situation within the apparel exporting sector in Bangladesh regarding renewable energy adoption. Solar energy remains the primary renewable source, with approximately 31 per cent of factories adopting solar panels on their factory premises. However, our findings also highlight that the average capacity is quite low and only half of the factories with renewable energy technology (RET) link the energy generation from renewables with their production processes, even though there is a strong association between RET adoption and reduction in incidences of lower capacity utilization from power disruption. Along with short payback periods and significant energy-related cost savings, increased reliance on renewables can make a viable "business case" for apparel exporters.

Upfront costs are one of the major barriers for factories to adopt large-scale energy generation capacity based on renewable sources, mostly rooftop solar panels. The adopting factories are motivated by environmental concerns as well as potential cost savings to meet their energy needs and maintain more reliable power sources. Larger factories are more likely to take advantage of renewable energy sourcing. Compliant factories (those that were part of the Accord or Alliance initiatives and had Workers' Participation Committees, WPCs) are also more likely to report having RET as their energy sources. There is also evidence of clustering of adoption, as factories within the same geographic locations are more likely to adopt RET, indicating possible spillovers as well as agglomeration benefits in new technology adoption.

Taken as a whole, our findings indicate public policies are likely to play important roles in promoting adoption of renewable energy technology within the manufacturing sector. Many industries in Bangladesh have taken initiatives to adopt sustainable production practices including RET installations, as evident from our findings. The apparel exporters can certainly further increase adoption of RET and integrate with their production processes. However, their meaningful contribution to achieving NDC or Paris Accord commitments will require careful coordination amongst different stakeholders that will include factory owners, suppliers, the National Board of Revenue (NBR) as well as buyers, development partners (through technology transfers), and academia. Moreover, as the latest NDC document also highlights the need for data to monitor and evaluate the effectiveness of different policies (see GoB, 2021), the barriers are present in many different contexts as identified in the prior literature (Karakaya & Sriwannawit, 2015). However, solutions will need customizing to fit the local context, and collective efforts can further the adoption of renewable energy technology within the manufacturing sector in Bangladesh.

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