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A Critical Environmental Sustainability Evaluation of a UK University Solar Panel Installation

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Abstract

This paper provides a forecast critical environmental sustainability evaluation of a UK university's proposed solar panel installation and impact assessment on key stakeholders. The objectives were to forecast greenhouse gas (GHG) emissions and identify areas for reduction, forecast payback and carbon neutrality periods, and map stakeholder relationships. A carbon audit gathered GHG emissions data for raw material extraction, solar panel manufacture, transportation and decommissioning. The functional unit for measuring greenhouse gas emissions was kg CO_2-eq. Stakeholder mapping analysed inter-relationships between various groups such as management, staff and students. The vast majority of GHG emissions arise from raw material extraction. However, the use of recycled materials could significantly reduce the installation's carbon footprint. The installation is forecast to become carbon neutral within 2 years and payback within 4 years. Stakeholder analysis suggests potential areas of resistance; specifically a challenging economic situation, timing and choice of system. Carbon auditing lacks a standardised methodology so different audits can yield different forecasts. Campus location, available space, choice of system and type of solar panels affect costs and payback periods. The findings are therefore indicative in nature. Accreditation of material suppliers and supply chain transparency is important. Recycled materials should be prioritised with contractors subject to cost. This significantly affects the installation's carbon footprint. The findings provide an indication of the environmental and cost benefits of solar installations on university campuses, whilst identifying the associated relationship dynamics and power influences of key stakeholders.

Keywords

Campus Sustainability, Solar Panels, Carbon Audit, Stakeholder Mapping,

Renewable Energy

1. Introduction

Solar energy adoption varies widely across campuses, affecting budgets, greenhouse gas (GHG) emissions, Corporate Social Responsibility (CSR) targets and sustainability rankings [1]. This study provides a forecast evaluation of the University of Huddersfield's intended strategic investment in installing 500 solar panels on the roof of one of its largest buildings as part of a wider carbon reduction plan [2]. The carbon reduction plan is proceeding amid a backdrop of a budget deficit, jobs cuts and department closures. This evaluation forecasts the installation's GHG emissions, cost and timescales involved, and how different stakeholders can be identified, prioritised and engaged in the installation. The forecast evaluation uses carbon auditing, and stakeholder mapping and management. The functional unit for measuring GHG emissions is kg CO_2-eq.

2. Objectives

- Forecast GHG emissions, identifying where and how these can be reduced.
- Identify potential cost and compliance requirements.
- Forecast the installation's payback period and when it becomes carbon neutral.
- Map stakeholder relationships, levels of interest and influence.
- Identify potential objections, synergies and advocacy.
- Develop a stakeholder engagement and communication strategy.

3. Carbon Audit

3.1. Methodology

Carbon auditing was used to quantify GHG emissions expressed as kg CO_2-eq based on a Lifecycle Assessment using the single impact category of climate change, consistent with ISO 14064, an international standard for quantifying and reporting GHG emissions [3]. The carbon audit system boundary explicitly included the following:

- Sourcing of solar panels covering raw material extraction, manufacture and transport to the installation site.
- Decommissioning of solar panels covering transportation of solar panel waste to recycling facilities, incineration of solar panel plastic and metal recovery from bottom ash.

Installation emissions arising from contractor mileage, on-site electricity usage, lifting equipment and mounting hardware, cabling, maintenance and roof strengthening are not included in the audit.

The three scopes are shown in **Table 1**. The carbon audit used in this study relates to scope 3 emissions.

Table 1. Three emission scopes of the audit.

Scope 1	University's own vehicles and equipment during installation.
Scope 2	Electricity that the university purchased during the installation.
Scope 3	Raw material extraction and solar panel manufacturing, transportation and decommissioning of panels.

Stakeholder mapping was used to understand the dynamics of the relationships and to develop a communication plan which addressed different stakeholder concerns.

3.2. Emissions from Raw Material Extraction and Solar Panel Manufacture

Table 2 shows Scope 3 emissions based on a standard commercial 350 W solar panel weighing 22 kg and 2 m^2 in size [4]. The choice of solar panel is based on optimising available roof space with more adaptable arrays compared to larger panels, whilst reducing installation costs per panel and potential failure points relative to smaller panels.

Table 2. Emissions per component.

Material	Composition of solar panel by weight	Composition per 22 kg solar panel	kg CO_2-eq/kg	kg CO_2-eq per solar panel
Glass (non-recycled) [5]	76%	16.7	2.5 - 3.0	41.8 - 50.1
Plastic polymer [6]	10%	2.2	1.9 - 5.8	4.2 - 12.8
Aluminium (virgin material) [7]	8%	1.8	6.8 - 16.1	12.2 - 29.0
Silicon [8]	5%	1.1	10.2 - 12.6	11.2 - 13.9
Copper and rare earth metals	1%	0.2	Sourced as by-products	0.0
Total	**100%**	**22.0**	**21.4 - 37.5**	**69.4 - 105.8**

- **Glass**: Most GHG emissions in producing solar panels come from glass production. Using recycled glass has a significant impact on emissions, with one study suggesting a 42% to 64% decrease [9].
- **Aluminium**: There is a large variability by source, e.g. 6.8 kg CO_2-eq in Europe compared to the global average of 16.1 kg CO_2-eq per kg of aluminium produced. Use of recycled aluminium has a significant impact on emissions, typically using 95% less energy [9].
- **Silicon**: Most panels are sourced from China [10]. China currently uses foreign industrial-grade quartz but plans to switch to low-quality domestic resources, which could almost double emissions. Emissions per solar panel also depend on the type of panel and its life cycle, e.g. polycrystalline vs crystalline [11].

- **Copper and rare earth metals**: The small amounts of copper and rare earth metals are typically obtained as by-products from refining other base metals that have already been extracted [12], and so contribute little in terms of additional emissions in manufacturing solar panels.

3.3. Transportation and Decommissioning of Solar Panels

It was assumed that the solar panels would be sourced from China and transported to the UK by sea as the most common procurement method [10]. **Appendix A** and **Appendix B** show the forecast transport emissions per solar panel as 8.4 kg CO_2-eq.

Decommissioning emissions from recycling facilities, incineration of plastic material and metal recovery was forecast to generate a further 9.9 kg CO_2-eq per solar panel as shown in **Appendix C**.

3.4. Total Emissions from Sourcing and Decommissioning of Solar Panels

Applying the preceding figures gives a range of 87.7 - 124.1 kg CO_2-eq per 22 kg solar panel. Across 500 panels that equates to 43,850 - 62,050 kg CO_2-eq.

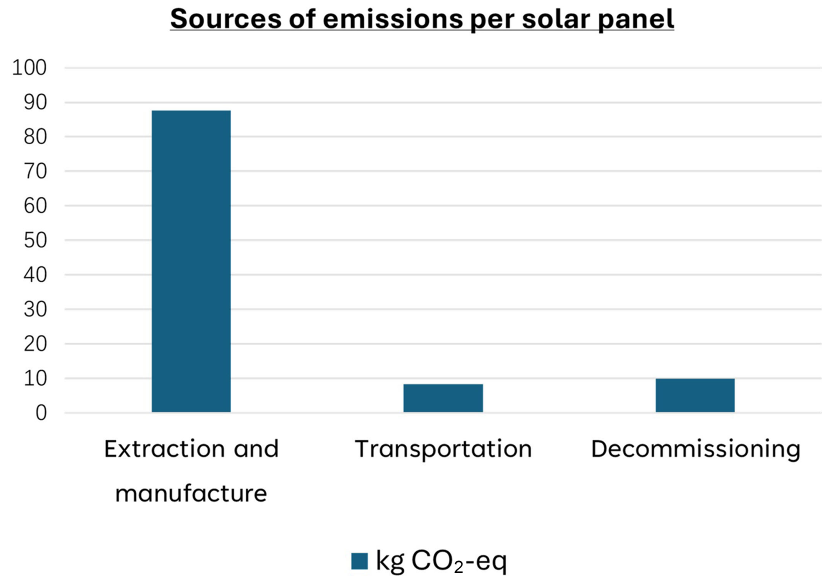

Figure 1. Emission sources.

Extraction of virgin materials and manufacture dominate emissions as illustrated in **Figure 1**, consistent with the findings of Bosnjakvic [13].

3.5. Power Output from Solar Panels

A site-specific annual power yield (E) can be calculated using the following equation:

$$E = P \times K \times SF \times PR$$

where:

- P is installed system peak power
- K is the site-specific solar irradiance factor
- SF is the shading factor
- PR is the performance ratio

Table 3 shows the assumed irradiance, shading and performance ratio for the installation based on a roof orientation of 40˚ generating electricity for an average of 12 hours per day in the north of England [14] [15].

Table 3. Power output.

Peak power	500 × 350 W = 175,000 W
Solar irradiance factor	0.75
Shading factor	0.90
Performance ratio	0.75
Effective power output	0.75 × 0.90 × 0.75 × 175,000 W = 88,594 W
Power output per day	88,594 W × 12/24 = 1063 kWh
Annual output	365 × 1063 kWh = 387,995 kWh

3.6. Costs and Payback Period

The actual cost of installation depends on factors such as sourcing of the panels, choice of contractor, complexity of the installation and system chosen as shown in Table 4.

Table 4. Installation costs and savings.

KiloWatt Peak (kWp)	175,000 W
Cost of installation per kWp [16]	£1278
Installation cost	175 kW × £1278 = £223,650
Cost per kWh from National Grid [17]	£0.22
Annual power output	387,995 kWh
Annual cost saving	£0.22 × 387,995 = £85,359

Applying the discounted cash flow method [18] in **Appendix D** with a 5% interest rate [19] results in a real cost of £285,444, which provides a payback within 4 years.

3.7. Timeframe to Become Carbon Neutral

The National Grid reported a carbon intensity averaging 149 g CO_2-eq per kWh in 2023 [20]. Applying the forecast 387,995 kWh annual output saves 57,811 kg CO_2-eq per annum against the carbon footprint of Scope 3 emissions of 43,850 - 62,050 kg CO_2-eq. The installation should therefore become carbon neutral within two years for Scope 3 emissions.

3.8. Carbon Audit Limitations

- The carbon audit does not include other environmental impacts such as pollution from leaching of toxic metals from solar panel waste [21].
- Since carbon auditing lacks a standardised methodology; different auditors may produce different forecasts [22].
- Campus location, available roof area, choice of system and type of solar panel (e.g. 350 W vs 550 W panels) can affect costs and payback periods. The findings of the audit are therefore indicative.

3.9. Carbon Audit Recommendations

- Since most emissions are due to raw, virgin material extraction and manufacture; accreditation of material suppliers and supply chain transparency is important.
- Manufacturers using recycled materials should be prioritised in discussions with the contractor subject to cost. This significantly affects the installation's carbon footprint.
- Further indirect emission reductions may be possible by addressing operation-specific emission factors, e.g. choosing manufacturers who extract raw materials using less carbon-intensive energy sources (e.g. gas v coal).
- The audit should comply with ISO 14064:2018 for quantifying and reporting emissions.
- The university should seek certification through meeting the requirements of ISO14067:2018 on the carbon footprint of products.

4. Stakeholder Mapping and Management

Successful implementation of the installation requires identification and engagement of key stakeholders, understanding their interests and influence, and effective management of relationships to address potential resistance.

4.1. Stakeholder Identification and Analysis

Several stakeholders are involved in the installation as detailed in Table 5.

Table 5. Stakeholder interest and influence.

Stakeholder	Interests	Power-interest
Management	Budgets, CSR reporting, rankings, reputation, energy usage, compliance	Key player
Donors	University reputation and success	Keep satisfied
Local authority	Planning permission and regulations	Keep satisfied
Contractor	Installation, compliance with regulations, profit	Keep informed
Students	Campus sustainability, disruption	Keep informed
Staff	Job security, spend prioritisation, disruption, campus sustainability	Keep informed
Local community	Disruption, visual impact	Keep informed

Figure 2 shows the power-interest grid for key stakeholders. Management is a key player with strong interest in the installation's success with the power to implement or postpone. Within this, different managers will have different perspectives, e.g. timing, sourcing of panels from China, choice and type of system to adopt.

The local authority has the power to approve the installation and impose conditions but lower interest in its eventual success. Donors are often passive though a significant source of university funding [23] and so need to be kept satisfied.

Staff, students, the contractor and local community will have a high interest in the installation as it affects them directly but with more limited power to influence decision-making.

Prioritisation could be assigned to management, local authority and donors based on their power relative to other stakeholders. However, interest-based bargaining is more likely to result in successful outcomes than power-based bargaining, or trying to impose solutions [24]. Stakeholders with high interest and lower power may act as influencers, thereby changing the attitudes of key players, e.g. staff influencing students, who in turn influence rankings with consequences for management.

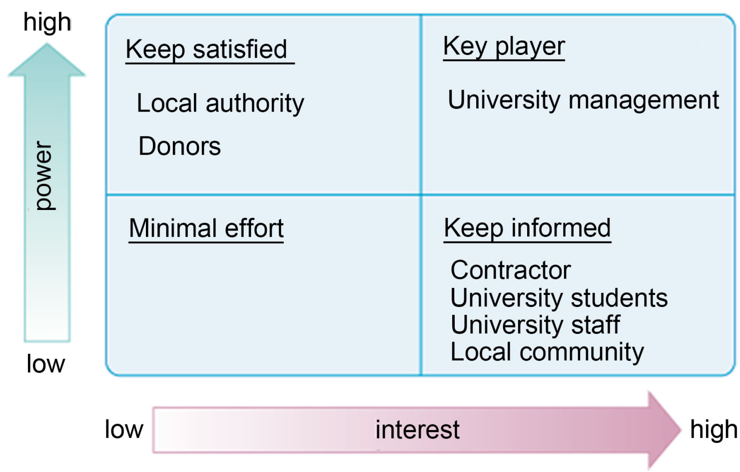

Figure 2. Power-interest grid.

4.2. Stakeholder Mapping

Mapping and understanding the dynamics of the relationships is important in developing a communication plan which addresses all stakeholder concerns. Figure 3 shows the relationships between different stakeholders.

Including all stakeholders in the planning stage ensures that different perspectives are considered, including both supporters and objectors.

Mapping illustrates the circularity of the relationships; the longer-term benefits of the installation feed back into CSR goals. However, the nature of short-term cuts vs long-term benefits may create resistance amongst some stakeholders.

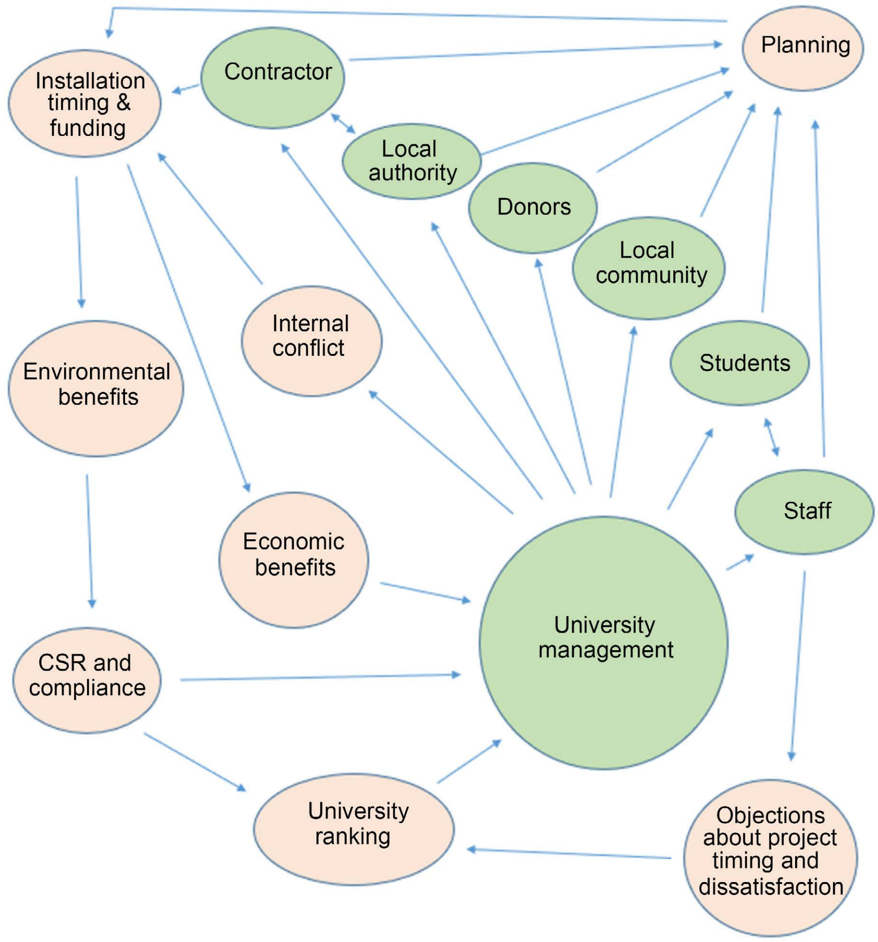

Figure 3. Relationships between key stakeholders.

4.3. Stakeholder Perspectives and Strategic Issues

- **Management**: budgets are under pressure due to the declining value of tuition fees and lower international student numbers. The carbon audit doesn't forecast a payback until year 4, which may lead to calls for postponement of the installation amongst some managers in favour of reducing short-term deficits.
- **Staff**: concerns regarding downsizing departments and job cuts may echo calls for postponement of the installation until more favourable economic conditions prevail.
- **Donors**: competing perspectives on how funding should be deployed may lead to conflict with management decisions, e.g. some donors may want funds allocated to specific research projects.
- **Local authority**: prior approval from the planning department may be required and conditions may be placed on the installation, which could add time and complexity to the installation.
- **Local community**: complaints about short-term disruption and the visual impact of the installation may be raised.

- **Students**: complaints about short-term campus disruption and possible concerns around deployment of funds may arise if these coincide with cuts in student services.

A recent survey [25] found that the university scored poorly for campus sustainability, with lower levels of staff participation. Concurrently, the university is facing a budget deficit [26]. This may lead to conflict between and within stakeholder groups on how the university should prioritise spending.

The length of time taken to influence detractors is uncertain and there may be lack of consensus amongst managers. The audit highlights uncertainty around economic and environmental costs, timescales and infrastructure. Complicating factors include legislative and technological changes, supply and workforce issues. The combination of stakeholder disagreement and level of uncertainty suggests that decision-making will be complex [27].

4.4. Stakeholder Engagement and Communication

Table 6 shows a proposed stakeholder communication plan.

Table 6. Stakeholder communications.

Stakeholder	Power-interest	Communication
Management	Key player	Face-to-face meetings and updates to achieve consensus.
Donors	Keep satisfied	Engage in decision-making as required.
Local authority	Keep satisfied	Submit required documentation, ensure compliance with regulations.
Contractor	Keep informed	Liaise with management and local authority. Dialogue with local community regarding disruption.
Students	Keep informed	Invite to presentations. Create common vision.
Staff	Keep informed	Invite to meetings and presentations. Create common vision. Address objections.
Local community	Keep informed	Update on progress and disruption.

4.5. Stakeholder Mapping and Management Limitations

- Stakeholder theory has been criticised for its premise that conflicting interests can be reconciled [24]. Staff facing redundancy may be less likely to advocate spending on long-term projects. Some might argue that the university's sustainability priority is shorter-term economic viability over longer-term environmental projects.
- Carroll's pyramid [28] and Friedman doctrine [29] espouse economic responsibility as foundational requirements. However, this ignores the circular nature of CSR strategies. In this case, economic and CSR goals overlap and conflict, creating a zone of complexity for stakeholder management [27].
- The decision around which stakeholders to prioritise can be subjective, e.g. students have limited decision-making power but can influence the university's rankings.

4.6. Stakeholder Mapping and Management Recommendations

- A common vision is required to minimise any resistance, e.g. the need to transition away from dependence on fossil-fuels, reduce emissions and achieve cost savings; a common perspective likely to be held by all stakeholders.
- Any internal conflict between managers needs to be resolved in the early planning stages, e.g. between finance and environmental managers, otherwise lack of consensus may lead to confusion and commitment to the common vision.
- Staff may influence student opinion regarding prudence and timing of the installation during a period of economic uncertainty. Consequent student dissatisfaction could affect university rankings. It is therefore important to provide regular staff and student updates.
- Utilitarian ethics should be emphasised [30]; adoption of solar energy provides a net environmental and economic benefit to universities, suppliers, students, staff and local communities, which advances the higher education system overall. However, closing departments, cutting jobs and services to address a budget deficit may be contrary to this ethical principle and the university's CSR commitments. Complex decision-making is needed to mediate the respective positions [27].

5. Conclusions

Carbon auditing suggests that the installation will become carbon neutral within 2 years and payback within 4 years. However, the audit requires several estimates and assumptions—without a standardised methodology the forecasts are necessarily broad in nature.

The audit shows that the vast majority of emissions for Scope 3 come from raw material extraction. China dominates solar panel manufacturing and its material extraction processes are energy-intensive compared to other countries. Supplier accreditation with ISO 14064:2018 and supply chain transparency are thus needed to ensure that all emissions are accurately accounted for in the audit. Subject to cost, university procurement should consider alternative suppliers using recycled materials as this will significantly reduce the installation's carbon footprint.

There are two main implications. Firstly, the university's goal to become carbon neutral for Scope 1 and 2 emissions by 2030 may be regarded as symbolic since emissions are overwhelmingly from Scope 3. Secondly, campus sustainability extends beyond reducing emissions, e.g. pollution from toxic metal leaching from solar panel decommissioning damaging ecosystems. CSR reporting should address these points for credibility and reputation.

The results of the audit have relevance for stakeholder management. Stakeholder acceptance of the installation requires transparency and communication of the audit's findings given that it coincides with a financial deficit and payback is not until 4 years. Some stakeholders may regard short-term economic viability as more urgent than longer-term investment, whilst other may be sceptical about the installation's environmental benefits given the preceding CSR implications. At the same time managing multiple, competing stakeholder interests may prove complex.

Stakeholder mapping highlights the dynamic nature of relationships and shifting power influences for this installation project. By creating a common vision and engaging different stakeholder perspectives with a documented communication plan resistance can be minimised.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Lottu, O.A., Ehiaguina, V.E., Ayodeji, S.A., Ndiwe, T.C. and Izuka, U. (2023) Global Review of Solar Power in Education: Initiatives, Challenges, And Benefits. *Engineering Science & Technology Journal*, **4**, 209-221. https://doi.org/10.51594/estj.v4i4.583

[2] University of Huddersfield (2024) Solar Panels Begin Carbon Reduction Scheme on Campus.
https://www.hud.ac.uk/news/2021/january/solar-panels-campus-carbon-reduction-plan/#:~:text=Over%20500%20solar%20panels%20are%20being%20installed,Plan'%20towards%20achieving%20Carbon%20Neutral%20status%20for

[3] Pahuja, S. (2021) Accounting for Greenhouse Gas (GHG) Emissions. In: Idowu, S., Schmidpeter, R., Capaldi, N., Zu, L., Del Baldo, M. and Abreu, R., Eds., *Encyclopedia of Sustainable Management*, Springer International Publishing, 1-6.
https://doi.org/10.1007/978-3-030-02006-4_565-1

[4] Panjawani, P., Jain, D.V., Bhandari, K.R., *et al* (2020) Design and Analysis of Solar Structural and Mountings for Solar Panel. *International Journal of Future Generation Communication and Networking*, **13**, 668-679.

[5] Furszyfer Del Rio, D.D., Sovacool, B.K., Foley, A.M., Griffiths, S., Bazilian, M., Kim, J., *et al.* (2022) Decarbonizing the Glass Industry: A Critical and Systematic Review of Developments, Sociotechnical Systems and Policy Options. *Renewable and Sustainable Energy Reviews*, **155**, Article 111885.
https://doi.org/10.1016/j.rser.2021.111885

[6] Nicholson, S.R., Rorrer, N.A., Carpenter, A.C. and Beckham, G.T. (2021) Manufacturing Energy and Greenhouse Gas Emissions Associated with Plastics Consumption. *Joule*, **5**, 673-686. https://doi.org/10.1016/j.joule.2020.12.027

[7] Tabereaux, A.T. and Peterson, R.D. (2024) Aluminum Production. In: Seetharaman, S., Guthrie, R., *et al.*, Eds., *Treatise on Process Metallurgy*, Elsevier, 625-676.
https://doi.org/10.1016/b978-0-323-85373-6.00004-1

[8] Sævarsdottir, G., Kvande, H. and Magnusson, T. (2021) Greenhouse Gas Emissions from Silicon Production-Development of Carbon Footprint with Changing Energy Systems. *SSRN Electronic Journal*, 11 p. https://doi.org/10.2139/ssrn.3926088

[9] Csiba-Herczeg, Á., Koteczki, R., Lukács, B. and Balassa, B.E. (2023) Case Study-Based Scenario Analysis Comparing GHG Emissions of Wine Packaging Types. *Cleaner Engineering and Technology*, **15**, Article 100649.
https://doi.org/10.1016/j.clet.2023.100649

[10] IEA (2024) Renewables 2023. IEA.
https://www.iea.org/reports/renewables-2023

[11] Heidari, S.M. and Anctil, A. (2022) Country-Specific Carbon Footprint and Cumu-

lative Energy Demand of Metallurgical Grade Silicon Production for Silicon Photovoltaics. *Resources, Conservation and Recycling*, **180**, Article 106171. https://doi.org/10.1016/j.resconrec.2022.106171

[12] Balaram, V. (2022) Rare Earth Element Deposits: Sources, and Exploration Strategies. *Journal of the Geological Society of India*, **98**, 1210-1216. https://doi.org/10.1007/s12594-022-2154-3

[13] Bošnjaković, M., Santa, R., Crnac, Z. and Bošnjaković, T. (2023) Environmental Impact of PV Power Systems. *Sustainability*, **15**, Article 11888. https://doi.org/10.3390/su151511888

[14] Zimmerman, R., Panda, A. and Bulović, V. (2020) Techno-Economic Assessment and Deployment Strategies for Vertically-Mounted Photovoltaic Panels. *Applied Energy*, **276**, Article 115149. https://doi.org/10.1016/j.apenergy.2020.115149

[15] (2026) Photovoltaic Geographical Information System. https://pvgis.com/en

[16] Microgeneration Certification Scheme (2021) Renewing Britain. https://share.google/jjAVagQI2IrgFT9th

[17] Energy Saving Trust (2024) Energy Price Cap Explained. https://energysavingtrust.org.uk/what-is-the-energy-price-cap/

[18] Harvard Business School (2025) Discounted Cash Flow (DCF) Formula: What It Is and How to Use It. https://online.hbs.edu/blog/post/discounted-cash-flow

[19] Bank of England (2024) What Is Bank Rate? https://www.bankofengland.co.uk/explainers/what-are-interest-rates#:~:text=Bank%20Rate%20is%20currently%205%25

[20] The National Grid (2024) Energy Explained.

[21] Sharma, H.B., Vanapalli, K.R., Barnwal, V.K., Dubey, B. and Bhattacharya, J. (2021) Evaluation of Heavy Metal Leaching under Simulated Disposal Conditions and Formulation of Strategies for Handling Solar Panel Waste. *Science of The Total Environment*, **780**, Article 146645. https://doi.org/10.1016/j.scitotenv.2021.146645

[22] Giordano-Spring, S., Larrinaga, C. and Rivière-Giordano, G. (2024) Field-Configuring Events and the Failure to Standardise Accounting for Carbon Emissions. *Accounting, Auditing & Accountability Journal*, **37**, 216-247. https://doi.org/10.1108/aaaj-07-2022-5946

[23] CASE (2024) Giving to UK and Irish Universities in 2022-23 Reaches All-Time High of £1.37 Billion in Funds Received. https://www.case.org/resources/giving-uk-and-irish-universities-2022-23-reaches-all-time-high-ps137-billion-funds

[24] Bryson, J.M. (2004) What to Do When Stakeholders Matter: Stakeholder Identification and Analysis Techniques. *Public Management Review*, **6**, 21-53. https://doi.org/10.1080/14719030410001675722

[25] People and Planet (2024) League Tables. https://peopleandplanet.org/university-league/2023/u1186/university-of-huddersfield

[26] University of Huddersfield (2024) Financial Statements. https://www.hud.ac.uk/about/financialstatements/

[27] Stacey, R. (2018) Complexity at the "Edge" of the Basic-Assumption Group. In: Gould, L.J., Ed., *The Systems Psychodynamics of Organizations*, Routledge, 91-114. https://doi.org/10.4324/9780429483387-5

[28] Carroll, A.B. (1991) The Pyramid of Corporate Social Responsibility: Toward the Moral Management of Organizational Stakeholders. *Business Horizons*, **34**, 39-48.

https://doi.org/10.1016/0007-6813(91)90005-g

[29] Friedman, M. (2007) The Social Responsibility of Business Is to Increase Its Profits. In: Zimmerli, W.C., Holzinger, M. and Richter, K., Eds., *Corporate Ethics and Corporate Governance*, Springer, 173-178. https://doi.org/10.1007/978-3-540-70818-6_14

[30] Babatunde, O., Adebisi, J., Emezirinwune, M., Babatunde, D. and Abdulsalam, K.A. (2024) How Serious Are Ethical Considerations in Energy System Decarbonization? *Current Opinion in Environmental Sustainability*, **71**, Article 101477. https://doi.org/10.1016/j.cosust.2024.101477

[31] Sui, C., de Vos, P., Stapersma, D., Visser, K. and Ding, Y. (2020) Fuel Consumption and Emissions of Ocean-Going Cargo Ship with Hybrid Propulsion and Different Fuels over Voyage. *Journal of Marine Science and Engineering*, **8**, Article 588. https://doi.org/10.3390/jmse8080588

[32] CLECAT (2024) Calculating GHG Emissions for Freight Forwarding and Logistics Services in Accordance with EN 16258. https://www.clecat.org/media/CLECAT_Guide_on_Calculating_GHG_emissions_for_freight_forwarding_and_logistics_services.pdf

[33] Donyoung, K. (2021) Recycling Solar Panels—Completing the Sustainability Cycle of Photovoltaic Power Generation. Reddie and Gros.

Appendix A

Transport from China to UK (Hull)

Transport mode	By ocean
Distance travelled[1]	25,000 km
Emissions per kg per km of shipping freight [31]	0.015 kg CO_2-eq
Emissions per solar panel[2]	8.25 kg CO_2-eq

[1]Distance travelled on one-way trip assuming return journey is for another commercial purpose. [2]Calculation is 25,000/1000 × 22 × 0.015 kg = 8.25 CO_2-eq kg per solar panel.

Appendix B

Transport from Hull to Sheffield (contractors' office) to Huddersfield

Transport mode	By road
Distance travelled[1]	150 km
Average GHG emissions for 7.5 t GVW diesel lorry [32]	454 g CO_2-eq/km
Emissions per solar panel[2]	0.14 kg CO_2-eq

[1]Distance from Hull to Sheffield to Huddersfield for transport of 500 solar panels. [2]Calculation is 150 × 454 g = 68.1 kg for 500 panels, which is 0.14 kg CO_2-eq per solar panel.

Appendix C

Emissions from decommissioning

Emissions per kg of solar panel waste [33]	0.45 kg CO_2-eq
Emissions per 22 kg solar panel	9.90 kg CO_2-eq

Appendix D

Discounted cash flow

Interest rate (%)	**1**	**2**	**3**	**4**	**5**
Period					
1	1.0100	1.0200	1.0300	1.0400	1.0500
2	1.0201	1.0404	1.0609	1.0816	1.1025
3	1.0303	1.0612	1.0927	1.1249	1.1576
4	1.0406	1.0824	1.1255	1.1699	1.2155
5	1.0510	1.1041	1.1593	1.2167	1.2763