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Research article

Current challenges and future perspectives of solar-PV cell waste in Bangladesh

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ABSTRACT

This study focused on the current situation and management after the end-of-life solar photovoltaic (PV) module in Bangladesh. The solar PV cells have a lifetime to serve properly, which is about 15–25 years from installation. Solar PV cell has recycling potentiality as well as the risk of producing hazardous wastes. After the end-of-life, the solar panel would turn into waste, specifically e-waste, which might be an environmental concern in the long run. Thus, it is crucial to estimate the waste production and to delineate the environment-friendly management. Therefore, this study aims to visualize the present status of solar PV cells, potential waste generation, and their management perspectives in Bangladesh. We also studied the existing policy of waste management. This study followed a mixed methodological approach, including the key informant interview (KIIs), synthesis of existing literature-based findings, stakeholder consultation and secondary data inventory. From the results, it was found that Bangladesh has huge potential to generate solar PV-based e-waste in the near future that needs to be tackled with high priority. A total about 33205.36 tonnes of potential e-waste can be generated from installed PV cells. A suitable management system might be able to recover materials such as glass (24,468 tonnes), aluminium (2,656.43 tonnes), silicon (1404. 92 tonnes), and copper (49.89 tonnes) from the PV cells wastes. As there is an excellent opportunity to recover resources from the waste panels, there is also scope to grow enterprise for recycling of waste panels. Unfortunately, such policy or plan from the government is yet to be taken into account. However, a long-term national plan is required to manage this waste, maintaining the high standard based on in-depth research.

1. Introduction

At present the solar photovoltaic (PV) system has become the leading green source of electricity all over the world to households and venturer in off-grid, and remote areas. As Bangladesh is a tropical country, plenty of sunlight is available all over the year, and the possibility of using solar energy has been considered very significant (Islam et al., 2006). There is also some national-level planning to supply solar electricity through conventional grid systems (Mondal and Islam, 2011). The PV system has been expanded in both urban and rural areas widely as it has many positive impacts in the form of solar rooftop, solar pump, solar mini-grid, solar microgrid, solar park, solar charging station, solar drinking water system, solar street light etc. As a result, people of outlying areas get access to electricity.

The PV system utilizes light and heat energy emitted from the Sun and converts them into electricity for supplying to entities like industry or households to fulfill needs where they suited. Since sunlight and heat are the free production of nature, both are renewable and do not have any negative impact on the environment. But the PV panel at its end of life possesses an important environmental issue to be tackled properly. Every solar panel has a designed lifetime for its proper functioning. After finishing their useful lives, they turn into a form of hazardous waste. Solar panels give service for a long time, generally, solar panels have 20–25 years of service life, and during this time, there Is nothing to be concerned about the recycling of waste PV panels (Tasnia et al., 2019). Some PV cells comprise hazardous materials, for example, lead, selenium, tellurium, and cadmium. In many countries, cadmium compounds are currently regulated as it is capable to create toxicity to fish and wildlife,

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and humans can get affected by this through the food chain (McDonald and Pearce, 2010). In addition, at some stage of their life cycle, some greenhouse gas (GHG) like CO_2 is also generated by PV panels as like as other power generation sources (Aman et al., 2015). In the industry of PV panels, Pure silicon metal (Si_{met}) is used to manufacture PV panel. To produce Si_{met} a basic carbo-thermic reduction is needed. At very high-temperature quartz react with reducing element such as charcoal, coal, wood chips, coke and the furnace graphite electrodes in electric arc furnaces to produce Si_{met} (Aman et al., 2015). The basic carbo-thermic reduction process equation is,

$$SiO_2 + 2C \rightarrow Si_{met} + 2CO \quad (1)$$

Based on its contain materials PV cell has non-cancer, cancer and ecotoxicity potentials for freshwater, marine water, natural soil and agricultural soil (Bang et al., 2018). In Bangladesh, a noteworthy count of the initial batch of PV panels inserted are now at their end-of-life and proper management of expired PV panels are gradually becoming an emerging environmental issue (Aman et al., 2015). For this research we tried to find out the answer the following research questions: how much PV cell waste can be generated from the installed solar system in Bangladesh? What is the existing policy to deal with this issues? What can be the opportunity to manage PV cell waste sustainably. Thus, this research work aims to quantify the recycle potentiality of PV cells in Bangladesh.

1.1. Photovoltaic cell – category and component

The solar panel was invented in 1954 at Bell Telephone Laboratories in the United States. Today, PV is one of the fastest-growing renewable energy technologies and is ready to play a major role in the future global electricity generation.

In a solar energy system, the base power generation unit is solar panels, those also known as photovoltaic or solar modules (PV modules). The basic building block of the PV devices is a semiconductor element known as PV cell. When several cells are interconnected, PV module is formed. Solar panels can be categorized into three generations: (1) Monocrystalline or multi-crystalline silicon; (2) thin film; and (3) concentrator photovoltaics and emerging technologies. As among these modules monocrystalline and polycrystalline silicon panels have more conversion skill from thin film, as worldwide commercial solar-panel materials they are currently used mostly.[7] A crystalline silicon PV panel is composed of Tempered glass (Glass), Battery piece (Silicon, cadmium, selenium, tellurium, gallium, molybdenum, indium, etc.), EVA (ethylene/vinyl-acetate copolymer), Backboard (TPT, TPE, etc.) Al alloy frame (97% Al) (Figure 1) (Xu et al., 2018).

In general, the composition of a solar panel, a solar controller, and a battery or group of batteries makes a solar-energy system. An inverter is essential when the unit output power, whether 220 V (AC) or 110 V, completes the solar energy system module configuration (Figure 2).

1.2. Overview of solar PV across the country

With time solar panels have become a very known technology. Now 414.91 MW of electricity comes from solar technology, in which 87.87 MW contribute on-grid, and 327.04 MW contribute off-grid (SREDA 2021). There are different running projects under the solar program. Solar parks, rooftop solar except NEM, net metering rooftop solar, solar irrigation, solar mini-grid, solar nano-grid, solar charging stations, solar drinking water systems are the large projects, and solar home system (SHS), solar street lights are the small projects.

SHS is the most extensive program among all the solar projects in Bangladesh. To ensure green energy (electricity) opportunities to the off-grid and remote rural areas of Bangladesh, IDCOL started the SHS project in 2003. Under the project, the amount of installed SHS would be about 4.49 million by September 2020 (SREDA 2021).

First installed PV cells are already at their end-of-life or very closed to end-of-life. To manage the waste produced from electronics and electrical product Department of Environment has recently published a draft policy (DoE) of Bangladesh named as "E-waste management rules 2017" (DoE report draft, 2017). In this draft PV panel waste is not mentioned as e-waste.

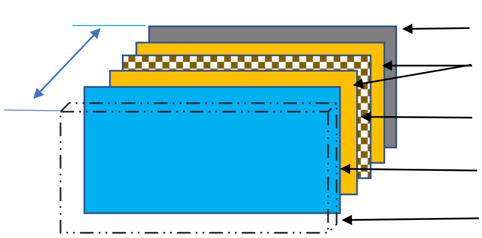

Figure 1. Illustration of a crystalline solar panel.

2. Methodology

A sustainable waste management system preparation needs country-level information about future waste generation and mass of waste flow. The study area is Bangladesh. The research is based on a combination of secondary data, field surveys, literature reviews, stakeholder consultations, and key informant interviews (KIIs). Informed consent was assured before interview with key informant and they were aware about the objectives and methodology of the study and the ethical issues were resolved by JU-Sub-committee. Most of the secondary data were collected from published reports and related web pages of the following organizations; Sustainable and Renewable Energy Development Authority (SREDA); Infrastructure Development Company Limited (IDCOL); International Renewable Energy Agency (IRENA). A respectable number of KIIs ($n = 10$) were conducted from the experts, academicians, and policy people. The methodological approach is given in Figure 3. Finally a Strength, Weakness, Opportunity and Threat (SWOT) analysis was performed based on the KIIs outcome.

3. Results and discussion

3.1. Total number of installed solar panels in Bangladesh

Renewable energy is gradually becoming a vital power generation source in Bangladesh. Among all sources of renewable energy, solar energy system contribute a large part. The Vision-2021 sets a target to generate 5% by 2015 and 10% by 2021 energy from the sources of renewable energy of total national energy shares. According to the annual report of the Power Sector Master Plan-2016, by 2021, the target is to achieve 2470 MW, and by 2041, the target is to achieve 3864 MW. By 2021, 748.3 MW is the estimated energy from solar technology, counting solar energy 40% of all renewable energy. For achieving these targets, some large and small solar technology projects have already been running (Table.1). The potential for material recovery is presented in Table 2.

Bangladesh is taking the initiative to expand the sector, and several projects are under construction. Currently, its producing 415.068 MW of electricity by 11 different size solar projects (Table 1). Among this running program, solar park provide 38.4 MW on-grid, rooftop solar except NEM generate 14.201MW off-grid and 27.565 MW on-grid, net metering rooftop solar generate 16.207MW on-grid, solar irrigation generates 42.384 MW off-grid and 0.025MW on-grid, solar charging station generates 0.262MW off-grid and 0.016MW on-grid electricity. Rest of the projects generates only off-grid electricity. In Figure 4, the different types of solar energy system are presented according to their contribution.

Solar nano-grid, solar charging stations, Solar drinking water systems are the lowest contributors to the energy system.

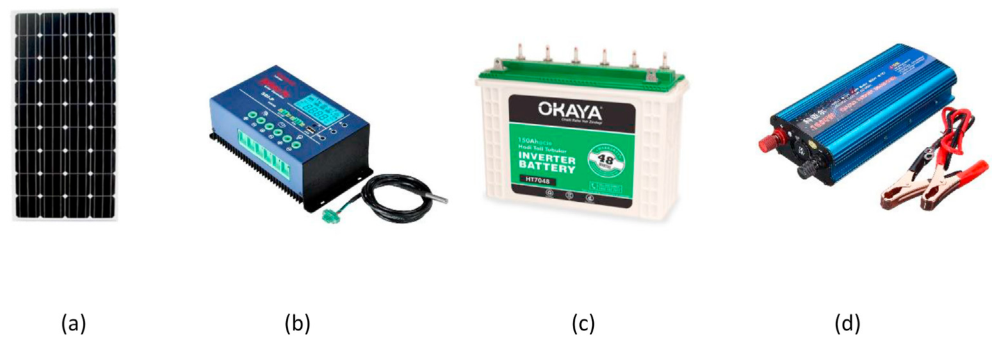

Figure 2. Components of Solar energy system. (a) solar panel, (b) controller (c) battery (d) inverter (Modified from LEONICS: https://www.leonics.com/support/article2_13j/articles2_13j_en.php).

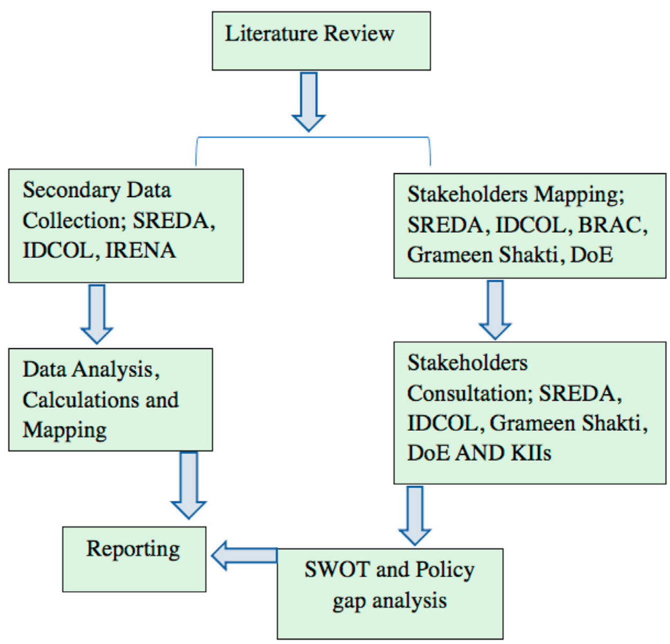

Figure 3. Methodological approach of the study.

Table 1. Total number of PV modules (IDCOL, 2018).

Sl.	Project Size	Technology Name	Number of Units	Capacity (MW)
1.	Large	Solar parks	4	38.4
2.		Rooftop solar except NEM	116	41.766
3.		Net metering rooftop solar	147	16.207
4.		Solar irrigation	1675	42.408
5.		Solar mini-grid	27	5.656
6.		Solar nano-grid	2	0.001
7.		Solar charging stations	14	0.278
8.		Solar drinking water system	70	0.062
9.		Solar powered telecom BTS	1933	8.06
10.	Small	Solar home system	5804422	251.64
11.		Solar street light	201754	10.59

Solar home system (SHS) contributes the highest amount of electricity among all projects. It complies with about 61% of total energy generated from solar technology (Figure 4). Under this project a large number of people are getting electricity facility in remote areas. SHS is installing solar panels all over the country in different amounts based on needs (Figure 5). Sunamganj has the highest number of solar panels. It has almost 226624 units of solar panels (Figure 5). A district-wise distribution of solar PV cells in Bangladesh is presented in Figure 6.

Table 2. Estimated amount of recovered materials of a PV panel (Choi and Fthenakis, 2013; Weckend et al., 2016; Yi et al., 2014).

Material to be recycled	Percentage of composition weigh	Percentage of recycled material	Amount of recovered material (kg/module)
Glass	76%	96.96%	18.42
Plastic	10%	66%	1.65
Aluminum	8%	>99.9%–100%	2
Silicon	5%	84.62%	1.06
Copper	1%	77.78%	0.175

3.2. Recycle potentiality

A commercial panel's average weight = 25 kg (Mondal and Islam, 2011).

If the amount of recovered material = m, then

$$m = \frac{\%\ composition\ weight \times \%\ of\ material\ recycled \times 25}{100 \times 100} \tag{2}$$

(Choi and Fthenakis, 2013; Mondal and Islam, 2011; Weckend et al., 2016).

The 250-watt crystalline panel weight around 20 Kg (greencoast.com (Solar Panel Roof Load Calculator)). And 1 MW panel weight around 80 tonnes. The amount of potentially recovered material from PV panel of a different running project in Bangladesh is estimated in Table 3. It is clear from the result that the solar home system contributed the highest amount waste production as well as material recovered from the spent panels. Glass, aluminium, silicon, and copper recovery was estimated and found that 14834.6, 1610.496, 851.751, and 156.58 tonnes respectively from the solar home system in Bangladesh (Table 3).

Recycling PV cell after end-of-life eventually helps to conserve natural resources. Recovered materials provide a considerable amount of raw materials and a big count of semiconductors for the PV cell manufacturing industry. It would cut the cost of PV cell production too. Recovered glass, plastic, aluminum, silicon, copper can be reused for different purposes.

Developed countries such as Japan, European countries, and the United States have been trying to find out a scientific solution to deal with the PV waste (Bombach et al., 2005, 2006; Doni and Dughiero, 2012; Palitzsch and Loser, 2012). In July 2012, PV cell-derived waste was added to waste electrical and electronic equipment (WEEE) by European Union (Xu et al., 2018). So the PV waste has to be managed by an electric waste management system; it must be managed, collected, reused, and recycled (Bio Intelligence Service, 2011; McDonald and Pearce, 2010). In EU, great Britain is the first country who take up the rules regarding the management and recycling of PV waste, which was revised in WEEE's

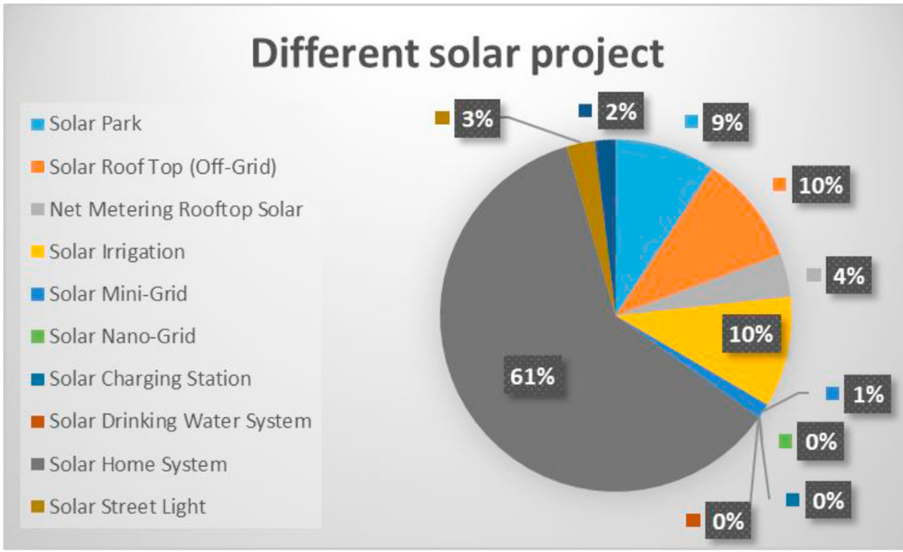

Figure 4. Contribution of each projects in total solar energy generation in Bangladesh, (in percentage).

directive (Chowdhury et al., 2020; Xu et al., 2018). Germany also revise and ratify the regulation of WEEE as a second EU country (Chowdhury et al., 2020; Xu et al., 2018). EU and the Czech Republic have formed a joint venture to recover, manage and recycle PV cell derived waste, regarding the WEEE directive (Chowdhury et al., 2020; Xu et al., 2018). Besides EU, very few countries have rules for recycling PV cell waste. Developing countries like India, Thailand, North Korea have not had any policy for PV waste recycling so far. South Korea has developed rules and regulations to manage and recycle PV waste (IRENA, 2016).

Several technologies have been developed in the world to recover and recycle PV waste. One potential technology to recycle PV panels for Bangladesh is described in Figure 7. Where, the material recovery can be achieved from both broken PV module and complete module following the subsequent processes as follows: cutting, grinding, heat processing, module disassociation (cell, back material, frame, glass cover, and junction box), reuse, recycle (chemical treatment, leaching and refining of crude materials) (Xu et al., 2018).

Bangladesh and Myanmar, and the seven sister states of India share the same land borders. In Myanmar, there is no regulation regarding PV waste management (Tasnia et al., 2019). As a consequence, there is no waste collection center or recycling center to manage waste generated from PV modules. In North-Eastern India, the Seven Sister States of India are the contiguous states of Arunachal Pradesh, Nagaland, Assam, Tripura, Meghalaya, Mizoram, and Manipur. It is not practically feasible to connect with the e-waste recycling centers of India for these states. In that case more practical and cheaper option to transport PV wastes from these states may be to Bangladesh. After PV waste collection centers are set up in Bangladesh, the PV wastes from the aforementioned regions might be sent to the collection center (Risingbd, 2013). This strategy can be very potential to implement a regional but co-management system in this region for the proper management of PV cell wastes.

3.3. Recent policies in PV recycling

3.3.1. Strategic E-waste management regime in Bangladesh

Environmental laws and regulations are managed and updated by the Department of Environment (DoE) under the Ministry of Environment, Forests and Climate Change (MOEFCC). Environmental laws and rules of Bangladesh such as the Environment Conservation Act, 1995 (DoE/MoEFCC, 2019), The Environment Court Act, 2000 (DoE/MoEFCC, 2019), The Environment Conservation Rules, 1997 (DoE/MoEFCC, 2019) had no inclusion of e-waste management during their promulgation. Besides, the acts were not updated. The management strategy of e-waste first appeared in the National 3R Strategy for Waste Management, 2010, and later in the draft E-waste management rules – 2017 and the National Environment Policy- Bangladesh 2018 (DoE/MoEFCC, 2019). The common feature of these policies and strategies is to promote 3Rs (Reduce, Reuse, and Recycle) (Table 4). However, introducing the policies just remains as paperwork unless the administering bodies do the implementation.

E-waste management from the renewable energy sources requires strategic interministerial and inter-departmental coordination. The gaps should be addressed by the respective governmental authority such as DoE, MoEFCC, PD (Planning Division), MPEMR (Ministry of Power, Energy, and Mineral Resources) and other relevant stakeholders.

3.4. Environmental impact

Though solar technology is a green technology, it can create threat to environment after it's end-of-life if the disposal system is not well maintained. Open dumping of solar panels would cause environmental pollution, and it contains heavy metals lead, tin, and cadmium (Bakhiyi et al., 2014). The presence of these heavy metals creates hazardous waste. Polycrystalline PV cell contains 0.15 g/W hazardous materials (Bang et al., 2018). An estimated 33205.36 ton PV cell waste would create 62.26 ton hazardous materials. These may pollute soil, groundwater, surface water and affect human health.

3.5. A proposed complete potential collection system

All districts of Bangladesh has the facility of electricity with the solar energy system. The collection of these solar panels is the first challenge to the way of recycling. To ensure safe and complete management of PV module waste, a complete collection system of PV waste should be organized. PV waste management body should develop a system with several steps of delegates. This chain can be made with three to four type delegates, 1. Primary collector delegate body, 2. Regional collector delegate body and 3. Recycle delegate body.

- > Primary Delegate body should be appointed at the district level and places like Sunamganj (226624 SHS) where the waste size is large, delegate should be starting from union level. These delegates would collect all the PV modules of the district. They would later deliver the waste product to the regional delegate body.
- > On the basis of the waste amount, 1 or 2 Regional delegate bodies can be made in a division. The regional delegate office should be set in the nearest place of recycling delegate office. The regional

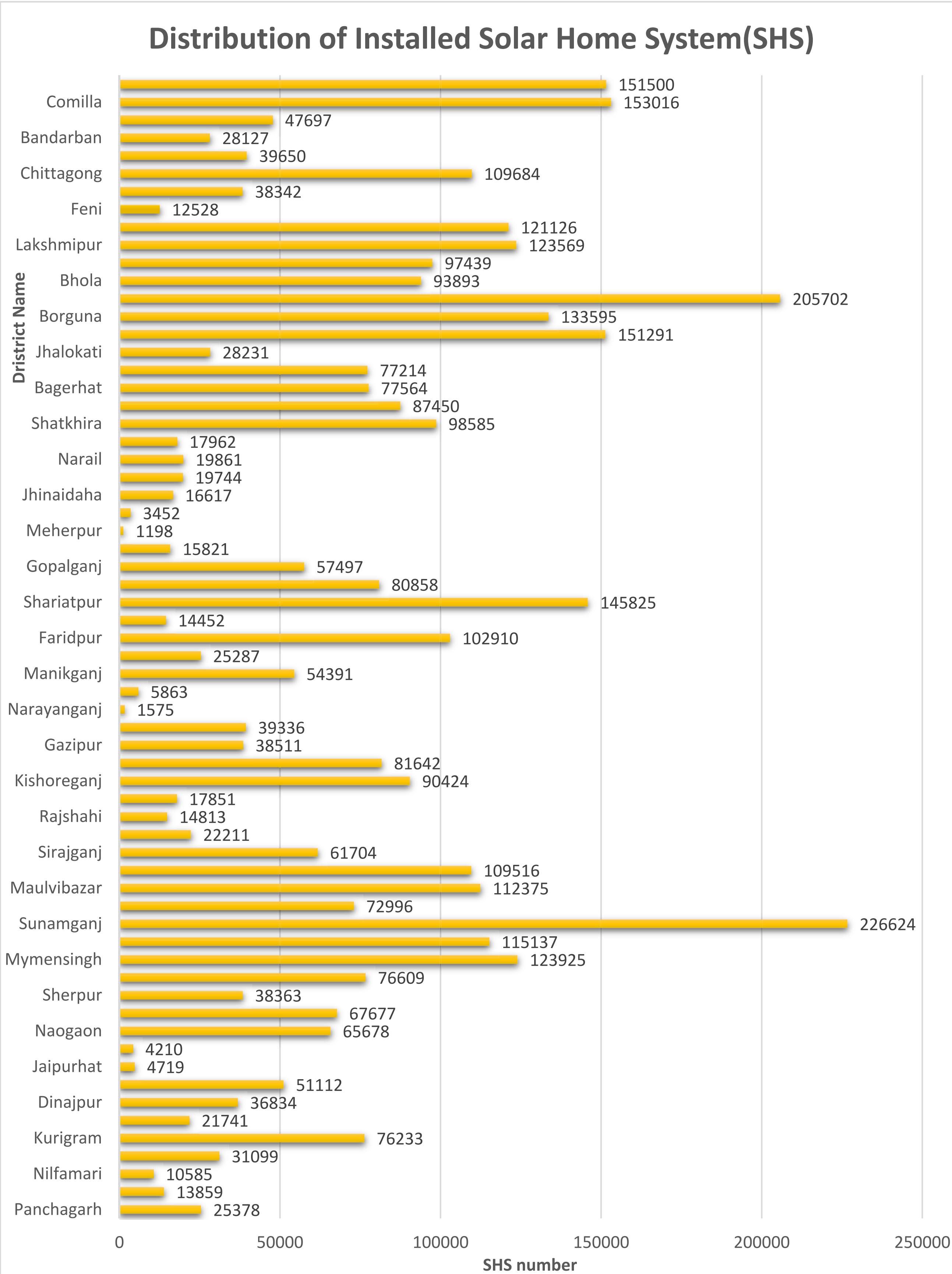

Figure 5. District wise distribution of solar home system (own calculation based on IDCOL, 2018).

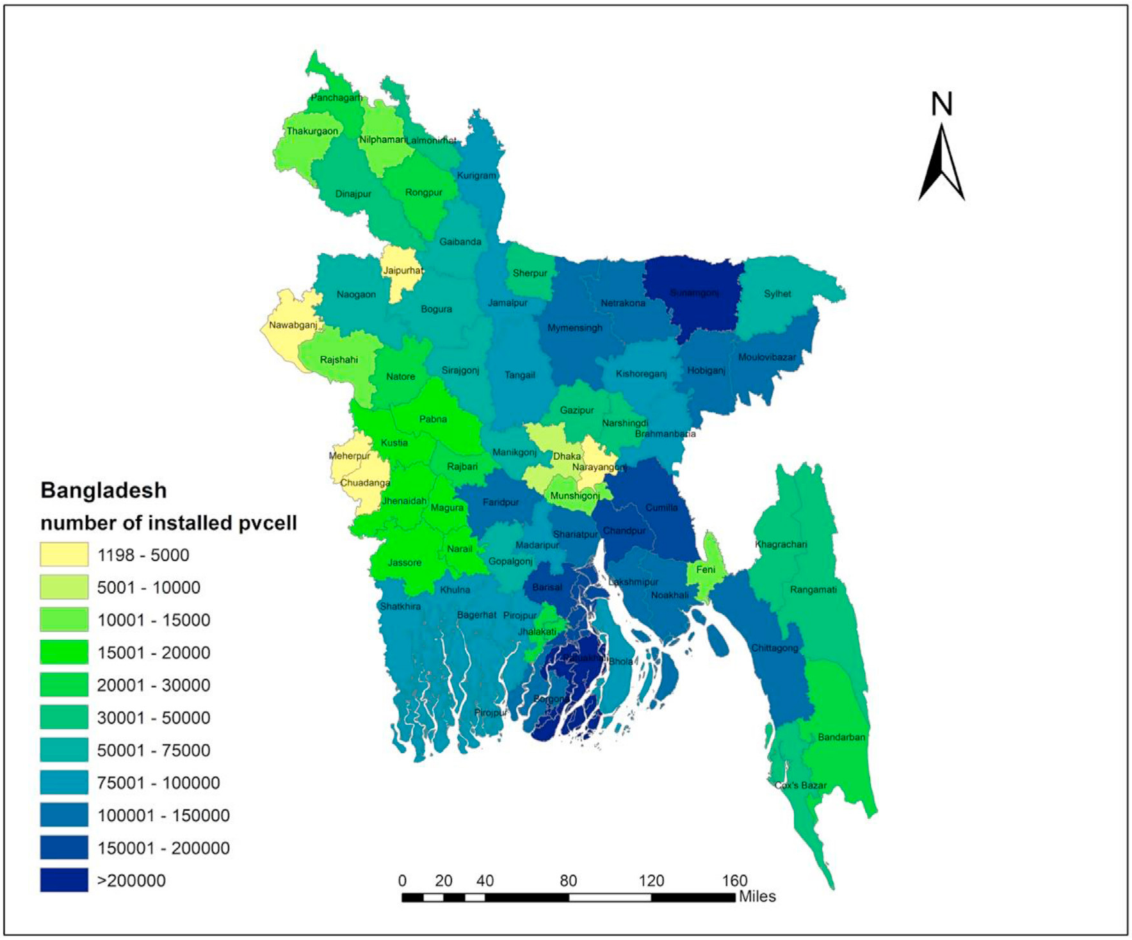

Figure 6. Spatial distribution of solar PV cells in Bangladesh.

Table 3. Estimation of potential recovered material from PV panel in Bangladesh.

Project name	Capacity (MW)	Estimated Weight of panel (tonne)	Recovered material (tonne)			
			Glass	Aluminum	Silicon	Copper
Solar parks	38.4	3072	2263.744	245.760	129.976	23.894
Rooftop solar except NEM	41.766	3341.28	2462.175	267.302	141.369	25.988
Net metering rooftop solar	16.207	1296.56	955.429	103.724	54.857	10.084
Solar irrigation	42.408	3392.64	2500.022	271.411	143.542	26.387
Solar mini-grid	5.656	452.48	333.430	36.198	19.144	3.519
Solar charging stations	0.278	22.24	16.388	1.779	0.940	0.172
Solar drinking water system	0.062	4.96	3.655	0.396	0.209	0.038
Solar powered telecom BTS	8.06	644.8	475.150	0.051	27.281	5.015
Solar home system	251.64	20131.2	14834.600	1610.496	851.751	156.580
Solar street light	10.59	847.2	624.298	67.776	35.845	6.589
Total		33205.36	24468.896	2656.428	1404.918	49.882

delegate body would be responsible for transporting PV waste to recycle delegate body.

> The recycle delegate body would be responsible for all the recycling processes of PV module waste. Recycle delegate body wouldpay the price of PV cell, and it would fairly distribute in every level, including the PV module owner.

An initiative cannot bring the desired result without the response and participation of all stakeholders. Stakeholders should know about the negative impact of expired PV modules on to the environment and human health. All the stakeholders have to be informed about the positive impact of recycling the PV modules and their benefits. PV module provider makes the new client aware at the time of installation about disposal procedure, told them to call primary delegate body at least 2 months before expected end-of-life of the module. The economic return may be possible along with the environmental benefits through implementing a comprehensive collection and management system as depicted in Figure 7. Previous study found that the market value of extracted

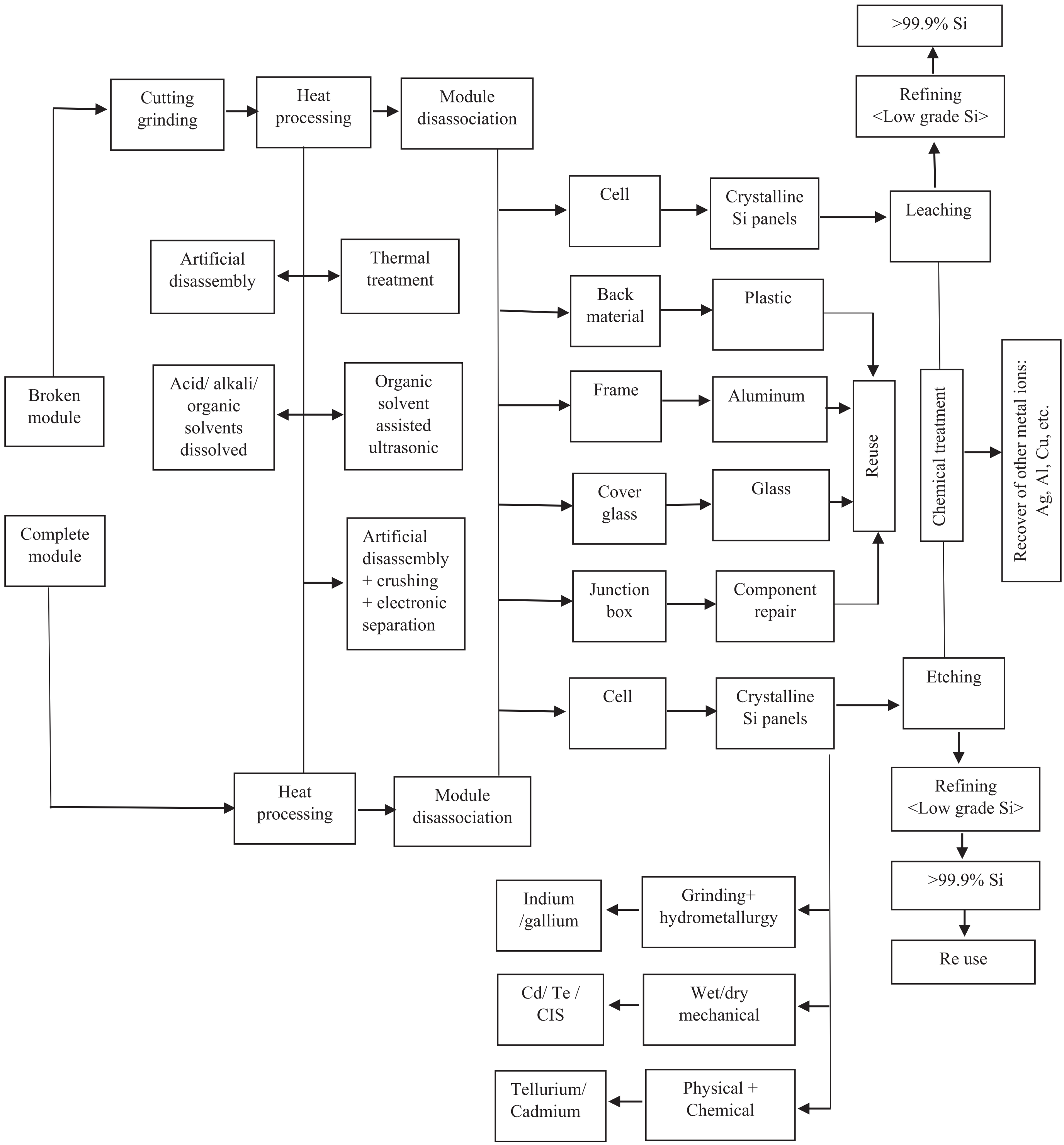

Figure 7. A technology brief for recovering and recycling of PV module (Xu et al., 2018; Yi et al., 2014).

materials from PV waste cell has been increasing nd by 2024 the projected value would be for silver 530 USD/kg, zinc 2.683 USD/ton, nickel 13.786 USD/ton, lead 2.398 USD/ton, and tin 21.82 USD/ton (Tasnia et al., 2019). Moreover, some recent study suggested the application of SiO_2 with TiO_2 to improve the performance of the solar box type cooker (Shanmugan et al., 2021) and the potential for the application of recovered SiO2 may be prioritized.

4. SWOT analysis

SWOT is known as a decision-making tool which used to analyze strategic case (Abdel-Basset et al., 2018). SWOT is described as Strength, Weakness, Opportunity, and Threat where strength and weakness are an external force; opportunity and threat are internal force. To make a successful strategic plan, one should use its opportunity and strength;

Table 4. Legal regime of e-waste management scenario in Bangladesh.

Policy regime	Strategic management features
National 3R Strategy for Waste Management, 2010 (DoE/MoEFCC, 2019)	The recycling of e-waste is required to be regulated due to the presence of hazardous constituents in the components of waste electrical and electronic assemblies.
	Governments should encourage e-waste recycling projects under public-private partnership mode.
E-waste management rules - 2017 (Draft) (DoE/MoEFCC, 2019)	Types of e-waste defined.
	The 3Rs (Reduce, Reuse, and Recycle) method will be followed to manage e-waste.
	Under the "Extended Producer Responsibility (EPR)" policy, the producers will treat and dispose of electronic items.
	Yet end-of-use solar panels not included as the e-waste
National Environment Policy- Bangladesh 2018 (DoE/MoEFCC, 2019)	Section 3.23.7 Electronic Waste Management/E- Pollution through reduce, Reuse, and recycling (3R) policy.
	E-waste from renewable energy sectors were not included.
Other relevant policies	
Renewable energy policy of Bangladesh (2008) (PD/MPEMR 2008)	The policy urged to promote the development of local technology in renewable energy and clean energy for Cleaner development mechanisms (CDM).
	However, nothing was mentioned in the policy regarding the management of e-waste generated from solar panels and relevant equipment such as batteries.
Biomedical Waste Management Rules 2008 (DoE/MoEFCC, 2019)	This rule recommends source separation of hospital waste as well as separate collection, transportation and treatment and disposal of all kinds of hospital and clinical waste.
	However, nothing was mentioned in the policy regarding the management of e-waste generated from medical equipment.

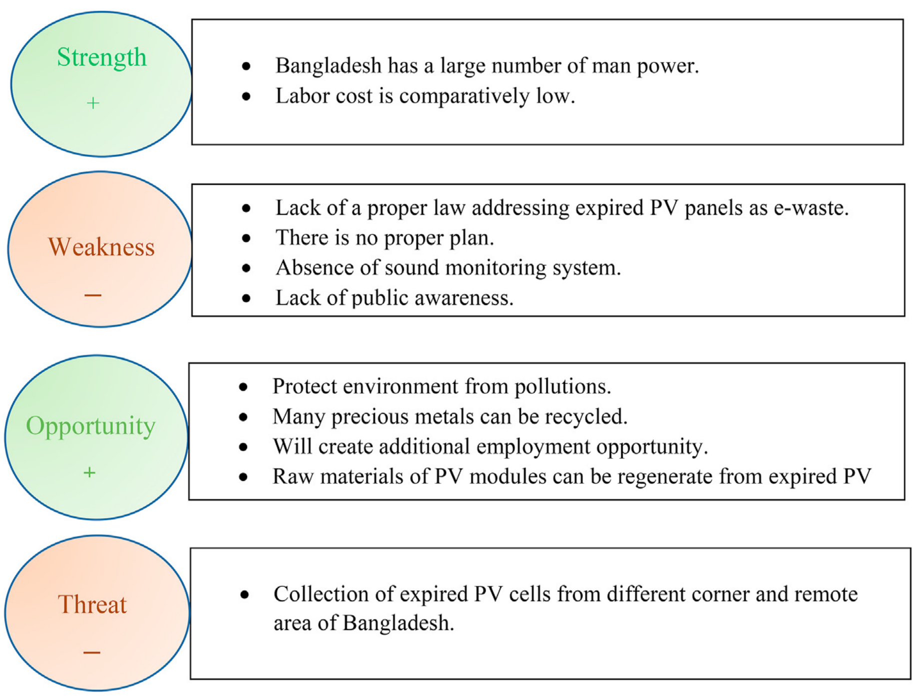

Figure 8. SWOT analysis of PV waste management in Bangladesh.

carefully deal with its weakness and threat. Maximum utilization of opportunities should be done at a maximum rate through existing strength. Here the SWOT analysis of PV waste management is described in Figure 8.

5. Conclusions

This study finds the potentiality of recycled PV-cell wastes in Bangladesh considering the easiness of processes such as retrieving and dismantling of obsolete PV panels. In Bangladesh, a dedicated PV cell recycling system is currently unavailable. Therefore, a huge scope of resource recovery from wasted PV cells might be lost along with escalating environmental threats. Despite having a huge number of solar PV cells, there is no plan and policy to deal with e-waste from solar cells for environmental safeguard. Therefore, it is high time to research more on PV cell recycling and formulate a suitable policy on the sustainable management of waste generated from solar PV cells to maximize resource recovery and reduce environmental burden.

Declarations

Author contribution statement

Sikder Sanchita Tasnim: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Md. Mostafizur Rahman: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Mohammad Mahmodul Hasan: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Mashura Shammi & Shafi Mohammad Tareq: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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