

**Development of social sustainability  
assessment methods for solar  
thermal energy systems applied to  
industrial processes**

**A Thesis Submitted for the Degree of  
Doctor of Philosophy**

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## Abstract

This thesis assessed the social sustainability of a newly developed Solar Thermal Energy (STE) system using the following methods. First, a Social Life Cycle Assessment (S-LCA) was conducted using Social Hotspot Database (SHDB) inventory data to assess social risks on employees involved in producing the system's three components: Fresnel solar collectors (SunDial), the Phase Change Material (PCM) storage tank, and the Control Unit. Next, surveys involving 56 employees engaged in the technology's Product Development phase were conducted to assess social impact in the following impact categories: Training Satisfaction (TS), Professional Development (PD), and Working Intensity (WI). Industrial and social acceptance of the technology was then assessed through surveys with 318 industries and 279 members of the public, capturing perceptions of the system's adoption potential, greenhouse gas (GHG) reduction, and economic savings. Finally, a regression model was conducted to predict future trends in social impact and industrial acceptance over a 10-year timeframe, providing insights into long-term technological and financial improvements. Results of the S-LCA revealed substantial Health & Safety (H&S) risks for employees involved in the technology's production, particularly in aluminium manufacturing of the PCM storage tank due to non-compliance with regional H&S policies. In the Product Development phase, positive impact was observed in PD and WI, whereas a negative impact score of -0.5 in TS revealed training provision gaps. Regression analysis identified strong correlations between social impact and influencing investments in Human Resource Management (HRM) including provision of training; PT ( $\rho = 0.54$ ), employee engagement in R&D; EE, ( $\rho = 0.48$ ), provision of professional development opportunities; PPD ( $\rho = 0.80$ ), and task allocation; AT ( $\rho = 0.63$ ), all statistically significant ( $p < 0.05$ ).

Next, surveys gauging the acceptance of worldwide industries showed strong results for the STE system's technical compatibility (82%), costs (82%), and impact on standard compliance (87%), with highest scores reported by the Aerospace (92%), Metallic (89%), and Automotive (86%) industries. Acceptance was particularly strong among large companies (84%) and medium-sized companies (87%), whereas lower rates were observed for small (45%) and micro (37%) enterprises, largely due to the upfront costs of STE systems, which posed a greater financial burden for firms of this scale. Moreover, surveys involving the general public showed strong agreement with STE's environmental benefits (86%) and willingness to consume products manufactured using STE's clean energy goods (79%). Results of the future predictions showed that social impact on employees improved over the decade, as indicated by the probability of observing TS = 5 increased from 0.10 to 0.30 and TS = 4 from 0.35 to 0.60 due to annual investment in EE. Similarly, the probability of observing PD = 5 increased from 0.20 to 0.50 and WI = 4 from 0.25 to 0.50 from investment in PPD and AT, respectively.

Industrial acceptance also marginally improved over the decade; most notably, AC = 5 rose from 0.44 to 0.52, and AC = 4 increased from 0.41 to 0.46. A large improvement was found amongst small and micro-sized companies as the probability of observing a high score rose 0.45 to 0.67 for small companies and 0.37 to 0.62 for micro-sized companies. The findings provide nuanced technological and monetary improvement measures to enhance the long-term sustainability and industrial relevance of newly developed STE systems.

The findings of this thesis demonstrate the strong influence of targeted investments in workforce development, technological improvements, and financial support mechanisms on enhancing both social impact and industrial acceptance of STE systems over the decade. These thesis insights on influencing factors provide valuable implications for workforce managers, industrial stakeholders, and policymakers by offering practical guidance on forecasting, prioritising, and strategically allocating resources to maximise stakeholder satisfaction and support industrial adoption of current and future emerging STE deployments.

## **Personal Tribute**

*After successfully obtaining my higher doctorate, I would like to sincerely recognise the contribution of several individuals who have aided me in this journey.*

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## Nomenclature

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AT	Allocation of Tasks
AC	Acceptance of Costs
AMTP	ArceloMittal
ASTEP	Application of Solar Thermal Energy to Processes
AW	Average Wage
BREO	Brunel Research Ethics Online
CS	Cost Subsidies
DALY	Disability-Adjusted Life Year
EA	Ethical Approval
EE	Employee Engagement with R&D Activities
H&S	Health and Safety

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HR	High Risk
HRM	Human Resource Management
MAND	Mandrekas
MR	Medium Risk
MS	Modular Scalability
LR	Low Risk
LS	Loan Support
NPL	Non-Poverty Guideline
R&D	Research and Development
RH	Risk Hours
PCM	Phase Change Material
PD	Professional Development
PPD	Provision of Professional Development Opportunities
PRP	Performance Reference Points
PT	Provision of Training Opportunities
SHIP	Solar Heat for Industrial Processes
S-LCA	Social Life Cycle Assessment
SHDB	Social Hotspots Database
SO	System Optimisation
SPSS	Statistical Package for the Social Sciences
STE	Solar Thermal Energy
TA	Weekly Hours Allocated for Tasks

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TE	Thermal Enhancement
TC	Technical Compatibility
TS	Training Satisfaction
WI	Working Intensity

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## Chapter 1: Introduction

The development of novel Solar Thermal Energy (STE) systems is core to the European Union's (EU) 2050 carbon-reducing strategy due to their capabilities of reducing greenhouse gas emissions by 80% as described by Guillen-Burrieza & Konigshofer (2020). In light of these goals, the same authors introduced an advanced technological development of STE systems, known as Solar Heat for Industrial Processes (SHIP) to fulfil the intense heating demands of medium temperature processes of 150-400°C and high temperature processes of more than 400°C in international industries. Tannous et al. (2023) stated that these industries include food and beverage, textiles, pulp and paper, chemical processing, non-metallic minerals, metallic, automotive, and aerospace. As noted by Kumar et al. (2022), these industries are increasingly keen to integrate newly developed STE systems to reduce reliance on fossil fuels and are heavily interested in conducting sustainability assessments in parallel with wide-scale deployments. The review of Kuhnen & Hahn (2017) reported that environmental and economic sustainability assessments have already been very well covered in the literature. However, the review of Zafar et al. (2024) established that a third type of sustainability, called **social sustainability**, has received much less attention than the first two types and has been labelled as a nuanced development within the scientific literature. Furthermore, Guillen-Burrieza & Konigshofer (2020) emphasised the need for a novel assessment of both current and future scenarios concerning the social sustainability of newly developed Solar Heat for Industrial Processes (SHIP) systems being implemented into global industries. Their report highlighted the novelty and ingenuity of the information that will be demonstrated by these scenarios, particularly regarding future social scenarios, adding substantial value towards the feasibility consideration of SHIP integration. Kühnen & Hahn (2017) added that generating such future scenarios of social sustainability need more consideration, particularly through including comprehensive data ranges across a broader time frame to reach more insightful, sustained conclusions on the sustainability of SHIP systems. To build on this development, Zafar et al. (2024) described the need for a dynamic model of social sustainability of STE systems, covering both current and future scenarios within the supply chain. Bouillaus et al. (2021) further emphasised how much value developing a time-based variation will add towards the understanding of social scenarios in industries.

Conducting such a comprehensive appraisal will explain how these technologies socially impact supply chain beneficiaries. These supply chain beneficiaries in this case are termed as 'social stakeholders' by Benoit et al. (2010), who further elaborated that these are cohorts who are directly affected by manufacturing, development, and application activities of STE systems. Their definition is elaborated in section 1.1.

## 1.1 Investigation of Social Stakeholders

The first stakeholder cohort encompassed employee occupations, which include shop line workers, lab technicians, equipment operators, engineering staff, research associates, and managers, as noted by Tarkoll & Bardol (2014). In their case study, they found that these employees engaged with different phases of the STE supply chain; manufacturing, assembly, system installation and operation. Shop line workers and lab technicians are engaged with construction and testing of STE components, and equipment operators encompass machinists, toolmakers, riggers, and maintenance personnel. Engineering staff and research associates focus on the design, development, and optimisation of these systems as supported by Jafarinejad et al. (2021). Managers were responsible for overseeing work packages of their employees, allocating resources through monetary investments for employee training and development, and ensuring compliance with H&S standards, as described by Adewale et al. (2024).

The next stakeholder group consisted of external industrial representatives, as defined by Tannous et al. (2023) to originate from Sustainable Process Industry through Resource and Energy Efficiency (SPIRE) and non-SPIRE industries, and comprise of SMEs and large companies with energy-intensive thermal processes. They further detailed that SPIRE industries, operating within the high temperature range at and above and 400°C, included automotive, aerospace, non-metallic minerals, chemical & petroleum, and metals. Their in-house processes included; forging, casting, chemical synthesis, annealing, glass melting, surface and heat treatment, distillation and drying. They also detailed that non-SPIRE industries, operating at medium-temperature in the range of 150°C to 400°C, included food and beverage, water treatment, textiles, paper & pulp, and pharmaceuticals, with processes such as pasteurisation, sterilisation, food drying, evaporation, dyeing, distillation, and disinfection processes. Zafar et al. (2024) explained that these industries are keen on implementing newly developed STE systems and show a level of industrial acceptance, which is a willingness to integrate them for the thermal supply of their processes. They described that industries are crucial sites for STE deployment due to their operational compatibility with the technical capabilities of STE systems and their demand for consistent medium to high-temperature heat delivery. They implored that substantial potential lies in these industries for reduction in carbon emissions, enhancing their environmental and energy accreditation; ISO14001 and ISO50001 respectively, and boosting their production volumes after the implementation of newly developed STE systems.

The last stakeholder group as defined by Corona & Miguel (2019) consisted of members of the general public, specifically domestic households in local communities affected by the

implementation of STE systems in neighbouring industrial supply chains. They noted that the general public are stakeholders who show social acceptance of STE's impact on environmental factors such as air quality and carbon emissions. Marzouk et al. (2024) also had stated that the general public urban residents who accept solar energy integration in agricultural supply chains for food produce. Sovacool & Ratan (2012) further explored this stakeholder group, defining them as residential consumers of products produced by STE systems, taking the example of consumers in Germany and the United States. They further described that this cohort consumes daily goods produced by STE systems applied to industries such as food, textiles, metallic and plastic items. Terrapon-Pfaff et al. (2019) agreed with this notion when examining public attitudes toward Concentrating Solar Power (CSP) technology being used for electricity generation in Morocco. They defined the general public as local consumers who interact with CSP infrastructure and hence are direct beneficiaries of STE.

## 1.2 Investigation of the Social Life Cycle Assessment Framework

To assess the nuanced social sustainability of newly developed STE systems, Corona & Miguel (2019) recommended using a Social Life Cycle Assessment (S-LCA) framework which has been built off of the Environmental Life Cycle Assessment (E-LCA) documented in ISO 14044 (BSI 2006). To further elaborate on the framework's definition, UNEP-SETAC guidelines (2020) split the framework into four distinct phases as follows; a) Goal and Scope, b) Inventory Analysis, c) Impact Assessment, and d) Interpretation. The first phase, Goal and Scope Definition, involves establishing the purpose of the assessment and defining the system boundaries. As highlighted by Corona & Miguel (2019), these boundaries encompass all of the STE system's life cycle phases; the manufacturing phase of STE's components, the product development to design the STE's components, the application of STE systems in industrial processes, the operation of STE in industrial processes, and the disposal of the components. The engagement of all social stakeholders introduced in section 1.2, are encapsulated within these boundaries.

In the second phase; Inventory Analysis, impact categories are formed to measure sustainability through social impact affecting STE's social stakeholders during their engagement with STE's life cycle phases. Benoit et al. (2010) mentioned that the impact categories for social risk include occupational H&S of employees, excessive working hours, fair wages and payment, gender inequality, and local employment. Zafar et al. (2024) described that impact categories for social impacts include employee training and skill development, professional development, and working intensity. Next, Benoit et al. (2010) explained that the inventory phase consists of the formation of data collection instruments to

measure social sustainability as perceived by the social stakeholders, which include Social Hotspot Database further introduced in section 2.3, online surveys, interviews, and audits.

Corona & Miguel (2019) described that the third phase; Impact Assessment phase, offers two methodological approaches to numerically quantify the measured social risk, social impact, and social acceptance. The first approach is the Type 1 reference scale, which uses predefined median criteria to quantify the direction of social risk, impact, and acceptance as defined by Costa & Oliveria (2022). They described that these criteria include standards and laws defining acceptable levels of social welfare for stakeholders throughout their involvement the life cycle of STE systems. These standards include the International Labour Organisation (ILO) conventions for Occupational H&S and Equal Remuneration and Non-Discrimination, national minimum wage law, and occupational working hour stipulations. They also elaborated that the median criteria include neutral survey scores indicating moderate satisfaction and/or acceptance. Benoit et al. (2010) further described social impact is labelled as positive or negative by comparing stakeholder perceptions to established median criteria. Negative stakeholder perceptions are measured by calculating their deviation below this median, while positive perceptions are assessed by their deviation above the median. The magnitude of these deviations is captured through Performance Reference Points (PRPs), which are numerical values that present the extent of positive or negative social impact.

The second approach is known as the Type 2 protocol, which explores cause-effect relationships by linking managerial activities to measured social risks, impacts and acceptance of stakeholders within STE settings as defined by Zafar et al. (2024). These managerial activities include corrective resource allocation through monetary investments for improving H&S conditions at sites where STE is installed, providing fair wages, employee training programmes, and professional development opportunities to employees. Wu et al. (2015) highlighted that these activities are correlated with quantified social impacts through numerical coefficients to quantify the strength of the cause-effect relationship.

Finally, Benoit et al. (2010) explain that the Interpretation phase involves evaluating all findings generated by either or both Type 1 and Type 2 approaches in order to produce actionable recommendations. These recommendations target identified areas of negative social risk, impact, or acceptance, and guide managerial interventions for investments that enhance stakeholder welfare within STE contexts.

Looking at S-LCA's application in case studies of STE and related renewable energy systems, Corona and Miguel (2019) assessed social impact of an STE system for industrial steam generation in Spain affecting employees by quantifying adverse risk affects experienced by employee stakeholders due to engaging with STE's manufacturing activities. Using SHDB,

they measured social risks in the H&S, fair wages, and working intensity categories. They applied a Type 1 reference scale and identified social risks in wage disparities and H&S during the production of STE components. Similarly, Terrapon-Pfaff et al. (2019) examined the social impact of a Concentrated Solar Power (CSP) grid installation in Morocco on 192 stakeholders including employees through online surveys and interviews. Their study gauged social impacts in training, fair payment, professional development, and local employment. They used a Type 1 reference scale to quantify social impact against national labour laws and neutral surveys scores. They had found that the CSP installation into the national grid positively influenced local employment of STE systems. Serreli et al. (2021) had applied social risk assessment to an industrial wastewater treatment plant for fair payment, working intensity, and H&S categories. They had also found high H&S risks to employees due to their interaction with chemical synthesis processes.

Next, the study of Borri et al. (2024) assessed the social impacts of a solar heating system deployed in a European residential setting, engaging employees, local community, and industrial representative stakeholder groups. Their study assessed social impact categories: H&S, fair wages, and training. They applied both SHDB as well as surveys and interviews to collect data from a total of 80 stakeholders, quantifying social impact using a Type 1 scale approach. The findings revealed moderate risks in worker training and H&S as well as high social and industrial acceptance by due to the system's environmental benefits and technical reliability. Costa & Oliveira (2022) assessed the social risk of biodiesel feedstock production in Brazil concerning employees in the agricultural sector. Using SHDB, they measured social risks in H&S, fair wages, and working intensity categories. Applying Type 1 protocol, they identified areas of negative social impact due to poor H&S conditions and payment below the national minimum wage. Next, Tsai (2018) surveyed 150 employees engaged in R&D activities for the development of PV panels in eastern China to assess job satisfaction, focusing on training, promotion, compensation, and health & safety. Results showed that limited training and career pathways reduced employee satisfaction, hence imposed negative social impact on those stakeholders. Wong et al. (2025) surveyed 372 production employees in a large solar module assembly facility in China, finding that low pay, poor benefits, and inadequate H&S measures drove high employee resignation rates, all of which were found to clearly influence negative social impact. Additionally, audits have been in the studies by Hannouf and Assefa (2017) and Singh & Gupta (2018) to assess compliance to H&S conditions in their polymer and steel industrial facilities respectively. Both sets of authors found negative social impact due to a lack of policy enforcement.

### 1.3 Industrial & Social Acceptance

After the social sustainability and impact is assessed, Marzouk et al. (2024) advocated for the nuanced study of industrial & social acceptance of newly developed STE systems being applied into industrial supply chains, elements rarely addressed in previous literature works as supported by Zafar et al. (2024). Kumar et al. (2022) emphasised that assessing the nuanced industrial acceptance of STE systems is critical to their successful integration and long-term viability within industrial processes due to how industrial representatives are keen to purchase the new STE technologies. Ali et al. (2022) noted that gauging the confidence of industrial representatives in STE's technical compatibility, financial viability, and impact on standards is important for STE integration into industrial processes. Kumar et al. (2022) then proceeded to explore key issues concerning industrial acceptance of STE systems by surveying 150 industrial firms in India and assessing the technical and economic feasibility of integrating STE systems. Their study found that perceived compatibility with existing processes operating in high-temperature ranges exceeding 400°C and viability of STE's cost savings were the influencers of industrial acceptance. Next, Elakanti & Singh (2021) surveyed 81 companies within the brewing industry in India. They used Likert-scale surveys distributed to industrial representatives to measure acceptance with implementing STE in their distillation processes. They revealed that the industry's perception of STE as having reliable thermal performance through consistent and sufficient output influenced high acceptance levels. Expanding on this, Schriever and Halstrup (2019) surveyed 101 German automotive firms to assess the acceptance of solar PV. They found that STE systems' positive impact on the industry's compliance with environmental standards strongly influenced their acceptance and adoption. Next, Qamar et al. (2020) had conducted a study in Pakistan's textile industry, surveying 127 industrial representatives to assess perceptions of STE's thermal output and performance. They found strong acceptance due to STE's reliable heat supply and high operating temperatures compatible with their processes. Similarly, Beske et al. (2008) had also surveyed industrial acceptance by 111 representatives from the German automotive industry. They found that STE's application positively impacted industrial compliance with environmental and energy management standards ISO 140001 and ISO 50001, respectively, increasing the industrial acceptance of STE and encouraging more purchases.

Following industrial acceptance, Marzouk et al. (2024) presented that gauging social acceptance of STE systems is important for their eventual implementation into industries due to how public support influences government policy. They stated that understanding public attitudes of STE's impact on cleaner air for the local community and consumer satisfaction is crucial to fully understand before its deployment. Terrapon-Pfaff et al. (2019) described the

key issue pertaining to social acceptance of general public members to be their perception of STE's environmental benefits, such as its contribution to lowering carbon emissions and providing cleaner air for the community. They explored this issue by assessing the social acceptance of a CSP plant in Morocco by surveying 107 general public members, finding positive public opinion of STE's environmental benefits. Rosso-Cerón & Kafarov surveyed 145 local residents in Colombia to identify barriers to public acceptance of STE systems, finding that public awareness of the environmental benefits of solar energy needs to be improved to enhance adoption in communities. Marzouk et al. surveyed 300 residents in Egypt regarding public acceptance of STE in agricultural systems, finding that acceptance is influenced by educational programmes promoting STE's contribution to clean air in neighbouring communities. Jung et al. (2016) further explored consumer satisfaction regarding products manufactured using clean energy from STE systems.

#### 1.4 Current Knowledge Gaps

Authors such as Kühnen & Hahn (2017) and Bonilla-Alicea & Fu (2022) described that the literature requires stronger evaluation and critical insight into social sustainability. They further elaborated that while current studies frequently report social impacts and social & industrial acceptance, they need to uncover the underlying causes and influencing factors. Moreover, Dantes & Soares (2016) described that these knowledge gaps persist in the field of renewable technological development, a reality which concerns the progression of SHIP development. Corona & Miguel (2019) further argued on this point, emphasising that the scientific literature requires a greater volume of case studies covering emerging STE technologies which adapt social sustainability assessment methods for STE applications to industrial processes. As a result, Zafar et al. (2024) further emphasised that S-LCA practitioners should use advanced methodologies for evaluating observed social impacts and acceptance for their influencing factors. Complementing this perspective, Wu et al. (2015) advocated for the integration of Type 2 cause-effect methodologies, as outlined in Section 1.2, into current S-LCA frameworks to numerically quantify the effect of monetary investments on social impact and acceptance. Lee & Bruvold (2003) defined these managerial investments affecting employee stakeholders as human resources (HR) and emphasised that appropriate allocation of these resources positively influences social impact in the form of employee job satisfaction regarding their training and career development. Similarly, Martín (2022) defined that strategic managerial investments also heavily influence industrial acceptance of STE systems into processes, citing innovation diffusion to enhance the technical performance of STE systems and financial support through loans and subsidies as key areas of investment. Both sets of authors stated

that evaluating cause-effect relationships will identify the correct managerial resources needed to rectify observed negative social impact.

Cadena et al. (2019) further noted that there is an under-representation of studies examining the acceptance of industries particularly concerning STE systems into their processes. They describe that more studies are needed to address how industrial stakeholders in energy-intensive SPIRE and non-SPIRE industries perceive and engage with STE technologies. Zafar et al. (2024) further highlighted that insight into industrial stakeholder acceptance is needed to reduce uncertainty with STE's technical in processes. Hannouf et al. (2024) mentioned that studies need to include considerations of industrial process requirements, operating temperature ranges, and impact on their environmental management standards when integrating STE systems. This approach is essential to realise the large energy potential identified by Tannous et al. (2023), who demonstrated that newly developed STE systems could supply 96.3 TWh annually to industries and reduce GHG emissions by 20%.

Zafar et al. (2024) then presented how current S-LCA frameworks intaking data on social impact and acceptance within a singular timeframe should expand into the future domain. This concern is expanded upon by Pascaris et al. (2021), who emphasised that the static assumptions within S-LCA should account for the dynamic nature of social sustainability, advocating for future predictions of social impact and acceptance. Onat et al. (2017) also agree with this notion, arguing that such models should capture changes in social impact over a 5-to-10-year future timeframe. Sureau et al. (2018) described that current dynamic models being developed extrapolate the influencing factors of social impact and acceptance over future domain. To expand, Poston et al. (2023) have referenced growth models of social impacts that function on identified cause-effect relationships between social impact and its influencing factors. Zafar et al. (2024) highlighted the importance of advancing dynamic methodologies in order to anticipate and devise future technological and monetary improvement measures for social impact and industrial acceptance. These improvement measures will enhance employee satisfaction with their training, professional development, and working intensity in future STE implementations, as well as supporting industrial acceptance by investing in STE's technical and financial viability.

Therefore, to fill these research gaps, a dynamic advancement must be made in S-LCA methodology in order to capture detailed current and future social scenarios of newly developed STE systems. Such methodology will anticipate negative social impacts and discern why such negative impact was observed, reducing uncertainty. Hai et al. (2019) further affirmed that equipping industrial buyers with comprehensive knowledge and reducing uncertainties regarding future technical and financial viability will considerably boost their

stakeholder engagement. This will increase acceptance from industries as a result, accelerating the deployment of emerging STE technologies. This expands STE's market reach, reducing the industry's reliance on fossil fuels and carbon emissions.

## 1.5 Aim and Objectives

The aim of this thesis is to investigate and evaluate the social sustainability and social and industrial acceptance of a newly developed STE system when applied to industrial processes. The research explores the social implications of the technology through S-LCA, stakeholder and employee feedback collected during the system's development and implementation. Furthermore, the study examines the global perception and acceptance of the STE technology and develops a dynamic model to assess its long-term sustainability and future industrial acceptance in order to identify technological and monetary improvement. To achieve this aim, the six objectives of this thesis are:

1. **Review the scientific literature** on the application of S-LCA to STE systems identifying methodological approaches and existing research gaps.
2. **Conduct an S-LCA** of the newly developed STE system through assessing social risks on employees engaged with the technology's production in order to evaluate its social sustainability.
3. **Assess the social impact** of the STE system through survey-based data collection involving employees engaged with the technology's product development.
4. **Assess global industrial acceptance** of the STE system by analysing international perceptions of the technology's economic savings, contributions to greenhouse gas (GHG) reductions, and potential for adoption across industries.
5. **Assess worldwide social acceptance** of the STE system by examining public perceptions of its environmental benefits for communities, impact on consumer preferences, and continual government support.
6. **Develop a dynamic model** to predict the future social sustainability and industrial acceptance of the STE system over the next decade in order to identify technological and monetary improvements needed to improve its overall sustainability and industrial relevance.

## 1.6 Thesis Overview

The present thesis includes eight chapters, as follows:

- **Chapter 1** introduces current social sustainability of STE systems applied to industrial processes and outlines the research gap, aim, and objectives of the thesis.
- **Chapter 2** critically reviews the existing literature on S-LCA of STE systems applied to industrial supply chains, discussing research gaps in current frameworks.
- **Chapter 3** outlines the research design and methodology for conducting the S-LCA study of the newly developed STE system, which includes goal, scope, inventory analysis, and impact assessment methods adopted in the study. Data collection methods for social & industrial acceptance are also detailed. The dynamic model for making future predictions in social impact and industrial acceptance is then developed. Assumptions and limitations made during the study are briefly mentioned.
- **Chapter 4** assesses the social sustainability during the Production phase of the newly developed STE system's main components using the Social Hotspot Database (SHDB), identifying high-risk levels in five social risk categories.
- **Chapter 5** assesses social impact during the Product Development phase of the newly developed STE system by analysing stakeholder satisfaction across three categories using surveys. Additional managerial feedback was used to determine the influence of resource allocation on satisfaction scores.
- **Chapter 6** assesses the global industrial acceptance of the newly developed STE system involving different international industries.
- **Chapter 7** assesses the social acceptance of the newly developed STE system from the perspective of the general public originating from regions worldwide.
- **Chapter 8** applies the dynamic model to forecast future social sustainability and industrial acceptance over a 10-year period using influencing investments into human resources and enhancing the newly developed STE system's technical and financial viability for the industry.
- **Chapter 9** summarises and concludes all findings of the thesis, providing technological and monetary improvement measures.

## Chapter 2: Literature Review of S-LCA Applied to STE Systems

A systematic review involving 41 publications from the literature was conducted on the S-LCA application of solar energy systems using the following search strategy. First, two databases were used for the search; Scopus and ScienceDirect. The inclusion criteria encompassed original research articles, case studies, and review articles published between 2017 and 2025. Other publication types, book chapters and conference proceedings, were excluded from the search.

Next, keywords were inputted into the search bar, which included *“social life cycle”*, *“social life-cycle”*, *“SLCA”*, *“S-LCA”*, and *“social sustainability assessment”*, which were applied to the title, abstract, and keywords of each article. This yielded an initial set of n = 647 publications. To further refine the search, only studies with an explicit focus on social assessment were retained. Hybrid studies combining environmental and economic data were excluded by applying the search condition *“social” AND NOT (“environmental” OR “economic”)* within the title field. This reduced the dataset to n = 395 publications.

A further refinement step was applied to focus on STE and similar renewable energy systems relevant to this study. The search was expanded using the expression: *(“social life cycle” OR “SLCA” OR “S-LCA” OR “social sustainability assessment”) AND (“solar” OR “wind” OR “hydropower” OR “bioelectricity” OR “biodiesel” OR “biofuel” OR “hydrogen” OR “energy”)*. This resulted in a reduced dataset of n = 190 publications.

Next, the selected studies were further screened based on their methodological approach to S-LCA. Only studies applying recognised S-LCA protocols, specifically Type I and Type II methodologies, were included at this stage of the search, reducing the number of publications considered to n=46. This step ensured that the analysis focused on studies employing established frameworks for assessing social impact and its underlying influencers.

Finally, a full-text screening was conducted to assess the quality, relevance, and methodological rigour of the remaining studies. Publications that either did not align with the scope of this research, lacked sufficient methodological rigour, or were duplicates were excluded, resulting in a final sample of n = 41 publications for the review.

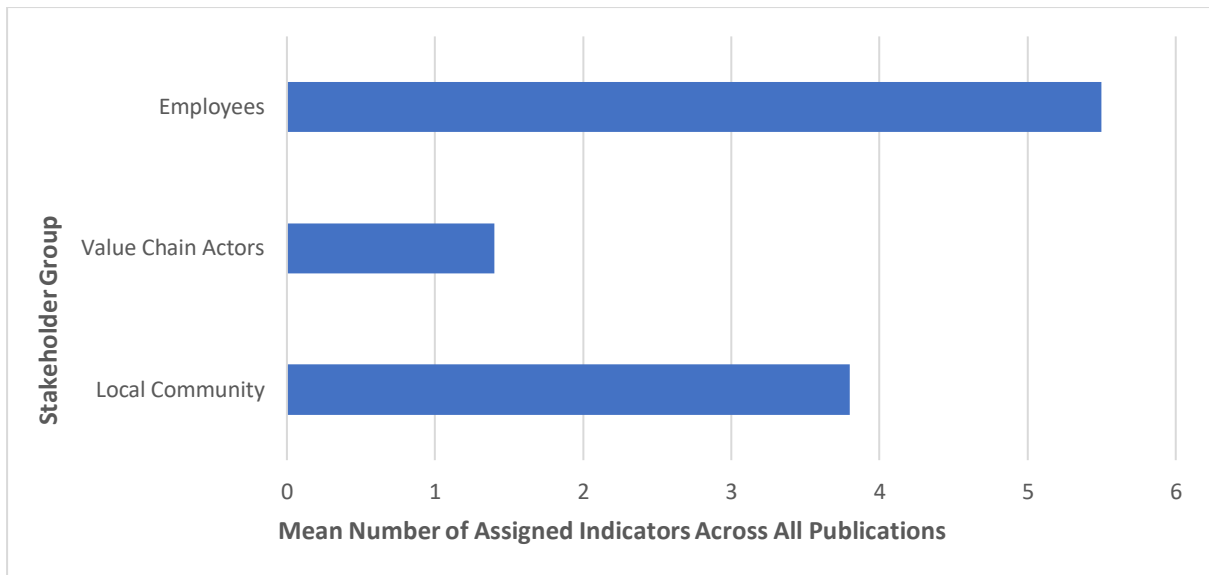


Figure 1: Mean Number of Indicators per Stakeholder Group for all Reviewed Publications

Figure 1 displays three groups of project stakeholders that were addressed in the reviewed S-LCA literature, which were predominately comprised of employees, value chain actors, and the local community. It can also be seen from Figure 1 that the mean number of social issues addressed per publication varies greatly across these three stakeholder groups, with employees assigned the highest number of indicators at approximately 5.5, followed by the local community at around 3.8, and value chain actors at only 1.4. This substantial disparity observed in Figure 1 demonstrates that employee-related issues receive considerably greater attention within the S-LCA literature, being examined at a rate more than three times that of value chain actors and notably higher than local community impacts. It can therefore be deduced that a strong publication bias exists in the current S-LCA literature towards studying employee-related social issues, with some attention given to local community issues and considerably limited representation of value chain actors.

To expand on the stakeholder definitions observed from the literature, Tavakoli & Barkdoll (2015) had presented the most comprehensive breakdown of employee stakeholders deployed at all life cycle phases. They considered occupations such as shop line workers, machinists, furnace operators, and miners at the manufacturing phase, lab technicians, mechanical engineers, and research associates at the product development phase, and technical employees such as operators of the STE system during its application and operation phases. Social issues affecting employees on an STE development project, as evidence in the works of Corona & Miguel (2019), fair pay using measurable indicators such as annual salaries, mean wages for part-time and full time workers, and the percentage of employees earning at or above the liveable wage. Josa & Garfí (2023) developed further on the use of this indicator by measuring differences between the national expected level of pay for each

occupation type in order to measure the fairness of pay. Costa & Oliveira (2022) had use similar methods to measure another social issue; fair employee working hours were managed in their feedstock production line. Their social indicators graded social impact based on how many employees had working hours exceeding the legal maximum stipulated working hours. Another key social issue concerning employees was their Health and Safety (H&S) at work, covered by Cooper et al. (2018). They compared the rate of worker injuries per unit energy of natural gas produced against solar and wind, to deduce the relative safety of employees working in their supply chain. Given the technical nature of solar thermal energy systems, these methods can easily be adapted due to the intensity of material production and risks that high temperatures pose on workers within the energy sector. Such technical employee classifications and breakdowns are important to the solar renewable energy sector.

The value chain actors in this case are segmented into different industrial organisations and representatives participating in the supply chain of the STE system, adding value to the STE product. Firstly, Corona & Miguel (2019) identified these to be the material and part suppliers where STE system components are procured from for assembly. The key social issue for these types of value chain actors was investigated by Wei et al. (2022) to be the upkeep of relationships between the material suppliers and the engineering company developing the STE system. They defined this issue as the impact of material suppliers due to the purchasing decisions of the engineering company. Terrapon-Pfaff et al. (2019) had built on this by measuring the satisfaction of material suppliers during their engagement with producing purchased parts for STE systems. This indicator was further explored Corona & Miguel (2019), who measured factors such as the satisfaction with the contract terms during the engagement, on-time delivery, communication and transparency of component design requirements.

More crucially, the other set of value chain actors are external industrial representatives from both SPIRE and non-SPIRE industries, previously introduced in Section 1.2. These stakeholders represent potential buyers who are interested in adopting STE systems into their industrial processes. According to Qamar et al. (2022), the issue affecting these stakeholders is known as 'industrial acceptance' which is comprised of different acceptance categories. They identified the first category as industrial engagement with sustainable energy practices, focusing on indicators measuring how aware industrial representatives are of the need in reducing carbon emissions from their processes, and whether they are actively involved in implementing STE and related renewable technologies within their operations. Other indicators identified by Beske et al. (2008) include the current implementation of environmental and energy management standards ISO 14001 and ISO 50001 in industries. They emphasise

a critical related indicator; perceptions of STE's impact on these standards, which, as Kumar et al. (2022) explain, measures the industries' perception on how much integrating STE systems will improve their compliance with these standards.

The next category as mentioned by Kumar et al. (2022) is STE's technical compatibility with industrial processes, encompassing indicators such as the industry's perception with STE's operating temperature range, its scalability to meet their production demands, and the overall thermal output. McMillan et al. (2021) supplemented this by identifying other indicators related with industrial perception on available space for installation and ease of installation with existing infrastructure ranging from pipe networks and current in-house machinery. The final category, as examined by Elakanti & Singh (2021), is industrial acceptance with STE's costs, which include opinion on STE's upfront investment for initial installation, return on investment, and expected operating costs. Additionally, Qamar et al. (2022) noted that perception of financial benefits is another key indicator under this acceptance category, which includes how industries perceive STE's energy savings and carbon tax reliefs. They elaborate with measuring how industries respond to receiving government-backed tax reliefs and subsidies for adopting STE technologies.

Finally, Figure 1 shows that the local community stakeholder group was addressed more frequently in publications, with an average assigned number of social indicators of 3.8. The main social issue affecting this stakeholder group was termed as 'social acceptance' as documented by Buchmayr et al. (2022). Sovacool & Ratan (2012) further defined the first acceptance category to be public perception of solar energy's environmental benefits, capturing public agreement with its contributions environmental impact. Segreto et al. (2020) expanded this by introducing indicators to assess public agreement with the displacement of fossil fuels using solar energy to reduce carbon emissions and mitigate climate change. Pagliuca et al. (2022) added by incorporating indicators that gauge public preferences for cleaner air quality in communities surrounding industries where STE is applied.

Sovacool & Ratan (2012) identified the next category to be public agreement with consuming products manufactured in industrial supply chains which have applied STE systems. Jung et al. (2016) in their study in Finland further reinforced this category by introducing indicators that examine public agreement with eco-labelling of products and carbon footprint disclosures. Carlisle et al. (2015) identified another crucial social acceptance category related to the public's agreement with continual government investment incentives for solar energy development, gauging public perceptions of tax reliefs schemes and subsidies to increase the adoption of STE systems in supply chains.

## 2.1 Data Collection Methods

Building upon the inclusion of social issues and assignment of indicators, the next step taken by S-LCA practitioners was to employ methods for data collection and assessment. Figure 2 examines presents the types of data collection methods and the frequency at which practitioners applied them for each of their real-life case study.

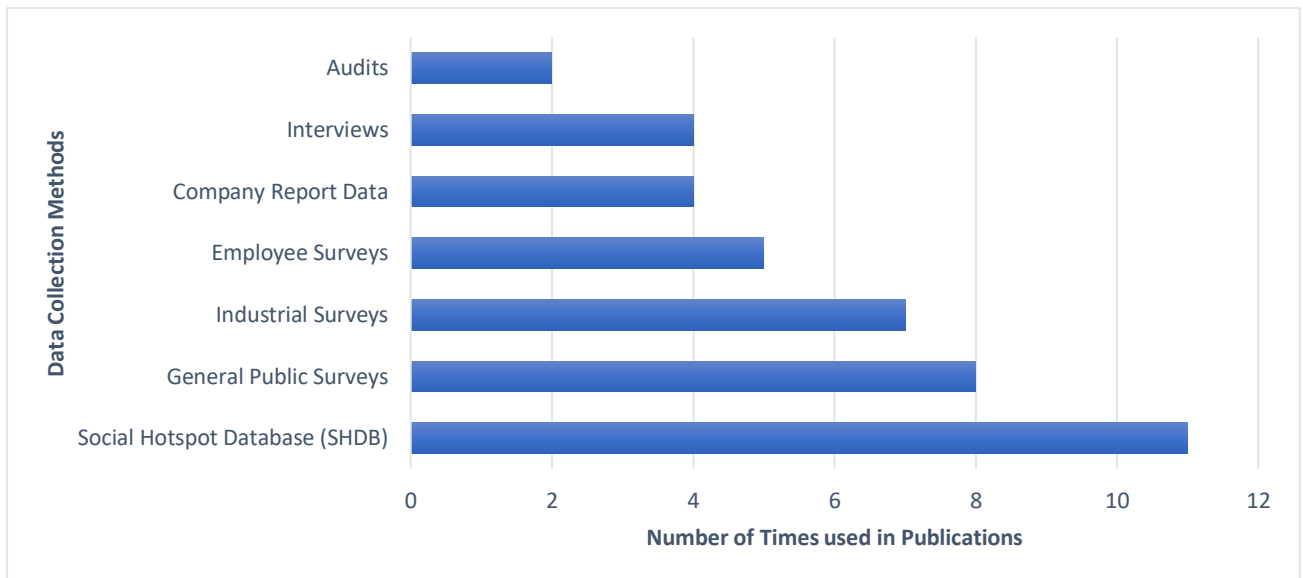


Figure 2: Data Collection Types and Frequency Used in the Literature

Figure 2 shows that the most popular data collection method in reviewed SLCA was the use of Social Hotspot Database (SHDB) with 11 times used. Two common SHDB platforms were found in the literature, one as documented by Norris & Norris (2019) was added as extension to PRé Sustainability's SimaPro, originating from Amersfoort, Netherlands. The other one was described Tragnone et al. (2023) as the Product Social Impact Life Cycle Assessment (PSILCA) database developed by GreenDelta in Berlin, Germany. Norris & Norris (2019) established a guide on the former platform, describing it as a software designed to forge a complete picture of the social impacts across the production supply chain using the software. In the SimaPro SHDB software, the critical input parameters include modelling the STE system appropriately. This will be by using SimaPro's GTAP-Based Input/Output model. In this model, reputable sources of statistical data have been used to develop social data as inputs, which are extract by country. These sources provide access to large amounts of social data on country-specific sector (CSS) level, which enables practitioners to assess social risks associated with certain economic sectors within a region of the world. Each economic sector in each country has a code which relates to a life cycle stage of the STE system. In the case for manufacture stage, for example, relevant interdependent economic sectors for the manufacturing of the STE system include Metals, Chemical products and Machinery.

First, quantitative material flows are inputted and are associated to the material's monetary value using the total working hours dedicated towards generating that material. These working hours are derived through inputting the material mass input and selecting the manufacturing process in the pertaining economic sector in the software. Next, the geographical location and pertaining economic sector where the material was produced is then selected as the second input. The output data can then be generated as risk hours (RH), which represent the quantified exposure of workers to adverse social conditions within the supply chain for a set of indicators which include metrics related to labour rights, working conditions, health and safety, fair wages, gender equality, and employment. The unit of risk hours is expressed as hours  $\times$  risk level, where one risk hour corresponds to one hour of labour weighted by the severity of a specific social risk, numerated into a factor. These weighting factors are applied to the estimated working hours, such that higher-risk sectors and regions generate proportionally greater risk hour values. Shi et al. (2023) maintained that these risk hours reveal the quantified impact on labour within that region by numerating the fairness of pay, working conditions, and H&S implications. These hours are then combined with indicator-specific risk criteria to calculate the levels of high, medium, and low social risk associated with each supply chain activity. An example of such criteria is given by Norris & Norris (2019) within the Health and Safety (H&S) category, risk is assessed using Disability-Adjusted Life Years (DALY) indicators, which quantify the potential loss of healthy life due to workplace injuries or hazardous conditions. In this case, a sector with a higher DALY rate, indicating more severe health impacts, would be assigned a higher risk weighting. When multiplied by the corresponding working hours, this results in a greater number of risk hours, reflecting increased exposure of workers to health-related risks. Conversely, sectors with lower DALY values would generate fewer risk hours, indicating comparatively lower health and safety risks.

This social risk is termed in the SimaPro SHDB database as potential geographical hotspots. In the guidelines of UNEP-SETAC (2020), social hotspots are defined as the likely presence of a social impact in a geographical location, resulting from the activities/behaviours of organizations linked to the life cycle of the product or service and from the use of the product itself. These hotspots indicate the potential occurrence of adverse social conditions arising from production activities, highlighting supply chain stages where stakeholders may be exposed to elevated risks, such as poor health and safety conditions, discrimination, low wages, and inadequate labour protections. Koese et al. (2023) performed these techniques for their S-LCA on lithium ion batteries, extracting considerably higher social risk in China-based production as compared to supply chain activities occurring in Germany. Werker et al. (2019) applied PSILCA to assess social risk to workers for an energy related application; hydrogen production. Their results agreed with the previously mentioned authors, who found

high risk of violation of labour rights in China's process chains. These authors provide further details of this approach, describing that it relies on aggregated, second hand, country-sector data and assumes homogeneity, reflecting average regional risks rather than site-specific conditions reflected by first-hand data.

As far as the review is concerned, Corona & Miguel (2019) is the only practitioner to have utilised SHDB techniques for an STE system, who conducted such an SLCA to identify high levels of H&S related social risks within metal manufacturing industries in China and African countries. Their results are important to SHIP systems due to the risk analysis conducted for crucial STE components, such as CSP collectors and energy storage.

The second most frequently used data collection methods in Figure 2 were online surveys administered to gain a subjective insight directly from the affected stakeholders regarding their satisfaction and/or agreement on related social issues. Zafar et al. (2024) found that these surveys were typically distributed to three primary stakeholder groups in S-LCA literature: employees involved in production or development activities, industrial stakeholders such as managers, engineers, and decision-makers responsible for technology adoption, and members of the local community to capture broader societal perceptions. They elaborate that surveys were commonly disseminated to participants through digital platforms, including email invitations, online survey tools, and professional or institutional networks.

The structure of these surveys generally comprised a combination of closed-ended and open-ended questions. Bryman and Bell (2019) described that closed-ended questions employed Likert-scale formats, allowing respondents to express their level of agreement or satisfaction on a standardised numerical scale, ranging from strongly disagree to strongly agree or very unsatisfied to very satisfied. This approach enables the conversion of qualitative perceptions into quantifiable data suitable for statistical description in the form of correlation, standard deviation analysis, confidence intervals, and bootstrapping. Bryman and Bell (2019) then described that open-ended questions were incorporated into these surveys to support closed-ended questions capture more detailed qualitative insights, allowing respondents to elaborate on their satisfaction through comments and written feedback.

Zafar et al. (2024) described that this instrument enables the direct assessment of social impact such as job satisfaction of employees, perceived technical compatibility of industrial users, and acceptance of the local community. A difference of surveys compared to secondary data from SHDB is that survey-based methods provide context-specific and first-hand insights into social impacts and acceptance rather than aggregated social risk. As a result, survey instruments are particularly effective for measuring social impact at an organisational/institutional level rather than representing the impacts in a region.

Such survey techniques were deployed by Sawaengsak et al. (2019), who assessed satisfaction amongst employees on their biofuel production line regarding social issues such as their pay, working hours, training, and their H&S at work. Xiao et al. (2024) had also conducted a survey examining employee satisfaction from a sample size of 100 for hydropower in China, gauging satisfaction with fair payment, training, and working intensity. Motilewa et al. (2018) surveyed a sample of 350 employees from Nigeria's oil and gas industry to survey satisfaction with H&S, working intensity, anti-discrimination policies, and contribution to career growth. Their survey structures included multiple-choice and Likert scale questions designed to capture varying degrees of satisfaction of specific employee occupations: shopline workers, machine operators, research associates, lab technicians, engineers, and managers.

Schriever & Halstrup (2018) had adapted this survey methodology for 101 representatives from German automotive industries, using the same 5-point scale ranging from 'Strongly Disagree' to 'Strongly Agree'. Such a scale was used to assess the industry's agreement with STE's technical compatibility with processes and financial viability. Qamar et al. (2022) conducted a similar survey among 127 industrial stakeholders in Pakistan's textile industry, utilising Likert-scale instruments to numerically quantify respondents' agreement with STE's operational suitability, cost-effectiveness, and environmental impact. In addition to Likert-scale responses, Kumar et al. (2022) included open-ended qualitative response fields in their surveys to capture feedback from 250 textile industry stakeholders in India. Comments given in this section of the survey related to perception on process compatibility, particularly with temperature ranges and financial viability of STE's energy savings and tax reliefs. Survey structures were also adopted to gauge public acceptance of STE technology, as conducted by Elmustapha et al. (2018) with 141 public stakeholders in Lebanon to investigate public perceptions of solar thermal systems, regarding their awareness, education, and agreement with continued government investment. Devine-Wright (2021) administered similar surveys to a community of 271 participants, examining indigenous perceptions of another renewable technology; wind farms and tidal turbines based on their perceived reliability, low-carbon benefits, and future advantages. The survey design also employed open-ended responses to capture qualitative dialogue from participants. Terrapon et al. (2019) had also used surveys to capture such qualitative feedback in this fashion to gauge public acceptance of CSP technology from 101 participants.

Another commonly used data collection instrument from Figure 2 are interviews. Kassem et al. (2016) expanded on the use of open-ended responses, conducting structured face-to-face interviews with 50 industry professionals and assessing industrial perception on cost-benefit trade-offs and investment priorities for STE. Zafar et al. (2024) found that interviews are

conducted in semi-structured or open-ended formats, allowing respondents to provide detailed oral explanations of their experiences and perspectives. Kumar et al. (2022) demonstrate that such approaches enable industrial participants to elaborate on operational challenges, technological compatibility, and financial considerations, while Devine-Wright (2021) highlighted their effectiveness in capturing public motivations and perceptions towards energy technologies. Kassem et al. (2016) stated questions are on current industrial processes, current energy sources, opinion on STE's technical performance, and financial considerations.

Bryman & Bell (2019) stated that the qualitative data obtained from interviews are analysed using thematic analysis, where responses are systematically coded into recurring themes and patterns, such that the sentiment of the participant can be obtained. The key differences of interviews lie in their ability to capture first-hand accounts of stakeholder experiences and organisational practices, offering greater flexibility and depth through open-ended and probing questioning compared to more rigid, closed-ended survey-based methods. They heavily contrast with SHDB-based approaches by capturing first hand perceptions rather than relying on aggregated estimates of social risk. Next, Figure 2 shows that evaluative audits were also adapted as another qualitative technique to measure the compliance of company practice to enforced regional policy. Hannouf and Assefa (2018) mentioned that these audits involve assessments of compliance of organisational procedures and quality of workplace conditions against established regulatory frameworks within the industry. They are conducted through on-site inspections, document reviews, and on-site observations, allowing auditors to evaluate whether companies adhere to required social and labour regulations in practice. Kumar et al. (2022) presented that unlike survey-based and interview methods, which capture subjective perceptions, audits provide evidence-based verification of compliance with established social procedures, enabling an objective assessment of actual workplace conditions and the identification of areas of adverse social impact. An example of audits was documented about the examination of Health and Safety policy, in the case studies related to High-Density Polyethylene (HDPE) production done by Hannouf and Assefa (2018), and by Singh & Gupta (2018) for a steel mill. In both case studies H&S labour policy was examined using indicators that grade the level of the chemical safety using qualitative observations. It was found by Hannouf & Assefa (2018) that exposure to hazardous substances among workers on the shop floor and among the local community was high due to the ineffective management practices within their HDPE production facility. Using audit reports, they found that only 10% of the chemical company's sites are certified to governing ISO standards ISO14001. Given that similar H&S standards are imposed for solar thermal energy production, the use of auditing can be implemented to cover a breath of social issues that could be qualitatively assessed. The last technique described in Figure 2 shows the scanning of company reports. Corona &

Miguel (2019) discussed that this approach involves extracting first-hand quantitative data directly from organisational records, such as financial disclosures, workforce statistics, and health and safety performance metrics, providing objective measurements of social indicators. These data enable the identification of both positive social impacts, such as fair wages, investment in employee development, and improved safety performance, as well as adverse impacts, including high accident rates, wage disparities, or non-compliance with labour standards. Unlike previous techniques, the key difference of this method is that it provides firm-level, quantitative evidence of actual conditions, rather than relying on estimated risks or subjective stakeholder perceptions. Company reports were widely used by Corona & Miguel (2019) to extract financial data on employee pay and salary while H&S records were used by Cooper et al. (2018) to determine the recorded annual accident rate in a production setting.

## 2.2 Data Analysis Methods

Proceeding the collection of data, two distinctive analysis models were identified in SCLA studies; Type I and Type II methodology. Parent et al. (2010) defined that a Type 1 approach is a model that aims to quantify social impact based on the measured data collected by all social indicators assessed for each stakeholder in Figure 2. Parent et al. (2010) explained that the numerical data from Type I is generated based of a grading scheming using points known as Performance Reference points (PRP). Such a grading scheme was adopted by Costa & Oliveira (2022), who used it to numerate social impact based off on how well a company is complying to objective standards of social acceptability, such as binding regional social policy. Corona & Miguel (2019) discussed that performance points calculate the magnitude of deviation of indicator data from those objective social norms acting as neutral criterion, which fit within the range of -2 to +2. The negative numbers demonstrate negative social impact of specific social indicator, and vice versa for positive numbers. Josa & Garfí (2023) had proposed to use the regional averages of each social indicator, which were sourced through national databases are government statistics. A frequently cited statistic in this paper was the national average salaries per occupation, which would be matched with collected employee salaries from the engineering firm. Based on the industrial average within the regional, their study showed to what extent employees were being paid fairly for a given job title by calculating the percent deviation. Such methodology can be adopted for audit based studies, as was in the case of Wang et al. (2019). Their S-LCA methodology used the national labour regulations to measure the company's treatment of their employees. Deviation from minimum or maximum allowances would be the magnitude of social impact on the appropriate stakeholders. Muthu (2019) agreed with setting labour laws at cut off thresholds, using the minimum wage law to determine whether workers are paid sufficiently. This was used to

highlight underpaid workers as negatively impacted, while workers above the minimum threshold are being positively impacted.

In stark contrast, Type II methodology is used to identify the influencing factors of negative social impact as described by Sureau et al. (2018). They stated Type II goes beyond reporting the magnitude of social impact on stakeholders as performed under Type I protocol, linking managerial activities such as investment into human resources to social impact on employees. Wu et al. (2015) further commented that multiple variables could impose negative social impact, such as a lack of employee training or imbalanced work schedules. In such cases, they advised that social data could be processed by multi-variable numerical techniques such as regression analysis to determine the correlation between managerial activities and social impact on employees. This protocol will be elaborated upon in section 2.3.

## 2.3 Research Gaps

The main knowledge gap that was present throughout this review of the literature was the lack of elaborative commentary and evaluation of measured social risk, impact, and acceptance. Evaluative discussions within most S-LCA case studies could provide more in-depth and comprehensive insight of social risk experienced by stakeholders. To elaborate, studies using SHDB platform such as those by Corona & Miguel (2019) and Costa & Olivera (2022) had covered the areas of high social risk within their supply chains but could have gone into more depth as to why risk was generated in those areas. These authors could have added commentary on how numerical data in the form of social impact impacts stakeholders and what implications they face, instead of presenting a set of percentages and impact points. The scope of their studies could have included an exploration into the key drivers generating the observed social data and why did it produce positive or negative impact, which could provide more insight for effective corrective resource allocation. This also holds true for the audit oriented S-LCA study of Hannouf & Assefa (2018), whose recommendations on improving H&S standards around hazardous chemicals were briefly explained in the discussion, and could have explained why malpractices and policy violations in H&S were observed. In a similar case study for a steel mill, Singh & Gupta (2018) had could have explained more why H&S violations exist within their steel mill when comparing to policies in place, backing up with more numerical statistical support.

Similar knowledge gaps persist for social acceptance studies such as those of Aung et al. (2021) and Buchmayr et al. (2021), in the context of hydropower and wind power respectively. Both studies could have had more precise recommendations aimed to inform policy makers on how to prevent negative public perception due to the construction of sustainable energy

systems. An appreciation of social acceptance and the impact on the public should also be more comprehensively demonstrated as evidenced in the studies of Bonilla-Alicea & Fu (2022) and Terrapon-Pfaff et al. (2019). Commentary in both studies relating to solar PV technology and CSP plants respectively could provide more detail on why public agreement with STE integration was positive and why public support for educational programmes and government invest in STE technologies is increasingly growing.

This knowledge gap extends into the realm of industrial acceptance studies, such as in the case of Qamar et al. (2022) and Kumar et al. (2022). Both studies could have addressed the influencing factors of observed industrial acceptance in greater detail, such as why certain industries exhibited reluctance to purchasing STE technologies for their processes. Schriever & Halstrup (2018) had found that industries had accepted STE systems into their existing infrastructure and had found STE compatible, yet the factors influencing this perception were not investigated. Similarly, Elakanti and Singh (2021) could have elaborated further on why certain industries exhibited uncertainty on STE's costs such as the upfront investment as well as why operational challenges existed. Corona & Miguel (2019) further argued that there must a greater volume of future industrial acceptance studies covering innovative STE system, going beyond traditional technologies.

The implications of the research gaps in current S-LCA approaches clearly impedes policymakers' ability to make well-informed decisions on managerial intervention in order to improve the social impact of STE supply chains. While areas of high social risk and negative impact can be highlighted, Kühnen & Hahn (2017) undermined that robust managerial decision-making for efficient resource allocation requires a deeper understanding into the key drivers and root causes of social risk, impact, and social & industrial acceptance. Sureau et al. (2018) highlighted the importance of identifying these key drivers towards developing S-LCA into a robust tool better suited for decision making. Such information can be used by policymakers to develop more targeted strategies for resource allocation and mitigate adverse social, risk, impacts, and negative industrial acceptance, improving the outcomes for all STE stakeholders.

For example, the key drivers of organisational gaps in compliance with labour laws should be better understood to facilitate interventions and enhance employee pay and job satisfaction. Similarly, training gaps should be correlated with employee qualification mismatches and poor job performance, so that policymakers can develop initiatives that focus on skills development programs to enhance employee productivity. Training gaps can also be correlated with high accident rates and health and safety (H&S) risks on the shop floor so that policymakers can prioritise occupational safety measures and design targeted training programs to mitigate risks

and improve workplace safety. These exact correlations between H&S and employee training can be established in follow up studies expanding on those of Hannouf & Assefa (2018) and Singh & Gupta (2018).

Similarly, the influencing factors of industrial acceptance within the studies of Qamar et al. (2022) should be better understood to facilitate investments that improve the viability of new STE technologies, particularly for small and medium-sized companies. More follow up studies can be conducted to find why smaller companies were found to be more reluctant in applying STE systems to their processes, and in which areas investment is needed. This will enable appropriate government subsidies and loan support programmes to remedy financial barriers. Similarly, perceived technical incompatibility found within the study of Schriever & Halstrup (2019) by smaller companies can be remedied by linking investments in technology integration training. Indeed, the discussed evidence demonstrates that noteworthy progress needs to be made to overcome persistent knowledge gaps in S-LCA methodological framework, emphasising the urgency of addressing these gaps advance the development of S-LCA as an effective managerial tool for STE systems.

Wu et al. (2015) evidenced an upcoming advancement by considering the combination of standard Type I protocol with Type II methodology in order to take advantage of both their benefits. The numerical techniques that they recommended consist of multi-variable correlation which could be integrated into Type II S-CLA framework in order to uncover interconnected relationships between social variables using quantified numerical coefficients. The numerical approach was deployed by Samman & Abdelnasser (2020) in their study of the drivers of job satisfaction in the form of multi-variable regression. The findings of their approach were used to prioritise interventions and implement targeted measures to correct any negative social impacts on employees. Another notable application of this technique is evident in the study by Katou & Budhwar (2010), which analyses the social impact of HR practices on employee satisfaction, commitment, and organisational performance within the Greek manufacturing sector. The authors were able to deduce the numerical impact of HR and business practices on multiple aspects of employee satisfaction. This technique can be further evidenced in the works of Vinh et al. (2022), who demonstrated how they were able to successfully analyse the influence of employee leadership training programs, employee skills, and professional development programs on employee satisfaction amongst 207 respondents. By modelling these relationships through dissecting numerical path coefficients, the study revealed how effective managerial investing into both leadership training and professional development programs contributed to enhanced employee skills.

Such techniques improve the insights generated in social assessments, providing the influencing factors of employee satisfaction and dissatisfaction and enabling improvement measures to be taken. To further expand, such a relations need to be extrapolated into a future temporal domain.

### 2.3.1 The Need for a Future Predictions in Social Assessment

A deeper examination into S-LCA literature excerpts appraised in section 2.3 reveal another fundamental knowledge gap. This knowledge gap has been addressed by scholars such as Shimako et al. (2018), García-Muiña et al. (2021), Kühnen & Hahn (2017) who have highlighted the limitations of traditional static models when applied to STE technologies. They stated more is left to be desired when considering social sustainability over a future temporal domain. Indeed, this was the case for all 41 studies reviewed in the evaluation presented in section 2.1, with the likes of Corona & Miguel (2019) and Terrapon-Pfaff et al. (2019) only covering social data for a single phase of the solar technologies represented in their studies. No mention of the use of temporal variations in social data was detected in any of the 41 studies reviewed.

García-Muiña et al. (2021) emphasised that advancement in the old S-LCA framework adopted by those authors would be to consider social data over multiple time intervals to create more comprehensiveness and breadth datasets available for decision makers to dissect and act on. Indeed, the author of this thesis argues that adding a temporal dimension in S-LCA, giving rise to Dynamic SLCA (D-SLCA), will enable accurate long-term predictions which can be used to mitigate social risks well in advance. The nuanced insights provided by D-SLCA allows management panels and policymakers of each future STE implementation to ensure that social sustainability is maintained and enhanced over time, at each stage of the product life cycle. Using D-SLCA will enable the efficient allocation of corrective investments over monthly or yearly intervals, gradually improving social impact and acceptance of STE projects.

To fill the discussed knowledge gaps, the author of this thesis suggests adapting dynamic probabilistic models which build on the multi-variable causal analysis as extracted from mainstream social assessments. This model is adapted from the statistical textbook of Hosmer Jr. et al. (2013), who have established an ordinal logistic regression model which builds on the multi-variable regression model. According to them, this tool can be used to progress multi-variate regression into the time domain by being able to predict the likelihood of observing data across multiple categories. Wang et al. (2019) further discussed how the model incorporates predictors as coefficients to estimate the probability of observing social data at a

time interval. The author of this thesis further develops on how such a tool can be integrated into D-SLCA to process social data collected in the works of Costa & Oliveira (2022) and Corona & Miguel (2019) in a manner such that social impact in the future can be extrapolated. Lee & Buvold (2013) suggested performing this extrapolation by using causal links between Human Resource Management (HRM) practices and employee satisfaction. Using the model by Wang et al. (2019), employee satisfaction over time can be predicted by using its probabilistic response to HRM resources progressively provided in a future domain, on an annual basis.

Chayjan et al. (2021) stated that such a framework can also be extended to assess industrial acceptance over time by dynamically linking annual investments into STE's technical and financial viability to probabilistic acceptance levels. Such investments are annual monetary instalments into improving STE's performance and subsidising its costs as mentioned by Alipour et al. (2018). The framework for this approach is further detailed in section 3.8.

### 2.3.2 The Need to Examine all Addressable Social Issues

This review had also picked up on a secondary knowledge gap within current SCLA literature. This builds upon the finding made by Bouillass et al. (2021), who had demonstrated that S-LCA need to go beyond covering over-addressed social issues affecting employees, such as H&S and fair payment. Zafar et al. (2024) highlighted that another set of issues that should be introduced in the S-LCA framework of STE systems include employee training, professional development and the impact on R&D, all of which are highly relevant to a novel solar thermal energy project being developed in an R&D environment. They further highlight that such issues have yet to be covered by S-LCA literature.

Bouillass et al. (2021) presented that S-LCA practitioners should consider external value chain actors more often, crucially including external industrial stakeholders. The results of Figure 2 corroborate with this notion as it shows that the overwhelming number of studies focus on employee stakeholders with the mean number of related indicators of 5.5 as compared to 1.4 indicators for the value chain actor group. Kumar et al. (2022) described that the three issues related to industrial acceptance; technical compatibility, financial viability, and impact on environmental and energy management standards, should be better understood. Corona & Miguel (2019) further highlighted that such issues should be more evident in the context of newly developed STE systems in order to better understand the readiness of external industrial stakeholders to adopt and integrate STE systems into their operations. The former authors elaborate that gaining perception of STE's technical compatibility will better align new technologies' thermal output and operating temperatures with existing industrial processes.

This is also applicable for understanding the industry's perception on STE' financial viability, such as upfront investment, operating costs, energy savings, and tax relief. Unveiling the industrial acceptance of these parameters is important in guiding where financial support in the form of loans and subsidies can be allocated. Similarly, Beske et al. (2008) emphasised that STE's impact on environmental and energy management standards should be assessed in better detail to encourage adoption. The demonstration of the net positive impact on employees and industrial stakeholders will attract more interest and acceptance of STE systems, proving itself as a highly feasible and sustainable alternative source of energy. This will attract more demand and investments leading to increased market size and thus contributing towards carbon-reducing goals.

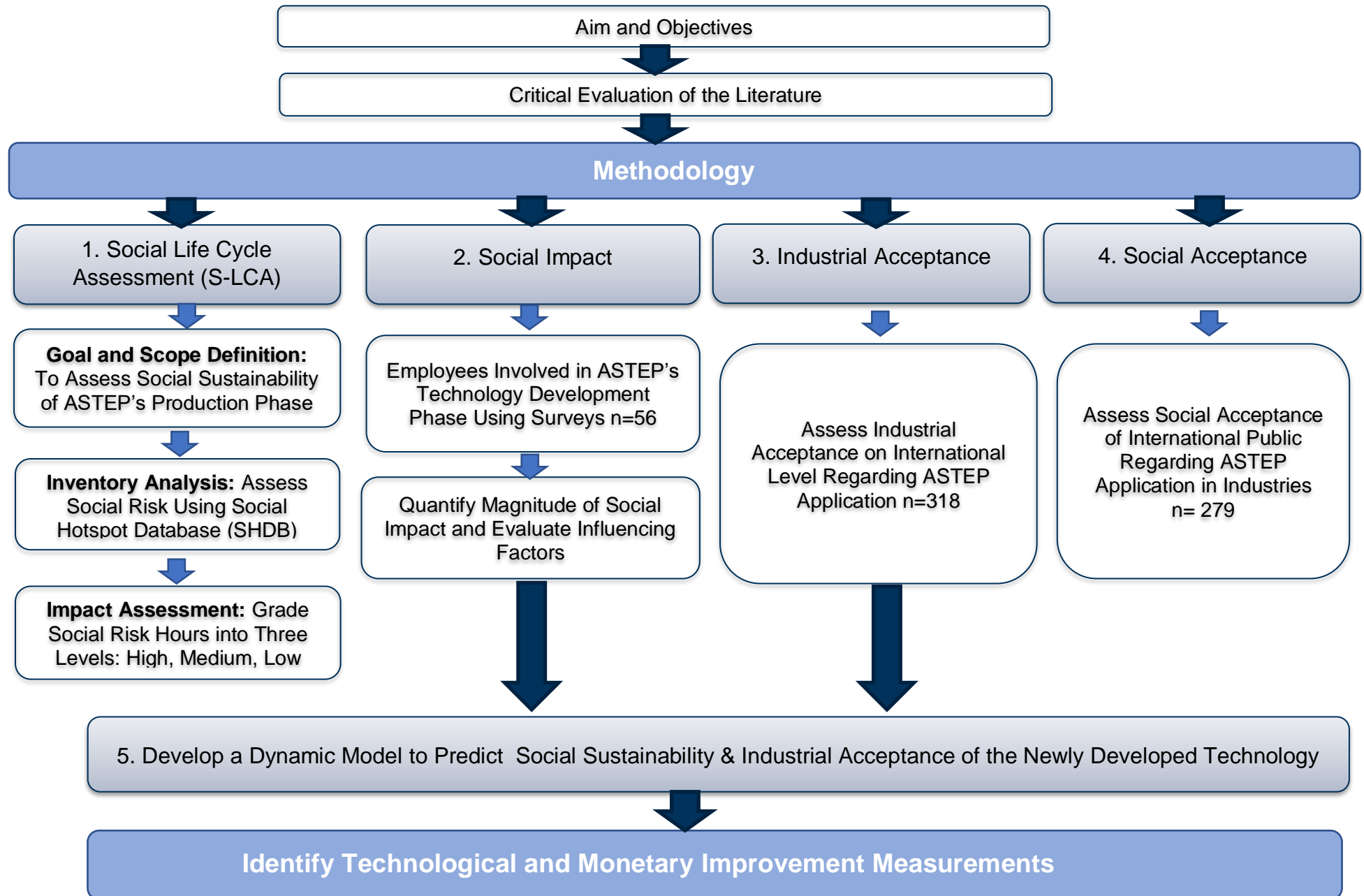
## Chapter 3: Methodology

This chapter presents the research design of this thesis in section 3.1. Section 3.2 proceeds with defining the goal and scope of the S-LCA for the newly developed STE system. Section 3.3 defines the inventory analysis phase of the S-LCA, and section 3.4 presents the S-LCA impact assessment methods. Section 3.5 presents the data collection methods for assessing the newly developed STE system's social impact. Section 3.6 covers the data collection methods for assessing the newly developed STE system's industrial and acceptance, and section 3.7 does the same for the newly developed STE system's social acceptance. Section 3.8 covers the methodology for making future predictions of the newly developed STE system's social impact and industrial acceptance, and section 3.9 covers the assumptions and limitations of this thesis.

### 3.1 Research Design

The research design of this thesis is displayed in Figure 3.

Figure 3: Research Design



1182 Figure 3 shows the first part of the Research Design, which includes the aim and objectives,  
1183 covered in Chapter 1. Chapter 2 then critically evaluated the literature on S-LCA of STE  
1184 systems. The methodology in Figure 3 is covered in Chapter 3, which first consists of the S-  
1185 LCA (1) on the newly developed STE system in accordance with the guidelines defined by  
1186 UNEP-SETAC (2020) guidelines, which contains the four fundamental stages as seen in  
1187 Figure 3: a) Goal and Scope, b) Inventory Analysis, c) Impact Assessment, and d)  
1188 Interpretation. The goal of the S-LCA was to assess social sustainability by considering social  
1189 impact data affecting employee stakeholders, further expanded in section 3.2. The scope of  
1190 the S-LCA contained the employee stakeholders involved at the Production and Product  
1191 Development lifecycle phases of the newly developed STE system as outlined in Figure 5.  
1192 Inventory data (1) for the Production Phase was collected as social risk in five categories  
1193 originating from social hotspot database as detailed Section 3.3. The impact assessment  
1194 method used to convert the inventory data into three risk grades is detailed in section 3.4. The  
1195 results of social risk are covered in Chapter 4. To assess social impact (2), surveys and  
1196 questionnaires were used to gauge employee satisfaction and managerial resource levels,  
1197 which were further evaluated through correlation analysis detailed in section 3.5. The results  
1198 for social impact are covered in Chapter 5.

1199 Data collection methods for the industrial (3) and social (4) acceptance of the newly developed  
1200 STE system are covered in sections 3.6 and 3.7 respectively, and the results for both types  
1201 of acceptance are covered in Chapters 6 and 7, respectively. The development of the dynamic  
1202 model to make future predictions of the newly developed STE system's social impact and  
1203 industrial acceptance (5) is covered in section 3.8, and the results of the future predictions are  
1204 covered in Chapter 8. The assumptions and limitations of this thesis are covered in section  
1205 3.9. Chapter 9 then concludes all findings and provides technological and monetary  
1206 improvement measures.

## 1207 3.2 Goal and Scope

1208

1209 The goal of the S-LCA is to assess the social sustainability of a newly develop STE system  
1210 called Application of Solar Thermal Energy to Industrial Processes (ASTEP) during its  
1211 production and development. The assessment considered social impact data in sections 3.3  
1212 and 3.4 in order to evaluate gaps in social sustainability, enabling improvement measures.  
1213 The ASTEP system is further introduced in section 3.2.1

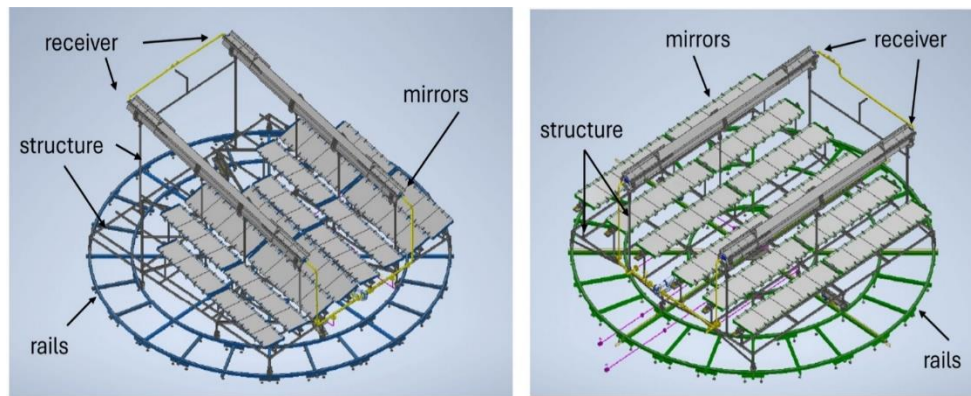
1214

1215

### 3.2.1 The ASTEP System

1216  
1217

1218 The ASTEP is a modular STE system designed to generate thermal energy for medium-  
1219 temperature industrial processes in the range of 150°C-400°C and high temperatures above  
1220 400°C (Montes et al. 2022). The ASTEP system comprises of three main components a)  
1221 Sundial which is constructed from concentrating multi-axis Fresnel collectors, b) PCM Storage  
1222 Tank which intakes excess thermal energy, and c) Electronic Control Unit which manages the  
1223 performance of the entire system. Please see Figure 4 for a visual reference as supplied by  
1224 Barnetche et al. (2025). The ASTEP system is currently being piloted to meet the thermal  
1225 requirements of two industrial end users: a milk production facility in Corinth, Greece,  
1226 codenamed MAND, and a manufacturer of steel tubes in Iasi, Romania, codenamed AMTP.



1227

1228 Figure 4: Full Visual Layout of ASTEP's SunDial Structure Source: Barnetche et al. (2025)

1229

### 3.2.2 S-LCA Boundary Conditions

1230  
1231

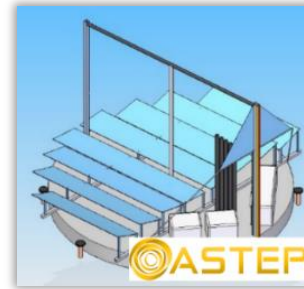
1232 To fulfil the goal of the S-LCA, boundary conditions for the S-LCA of the ASTEP system are  
1233 established, as presented in Figure 5. These boundaries include all stakeholders involved with  
1234 the project activities involved in in the Production and Product Development phases of  
1235 ASTEP's life cycle.

1236 During the Production Phase, the stakeholders tasked with producing ASTEP's three  
1237 components include the following employee occupations; miners, furnace operators, line  
1238 operators, machinists, chemists, lab technicians, and electricians. The associated business  
1239 activities to produce the three components encompass metal fabrication, glass annealing,  
1240 chemical synthesis, and electrical configuration. Social issues addressed during this phase  
1241 include risk to fair payment, working intensity, equal opportunities, employee H&S, and  
1242 employment.

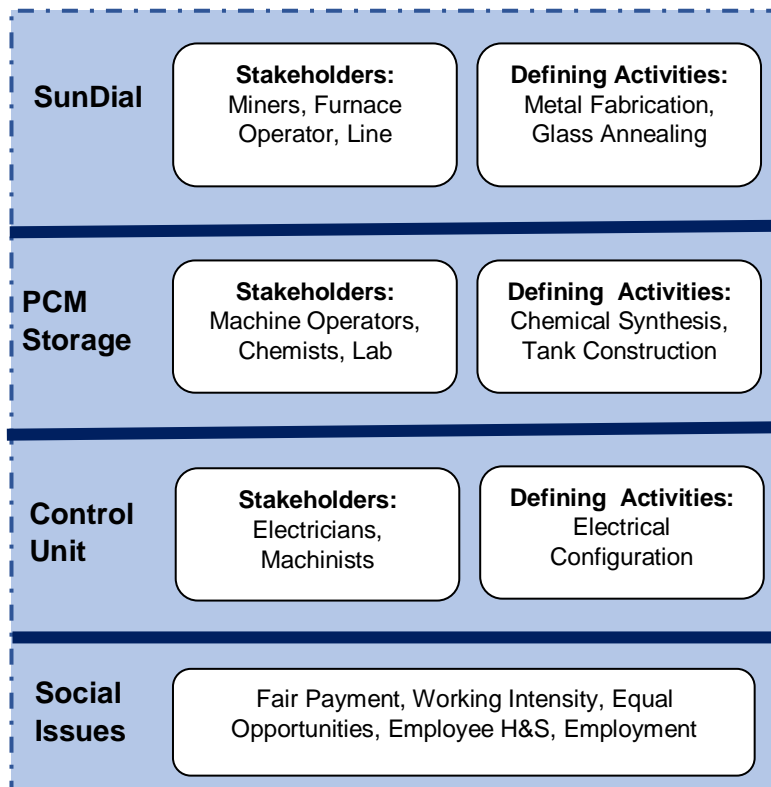
1243    ASTEP’s Product Development phase includes all R&D activities and involves 56 employees  
1244    which is deemed sufficient as supported by both Witte (2008) and Memon et al. (2020). There  
1245    are 5 total occupations: 11 Managers who are leading the development phase and managing  
1246    all human resources during project activities, 11 Engineers responsible for the design of the  
1247    system, 7 Technical staff responsible for laboratory testing, 19 Researchers involved with  
1248    developing the novel STE technology, and 8 consultants tasked with the installation of the  
1249    system. The ASTEP project consists of 11 subdivisions which employ a subset 56 employees,  
1250    where each subdivision is led by one of the 11 managers. The social issues addressed at this  
1251    stage of the assessment include Employee Satisfaction with Training, Professional  
1252    Development, and Working Intensity.

1253    .

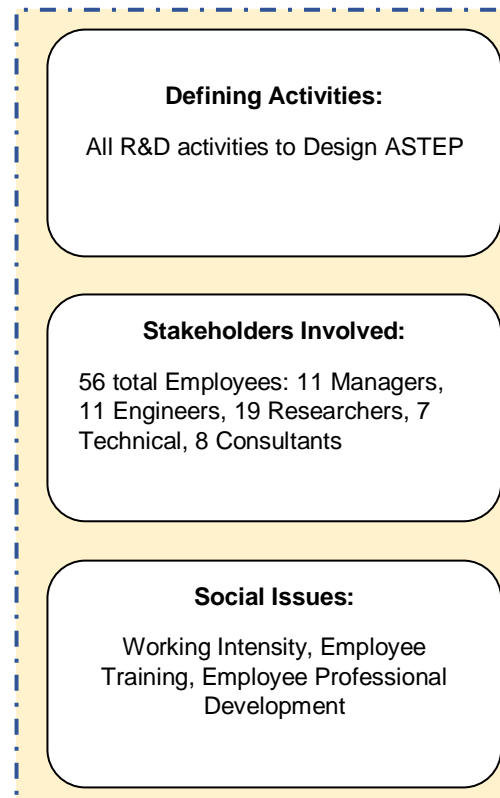
Figure 5: All Social Stakeholders, Life Cycle Phases, Activities, and Social Issues in the S-LCA of ASTEP



Social Stakeholders and Activities for the Production Phase



Social Stakeholders and Activities for the Product Development Phase



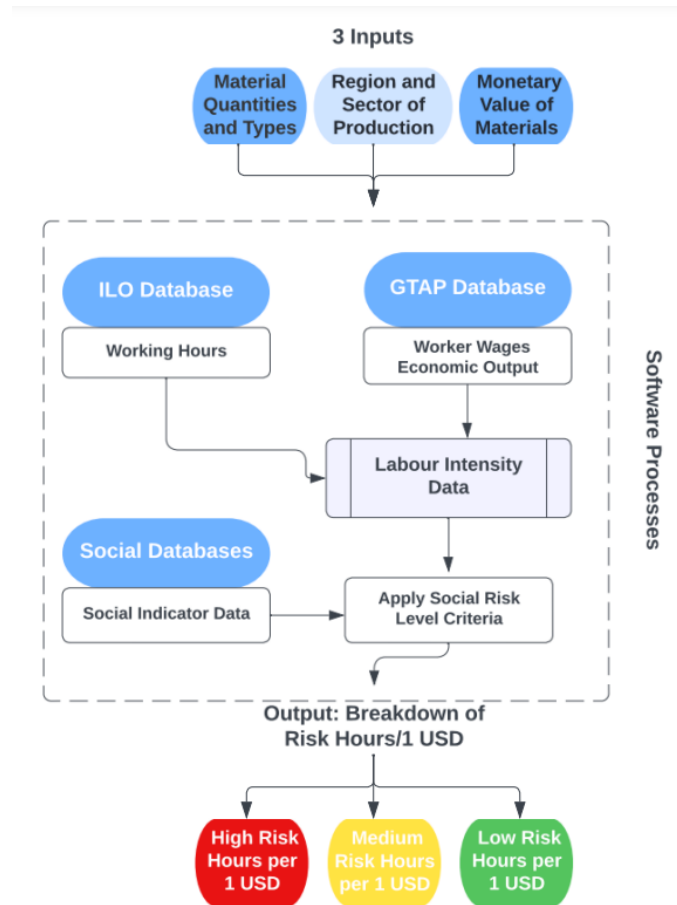
Social Stakeholders and Activities for the Application Phase



1254 **3.3 S-LCA Inventory Analysis**

1255

1256 To perform the inventory analysis of the S-LCA, inventory data was collected by the SimaPro  
 1257 SHDB software following the works of Norris & Norris (2019). This software is an extension of  
 1258 the main SimaPro developed by Pre-Sustainability in Amersfoort, the Netherlands (Benoit et  
 1259 al., 2010). This database was used to simulate social risk on employees involved in the  
 1260 Production Phase of ASTEP using three software inputs (Fig 6).



1261

1262 Figure 6: Map of SHDB Input-Output Model with Input Types, Software Processes, and Risk Grades

1263 The first input shown in Figure 6 comprised of the material quantities and types used for the  
 1264 underlying subcomponents of the three main components of the ASTEP system; a) SunDial,  
 1265 b) PCM Thermal Storage Tank, and c) Control Unit, further explored in Table 1. The material  
 1266 quantities are split for both ASTEP systems for the two system End Users: AMTP and MAND.  
 1267 The second software input provides the economic sector and country of origin where the  
 1268 material types was manufactured. Following that, the monetary value of the material, in United  
 1269 States Dollars (USD), was considered as the third input to the software.

1270

1271 3.3.1 Input Material and Sector Data for both ASTEP Units  
1272

1273 Table 1 presents the input data for both ASTEP systems for the two End Users AMTP and  
1274 MAND. All material data was provided by ASTEP's developers, who recorded the material  
1275 quantities, the total value attributed to the raw material procured, and the country of origin  
1276 used for each subcomponent. The complete materials datasheet is provided in Appendix 1,  
1277 where Appendix 1.1 contains the material data of the SunDial, Appendix 1.2 for the PCM tank,  
1278 and Appendix 1.3 for the Control Unit.

**Table 1:** Material Input Data of all Components for AMTP and MAND Systems

Component	Subcomponent	Material Type	Country of Origin	Economic Sector	AMTP		MAND	
					Material Quantities (kg)	Value (USD)	Material Quantities (kg)	Value (USD)
PCM Tank	Steel Tank	Steel	Spain	Iron & Steel	2000	\$1,040	2000	\$1,040
	Thermal Storage Material	Chemicals	Netherlands	Chemical Products	2200	\$1,497	2200	\$1,497
	Shell Inserts	Aluminium	Poland	Non-Ferrous Metals	2928	\$1,052	2928	\$1,052
SunDial	Concentrator	Steel	Spain	Iron & Steel	1,640	\$860	1,964	\$1,033
	Mirrors	Annealed Glass	Spain	Glass Products	3562	\$90	3562	\$90
	Rotating Platform	Steel	Spain	Iron & Steel	2,500	\$1,310	2,500	\$1,310
	Receiver Tubes	Borosilicate Glass	Spain	Glass Products	233	\$346	233	\$346
	Foundation Base	C30 Cement	Spain	Non-Metallic Minerals	2,410	\$184	2,410	\$184
Control Unit	Unit Board	Steel	Germany	Iron & Steel	255	\$136	169	\$90

Table 1 outlines the material flow of the three main components of ASTEP. Firstly, the PCM Tank comprises three subcomponents: aluminium shell inserts (2,928 kg) from Poland’s non-ferrous metals sector, thermal storage material (2,200 kg, USD 1,497) composed of chemicals from the Netherlands’ chemical products sector; and a steel tank (2,000 kg, USD 1,040) produced by Spain’s iron and steel sector. The second component, the SunDial, includes concentrators which have slightly different material quantities between the two End Users. The SunDial for the MAND system uses 1,964 kg of steel (USD 1,033), while the AMTP system uses 1,640 kg (USD 860), both from the iron and steel sector in Spain. The rotating platform also uses 2,500 kg with a value of USD 1,310 from the Spanish steel sector. Finally, the Control Unit consists of a single unit board using 255 kg (USD 136) for AMTP and 169 kg (USD 90) for MAND of steel from Germany. All market price data were obtained from TradingEconomics (2019).

3.3.2 Social Risk Categories for Data Collection

After the inputs described in section 3.3.1, Table 2 portrays issues that impose social risk to the downstream employee stakeholder group as a result of engaging with production activities. These issues, extracted from the software as per Norris & Norris (2019), are tabulated as impact categories and were measured by impact indicators in Table 2.

**Table 2:** Social Risk Categories and Indicators Source: Norris & Norris (2019)

Social Risk Category	Social Risk Indicators
Employee Fair Payment	Risk of Low Occupational Wage
Excessive Working Hours	Risk of Overtime Work
	Risk to Compliance of Labour Law
Equal Opportunities for Employees	Risk of Low Female Representation in the Workforce
	Risk of Compliance with Anti-Discrimination Policies
Employee H&S	Risk of Non-Fatal Work-Related Injuries
	Risk of Diseases DALYs
	Risk to Compliance of H&S Policy
Local Employment	Risk of Unemployment

The first risk category in Table 2, Employee Fair Payment, measures the risk that the Average Wage (AW) for a given employee is below the living wage as regulated by the regional location of that economic sector. The living wage for an economic sector is represented in the software by the Non-Poverty Guideline (NPL) established in each country as described by Norris & Norris (2019). The next category consists of the risk that employees are working excessively,

measured by the risk that a given employee is made to work overtime. Complimenting this social indicator is another indicator relating to how well labour laws particularly relating to working hours are enforced and implemented within a given economic sector. Following this, the second category in Table 2 is the risk of gender inequality among the employee pool within a given economic sector. This is represented by how low the representation of female employees in the workforce is in an economic sector. To complement this indicator, the risk that non-compliance to Anti-Discrimination policies which enforce gender equality in an economic sector is measured to aid the critical evaluation of its complementary indicator.

The next category, Employee H&S, includes the measurement of risk that specific hazards associated with the working environment have on the health of the employees. This risk to the H&S on the Employee stakeholder group during the manufacturing of all subcomponents in Table 1 is represented by three indicators in the right Column of Table 2: non-fatal and fatal injuries and the risk of disease-related Disability-Adjusted Life Years (DALYs) that an employee may experience working in a given economic sector. The non-fatal and fatal injury indicators are measured per 100,000 workers for a given economic sector. Disability-Adjusted Life Years (DALYs) is an indicator which represents one year lost by an individual due to disease (Norris & Norris, 2019). The fourth indicator is the risk of non-compliance to H&S policy within a given economic sector and will be used to complement the risk levels observed by the three other indicators within the H&S social risk category for evaluation. For the H&S category, all risk levels for each of the four indicators will be averaged out with equal weightings to give the overall risk in this impact category in the results. The last indicator in Table 2 measures the risk of unemployment generated by the economic sector to highlight the social risk to job creation as the result of producing within that economic sector.

### 3.4 S-LCA Impact Assessment

To perform the impact assessment of the S-LCA, the material data from Table 1 was converted into social risk by breaking down working hours per unit USD into three grades of social risk; a) High Risk (HR), b) Medium Risk (MR), and c) Low Risk (LR) as can be seen in Table 3. These grades, known as Risk Hours (RH), represent the portion of working hours that contribute to the presence of social risk under each category in Table 2. The working hours that the portion is taken from are the number of hours needed to produce 1 USD worth of the material type being processed in the simulation. The exact criteria are then applied from the software, as provided by Norris & Norris (2019), to convert each social risk indicator from Column 2 of Table 2 into the risk grades are described in Table 3. The criteria determined the level of risk for each indicator based on the quantified amount that is measured by that indicator in an economic sector. For example, the risk level of Overtime Work is defined by the

percentage of employees in an economic sector that work more than 60 hours per week. The risk level for Low Occupational Wage is represented by the percentage of employees that are being paid below the living wage, i.e NPL>AW. The H&S indicators use DALY per 100,000 employees in that sector.

**Table 3:** Risk Conversion Criteria Source: Norris & Norris (2019)

Social Impact Indicator	Risk Level		
	High	Medium	Low
	<b>Conversion Criteria Based on Measured Amount of Social Indicator</b>		
Risk of Overtime Work	> 15% and <20% work > 49 hours/week	> 10% and < 15% work > 49 hours/week	< 9% work > 49 hours/week
Risk of Low Occupational Wage	NPL>AW by 25-50%	NPL>AW by <25%	NPL<AW
Risk of Fatal Work-Related Injuries per 100,000 Workers	>5	>1	1
Risk of Non-Fatal Work-Related Injuries per 100,000 Workers	>500	>100	< 100
Risk of Average Diseases DALYs	> 50,000	> 40,000	< 40,000
Female Representation in the Workforce	10-20%	20-33%	>33%
Risk of Unemployment	10-15%	5-10%	<5%

The output included variation of risk levels recorded for each social indicator label in Column 2 of Table 2, associated with producing 1 USD worth of each material type from Table 1. The simulation is repeated for each of the three main components. High-risk components were identified and prioritised for analysis in order to identify high risk hotspots in its production. Separate simulations were performed for both ASTEP systems at MAND and AMTP.

### 3.5 Data Collection Methods for ASTEP’s Social Impact

Inventory data of social impact of the ASTEP system was collected through conducting a study involving 56 employees tasked with designing, developing and engineering the STE system. The sample size of employees was deemed sufficient as supported by Witte (2008) and Memon et al. (2020). This sample size includes 11 Managers that are leading and managing all human capital during project activities, each of them in charge of a project subdivision. The other occupations include 11 Engineers responsible for the design of the system, 7 Technical staff responsible for laboratory testing, 19 Researchers involved with developing the novel STE technology, and 8 consultants tasked with the installation of the system at the End User sites.

The study consisted of an online Employee Survey to assess the satisfaction of the 56 employees with three key social issues; employee training, professional development, and working intensity, further elaborated in section 3.5.1. This was conducted using the Microsoft Forms platform, as developed by Microsoft headquartered in Redmond, Washington (Bryman and Bell, 2019). A Likert Scale was deployed as adapted from Bryman and Bell (2019), which grades employee satisfaction from a 'Very Satisfied' to 'Very Unsatisfied' on a 1 to 5, 1 being the 'Very Unsatisfied' and 5 being 'Very Satisfied'. Of the 56 participants who were invited to partake in the Employee survey, **41 responded**. This sample size is deemed sufficient to produce accurate analytical results in accordance with Witte (2008) in their book of statistics, who have identified as 30 participants as the universal minimum needed for a noteworthy study. A blank sample of the Employee Survey is attached in Appendix 2.1. Additionally, the participant information sheet provided to participants as per Ethical Approval in section 3.5.2, containing all information about the survey questions, confidentiality of responses, voluntary nature of the study, is attached in Appendix 2.3.

Additionally, 11 Managers were given an online questionnaire to report on the levels of human resource provisions for the ASTEP project, providing insight into the influencing factors of social impact measured in the Employee Survey. This questionnaire was also developed on Microsoft Forms platform, provided by Microsoft headquartered in Redmond, Washington (Bryman & Bell, 2019). The managers were asked to report on the provision of resources allocated towards employee training, working hours balance and employee professional development within their respective subdivisions, as resented by the indicator labels in Table 2. Out of the 11 subdivision Managers, only **9 responded**. In total, 50 observations were made considering the responses from the previous Employee Survey, therefore data is sufficient as per Witte (2008). A blank sample of the Manager Questionnaire is attached in Appendix 2.4. Additionally, the participant information sheet provided to participants as per Ethical Approval in section 3.5.2, containing all information about the survey questions, confidentiality of responses, voluntary nature of the study, is attached in Appendix 2.6.

### 3.5.1 Social Impact Categories

To categorise the inventory data, the assignment of topics considered in the Employee Survey and Management Questionnaire was done with respective indicator labels and impact categories as shown in Table 4.

**Table 4:** Indicators Assigned to Social Impact Categories

<b>Social Impact Categories</b>	<b>Indicator Labels</b>
<b>Training</b>	Employee Satisfaction with Training (TS)
	Provision of Training Opportunities (PT)
	Engagement with R&D Activities (EE)
<b>Working Intensity</b>	Employee Satisfaction on Working Hours (WI)
	Allocation of Tasks (AT)
	Weekly Hours Allocated for Tasks (TA)
<b>Professional Development</b>	Employee Satisfaction on Professional Development (PD)
	Provision of Professional Development Opportunities (PPD)

Table 4 presents the Employee Training Category in the first entry of column 1, which is the participants' perception of how satisfied they feel about their training for carrying out their project work assignments. For this impact category, the Manager Questionnaire reported on the provision levels of two types of resources. The first type of resource is the Provision of Training (PT) indicator which includes the provision of educational topics to ASTEP employees specifically focused on the development of novel STE systems. The second type of resource is the Engagement with R&D (EE) which is the level of engagement of employees with publishing research findings, scientific laboratory work, and conducting field research. It is expected that the HRM provisions of EE and PT are correlated with TS.

The next entry in Table 4 is the Working Intensity category, which is comprised of questions on the Employee Survey that measure the satisfaction of participants towards their working schedule and how well their tasks have been distributed as reported by the Management Questionnaire. For this impact category, the associated managerial practices and responsibilities of each ASTEP subdivision is fair Allocation of ASTEP Tasks (AT) to each employee working under them and Weekly Time in Hours Allocated to allow each of those employees to complete their ASTEP Tasks (TA).

Next, the Employee Professional Development (PD) impact category intakes participant satisfaction on the relevance of their project work assignments to their desired career paths. This satisfaction portrays whether employees feel that working on ASTEP is actively contributing towards the development of the skillsets needed for future opportunities. This assessment was complemented by the HRM practice of providing of career support to the participants as reported in the Manager Questionnaire, which forms the Provision of Professional Development Opportunities (PPD) indicator label. PD is also expected to be

correlated with EE, given the career paths in academia and R&D pursued by a number of ASTEP employees.

### 3.5.2 Ethical approval

Ethical Approval (EA) for the Employee Survey and Management Questionnaire was granted by BREO, Brunel University London. The reference no. is 7581-LR-Aug/2022- 41337-2. The letter of ethical approval is attached in Appendix 4.1.

### 3.5.3 Scoring Criteria for Social Impact

The positivity or negativity of measured social impact data from the Employee Survey in section 3.5 was measured using a scoring scale adopted from the UNEP-SETAC guidelines (2020), which utilised a Type 1 reference scale grading social impact from -2 to +2 as represented in Table 5. This process converts the measured social impact in each category in Table 4 into impact points, directly magnifying stakeholder satisfaction. To elaborate, a neutral criteria was set as per the UNEP-SETAC guidelines (2020), which in the case for the ASTEP study is the middle number on the Likert scale spectrum; 3. According to that criteria, deviations in social impact as signified positive or negative employee satisfaction were graded as +2 to -2 depending on whether the score was above or below 5, as tabulated in Table 5:

**Table 5:** Scoring Criteria for all Survey Likert Questions Source: UNEP-SETAC (2020)

Recorded Survey Response				
Very Unsatisfied	Unsatisfied	Somewhat Satisfied	Satisfied	Very Satisfied
Reference Score for Response				
1	2	3	4	5
Converted Impact Points				
- 2	- 1	- 0.5	+ 1	+ 2

Table 5 shows that the survey score to impact point conversion has a key adjustment at the "Somewhat Satisfied" response. Hair et al. (2021) explained that the midpoint of the Likert with the phrase 'Somewhat Satisfied' implies a slightly dissatisfactory response from the participant, making a negative score a more accurate representation of the participant's perception. Bryman and Bell (2019) support that this practice is common across social

studies involving participant surveys to gain more accurate results of social impact. Hence, the converted points for this response is -0.5. The end results transcribed the project's social impact for each category addressed in the Employee Survey. Thereafter, the next step this was to perform a regression analysis.

### 3.5.4 Multi-Variable Regression Models

This section examines the factors influencing adverse social impacts on ASTEP employees by intaking the social impact data from Section 3.5.1 and correlating it with resource levels for training, professional development, and workload distribution. The analysis applies Multi-Variable Regression Modelling, adapted from Hair et al. (2021), to social impact data with resource levels. These models were available on Statistical Package for the Social Sciences (SPSS) (IBM, New York, US) (Hair et al. 2021). The first step in using these models is to formulate hypotheses that predict the expected influence of two independent variables (IV) on a dependent variable (DV). The two IV's in this case are the resource provision levels recorded in the Management Questionnaire as found within Column 2 of Table 2 pertaining to each social impact category. The DV in this case would be the satisfaction indicator pertaining to each social impact category. The three hypotheses for each social impact category are generated as follows.

H1. HRM practices related to the provision of STE-specific training topics (PT) and engaging ASTEP employees with R&D activities (EE) are correlated with the perceived training satisfaction of employees engaged with ASTEP's development (TS).

H2. HRM practices related to work package allocation (AT) and fair distribution of weekly working hours for completion of ASTEP work packages (TA) are correlated with ASTEP employees' perceived satisfaction on working intensity (WI).

H3. HRM practices related to provision of professional development opportunities (PPD) and engaging ASTEP employees with R&D activities (EE) are correlated with ASTEP employees' perceived satisfaction on working intensity (WI).

These three hypotheses H1-H3 were used to produce the numerical structure of the regression models. These models correlated the dependent variable (DV) with the two independent variables (IV) measured, which is shown for the Employee Training impact category in Equation 1 considering H1:

$$TS = c_0 + b_1 \cdot PT + b_2 EE \quad (\text{Eqn 1})$$

Where:

*TS*: The DV of the model, which is directly affected by the IV's

$c_0$ : The y-intercept of the model which has a constant value

$PT, EE$ : The respective IV's measured in the study

$b_1, b_2$ : The Correlation coefficients of their respective IV's on TS.

$e_{JS}$ : The residual error term, which is included to take into account the unexplained variance in TS.

The regression model in Equation 1 is an input function in SPSS and therefore is handled by the SPSS software after the input and label mapping of all data in the software's spreadsheets. The software automatically handles the process of calculating the correlation coefficients  $b_1, b_2$  and constant  $c_0$  to explain how much of the variance of TS is affected by EE and PT, as well as the remaining residual  $e_{JS}$  which accounts for the rest of the unexplained variance in TS.

To continue, Working Intensity impact category has DV of WI and two IV's; AT and TA. In this case, numerical model following H2 is presented in Equation 2:

$$WI = c_2 + b_3 \cdot AT + b_4 \cdot TA + e_{WI} \quad (\text{Eqn 2})$$

Where:

$WI$ : The DV of the model, which is directly affected by the IV's

$c_1$ : The y-intercept of the model which has a constant value

$AT, TA$ : The respective IV's measured in the study

$b_3, b_4$ : The Correlation coefficients of their respective IV's on WI.

$e_{WI}$ : The residual error term to take into account the unexplained variance in WI.

In similar fashion to Equation 1, the regression model in Equation 2 was handled by SPSS to calculate the correlation coefficients  $b_3, b_4$  and constant  $c_1$  to explain how much of the variance of WI is affected by AT and TA, as well as the remaining residual  $e_{WI}$  which accounts for the rest of the unexplained variance in WI.

Finally, the Employee Professional Development Category contains DV of PD and IV's of PPD and EE. The numerical model following H3 is presented in Equation 3:

$$PD = c_1 + b_3 \cdot PPD + b_4 EE + e_{PD} \quad (\text{Eqn 3})$$

Where:

$PD$ : The DV of the model, which is directly affected by the IV's

$c_1$ : The y-intercept of the model which has a constant value

$PPD, EE$ : The respective IV's measured in the study

$b_3, b_4$ : The Correlation coefficients of their respective IV's on PD.

$e_{PD}$ : The residual error term to take into account the unexplained variance in PD.

The strength of interdependency between the DV and each IV in each model in Eqns 1-3 was measured using Spearman's Rho coefficient ( $\rho$ ). The criteria to for this coefficient are provided below in Table 6, as adapted from the works of Leclezio et al. (2015).

**Table 6:** Criteria of Spearman's Rho Coefficient ( $\rho$ ) (Leclezio et al. 2015)

Observed Value of $\rho$	Strength of Correlations
0.2 – 0.29	Weak
0.3 – 0.39	Moderate
0.4 – 0.69	Strong
0.7 – 0.89	Very Strong
<0.9	Almost Perfect

Table 6 presents the descriptive level of strength that was associated with a range of  $\rho$  values, showing that the strength of correlation increases as the observed  $\rho$  approaches 1. On another note, a positive value of  $\rho$  indicates a positive correlation between the two variables, meaning that as the IV increases, the DV tends to increase as well. A negative value of  $\rho$  indicates vice versa.

### 3.5.5 Validation of Multi-Regression Analysis Using Chi-square Method

The validation of the data in section 3.5.4 was conducted using a test which verifies the strength of interdependency, known as the Chi-Square method as available on SPSS (IBM, New York, US) (Hair et al. 2021). This test was conducted at a 95% confidence level, denoted by a significance level of 0.05 as described by Hair et al. (2021). Being within the 95% interval means that the results are statistically significant at the 0.05 level, indicating a 5% chance that the observed relationship occurred by random chance. Hence, all coefficients from the correlation analysis were considered significant if they fall within the 95% confidence interval, i.e if the observed p-value associated with each correlation coefficient was  $p < 0.05$  as recommended by Hair et al. (2021). This evaluation suggested that the relationship between the variables represented genuine association and not by random chance.

### 3.5.6 Qualitative Analysis

NVivo software (Burlington, Massachusetts) (Bryman and Bell, 2019), was used to analyse employee comments from the Employee Survey as outlined in section 3.5. Such analysis was conducted against generational trees, which sets dialogue for positive or negative feedback under the three categories from Table 2. The generational trees assign the DV from each impact category as a parent node, and branches out into child nodes. These child nodes are then assigned to a qualitative employee comments as shown in Table 7.

Table 7: Generational Tree for Qualitative Analysis

Parent Node	Child Node	Positive Feedback	Negative Feedback
TS	Access to Training	"I have many opportunities for training."	"There is a lack of available training sessions."
	Relevance of Training	"The training is highly relevant to my job."	"The training does not apply to my role."
PD	Career Advancement Opportunities	"I see potential for growth in my role."	"There are limited opportunities for promotion."
	Skill Development	"I am gaining new skills relevant to my career."	"I don't feel I am developing any new skills."
WI	Workload Balance	"My workload is manageable."	"I feel overwhelmed by my workload."
	Work-Life Balance	"I am able to maintain a healthy work-life balance."	"Work demands often interfere with my personal life."

Table 7 incorporated the three impact categories as 'Parent Nodes' in the Nvivo software, acting as the main heading where the qualitative feedback fits into. The software then organised the Parent Nodes into 'Child Nodes,' representing specific social issues relevant to ASTEP employees under the three main satisfaction categories. General qualitative dialogue was then generated under each Child Node to code what was defined as positive or negative feedback. Comments from the employee survey were then matched with positive or negative criteria to support whether positive or negative social impact was observed under the main satisfaction heading for each of the three impact categories. The frequency of observing positive or negative feedback under each child node was then noted to support which direction satisfaction tended towards considering the perspectives of all participants.

### 3.6 Data Collection Methods for Assessing ASTEP's Industrial Acceptance

To assess the industrial acceptance of ASTEP, **N=318** industries who are keen in purchasing and implementing ASTEP were recruited for an industrial survey following the methods of Kumar et al. (2022). The survey was developed using Qualtrics XM platform (Qualtrics, Seattle, USA) (Miller et al. 2020). The industries includes Non-SPIRE who operate at low to medium temperatures in the range of 150–400°C, originating from food and beverage, textiles, and water treatment industries, as well as SPIRE industries operating at high temperatures exceeding 400°C, which include automotive, aerospace, chemical processing, non-metallic minerals, and metallic industries. The industries were distributed across 15 regions as follows: the UK (22), Germany (22), France (20), Spain (21), Sweden (22), Greece (22), Romania (22), Austria (21), Poland (22), the Czech Republic (22), the US (21), Canada (21), India (19), China (20), and Australia (21). These targeted industries encompass company sizes defined by employee count: micro companies have less than 10 employees, small companies have 10–49 employees, medium-sized companies have 50–249 employees, and large companies have 250 employees or more (OECD, 2021). The representative in the industry be being surveyed may hold any of the four positions: managing directors, project managers, technical leads, and HR. Out of the 318 participants invited to the survey, all had responded, which is sufficient for a meaningful study as per Memon et al. (2020). A copy of the industrial acceptance survey is attached in Appendix 3.1. Additionally, the participant information sheet provided to participants as per Ethical Approval in section 3.6.1, containing all information about the survey questions, confidentiality of responses, voluntary nature of the study, is attached in Appendix 3.3.

The four categories that were assessed in this study included current energy use and perception on ASTEP's technical compatibility with processes, costs, and impact on standards, as tabulated in Table 8.

**Table 8:** Industrial Acceptance Categories and Indicators

Industrial Acceptance Categories	Industrial Acceptance Indicators
Current Energy Usage and Standards	Current energy sources
	Current process types and temperature ranges
	Current Standards environmental and energy
ASTEP's Technical Compatibility (TC)	Perceived compatibility of ASTEP's operating temperature for processes
	Perceived adequacy of ASTEP's thermal output
ASTEP's Costs (AC)	Perception investment of ASTEP's upfront costs
	Perception of ASTEP's cost savings
ASTEP's Impact on Standards (IS)	Perception of ASTEP's impact on compliance with environmental standards
	Perception of ASTEP's impact on compliance with energy standards

Table 8 shows the four categories which industrial acceptance of ASTEP is assessed under. The first category; Current Energy Usage and Standards includes three underlying indicators. The first indicator, current energy sources, gauges whether industries use conventional fuel, electricity, and renewable energy systems, such as solar and wind, to supply energy for their processes. The second indicator assesses the industry's in-house current process types and operating temperature ranges. The third indicator, current environmental and energy standards, gauges whether industries have implemented ISO14001 and ISO50001 standards to reduce emissions and improve energy efficiency. The second category in Table 8, Acceptance of ASTEP's Technical Compatibility, consists of two underlying indicators. The first indicator assesses industries' perceived compatibility of ASTEP's operating temperature with current in-house thermal processes, which gauges if ASTEP's temperature range matches specific requirements of the industry's processes. The second indicator measures industries' perceived adequacy of ASTEP's thermal output, gauging whether ASTEP's thermal output meets their operational needs. Thirdly, the Acceptance of ASTEP's Costs category consists of two underlying indicators. The first indicator gauges industries' perception of ASTEP's upfront

investment, assessing their views on initial capital costs associated with ASTEP's implementation. The second indicator examines industries' perception of ASTEP's cost savings regarding potential financial benefits derived from reduced operational and energy costs if they were to implement it. Lastly, the Acceptance of ASTEP's Impact on Standards category includes two underlying indicators. The first indicator assesses industries' perception of ASTEP's impact on their compliance with environmental standards; ISO14001. The second indicator industries' perception of ASTEP's impact on their compliance with energy standards; ISO50001.

The survey was distributed to N=318 industries to collect data in the acceptance categories and measurable indicators outlined in Table 2. Out of the 318 participants invited to the survey, all had responded, which is sufficient for a meaningful study as per Memon et al. (2020). Blank copies of the survey are attached in Appendix 3.2.

### 3.6.1 Ethical Approval (EA)

EA for the Industrial Acceptance Survey was granted by BREO, Brunel University London. The reference no. is 44195-LR-Feb/2024- 49809-3. The letter of ethical approval is attached in Appendix 4.2.

## 3.7 Data Collection Methods for Social Acceptance

To assess the social acceptance of ASTEP, **N=279 members** from a targeted segment of the global general public were recruited for an online social acceptance survey following the methods of Elmustapha et al. (2018). The recruitment of the study targeted a segment of the public consisting primarily of well-educated young and middle-aged adults above the age of 18, drawn from academic and professional environments such as universities, research institutes, and engineering firms across the following regions: the UK, Spain, France, Greece, Germany, Poland, Austria, USA, Canada, and Argentina. While this sampling approach enabled the collection of informed public perspectives on STE systems, it may be exposed to a degree of selection bias, as the sample is more likely to be knowledgeable and receptive towards sustainable technologies in particular regions compared to the broader global public.

The sample size of n=279 participants is sufficient to capture the perceptions of this segment from the general public following the guidelines of previous S-LCA practitioners [Jung et al. (2016), Devine-Wright (2021)]. However, the perceptions of this segment is appropriate to the context of this demographic scope only, as opposed to being fully representative of the general population.

The survey was hosted on Microsoft (MS) Forms (Microsoft, Redmond Washington) (Bryman and Bell, 2019). A survey link was distributed through social media channels and shared at communal networking events. A total of 279 participants responded, which is sufficient enough for a noteworthy study as per Memon et al. (2020). A blank copy of the social acceptance survey is attached in Appendix 3.4. Additionally, the participant information sheet provided to participants as per Ethical Approval in section 3.6.1, containing all information about the survey questions, confidentiality of responses, voluntary nature of the study, is attached in Appendix 3.6.

Four acceptance categories were assessed in this study, each with two attached associated indicators affecting the general public stakeholders from the targeted segment, were formulated in Table 9.

**Table 9:** Social Acceptance Categories and Indicators

<b>Social Acceptance Category</b>	<b>Social Acceptance Indicators</b>
ASTEPA’s Environmental Benefits	Agreement with developing ASTEP to reduce carbon emissions
	Agreement with ASTEP’s contribution to clean air in the community
Applying ASTEP in Industrial Processes	Awareness of STE technologies similar to ASTEP being applied to industries
	Agreement with ASTEP’s integration into industrial processes
Products Manufactured using ASTEP	Agreement with consuming products manufactured using ASTEP
	Agreement with shifting purchasing habits for products manufactured using ASTEP
Government Support for STE Systems Similar to ASTEP	Agreement with education programmes about STE systems and similar to ASTEP
	Agreement with continual investment for STE systems similar to ASTEP

The first social acceptance category in Table 9, ASTEP’s Environmental Benefits, includes

two indicators. The first indicator measures the level of public agreement with the development of the ASTEP technology as a means to reduce carbon emissions from industrial processes. The second indicator assesses public agreement with the role of ASTEP in contributing to cleaner air within local communities by reducing industrial air pollution. The second category in Table 9, Applying ASTEP in Industrial Processes, is measured by two indicators. The first indicator assesses public awareness of specific industries, such as food, textile, ceramics, or chemicals, that currently use STE systems similar to ASTEP. The second indicator measures public agreement with integrating the ASTEP system into industrial processes as a sustainable energy solution to reducing carbon emissions. The third category in Table 9, Products Manufactured using ASTEP, includes two indicators. The first indicator captures the current public agreement with consuming products produced by supply chains that have adopted the ASTEP system and operate using its clean energy. The second indicator measures agreement with shifting future purchasing habits towards products manufactured using ASTEP, building upon the first indicator by assessing the consumer's intent to actively prioritise them in future buying decisions rather than just acceptance. The final category in Table 9, Government Support for STE Systems Similar to ASTEP, contains two indicators. The first indicator captures public agreement with adopting government-led awareness campaigns and initiatives that educate the general public about the environmental benefits of STE systems similar to ASTEP. The second indicator gauges agreement with government funding, subsidies, and policy support for STE systems similar to ASTEP should be continued and further expanded going into the future.

### 3.7.1 Ethical Approval

EA for the Social Acceptance Survey was granted by BREO, Brunel University London. The reference no. is 44195-LR-Feb/2024- 49809-3

## 3.8 Development of a New Dynamic Model to Make Future Predictions

This section introduces a new dynamic model developed to generate future predictions over a 10-year time frame for social impact, intaking data from section 3.5, and industrial acceptance, intaking the data from section 3.6. To establish the foundational framework for developing this new model, the Ordinal Logistic Regression (OLR) approach was adapted from the works of Poston et al. (2023). This approach initially incorporates industrial acceptance data in its current state collected for each category in Table 2, which is categorised on a five-point scale ranging from 1 to 5. The static case using this scale is expressed in a logit form as per Poston et al. (2023), which is the transformation of a range of outputs into a cumulative probability function as shown in Equation 1:

$$\text{logit}(P(Y \leq j)) = \alpha_j + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_N X_N \quad (\text{Eqn 4}) \quad \text{Source: Poston et al. (2023)}$$

Where:

$Y$ : The ordinal response

$j$ : A ceiling threshold on the ordinal scale which can be set to calculate the cumulative probability

$P(Y \leq j)$ : The cumulative probability of an observed response falling into  $j$

$\alpha_j$ : The y-intercept at a given value of  $j$ . Note, each ordinal rank  $j$  has a different y-intercept.

$X_1, X_2, X_N$ : The predictor variables of  $Y$

$\beta_1, \beta_2, \beta_N$ : The correlation coefficients associated with each predictor variable

According to Poston et al. (2023), the logit function represented in Equation 4 must be transformed into a natural logarithm, as shown in Equation 5:

$$\ln\left(\frac{P(Y \leq j)}{1 - P(Y \leq j)}\right) = \alpha_j + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_N X_N \quad (\text{Eqn 5}) \quad \text{Source: Poston et al. (2023)}$$

Next, the probability parameter  $P(Y \leq j)$  must be isolated to demonstrate the model in its numerical format. This is by simplifying and rearranging Equation 5, leading to Equation 6:

$$P(Y \leq j) = \frac{1}{1 + e^{-(\alpha_j + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_N X_N)}} \quad (\text{Eqn 6})$$

It is important to note that in a cumulative probability function, all probabilities of scoring ranks of  $j$  or below are calculative and summed up. To calculate the probability of scoring an individual rank of exactly  $j$ ; i.e  $P(Y = j)$ , the following formulation can be used to isolate that single probability as provided by Poston et al. (2023):

$$P(Y = j) = P(Y \leq j) - P(Y \leq j - 1) \quad (\text{Eqn 7}) \quad \text{Source: Poston et al. (2023)}$$

Equation 6 is then further developed upon in this thesis over a temporal domain to dynamically predict both social impact and industrial acceptance outcomes resulting from progressive investments over time. To perform this transformation into the temporal domain, the predictor variable  $X_N$  in Equation 6 is defined as a function of incremental monetary investments and unit time, as demonstrated in Equation 8:

$$X_N = mt \quad (\text{Eqn 8})$$

Where:

$m$ : The incremental investment in thousands of Euros (€) per unit time

$t$ : Time in years

With the predictor variable defined, the next step is to integrate the three social impact categories affecting ASTEP's employees from Table 8; TS, PD, and WI; and three industrial acceptance categories from Table 9; TC, AC, and IS, into this model. An adaption of the first category, TS, is demonstrated in Eqn 9, where the dynamic relationship between TS and its  $X_N$  predictor variables: overtime investment in PT and EE, is represented as such:

$$P(TS \leq j) = \frac{1}{1+e^{-(\alpha_j+b_1*PT(t)+b_2*EE(t))}} \quad (\text{Eqn 9})$$

This model presents the probability of observing a score  $P(TS \leq j)$  in the range of 1-5 in the TS impact category given its predictor variables. This delineates that the probability of observing higher TS directly reflects higher investment amounts in PT and EE. It is important to note that the correlation between the predictor variable and the outcome TS is signified by the coefficients which were extracted from the multi-variate model in Eqn 1;  $b_1$ , and  $b_2$ . This adaption can be advanced for the PD and WI social impact categories from Table 4, shown in Eqns 10 and 11:

$$P(PD \leq j) = \frac{1}{1+e^{-(\alpha_j+b_3*PPD(t)+b_4*EE(t))}} \quad (\text{Eqn 10})$$

$$P(WI \leq j) = \frac{1}{1+e^{-(\alpha_j+b_5*AT(t)+b_6*TA(t))}} \quad (\text{Eqn 11})$$

For predicting future industrial acceptance,  $m$  is a variable which influences the industrial acceptance levels, and  $Y$  is hence the industrial acceptance level within the three acceptance categories listed in Table 9, and  $P(Y \leq j)$  is the cumulative probability of observing industrial acceptance within an ordinal rank less than or equal to  $j$ , which is a number between 1-5. To apply Equation 6 to the ASTEP study, the investment variable  $m$  is incrementally increased by 5% per unit time, where each unit time represents one year. This indicates that the investment is compounded annually, meaning the amount invested each year increases by 5% over the previous year's value. The three acceptance categories from Table 9 are then correlated with their influencing investments variables and simulated per unit time depending on the incremental increase in investment, as provided by Chayjan et al. (2021) and Alipour et al. (2019). The first category, Acceptance of ASTEP's Technical Compatibility (TC), is dynamically correlated with its two associated influencing investments: Thermal Enhancement (TE), which is annual investment (€) to increase ASTEP's thermal capabilities through higher operating temperatures and power output, and System Optimisation (SO), which is annual investment

(€) into supplementary components such as high-absorption surface coatings, advanced thermal insulation, anti-soiling systems, and hybrid photovoltaic integration to improve overall system efficiency. The second category, AC has two associated influencing investments; Cost Subsidy (CS), which is annual investment (€) in supporting the reduction of upfront ASTEP implementation costs, and Loan Support (LS), which provision which is annual investment (€) in providing low-interest loans and financing options to support ASTEP adoption into industries. These dynamic relationships are illustrated in Equations 12-13 as follows:

$$P(TC \leq j) = \frac{1}{1+e^{-(\alpha_j+b_7*TE(t)+b_8*SO(t))}} \quad (\text{Eqn 12})$$

$$P(AC \leq j) = \frac{1}{1+e^{-(\alpha_j+b_9*CS(t)+b_{10}*LS(t))}} \quad (\text{Eqn 13})$$

Equation 12 presents the probability of observing a score  $P(Y \leq j)$  in the range of 1-5 within each of the three categories. This means that the probability of attaining higher TC scores over time is directly influenced by an incremental increase of 5% in investments in TE and SO. Given this relationship, the probability of achieving a high acceptance score at any given time can be computed for any industrial demographic, such as for industry type or company size (large, medium, small, or micro), by combining the probability of achieving the two highest scores of TC = 4 and TC = 5.

The models for future industrial acceptance require correlation coefficients  $b_7 - b_{10}$  between observed acceptance and influencing factors to be defined. These correlation coefficients are extracted from the literature as follows in Table 10.

**Table 10:** Coefficients Between Industrial Acceptance and Influencing Investments

Coefficient Pathway	Extracted Coefficient	Reference
TC → TE	$b_7 = 0.72$	Atchike et al. (2022)
TC → SO	$b_8 = 0.66$	Asante et al. (2021)
AC → CS	$b_9 = 0.68$	Ali et al. (2022)
AC → LS	$b_{10} = 0.45$	Ali et al. (2022)

Table 10 shows the quantified impact of each influencing investment variable on the three industrial acceptance categories as provided by the literature. A coefficient of  $b_7 = 0.72$  for investment into TE indicates its strong influencing on industrial acceptance of STE's technical compatibility TC, confirmed to be statistically significant with a p value of less than 0.05. A similarly strong influence was seen in the literature between TC and SO ( $b_8 = 0.66$ ,  $p < 0.05$ ), confirming that efficiency optimisation of STE systems through adding supplementary components influence industrial acceptance in TC. For AC, CS in the form of investments for

cost subsidies exerts a strong influence ( $b_9 = 0.68$ ,  $p < 0.05$ ) on perceived financial viability, with LS in the form of investment in loan support produces a moderate influence ( $b_{10} = 0.45$ ,  $p < 0.05$ ). These coefficients quantify the influence of annual investment levels on industrial acceptance when plugged back into Equations 12 and 13.

### 3.8.1. Selection and Justification for the Temporal Domain

The timeframe  $t$  for the ASTEP study was selected to be **10 years**, meaning the start year of the analysis was selected to be 2025, and the end year was 2035. This selection suits well with predicting future social impact on employees as justified by Louie and Pearce (2016), who, in their longitudinal study, demonstrated that investments in employee training and professional development successfully enhanced employee skills and increase engineering expertise within a 10-year horizon. Ao et al. (2022) reinforced this perspective by noting that the effectiveness of training-related investments are maximised at 10-year mark, after which diminishing marginal returns are then experienced. They further highlighted that predictions beyond 10 years lose accuracy due to saturation of employee skills, evolving labour market demands driven by technological advancements, and natural employee turnover.

Further justification for this 10 year timeframe is supported by Chayjan et al. (2021), who demonstrated that incremental investments in STE technologies and financial support mechanisms generate substantial returns for the industry within a decade, particularly in improving industrial perception of STE's technical compatibility and upfront costs. Ali et al. (2022) further supported this by noting that a 10-year period is sufficient for industries to attain the full benefits of investments into lowering installation costs of STE systems. Additionally, Alipour et al. (2019) observed that industrial acceptance rates stabilise at the 10-year point, after which further investments yield diminishing marginal returns. This is experienced when a single STE system has been fully deployed in an industry. After this, predictive accuracy will decline due to shifting market competition for newer STE technologies and evolving industrial preferences.

### 3.8.2 Coding of Future Predictions

Future predictions in section 3.8 were derived using coding techniques, with the complete coding schedule presented in Appendix 5. The coding was performed on Python using the Anaconda software provided by Anaconda based in Houston, US (Anaconda 2012). The software contained the '*mord*' library which was imported using the command from '*mord import LogisticIT*'. This loaded the ordinal logistic regression function into the Python coding script, which corresponds to the logit structure specified in Equation 4. The model object was

initialised with the command `model = LogisticIT()`, establishing the proportional odds logistic regression function.

All survey datasets for employees and industrial acceptance survey were imported using the pandas library used for the creation of structured data frames. This was performed with `import pandas as pd` and the corresponding dataset was loaded using `pd.read_csv()`. The dependent outcome variable  $y$  and the predictor matrix  $X$  were then extracted into the model. To ensure compatibility with the regression algorithm, the predictor matrix  $X$  was formatted as a two-dimensional NumPy array using `import numpy` as np followed by `np.array()`. Similarly, the outcome variable  $y$  was explicitly cast to ordinal integers using the command `.astype(int)`.

The five ordinal logistic regression models from Equations 9–13 were then mapped into the Python script using the command `model.fit(X, y)`, where  $X$  represented the predictor variables; PT, EE, AT, PPD, TE, SO, CS, LS and  $y$  denoted the corresponding ordinal outcomes measured on the 1–5 Likert scale for the dependent categories; TS, WI, PD, TC, and AC. Each model was instantiated separately using the `LogisticIT()` function, with the detected influencing correlation coefficients incorporated to capture the strength of relationships between predictors and outcomes.

Python was then used to assess model validity, done through using chi-square tests for significance at the 95% confidence level, which determines statistical significance at  $p < 0.05$ . This was done by loading the `statsmodels library`. The chi-square statistic was then calculated and the p-value was obtained using `scipy.stats.chi2.sf`. To simulate ten-year forecasts, predictor variables were incremented by +5% annually using NumPy commands; `X = X * 1.05` in iterative loops.

The predicted probability distributions were visualised using the matplotlib library, imported with `import matplotlib.pyplot as plt`. Figures 27 to 33 were generated by plotting the model output across the ten-year horizon using `plt.plot()`, with axis labels and legends applied through `plt.xlabel()`, `plt.ylabel()`, and `plt.legend()`. To present the final results, outputs were exported as CSV files using `df.to_csv()`.

### 3.9 Assumptions and Limitations

The four assumptions of this thesis are:

1. The social impact of downstream stakeholders was represented by regional social risk levels based solely on the geographical location of material manufacturers, as provided by the SHDB software. This assumes social risk profiles of the geographical sector are sufficient to calculate the social impact experienced by stakeholders within those

supply chains without considering site level data. Manager-reported HRM practices were assumed to directly reflect all resource allocations affecting employee well-being and performance across the ASTEP project. Thus, all managerial responses accurately captured the design and real-life implementation of organisational practices to support employee training, workload management, and professional development.

2. Public and industrial stakeholders' self-reported acceptance of ASTEP was assumed to accurately predict their real-world adoption behaviour once the system is made available on the market. All reported preferences and attitudes captured through survey responses are indicative of likely decision-making by consumers and industrial buyers in practice, thus showing the potential market uptake of ASTEP. Correlation coefficients between annual investments and future outcomes were fixed while conducting future predictions over 10 years, excluding external influences such as organisational changes, market dynamics, or policy shifts. This assumes that the relationships observed between investment variables and social impact and industrial acceptance outcomes remain stable over time, with probability transitions between different outcome states governed solely by these fixed relationships. This simplified the dynamic modelling and enabled linear temporal extrapolation of observed trends into future scenarios over the decade.

The five limitations of this thesis are:

1. The SHDB software used in the S-LCA was limited to certain second-hand data collection mediums which relied on company disclosure reports, and national/governmental databases, restricting first-hand data originating from employee surveys, interviews, and audits.. Hence, the analysis relies on aggregated country- and sector-level datasets, which may not fully capture site-specific variations in organisational practices, regulatory enforcement, or actual working conditions. This limitation may lead to discrepancies between estimated and actual social risk levels experienced by individual stakeholders at site level. However, the use of SHDB remains appropriate for identifying patterns of social risk different economic sectors for different geographical locations for material production experienced by broader groups of stakeholders, providing a robust and systematic framework for comparing social risk profiles across production regions.
2. Data for social impact on employees was confined to training, working intensity, and professional development categories due to ethical and practical constraints, preventing the inclusion of other sensitive and important issues such as wages and fair payment. This restriction limits the comprehensiveness of the employee social impact

assessment, as financial and contractual factors are recognised as key determinants of employee well-being and imposing social impact. Consequently, the analysis may not fully capture all dimensions of employee-related social impact within the ASTEP system. However, the selected categories still represent critical aspects of workplace experience and are directly influenced by managerial practices, enabling a detailed and informative evaluation of the influencing factors that employee satisfaction and thus social impact within the context of the case study.

3. Industrial & social acceptance was measured on ASTEP's performance and cost data provided before its actual implementation, limiting the depth of understanding into how public and industrial stakeholders may respond to its real-world implementation. This means that the findings reflect anticipated perceptions and opinions rather than observed behaviour, which may differ once practical constraints, such as system reliability, integration challenges, and operational uncertainties, are encountered post-implementation of STE. This may affect the accuracy of predicted acceptance levels, particularly in industrial settings where the purchase of STE systems is influenced by real performance outcomes. However, such pre-implementation assessments remain valuable for identifying influencing factors of adoption and key barriers at an early stage of STE application, supporting informed decision-making during the development and planning phases of such emerging technologies.
4. The demographic composition of the social acceptance survey was concentrated in European regions with limited representation from other regions such as Asia, the Middle East, and Africa. Furthermore, the sample primarily consisted of only young to middle-aged, well-educated individuals recruited through university and professional networks. As a result, the findings may reflect the perspectives of a more informed and sustainability-aware population, potentially limiting the generalisability of results to the broader global population. Nonetheless, the sample remains valuable for capturing trends in public acceptance among engaged stakeholders within these regions, who are likely to play a key role in the early adoption of emerging STE technologies.

The future predictions of social impact and industrial acceptance do not fully account for external influences such as employee turnover, labour policy changes, or market competition from other renewable technologies which may sway the preferences of industrial buyers. This limits the accuracy of long-term forecasts, as it does not account for variations in employee personnel who may hold differing perceptions of the technology. It also excludes the influence of opportunity cost considerations used by industrial buyers when deciding between adopting STE systems and alternative renewable technologies. In practice, such

decisions are influenced by factors including capital costs, return on investment, technological maturity, and operational flexibility of competing solutions, which may evolve over time and shift the relative attractiveness of STE systems, leading to deviations from the predicted acceptance trends post implementation. However, the model remains valuable for identifying the probabilistic influence of specific investment variables on social impact and industrial acceptance over the decade, providing insight into potential future scenarios under current implementation conditions and stakeholder engagement. This approach still offers practical guidance for industrial practitioners at the early stages of STE deployment by supporting informed resource allocation decisions, highlighting priority investment areas with the greatest expected impact, and reducing uncertainty in strategic planning.

# Chapter 4: Assessment of Social Risk of ASTEP

This chapter presents the assessment of ASTEP’s social risk on employee stakeholders involved in the Production phase. Section 4.1 presents these results for all ASTEP components enlisted in Table 1, with section 4.2 detailing the individual social risk results for the PCM Tank, section 4.3 for the SunDial, and section 4.4 for the Control Unit.

## 4.1 Social Risks During the Production of All Components

Figure 7 shows the total amount of Risk Hours (RH) associated with producing one USD of material for all three ASTEP main components.

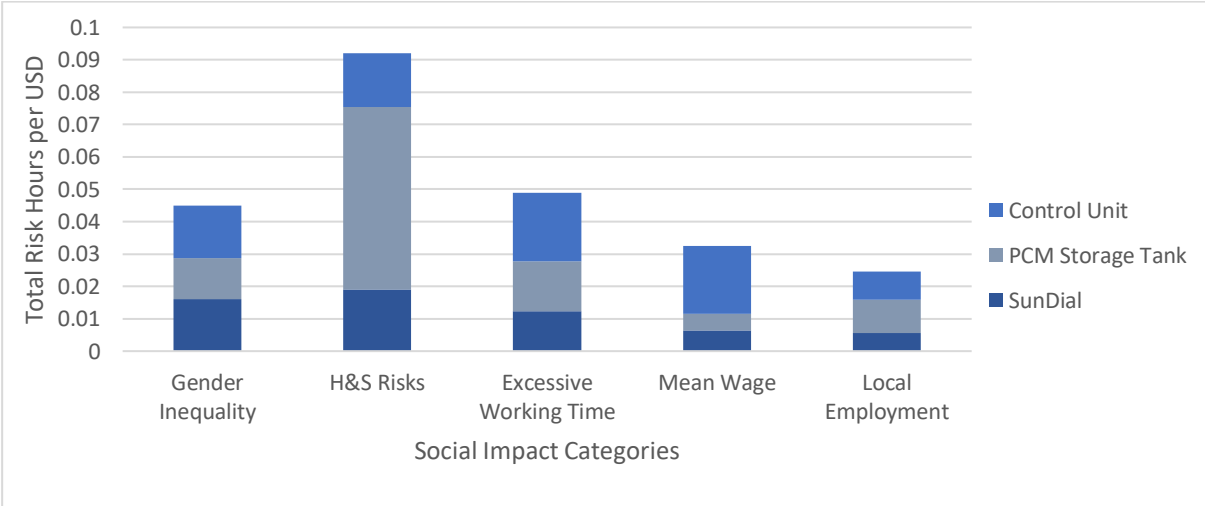


Figure 7: Total Risk Hour Distribution per Impact Category for Manufacturing of ASTEP Components

Figure 7 shows that the H&S social impact category had the highest overall risk level, totalling 0.09 Risk Hours (RH). Of this, approximately 0.049 RH, representing 54% of the total H&S risk, is attributed to the production of the PCM Storage Tank. Breaking down this component for its risk levels, it was found that 0.037 RH was from the production of aluminium inserts in Poland, while the 0.012 RH was from the PCM chemicals produced in the Netherlands. In comparison, The SunDial produced in Spain generated 0.017 RH, and the Control Unit produced in Germany generated 0.014 RH, both much less than the PCM tank. The concentration of risk within the PCM tank component corroborates with the findings of Nartowska et al. (2023), who reported high H&S risks during the production stages of PCM tanks used in STE systems due to chemical, metal dust exposure and poor use of Personal Protection Equipment (PPE). Otieno & Loosen (2016) also agree that the highest H&S risk attributed to CSP technology is in the PCM tank, citing that the heat transfer fluid chemicals used between the collectors and the PCM tank creates this risk. Their H&S assessment of a CSP system noted high injury incident rates due to chemical leakages. Aridi & Yehya (2022)

have additionally found a high risk of injuries and fatalities related to the production of chemicals needed to store thermal energy in their analysis of the supply chain of a PCM tank. Given the high concentration social risk observed in the PCM tank’s production, specific countries and economic sectors are further explored in Section 4.2

### 4.2 Social Risks During the Production of the PCM Storage Tank

Figure 8 presents the social risk hours per USD for the PCM Storage Tank considering its production in Poland (PL) and the Netherlands (NL), split between High Risk (HR), Medium Risk (MR), and Low Risk (LR) for all five impact categories.

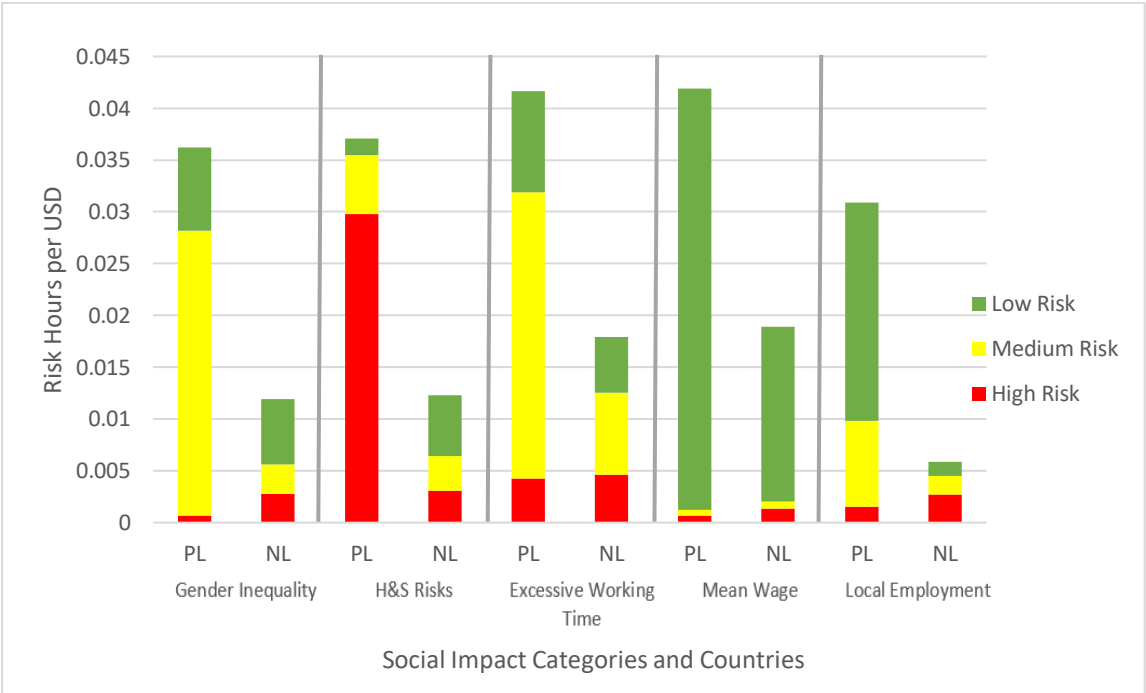


Figure 8: Social Risk Levels per Impact Category for Manufacturing of PCM Storage Tank (PL and NL)

Figure 8 compares the PCM storage tank’s social risk hours per USD across five categories for the aluminium insert subcomponent produced in Poland in the Non-Ferrous Metals sector and the PCM chemical subcomponent produced in the Netherlands in the Chemical Products sector. The H&S category shows the highest overall risk in Poland in the Non-Ferrous Metals sector, totalling 0.038 RH, with most of the distribution in high risk at 0.029 RH. The Netherlands is notably lower in the Chemical Products sector, about 0.012 RH with most of the distribution inking towards the medium and low risk hours. The risk in the Excessive Working Time category is also higher in Poland, at 0.041 RH comprising mainly of 0.032 MR, while the Netherlands is at 0.017 RH with only 0.0075 MR. Gender Inequality is also greater in Poland in the corresponding sector, about 0.036 RH, compared with about 0.012 RH in the Netherlands in the corresponding sector. Mean Wage is largely low risk in both countries; totals

with 0.04 LR in Poland and about 0.018 LR in the Netherlands. These results support the argument in section 4.1 that the PCM storage tank is the principal contributor to H&S risk, with the aluminium subcomponent produced in Poland as the origin of the majority of social risk observed in the study.

A deeper examination of why the differences in risk levels between the two countries and sectors exist is conducted in Figure 9, which presents the risk levels of policy non-compliance to three policy types during the production of the PCM Storage Tank.

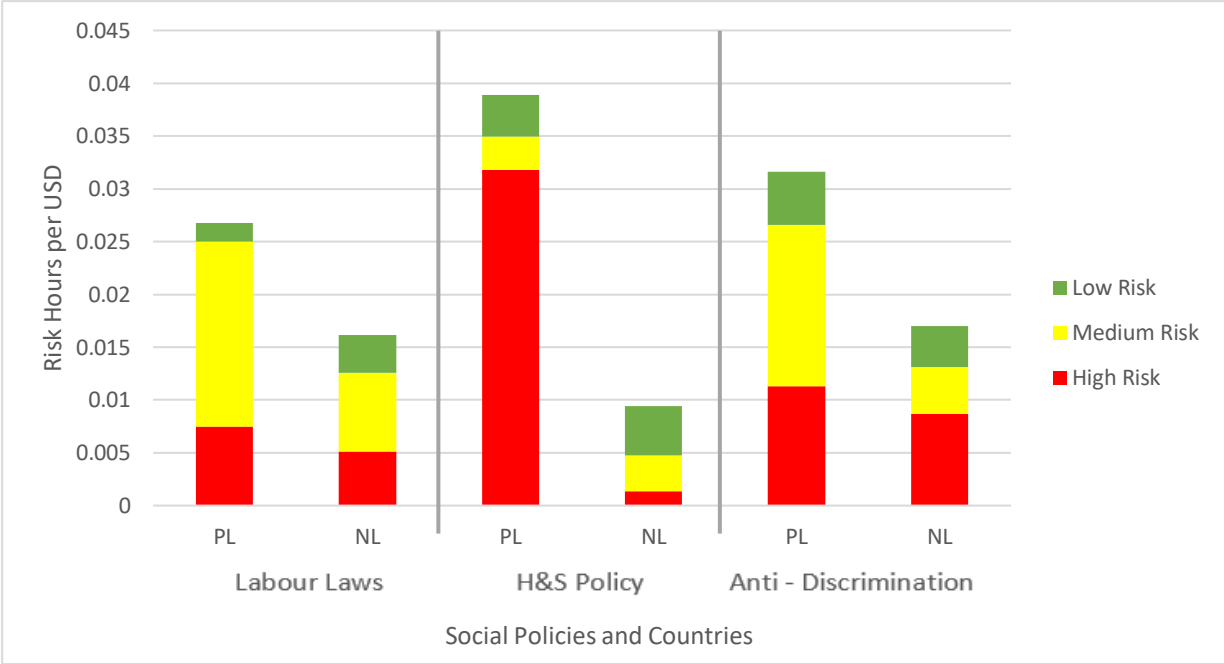


Figure 9: Risk of Compliance to Policy Types for Manufacturing of PCM Storage Tank (PL and NL)

It can be seen in Figure 9 that risk of non-compliance to H&S policy is substantially higher in Poland within the Non-Ferrous Metals sector, totaling about 0.039 RH and dominated by high risk at 0.03 HR, whereas the Netherlands in its Chemical Products sector is about 0.009 RH with a low to medium risk distribution. Risk of non-compliance to labour laws is also slightly higher in Poland in its corresponding sector, at 0.027 RH mainly comprising of 0.017 MR, compared with about 0.016 RH in the Netherlands in its corresponding sector comprising of 0.008 MR. The risk profile of non-compliance to policies in Figure 9 explains the higher H&S and Excessive Working Time risks affecting employees involved in the production of the aluminium inserts in Poland as seen in Figure 8. The same relationship is evident for the Netherlands, where lower levels of policy non-compliance in Figure 9 correspond with reduced H&S and Excessive Working Time risks for employees in the Chemical Products industry, as reflected in Figure 8.

Evidence from the literature supports the higher H&S risks observed in Poland in Figure 8. Dziubanek et al. (2017) reported similar findings in their study of non-ferrous metal mining, highlighting ongoing H&S problems in this industry where employees are at risk. They supported that elevated levels of metal dust in the air and soil at production sites within Poland causes elevated risk on those employees, reflecting in the higher H&S risks seen in PL in Figure 8. Their research stated that stricter enforcement of H&S regulations is needed in PL, especially around the supply and proper use of Personal Protective Equipment (PPE). This observation is consistent with the high levels of non-compliance identified for PL in Figure 9.

By contrast, the lower H&S risk in the Netherlands is consistent with findings of the study of Zwetsloot et al. (2020), who conducted repeated H&S assessments of nineteen companies in the chemical industry over a six-year period between 2012 and 2018 through conducting interviews with management boards. Their results showed strong adherence to H&S procedures across the industry, including effective application of accident monitoring systems. In addition, effective communication and training were found to be maintained through adequate supervision to ensure employees were well informed on appropriate H&S practices. Similarly, Schenk and Antonsson (2015) reported strong compliance with the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) protocol, which they found to be well-implemented in order to manage employee H&S in the Dutch chemical sector. These insights in the literature verifying the findings for low risk of non-compliance to H&S policies in NL in Figure 9.

The literature and the results in Figures 8 and 9 reveal that both the country of origin and the producing economic sector influence social risk on employees, with the Polish aluminium industry generating substantially higher H&S risks than the Dutch chemical industry, which is likely attributed due to stronger policy compliance in the latter. This revelation is consistent with Thies et al. (2019) and Aridi & Yehya (2022). The former had found higher social risks in China-centred battery production compared with German-centred assembly, and the latter reported that outsourcing PCM-related production to Africa and Asia elevated H&S and fair payment risks. This translates to the case of ASTEP, where the portion of the PCM tank sourced from the aluminium sector in Poland was found to be associated with higher H&S risk, while materials sourced from the Netherlands had lower H&S risk.

The moderate Excessive Working Time risk (0.027 MR) and low Mean Wage risk (0.04 LR) observed in Figure 8 are consistent with the low non-compliance to labour laws in Figure 9 (0.016 MR), indicating that Poland generally upholds strong adherence to regulations governing wages and working hours. This is supported by Obolewicz (2013), who found in their assessment of H&S in Poland that compliance with EU-mandated wage and working time

laws is generally good, with enforcement mechanisms in place to prevent excessive hours and underpayment. Surdykowska and Pisarczyk (2021) also reported compliance with labour laws is good across EU members including Poland and the Netherlands, which likely explains the low risk levels for these countries in Figure 8.

### 4.3 Social Risks During the Manufacturing of the SunDial

Figures 10 show the social risks attributed to the second highest contributor of overall system social risk; the SunDial component.

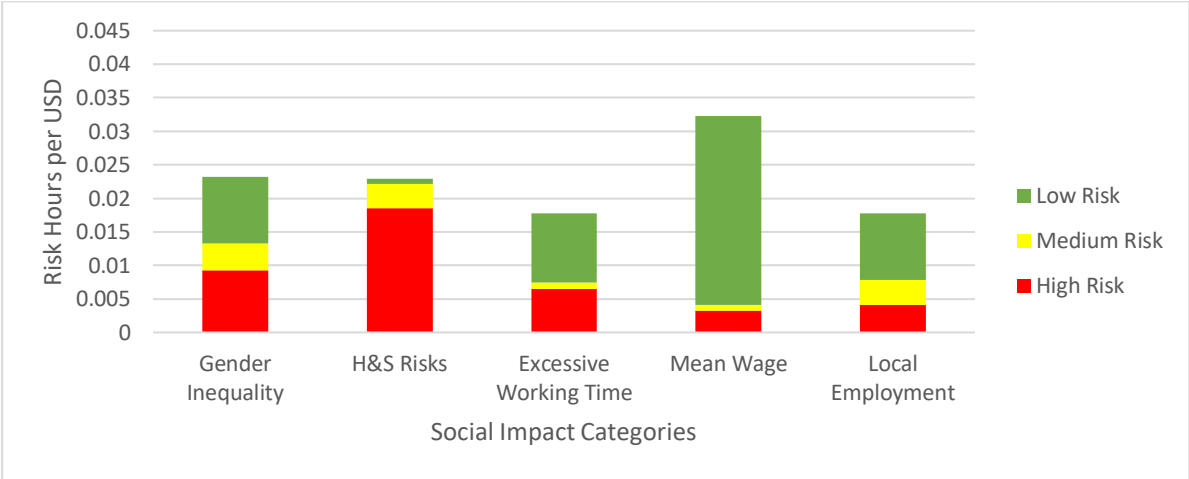


Figure 10: Social Risk Levels per Impact Category for Steel Sector in Spain Responsible for Manufacturing the SunDial

Figure 6 shows that the H&S risks are moderate within the Spanish steel sector with 0.023 RH. This finding is consistent with evidence from Torrecilla-García et al. (2021), who reported moderately high accident rates in Spain’s metal sector, particularly in steel processing operations. Similarly, Rodríguez et al. (2018) identify modest cancer risks among Spanish steel workers due to exposure to industrial fumes and inadequate ventilation systems. In contrast, labour-related issues such as Excessive Working Times and Mean Wage are very low risk for the sector in Spain, which can be explained by the study of Surdykowska & Pisarczyk (2021), who demonstrated strong engagement with labour laws in EU members.

Another noteworthy result from Figure 6 is the risk that Gender Equality, i.e the risk that ratio of male to female workers in the steel sector is imbalanced beyond national averages. This was found to be relatively high as denoted by a combined MR and HR of 0.012 under the related indicator. This was in agreement with the findings made by Toletini & Maria (2025), who also found great imbalances in the gender ratio from their site assessment based in Spain. They found that female representation is low within management positions. These findings can be further supported by the commentary of Figure 11.

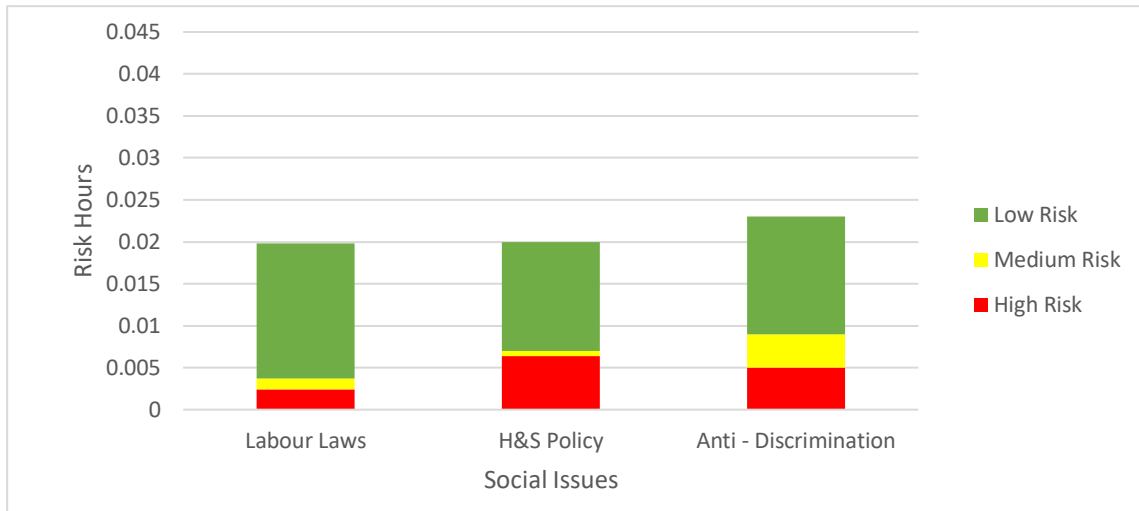


Figure 11: Risk of Compliance to Policy Types in Steel Sector for Spain Responsible for Manufacturing the SunDial

It can be seen in Figure 11 that the risk hours under Anti-Discrimination are high. This indicator is related to the level of engagement with gender equality and anti-discrimination policies by firms within a particular sector, and moderately high-risk levels in the Spanish steel sector show non-compliance. This finding is supported by a mass survey study by Yedra et al. (2022), who found resistance by Spanish metallic industries towards adopting gender equality policies and empowering women in the work environment. This resistance is reinforced by Collado & Vázquez-Cupeiro (2023), who found that gender equality policies need more enforcement in metallic industries in Spain, as they observed that women are often side-lined from leadership and management roles in the industry, likely explaining the moderately high-risk level of gender inequality in Figure 10.

#### 4.4 Social Risks During the Manufacturing of the Control Unit

The risk levels imposed by the production of the Control Unit manufactured in Germany in the Iron and Steel sector are shown in Figure 12.

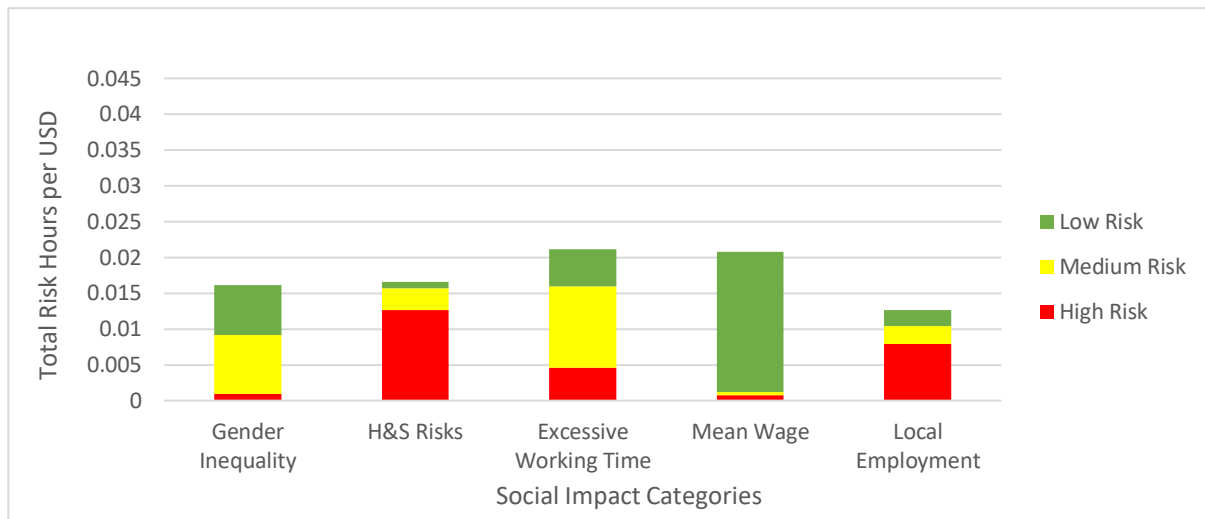


Figure 12: Social Risk Levels per Impact Category for Steel Sector in Germany Responsible for Manufacturing the Control Unit

Figure 12 shows low risk levels in all categories, with the highest being H&S at only 0.015 RH. This finding is corroborated by the study of Zimmer et al. (2017), who that showed that overall social risks attributed to the German steel sector are consistently low. Beske et al. (2008) validated this finding using surveys and audits involving 53 companies, and found strong enforcement of H&S and labour law in the German steel sector. They found detailed evidence that the majority of the companies had a comprehensive H&S management system in place, which led to progressively fewer accidents and injuries per year.

#### 4.5 Chapter Summary

In summary, this chapter assessed social risk across the production of ASTEP's three components, and it was identified that the PCM storage tank as the principal contributor to social risk on employees, originating primarily from the aluminium manufacturing sector in Poland. The findings revealed that H&S risks were most relevant within this sector, with additional contributions from excessive working time and gender inequality. Comparative analysis shows that variations in social risk are likely influenced by differences in policy compliance and regulatory enforcement across regions, with higher risks observed in sectors and regions with weaker adherence to occupational and labour standards. In contrast, components produced in regions with stronger compliance frameworks, such as the Netherlands and Germany, exhibit comparatively lower social risk levels.

# Chapter 5: Assessment of the Social Impact of ASTEP

This chapter presents an assessment of the social impact on ASTEP’s employees collected during the Product Development phase. The social impact data in the form of scored survey results from the Employee Survey are presented in section 5.1. The influencing factors of observed social impact were found in section 5.2. Section 5.3 further presents the breakdown of the survey results according to employee demographics.

## 5.1 Reported Employee Survey Results

Figure 13 shows the survey results for the Employee Training Impact Category pertaining to the TS indicator. The results are extracted the Employee Survey, totalling 41 participants that have completed the survey, a number sufficient as per Witte (2008). The satisfaction scores presented in Figure 13 average the score from each question in the training section per participant.

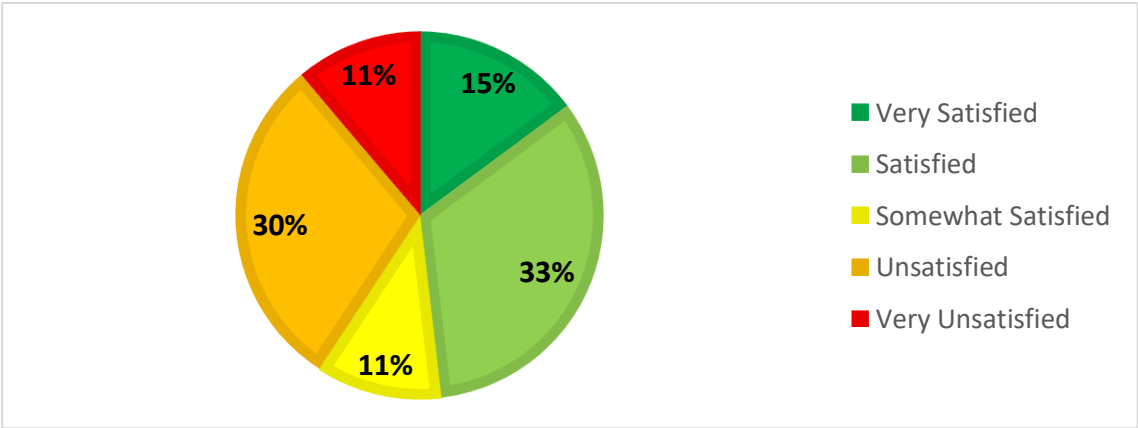


Figure 13: Employee Satisfaction Scores on the Level of Provided Training

It can be seen from Figure 13 that nearly half of the surveyed sample showed satisfaction with the level of training provided for the project by their managing employers, totalling 48%. 11% were ‘Somewhat’ satisfied while the other 41% of participants averaged lower scores with their training for the project, indicating that more engagement is needed with project activities and material for those employees. After converting these satisfaction scores into impact points using the scale provided in Table 5, the average score of the project for this impact category was found slightly negative, being measured at -0.5. This result indicates that from the participant’s perspective, more was desired in terms of training that could supplement their employment for the STE project. To further support these social impact findings, qualitative dialogue collected from participants described cited potential opportunities where training could be given to equip themselves with skills that could enable them to perform better within

their project work. All satisfaction scores were reported by engineers tasked with design assignments.

The next indicator to report on is the ASTEP Employee Satisfaction on their Working Intensity, which reported the perception of employees regarding their satisfaction on their workload when engaging with ASTEP project activities. Figure 14 demonstrates the satisfaction scores reported by the Employee Survey.

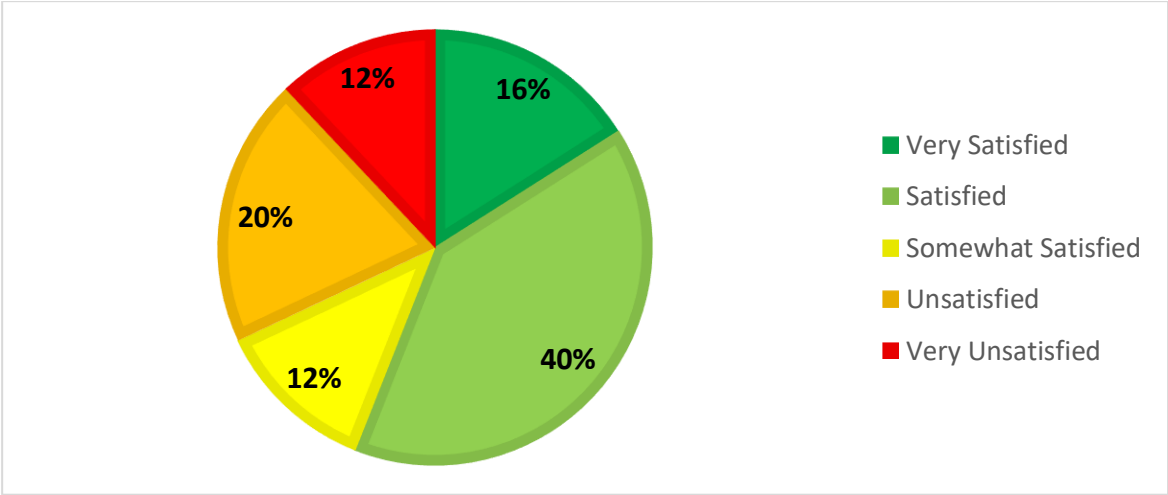


Figure 14: Employee Satisfaction Scores on their Working Intensity (WI)

Figure 14 shows that over half of the surveyed sample of 41 participants showed satisfaction with their work intensity, amounting to 56%. 12% were ‘Somewhat’ satisfied, while 32% of participants chose lower scores with their current workload imposed by their work assignments, indicating that workload needed to be distributed more evenly across the work schedule of those participants. These satisfaction scores were converted into social impact points using the criteria in Table 5, which outputs average score of +0.6.

The last set of satisfaction scores to report on entails ASTEP employee perception on how well their work assignments are contributing to their Professional Development as a result of being employed on the project. Figure 15 demonstrates these satisfaction scores for all 41 participants that partook in the study.

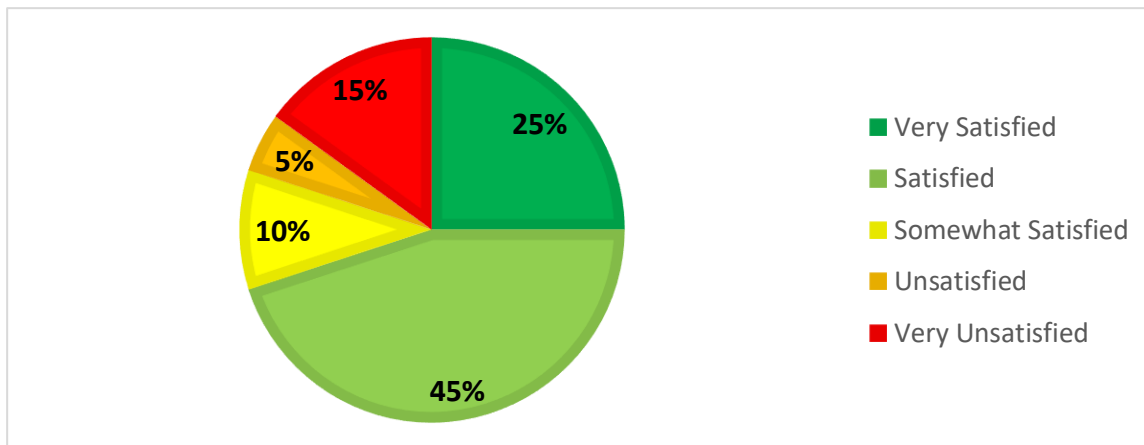


Figure 15: Employee Satisfaction Scores on Professional Development (PD)

Figure 15 shows that the satisfaction for the level of PD provided in the project was good, with 70% of participants producing an overall satisfactory response about their career and skill development. It was heavily expressed that the assigned work during employment on an STE project was relevant and appropriate towards their desired career goals. The other 30% chose neutral or lower scores with how relevant their project work is to their desired career path. Converting these satisfaction scores to impact points produced an average score of +1, which indicates a positive result.

To support the argument, qualitative data from the Employee Surveys in the form of comments made by employees was used. The NVivo software had picked up positive comments under the 'Job Satisfaction' employment theme. Participants expressed how they were satisfied with the opportunities to attend international conferences and disseminate research for their work assignments.

## 5.2 Results of Multi-Variable Regression Models

To evaluate the reported ASTEP Employee satisfaction scores from section 5.1 for their influencing factors, coefficient results of the SPSS simulation were used for all three impact categories; TS, WI, and PD. The results were in the form of a matrix containing all relevant Spearman's  $\rho$  correlation coefficients between an observed employee satisfaction indicator in its respective impacting HRM resources. The recorded Spearman's  $\rho$  between a satisfaction indicator and an allocated HRM resource forms one entry of the matrix, and all possible relationships in the data between the Employee Survey scores and reported HRM practices in the Manager Questionnaire are given in Table 11.

**Table 11:** SPSS Matrix of Spearman's  $\rho$  Correlation Coefficient Results

	<b>PT</b>	<b>EE</b>	<b>PPD</b>	<b>AT</b>	<b>TA</b>
TS	0.54	0.48	-	-	-
WI	-	-	-	-0.63	0.21
PD	-	0.20	0.8	-	-

From Table 11, all expected variable relationships can be quantified, with the satisfaction indicators in the leftmost column and the HRM practices in the first row. The entries of noteworthy relationships are shown, while variable combinations that do not have any meaningful correlation as detected by the SPSS software have a dash in their entry. Firstly, it can be seen that the relationship TS --> PT has a Spearman's  $\rho$  value was 0.54 from Table 8, and for TS  $\rightarrow$  EE, the value was 0.48, which indicates that the PT and EE act as moderately strong predictors of TS as defined by the Spearman's  $\rho$  criteria by Leclezio et al. (2015). Additionally, the p-value was well below 0.05 for both correlations;  $p=0.006$  for TS --> PT and  $p=0.03$  for TS  $\rightarrow$  EE, verifying that both relations have statistical significance as per the criteria set by Hair et al. (2021) at a 95% confidence interval. This result verifies the observed patterns detected in an initial examination of the results from the Manager Questionnaire, as it was observed that a project subdivision that scored impact points +1 was providing strong amounts of PT and EE resources, whereas subdivisions with producing impact points of -0.5 provided little to no amount of PT and EE. These results evidence a positive and moderately strong linear correlation between these two resources and TS, hence organisations scoring low in TS could improve social impact by engaging employees with PT and EE resources.

Critically evaluating these results against findings from similar studies from the literature on solar energy system reveals why negative SP was observed in the ASTEP study, and why PT in the form of training resources specific to STE have such a strong influence on social impact. Lucas et al. (2018) in a study of training requirements for solar PV panels cited a shortcoming in the education of design engineers at a university level, evidenced by a mismatch in the qualifications of fresh graduates and the job requirements for a design engineer employed on a solar energy project. This mismatch in an R&D environment was also cited by Terrapon-Pfaff et al. (2019) and by Harper et al. (2014), the latter in a similar assessment in the UK found a need for the taught content in postgraduate engineering qualifications to include more content specific to the efficient engineering design of solar energy systems. An analysis conducted by PACE (2023) found that education specific to solar technology as provided by university-level qualifications and training in the laboratory environment are more needed amongst graduates in order to better equip new design engineers with skillset for solar energy projects. Korir et al. (2023) further revealed a significant correlation ( $R=0.81$ ,  $p<0.05$ ) between investment in HRM resource provisions into employee training programmes aimed at facilitating innovation diffusion and the technical performance of emerging solar energy systems. Given the evidence

from the previous three studies, it can hence be deduced that training requirements for employees working in STE design in lower scoring subdivisions are not being met, with strong evidence from the literature pointing towards the lack of training in renewable energy design at a university level. Additionally, certain subdivisions supplied low amounts of training in renewable energy design, likely correlated with lower impact scores. Positive impact was only observed for subdivisions supplementing their design engineers with STE-specific topics generated positive social impact, a critical requirement outlined by Harper et al. (2014) due to how these topics were able to fill any gaps in knowledge and skills which may not have been covered by their degree-level qualifications.

Novel findings from the ASTEP study, previously undocumented in the literature, uncovered the exact types of training resources specified under PT which correlate with positive impact as observed within high-performing subdivisions, particularly in those producing scores of +1 or higher. These resources were unveiled to be:

- a) Specialised workshops in STE design, covering topics such as STE design principles, advanced simulation techniques, and energy transformations. These were found equip employees with the skills and knowledge needed to develop novel STE systems. It was found that application of the theoretical knowledge supplied by these workshops to practical experiments for STE development correlated with better training for employees, hence leading to higher training scores.
- b) Collaboration with material suppliers and site visits to end users. This resource included engaging employees with understanding material selection with downstream part manufacturers and with ASTEP's end-user process requirements. This was found to be correlated with improved employee training as they gained insight into real-world implementation and operation of STE systems, and were able to better design the STE system according to the end-user's requirements
- c) Workshops in data analytics, which included statistical analysis, machine learning techniques, and data visualization tools. These resources were found to enable employees to make appropriate STE design changes from large datasets and improve STE designs through data driven problem solving, correlated with better employee training scores.

On the other hand, subdivisions relying on university-level qualifications alone and allocating lower and/or none of these resources was correlated with negative social impact scores, conforming to the findings made by Harper et al. (2014).

Next, the TS to EE relationship has a correlation coefficient ( $\rho$ ) of 0.48 with a high significance level  $p < 0.05$ . This finding indicates that the extent to which managers involved their employees

in research publication and dissemination activities was positively correlated with training satisfaction, and the reverse holds true. Such a finding reveals the importance of R&D engagement in STE projects, supported by Liu et al. (2010) who highlighted that this is due to the innovative design of the STE collector. They further emphasise the rapid technological growth in novel STE systems, which designers need to become well-acquainted with through scientific research to successfully fulfill their work assignments.

The findings of the ASTEP study go further by identifying the R&D resources which positively influence employee training. These exact resources include:

- a) Engagement in laboratory testing, which was shown to equip employees with hands-on experience with prototyping new STE technologies, enabling them to understand and innovate upon current systems. These activities were found to include prototyping various components and systems, assembling different parts to understand their integration and performance, and conducting experiments to test the efficiency and durability of the designs.
- b) Dissemination through scholarly publications and conference proceedings, which was found to have updated employees with the latest advancements available in the scientific literature and community in STE development which can be applied to the ASTEP's design.
- c) Conducting field research, which was found to provide employees with new engineering data that is essential for designing and optimising STE systems.

These novel findings indicate that engaging activities with R&D work encompassing laboratory work, scholarly dissemination, and field research, is crucial for the satisfaction of employees working on novel STE technologies.

The next satisfaction indicator to analyse is WI, for which the correlation  $WI \rightarrow AT$  had a Spearman's  $\rho$  value of -0.63 indicating a strong negative relationship with AT. Additionally, Table 11 shows that  $WI \rightarrow TA$  had a correlation value of 0.2, indicating a rather weak but noteworthy relationship. The p-value was  $p=0.002$  for  $WI \rightarrow AT$  making it statistically significant, while  $p=0.15$  for  $WI \rightarrow TA$ , making it statistically insignificant. This result matches with the observed results from the Manager Questionnaire, as it was observed that a project subdivision that evenly allocated up to 3 project tasks for each of their respective ASTEP employments correlated with observing stronger WI scores of +1 or above. On the other hand, project subdivisions allocating more than 3 tasks with an uneven distribution correlated with observing lower WI scores below -0.5. This result was also supported qualitative comments made under the 'Working Schedule' employment theme in Table 7, where participants with lower assigned tasks expressed that their work-life balance was satisfactory. The majority of

participants reported how their working time allocated to project tasks was fair and suitable, while participants with more workload expressed their concerns in the comments. The few project subdivisions scoring lower in WI should therefore consider first consider lowering their employees' task assignments, and may consider adjusting their weekly working hours so that more time can allocated to those ASTEP work assignments.

To verify with the literature, this result is in agreement with the result found in the matching social category in the study of Corona & Miguel (2019), who found that the working hours of the employees employed in their solar CSP plant were fair and compliant with regional labour policy, producing positive SP in their results for working hours. Given that their social assessment took place in Spain, it can be verified that strong implementation of labour policy produced positive SP in our study as well due to how the majority of our project activities occurred in a similar regional industrial sector. Results from Sala-Bubaré et al. (2023) on the job satisfaction of employees working in an R&D environment found good satisfaction concerning employee working hours in Spanish research settings.

The weak correlation between WI and TA of  $\rho=0.21$  still has some importance in the study, a notion which aligns with the study of Hill et al. (1998) in the field of job satisfaction which documents TA as a factor in Employee satisfaction with working hours. The result suggests that better allocation of weekly working hours, noted to be in the range of 20-25 hours for an ASTEP employee as recorded by the Manager Questionnaire, correlated with to yielding stronger WI scores, while employees with only 5-10 weekly hours to complete their ASTEP assignments contributed to lower WI scores. This underscores the role of HRM in optimising working conditions to influence overall job satisfaction within ASTEP, as minor tweaks in WI be made by ASTEP's HRM panels by allocating more weekly hours for their employees to complete their tasks.

Lastly, it can be seen that PD  $\rightarrow$  PPD has a strong positive relationship with an indicated Spearman's  $\rho$  value of 0.8 from Table 11. Additionally, the p-value was well below 0.05, nearing 0.000 for PD  $\rightarrow$  PPD, making it very statistically significant and verifying a very strong association. This result matches with the observed results from the Manager Questionnaire, as it was observed that a project subdivision that scored an SP result of +1 or above in providing professional development opportunities correlated with observing stronger PD scores in same range of +1 or above, as recorded by the Employee Survey. Project subdivisions with an SP result of -0.5 or below correlated with observing lower PD scores from the perception of their respective employees. To the author's best knowledge, no related literature exist to verify the correlating factors of PD in an STE project.

However, novel findings from the Manager Questionnaires in the ASTEP study show that providing employees with workshops to develop their soft skills, allowing ASTE employees to engage with international conferences, and frequently providing career and CV-building workshops was correlated with stronger PD. ASTEP employees reported that their ASTEP work was more relevant towards progressing them to towards their desired career paths in project subdivision with better provision of these opportunities. However, a few projects subdivisions scoring lower in PD were found to correlated with lower amounts of career building guidance to their employees during project work, such as engaging with discussions about future career opportunities.

In similar circumstances with WI, another weak relationship exists which has a slight influence. In this case PD → EE has a  $\rho$ -value of 0.2, which states that engaging employees with R&D activities has a slight positive correlation with PD. While the p-value is statistically insignificant, of 0.16, it was found that employees who desired career paths in academics benefited from opportunities that allowed them to interact with the scientific community through extracting and writing up about literature works. Such a relationship amongst academically oriented R&D projects is evidenced in the literature, namely in the works of Loyarte-López et al. (2020) and Zacher et al. (2018). Therefore, this weak relationship is still noteworthy and meaningful to decision-making, with a recommendation for managers to allocate these resources to specific employees with particular desires in academia.

### 5.3 Demographic Breakdown of ASTEP Employee Satisfaction Scores

This subsection expands on the examination of ASTEP's social impact performed in section 5.1 by further delving into the demographic breakdown of ASTEP employees, categorizing data based on three defining parameters: gender (section 5.3.1), occupational category (section 5.3.2), and work and/or study longevity (section 5.3.3). This is to observe patterns and correlations within satisfaction scores across different demographic groups.

#### 5.3.1 Evaluation of ASTEP Employee Satisfaction Based on Gender

Table 12 presents the mean satisfaction scores for male and female ASTEP employees across TS, WI, and PD, the calculated 95% confidence intervals (CI) as extracted from SPSS for each mean score in brackets, and the overall mean score on a 1-5 scale.

**Table 12:** Mean Satisfaction for Male and Female ASTEP Employees with 95% CI

Gender	Sample Size n=	TS Mean Score	PD Mean Score	WI Mean Score	Mean Score
Female	14	2.6 (2.4-2.8)	2.4 (2.2-2.6)	2.8 (2.6-3.0)	2.6 (2.4-2.8)
Male	27	3.4 (3.3-3.5)	3.2 (3.1-3.3)	3.7 (3.6-3.8)	3.5 (3.4-3.6)

In terms of Training Satisfaction, Table 12 shows that male employees show a higher mean score of 3.5 compared to female employees with a mean score of 2.6. Similarly, in the PD category, male employees demonstrate a noticeably higher mean score of 3.2, surpassing the mean score of female employees at 2.4. Similarly WI category, male employees reported a higher mean score of 3.7 in contrast to the mean score of 2.8 for female employees. In addition to the measurement of satisfaction, another noteworthy finding from this demographic breakdown is the gender equality level shown by the number of males (n=27) and females (n=14) employed in the ASTEP project. With a ratio of males to females being approximately 2:1, it can be seen that recruitment and work allocation for female employees needs to be improved.

Evaluating the trends observed in Table 12 involves further correlation analysis shown in Table 13, which compares the influence of allocating human resources PT, EE, PPD, AT, and TA towards the satisfaction of both male and female ASTEP employees in the three related categories; TS, PD, and WI.

**Table 13:** Effect of Human Resources on Male and Female ASTEP Employee Satisfaction

Categorical Correlation	Female		Male	
	Pearson's R	p-value	Pearson's R	p-value
TS → PT	0.74	0.04	0.52	0.02
TS → EE	0.77	0.03	0.48	0.03
PD → PPD	0.82	0.02	0.44	0.05
PD → EE	0.15	0.35	0.35	0.08
WI → AT	-0.53	0.09	-0.69	0.005
WI → TA	0.08	0.42	0.40	0.05

The examination of human resource investment's impact on ASTEP's employee satisfaction, as shown in Table 13, revealed differences in the observed level of influence between the two genders. Notably, the provision of training resources (PT) was a significant factor positively influencing Training Satisfaction (TS) for both male and female employees, with stronger correlations observed in the female cohort (Pearson's R = 0.74), found to be statistically significant with a p-value of 0.04. This is in contrast with the male employees, demonstrating a moderately strong relationship as denoted by a Pearson's R of 0.52 and a statistically significant p-value of 0.02. Additionally, EE was found to an influencing factor on TS for both male and female cohorts. A strong positive correlation (R=0.77) was observed for the female cohort at a high statistically significant p-value of 0.03. In comparison, male employees demonstrated a moderate yet positive relationship (R=0.48), with strong statistical significance (0.03). This demonstrates that the TS of both the male and female cohorts is strongly

correlated with engagement with R&D activities, with a stronger influence observed among female employees compared to males. Next, robust positive correlation of Pearson's  $R = 0.82$  at a statistically significant level of  $p = 0.02$  from Table 13 was found for the relationship between the Professional Development (PD) satisfaction category and the Provision of Professional Development resources (PPD) for the female cohort, highlighting the influencing role of tailored professional development support for the female cohort. In contrast, male employees demonstrate a positive correlation, with Pearson's  $R = 0.44$  and at a statistical significance of  $p = 0.05$  for the same categories. These results show that that females are more responsive to engagement with career support activities. In contrast, the relationship between PD and EE was found to be weak and not statistically significant for both female cohorts ( $R = 0.15$ ,  $p=0.35$ ) and male cohorts ( $R = 0.35$ ,  $p=0.08$ ).

This finding aligns with the findings of Ro & Knight (2016) in their study of gender differences in learning outcomes as a result of education in engineering, who explained that the female cohort displayed more responsiveness to allocated engineering-related training and education resources. These findings are further validated in a similar study done by Kamphorst et al. (2015) comparing the effect of deploying engineering training programmes on males and females. They concluded that allocating resources for females greatly improves training satisfaction and career prospects for females. Du & Kolmos, (2009) further supported the argument by emphasising the need to make engineering education and career development opportunities more accessible to females. Such a recommendation could be implemented for ASTEP project to improve the 2:1 gender balance and mean TS score for females found in Table 13. Hence, more training and career support resources could be allocated specifically for ASTEP's female employees to improve female professional presence in the field of solar thermal engineering.

The relationships within the Working Intensity (WI) category in Table 13 exhibit varying low levels of statistical significance, particularly in the correlations with task allocation (AT) and time allocation (TA). For the female cohort, a moderate and insignificant negative correlation was observed between WI and AT ( $R = -0.53$ ,  $p=0.09$ ). Similarly, the relationship between WI and TA was found to be negligible ( $R = 0.08$  and a  $p$ -value of 0.42), suggesting no statistically significant relationship exist between the variations in task and time allocation and the WI for female employees within the ASTEP project. . In contrast, the Male category shows statistically significant correlations for WI with both AT and TA. A significant negative correlation was observed between WI and AT ( $R = -0.69$ ,  $p=0.005$ ), indicating that more appropriate task allocation is strongly associated with reduced working intensity. Additionally, a moderately positive correlation at high significance level was identified between WI and TA ( $R = 0.40$ ,  $p =$

0.05), highlighting that task and time allocation play a more influential role on WI for male employees compared to the female cohort.

### 5.3.2 Evaluation of ASTEP Employee Satisfaction Based on Occupational Category

The examination of all three satisfaction categories across different occupational categories for all ASTEP employees is shown in Figure 16, on a scoring scale of 1-5.

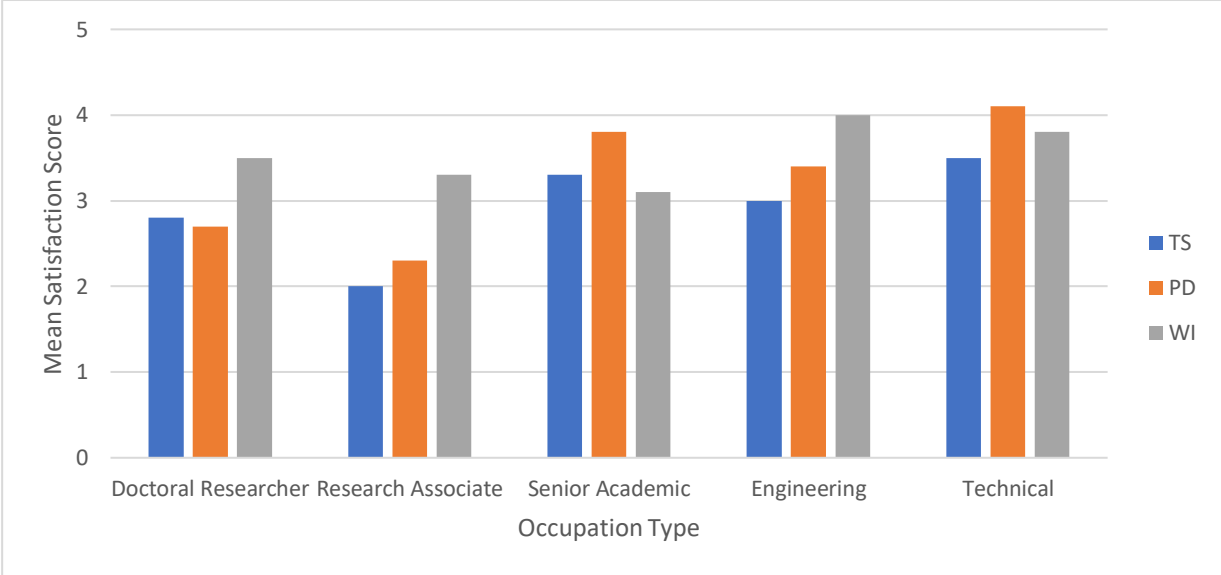


Figure 16: Mean Satisfaction Scores of Different Work Occupational Categories

Trends shown in Figure 16 regarding job satisfaction were observed to be higher among non-academic engineers and technical staff compared to academic employees, including doctoral researchers, research associates, and senior academics. For Doctoral Researchers, the average satisfaction scores were 2.8 for Training Satisfaction (TS), 2.7 for Professional Development (PD), and 3.5 for Working Intensity (WI), resulting in an overall average score of 3.0. Research Associates, on the other hand, displayed lower satisfaction scores across all three categories, with averages of 2.0, 2.3, and 3.3 for TS, PD, and WI, respectively, leading to an overall mean score of 2.5. Senior Academics showed higher satisfaction scores, with averages of 3.3, 3.8, and 3.1 for TS, PD, and WI, respectively, resulting in an overall average score of 3.4.

In contrast, non-academic Engineering staff were found to have higher job satisfaction across all categories, with average scores of 3.0, 3.4, and 4.0 for TS, PD, and WI, respectively, resulting in an overall average score of 3.5. Technical staff, encompassing roles such as engineering technicians and support personnel, showed higher satisfaction, with average scores of 3.5, 4.1, and 3.8 for TS, PD, and WI, respectively, leading to an overall average

score of 3.8. These findings show that job satisfaction tends to be higher among non-academic roles, particularly for technical and engineering employees, compared to academic ones.

Validation against the literature will provide comment as to why these results were observed in the ASTEP study. A study conducted by Fontinha et al. (2019) focused on the comparison of job satisfaction between academic and non-academic staff in Higher Education Institutions (HEIs). They discovered that one of the contributing factors for lower job satisfaction amongst academics was found to be a reported poorer quality of working life compared to their non-academic counterparts within HEIs, in particular with their working hours and training. This aspect of work life consistently led to lower satisfaction of academic staff as verified by Frei & Grund, 2022. The findings in the literature align with the ASTEP study's findings, where academic staff, including doctoral researchers, research associates, and senior academics, showed lower average satisfaction scores across Training Satisfaction (TS), Professional Development (PD), and Working Intensity (WI) compared to non-academic engineering and technical staff. These academic employees cited reasons relating to additional stress induced by more extra hours worked per week from academic staff in their comments. The observations made in Figure 16 showing an overall lower average WI score of 3.1 for academics vs 3.9 for non-academics can be supported using the qualitative evidence and the empirical evidence from the literature. The study by Kyvik and Olsen (2013) highlighted that research positions often involve a lot of individual work, which may lead to feelings of isolation as well as less access to training and career development programs compared to what is available for non-academic employees. Moreover, the study by Bozionelos (2007) investigating job satisfaction among academics emphasised that the nature of academic work, which primarily includes research, was shown to induce conflict between individual aspirations and organisational expectations. They stated that Research Associates for example, demonstrating the lowest satisfactions scores at an average of 2.5 in the ASTEP study, were found to experience job dissatisfaction because they perceive that their career goals did not align with performing research tasks. Fontinha et al. (2019) cited that factors such as the organisational expectations for research productivity, limited access to training programs, and feelings of isolation are prevalent issues for academic employees involved in research. Qualitative evidence from the ASTEP study support this claim, stemming from remarks made by both Research Associates and Doctoral Researchers in the Employee Survey about how better training and career development programs could exist to support their development in academia.

## 5.4 Chapter Summary

In summary, this chapter assessed the social impact of ASTEP on employees during the product development phase across three impact categories; TS, WI, and PD. The findings revealed that PD and WI produced overall positive outcomes, while TS scores were lower, indicating a need for improved engagement with training resources. Correlation analysis further demonstrated that specific training resources, particularly design workshops for STE systems, engagement with R&D activities, and career support play an influential role in influencing TS scores of employees, verified by statistical significance measures. Demographic analysis highlighted disparities in satisfaction between male and female cohorts, with females' TS being more responsive to training and R&D resources, as well as between academic and non-academic roles, with non-academic and technical staff reporting higher levels of satisfaction.

# Chapter 6: Assessment of ASTEP's Industrial Acceptance

This chapter presents the results for the industrial acceptance of ASTEP. First, Figure 17 presents percent breakdown of reported industry type and Figure 18 presents the percent breakdown of the company sizes of the participants.

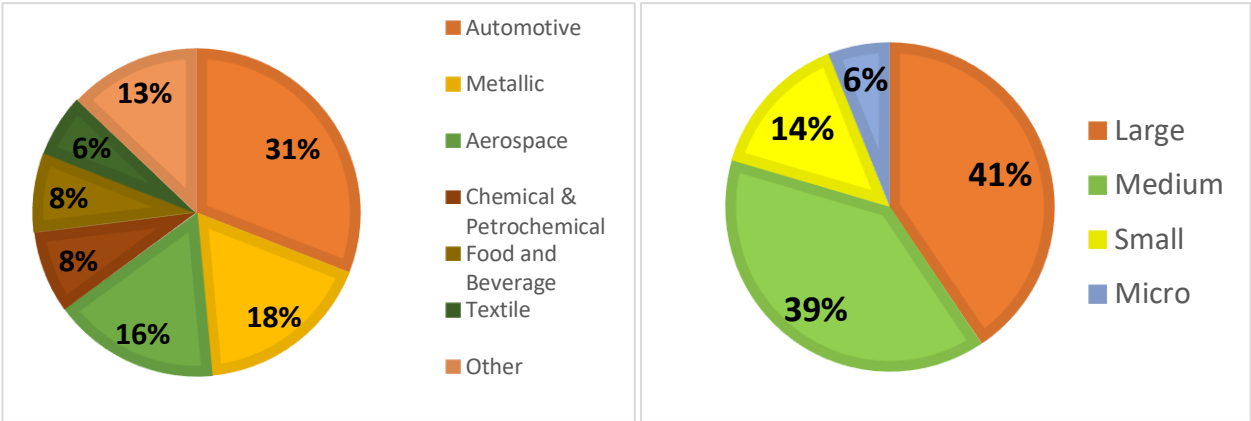


Figure 17: % Breakdown of Industry Types

Figure 18: % Breakdown of Company Sizes from Industries

It can be seen that from Figure 17 that the majority of the participants belonged to the automotive industry (31%) followed by metallic (18%), aerospace (16%), chemical & petrochemical industry (8%), then food and beverage industry (8%), textile industry (6%) and other industries; mining & quarrying (5%), paper & pulp (8%). Next, Figure 18 shows that the majority of company sizes from those industries, were found to be large (41%), followed by medium sized (39%), small (14%) and micro (6%). Next, Table 14 presents the in-house process types reported by participants. Please note that participants were allowed to choose multiple processes, so combinations are presented.

**Table 14: Process Types by Industries**

Process Type (s)	% of Participants Reporting This Process Type(s)
Heat Treatment + Metal Curing	21%
Heat Treatment + Metal Casting + Metal Curing	19%
Food Drying	12%
Food Drying + Pasteurisation	10%
Metal Casting + Metal Curing	9%

Pulp Drying	8%
Baking + Food Drying	7%
Smelting	6%
Other	8%
<b>Sum</b>	<b>100%</b>

Table 14 presents that participants currently operate multiple in-house process types, with the most common combinations being Heat Treatment and Metal Curing (21%), followed by Heat Treatment, Metal Casting and Metal Curing (19%). This is followed by Food Drying (12%), Food Drying and Pasteurisation (10%), Metal Casting and Metal Curing (9%), Pulp Drying (8%), Baking and Food Drying (7%), and Smelting (7%), while the 'Other' category (8%) includes processes such as Distillation and Sterilisation. Concurrently, the temperature ranges that participants' industries operate in are reported in Table 15.

**Table 15:** Industrial Operating Temperature Ranges

<b>Process Temperature Range (s)</b>	<b>% of Participants Operating in this Temperature Range(s)</b>
Low (T < 150°C)	14%
Medium (150°C < T < 400°C)	35%
High (T > 400°C)	18%
Low + Medium (T < 400°C)	14%
Medium + High (T > 150°C)	19%
<b>Sum</b>	<b>100%</b>

Table 15 shows that 35% of participants reported operating processes in the medium temperature range (150°C < T < 400°C), followed by 19% in the medium and high range (T>150°C), and 18% exclusively in the high range (T>400°C). An additional 14% reported using both low and medium temperature ranges (T<400°C), and 14% operated solely in the low range (T<150°C). Table 16 presents the breakdown of energy sources used by the industry for their processes. Please note that participants were allowed to choose multiple energy sources, so combinations are presented.

**Table 16: Current Energy Sources for Processes**

<b>Energy Source (s)</b>	<b>% of Participants Using This Energy Source(s)</b>
Electricity via the Grid + Solar	19%
Gas/Fuel + Solar	13%
Solar	13%
Electricity via the Grid + Other Renewable Sources + Solar	12%
Electric Generators + Electricity via the Grid	11%
Electricity via the Grid	11%
Gas/Fuel + Other Renewable Sources	11%
Gas/Fuel + Electricity via the Grid	10%
<b>Sum</b>	<b>100%</b>

Table 16 shows that the most common energy source was a combination of Electricity via the Grid and Solar, used by 19% of participants, followed by a combination of Gas/Fuel and Solar (13%), and Solar alone (13%). Electricity via the Grid with both Other Renewable Sources and Solar accounted for 12%, while Electric Generators and Electricity via the Grid and Electricity via the Grid alone were each reported by 11%. Gas/Fuel with Other Renewable Sources also accounted for 11%, and Gas/Fuel with Electricity via the Grid was cited by 10%. From Table 16, it can be seen that 57% of participants, equivalent to 181 out of the 318 surveyed, use solar energy either exclusively or in combination with other energy sources, while the remaining 43% rely solely on non-solar energy sources. Table 17 provides a detailed breakdown of the types of solar collector technologies adopted by these participants. Please note that participants were allowed to choose multiple collector types, so combinations are presented.

**Table 17: Solar Collector Types used by the Industry**

<b>Solar Collector Type(s)</b>	<b>% of Participants Using Solar Collector Type(s)</b>
PV	28%
Flat Plate Thermal	17%
CSP	15%

Evacuated Tube Thermal + Flat Plate Thermal	12%
CSP + Flat Plate Thermal	10%
Flat Plate Thermal + PV	7%
CSP + PV	6%
CSP + Evacuated Tube Thermal	5%
<b>Sum</b>	<b>100%</b>

Table 17 shows that the most commonly used solar collector among participants using solar energy was Photovoltaic (PV), reported to be at 28%. This was followed by Flat Plate Thermal systems (17%) and Concentrating Solar Power (CSP) systems (15%). Combinations of Evacuated Tube Thermal and Flat Plate Thermal (12%), CSP and Flat Plate Thermal (10%), and Flat Plate Thermal and PV (7%) were also used. Smaller shares reported using CSP with PV (6%) and CSP with Evacuated Tube Thermal (5%).

Lastly, 100% of participants had reported that environmental and energy management standards through ISO14001 and ISO50001 were in place. Next, Figure 19 presents the assessed industrial acceptance of ASTEP's technical compatibility.

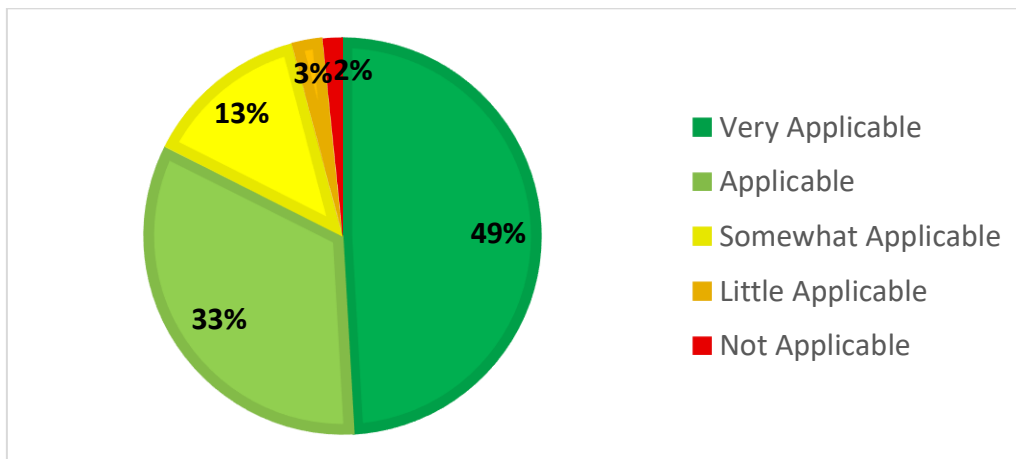


Figure 19: Industrial Acceptance Level for ASTEP's Technical Compatibility into Processes

It can be seen in Figure 19 that 82% of the industry has shown positive acceptance of ASTEP's operating temperature and thermal output, perceiving it as highly applicable for their current industrial processes. This was supported by additional qualitative comments made in the survey, which mentioned that ASTEP was highly compatible with annealing, tempering, stress relieving, preheating, and sterilisation processes within the 150–400°C temperature range. Participants in their comments (68%) also praised ASTEP's continuous operation capabilities due to its Thermal Storage system. These results are heavily corroborated by the study of

Kumar et al. (2022), who had found that the Fresnel solar collectors used by STE systems are easily capable of providing up to and above 400°C for processes similar to ones reported in this study. Another study by Qamar et al. (2022) further supports this by showing 127 textile industry stakeholders express strong confidence in STE systems for processes such as preheating, fabric processing, dyeing, sterilisation and drying within the 150–400°C range. Their results showed that industries perceived the thermal output as reliable and remarkable, perfectly matching their operational heat requirements of processes.

To build on this, positive acceptance for ASTEP's technical performance in the current scenario was mostly shown by the aerospace industry (92%), metallic industries (89%), automotive (86%), paper & pulp (84%), chemical & petrochemical (76%), and food & beverage (74%). This result is validated by the studies of Verma et al. (2024), who found that metallic, automotive, and food and dairy industries had found similar STE technologies to be highly applicable for their operating temperatures. Further supporting this, Sankar & Muniraja (2020) conducted a case study on industrial companies in India and found that aerospace, automotive, and metallic industries showed high acceptance for STE systems, citing alignment with their high-temperature process requirements and long-term operational feasibility. Their findings highlighted that industrial acceptance is positively influenced by STE's strong compatibility with heat-intensive processes for metal forging, casting, smelting, and annealing up to and above 400°C.

Furthermore, a large amount of large (84%), and medium-sized (87%) companies had shown positive acceptance as compared to small (70%) and micro-sized (63%) companies who had shown positive acceptance, a supported finding by Qamar et al. (2022), who found that larger companies showed strong industrial acceptance with the deployment of STE systems. Schriever & Halstrup (2018) further supported this trend by observing similar patterns in Germany's automotive industry, where large companies showed the highest acceptance STE adoption, driven by the large operating temperature range of STE systems for high-temperature in-house processes and the potential of STE to reduce carbon emissions across their operations.

A few participants from the Mining industry (13%) expressed opportunities to improve the compatibility of ASTEP to their process requirements, with the study of Akofa & Ali (2025) finding that these industries required temperatures in the range of 500-600°C, exceeding the capability of ASTEP at 400°C. They found that further investment to scale up STE's thermal output is needed to improve compatibility with the industry's ore smelting processes. Next, Figure 20 presents the assessed industrial acceptance of ASTEP's costs.

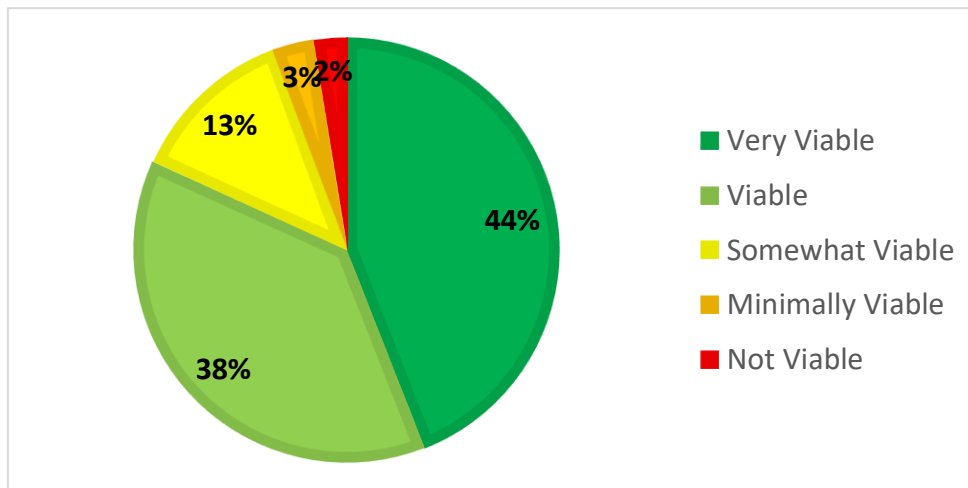


Figure 20: Industrial Acceptance Level of ASTEP's Costs for Operating Their Processes

Figure 20 shows that 82% of the industry found ASTEP's costs to be viable, with qualitative participant comments (74%) demonstrating strong interest in ASTEP's financial benefits, including its potential to reduce annual energy bills, provide relief from carbon taxes, and increase production volumes. These comments cited ASTEP's ability to lower operational expenses and reduce taxes due to carbon emissions. These findings are supported by Kumar et al. (2022), who also identified that STE systems offer financial savings and carbon tax advantages for industries while supplementing additional energy for higher production volumes. This is further reinforced by Elakanti & Singh (2021), whose survey revealed that the industry perceived STE systems to be a cost-effective solution due to their good return on investment and long-term energy cost reductions.

Furthermore, ASTEP study found that large (82%) and medium-sized (86%) companies showed that highest industrial acceptance due to how they possess the financial capabilities, budgets, and resources to manage the upfront costs as supported by Kumar et al. (2022). These authors further elaborate that larger companies perceive STE systems as economically viable due to the expected returns on their investment from energy savings and relief from carbon taxes after installation.

On the other hand, only 45% of small and 37% of micro-sized companies found ASTEP's costs to be viable. Qualitative comments revealed that this was primarily due to high upfront costs exceeding their budgets and investment capacity, highlighting a clear opportunity to introduce financial subsidies tailored for small-scale applications of ASTEP. This finding is supported by Qamar et al. (2022), who emphasised that investment in subsidies is essential for promoting STE adoption among small companies to increase their purchasing capabilities and hence improve their perception of STE's installation costs. Their study showed that investment into low- interest loans and government grants would support STE adoption among smaller

companies. Next, Figure 24 presents the assessed industrial acceptance of Acceptance of ASTEP's Impact on Standards.

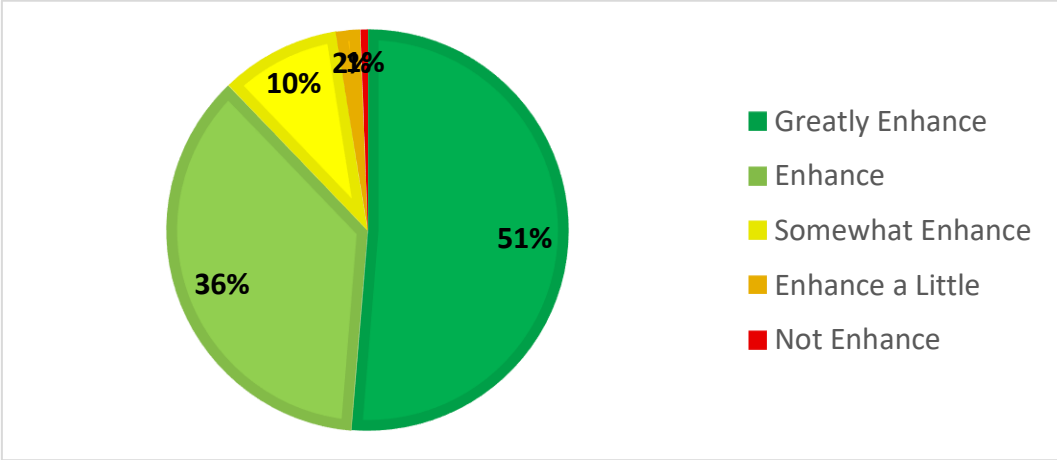


Figure 21: Industrial Acceptance Level of ASTEP's Impact on Standards and Compliance

It can be seen in Figure 21 that 87% of the industry anticipated that applying ASTEP would positively enhance their compliance with current environmental and energy standards; ISO14001 and ISO50001, respectively. This was further evidenced by qualitative comments (72%) mentioning how ASTEP would enhance industrial accreditation to ISO 14001, ISO50001 and Quality Management Standard ISO 9001. It was further found that this positive view was held amongst 77% of large, 81 % of medium, 74% of small, and 69% of micro sized companies. This increased compliance to standards was cited to be attributed to ASTEP's carbon tax relief and energy savings in participant comments. This finding is corroborated by Kals (2015), who found that STE contributes to energy efficiency and emissions reduction in industries of all sizes, leading to greatly improved industrial compliance to ISO 14001 and 50001 standards. Olabi et al. (2022) further explain that integrating STE systems enhances compliance by enabling industries to meet the regulatory expectations set by accrediting bodies.

### 6.1 Chapter Summary

In summary, this chapter assessed the industrial acceptance of ASTEP across industries, identifying high levels of acceptance across technical compatibility, cost viability, and impact on standards. The findings show that ASTEP is widely perceived as technically compatible with industrial processes operating within the 150–400°C range, with strong alignment observed in automotive, metallic, aerospace, and related industries. Cost acceptance was also found to be high among large and medium-sized companies, while smaller companies exhibited lower acceptance due to financial constraints associated with upfront investment. Furthermore, the majority of participants agreed that ASTEP would enhance compliance with environmental and energy standards, particularly ISO14001 and ISO50001.

# Chapter 7: Assessment of ASTEP's Social Acceptance

This chapter presents the results of the assessment of ASTEP's social acceptance. First, figure 22 reports the percent breakdown of the regions where the surveyed general public originated from, obtained from 279 participants, which is sufficient as per Memon et al. (2020).

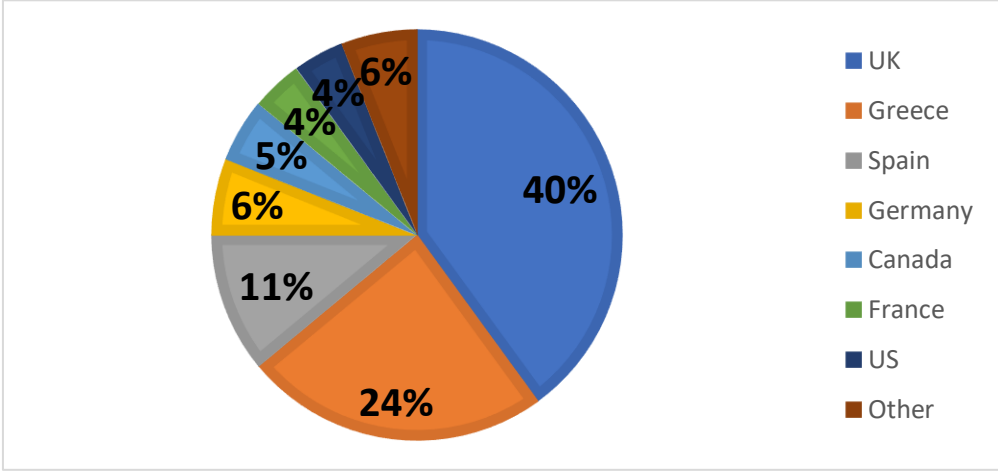


Figure 22: % Breakdown of Regions of Origin Among Surveyed Public Participants

Figure 22 shows that the majority of participants (40%) originated from the UK, while 45% of participants originated from an EU member; Greece (24%), Spain (11%), Germany (6%), France (4%). Furthermore, 5% originated from Canada and 4% from the US, while other regions (6%) included Argentina, Japan, and India. This means that 64% of the sample is concentrated within UK and Greece, with 85% participants originating from the continent of Europe. After critically evaluating the result, it can be deduced that there the representation of the global public has been potentially limited, as the findings predominantly reflect perspectives from Europe rather than a globally distributed population. Public perspectives from other regions such as Asia, the Middle East, and Africa could be incorporated to improve the global distribution of the findings. Such further assessment is detailed in future works (section 9.2).

However, within the context of social acceptance studies (Jung et al. 2016, Elmustapha et al. 2018), such discrete samples concentrated within a select number of regions are commonly used to capture early public perceptions of emerging technologies. Therefore, the sample remains valuable and informative for identifying emerging trends in public acceptance of ASTEP.

Next, Figures 23-26 show the observed social acceptance levels under each of the four categories from Table 8.

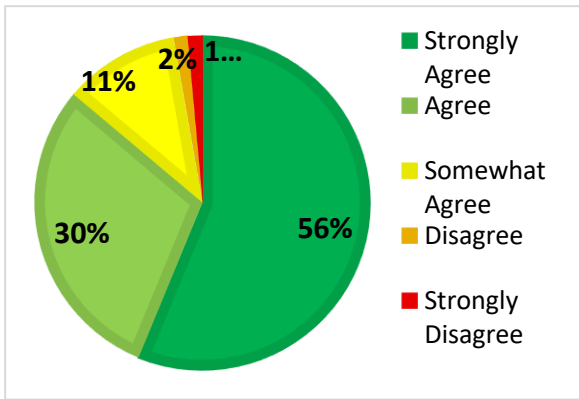


Figure 23: Level of Public Agreement with ASTEP's Environmental Benefits

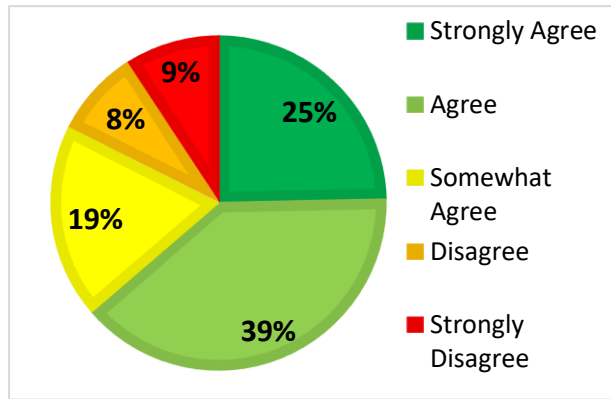


Figure 24: Level of Public Agreement with ASTEP's Integration

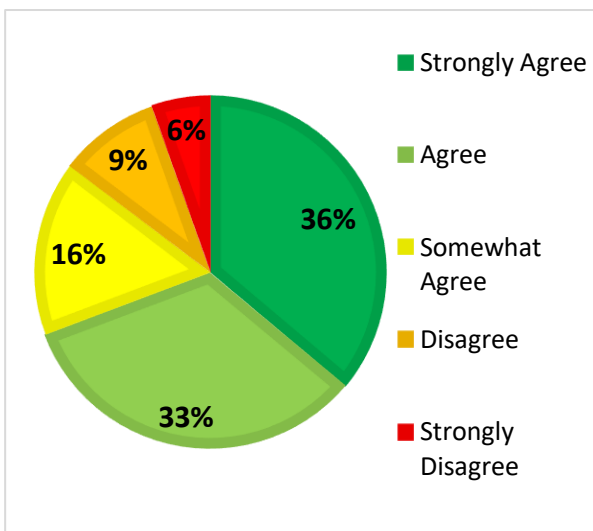


Figure 25: Level of Public Agreement with Consuming ASTEP's Products

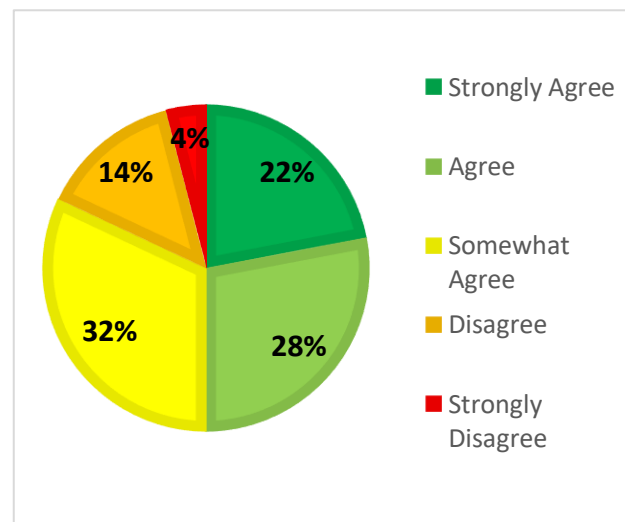


Figure 26: Level of Public Agreement with Continual Investment into Similar STE Systems

It can be seen from Figure 26 that 56% of participants selected that they Strongly Agree, with 30% selecting Agree and 11% choosing Somewhat Agree with ASTEP's environmental benefits, totalling to 97% of the general public who agreed. Only a small proportion reported Disagree (2%) or Strongly Disagree (1%), indicating a high overall level of public acceptance of ASTEP's environmental contributions to decarbonisation and clean energy in the community. This is reinforced by qualitative feedback, where 84% of participant comments expressed strong agreement with integrating ASTEP systems to support carbon neutrality. These positive comments align closely with Yuan et al. (2011) in their study for the general public in China, who found that 94% of participants agreed that STE's impact in reducing climate change, and with Sovacool & Ratan (2012), who reported similar agreement levels (over 90%) among the general public in Germany with STE's influencing in reducing industrial emissions. Moreover, Smith & Jenkins (2021) reported that 60% of residents living near solar

thermal installations agreed with STE's environmental benefits, corroborating the finding of Nguyen et al. (2020).

Next, Figure 27 shows that 25% of participants selected that they Strongly Agree, 39% also Agreed, and 19% selected Somewhat Agree with ASTEP's integration in industrial settings, totalling 83% of the general public who agreed. Only 8% and 9% reported Disagree or Strongly Disagree, respectively. This aligns with qualitative responses, where 68% of participants stated they strongly supported ASTEP adoption in food, textile, and metallic industries. This aligns with the findings of Carmona-Martínez et al. (2021), who observed in their study that public backing for STE deployment in industries was strong. Becker et al. (2023) also reported similar trends, noting that 85 % of participants in their study supported STE adoption in industrial zones due to its role in decarbonising industrial heating.

Figure 28 shows that 36% of participants indicated they Strongly Agree, while 33% selected Agree and 16% Somewhat Agree with consuming products manufactured from supply chains applying ASTEP, totalling to 85% of the general public who agreed. Only 9% selected Disagree and 6% Strongly Disagree. Qualitative feedback supported this, with 65% of participant comments indicating how consumers agree to shift purchasing habits toward goods produced with clean energy after ASTEP's implementation, and how they will be happier once goods are labelled as eco-friendly. Jung et al. (2016) similarly found that eco-labelling of STE-produced products led over 80% of consumers in Finland to express stronger acceptance, while Pagliuca et al. (2022) documented that in Italy and Spain, the general public was willing to adjust future purchasing preferences in favour of goods made with STE's clean energy. Anderson & Tushman (2018) had also observed that over 70% of consumers reported higher willingness to buy goods labelled as produced with clean energy, while Huang & Rust (2018) demonstrated that eco-labelling can increase purchase probability by up to 25%.

Lastly, Figure 29 shows that 22% of participants Strongly Agreed, while 29% Agreed and 32% Somewhat Agreed with continual government support through investment and educational programmes for STE systems similar to ASTEP, totalling to 82% of the general public who agreed. A total of 18% expressed opposition, with 14% selecting Disagree and 4% Strongly Disagree. Some participants (54%) showed support for sustained public backing, as further supported by comments praising large EU initiatives to fund STE development. Comments made by 46% of participants delineated the need for more cost-effective investment strategies and more educational programmes which educate the general public about the environmental benefits of STE integration into industrial processes. Thompson et al. (2020) reported that 80% of participants support funding for solar energy projects, emphasizing that the public views that subsidies are necessary to reduce initial cost barriers. Segreto et al. (2020) had also similarly found that public support was conditional on sustained financial incentives, and Stigka et al.

(2014) further reported that the general public desires more investment in education programmes that showcase STE applications and their impacts on local air quality.

## 7.1 Chapter Summary

In summary, this chapter assessed the social acceptance of ASTEP among the general public, revealing high levels of agreement for environmental benefits, industrial application near communities, consumption of ASTEP-produced goods, and government support. The findings indicate strong acceptance of ASTEP's environmental contributions, with similarly high support for its application in industrial processes and the consumption of goods produced using clean energy. Public willingness to support continued government investment and educational initiatives was also evident through qualitative feedback.

# Chapter 8: Assessment of Future Social Impact & Industrial Acceptance

This section presents the future predictions of social impact and industrial acceptance of ASTEP over a 10-year future time domain using the dynamic model developed in section 3.8. Section 8.1 presents the future predictions of social impact over the 10-year time frame, and section 8.2 presents the future predictions of industrial acceptance.

## 8.1 Future Predictions of Social Impact

Figure 27 shows future predictions of social impact in the TS, WI, and PD categories, considering the responses of 50 participants which is sufficient as per Memon et al. (2020).

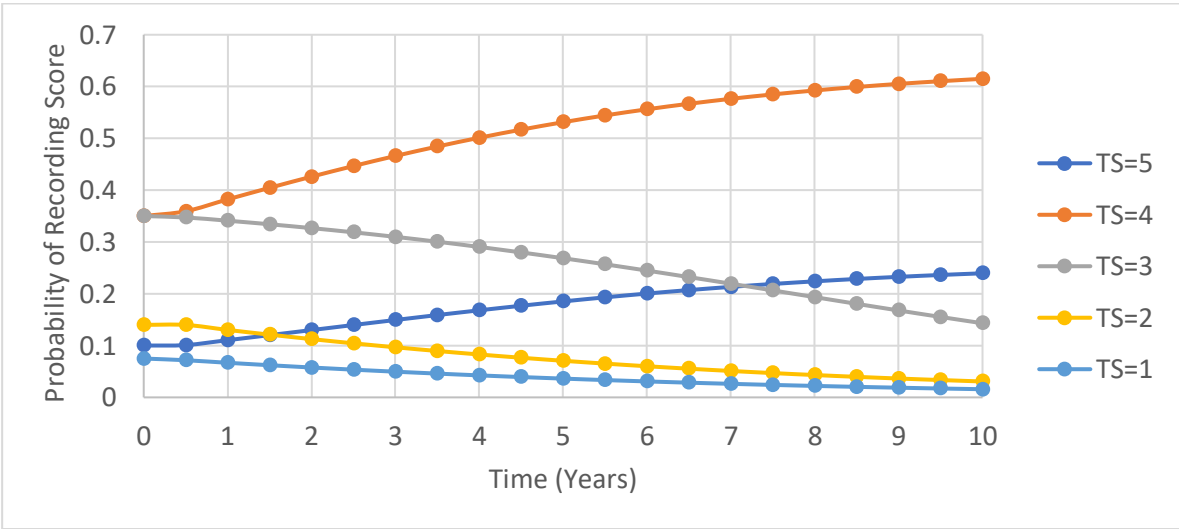


Figure 27: Projected Probabilistic Future TS Scores Over 10 Years Time from Investment in PT & EE

Figure 27 shows that the probabilistic satisfaction scores for TS over a 10-year period experienced remarkable improvements across positive satisfaction rankings due to an incremental +5% investment per annum into PT and EE. Both of these influencing investments were found to be statistically significant; PT was associated with a correlation coefficient of 0.54 ( $p < 0.05$ ) and EE with a coefficient of 0.48 ( $p < 0.05$ ), validating that both had a statistically significant influence on future predictions in TS. The probability of achieving the highest satisfaction score (TS = 5) increased from an initial probability of 0.1 to 0.3 by the end of the 10 years. The probability of achieving a score of 4 also experienced a significant increase, rising from 0.35 to 0.6.

This revelation is strongly corroborated in multiple literature works. Louie, E.P. and Pearce, J.M. (2016) in their study covering the transition to solar energy from coal power in the United States found that investments in employee training over a time period of 9 years had the most

substantial effect on employee satisfaction. They stated how providing well-designed training programs for solar energy design and prototyping was directly linked to improved job satisfaction overtime. Such findings directly align with the ASTEP study over the decade, as employee satisfaction scores were observed in Figure 27 to increase in this time frame. Shazadi et al. (2017) expanded on these findings in a longitudinal study, showing that incremental investments in high-performance work practices, including performance-based rewards for employees, team-building workshops, job rotation, and flexible work schedules, markedly enhanced job satisfaction and employee commitment over time. These outcomes closely parallel the ASTEP study, where an increase in the probability of achieving the highest training satisfaction score was observed when similar investments were allocated to PT and EE as seen in Figure 27. Similarly, Çetin & Eğrican (2011) highlighted that financial investments into CSP-focused training programmes, specifically for thermal storage integration, greatly improved employee satisfaction over a 10-year period by increasing perceived competence and support. These results were further verified by Arthur et al. (2003), who found that investments in training resources in manufacturing settings significantly boosted operational efficiency and employee satisfaction, leading to a decrease in the observed frequency of negative satisfaction scores. Hence, as validated by the literature, an increase in investment into PT and EE was shown to influence training satisfaction toward higher scores over the decade, associated with reducing dissatisfaction and influencing better overall satisfaction levels among employees.

Next, Figure 28 depicts the probabilistic satisfaction scores for WI over 10 years given an incremental increase in investment of 5% per annum into AT.

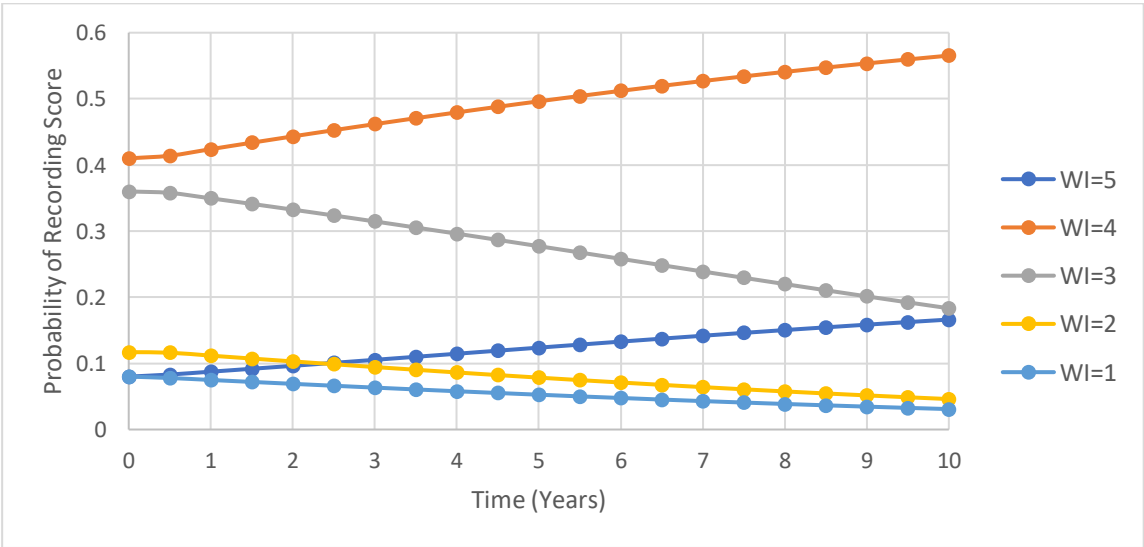


Figure 28: Projected Probabilistic WI Scores Over 10 Years Time from Investment in AT & TA

Figure 28 shows that the probabilistic satisfaction scores for WI over a 10-year period moderately improved across positive satisfaction rankings due to an incremental +5% per annum investment into AT. Such impact was observed due to a correlation coefficient of 0.63 between WI and AT at a high statistical significance of  $p < 0.05$ . It can be observed that the probability of the highest satisfaction score (WI = 5) increased from 0.15 to over 0.50. The probability of achieving a score of 4 also improved from 0.25 to 0.50. On the other hand, the probability of the lowest satisfaction score (WI = 1) decreased from 0.15 to 0.05. Similarly, the probability of WI = 2 fell from about 0.30 to nearly 0.10, and WI = 3 decreased from 0.35 to 0.25.

These improvements in satisfaction with WI overtime corroborate with findings from the literature as supported by Kramer & Son (2016). They showed that such investments into the management of working hours and task distribution improved job satisfaction and imposing impact on employees over a time of 18 years. Their study showed that reducing excessive workloads and even task allocation across employees improved employee satisfaction. Building on these findings, Garmendia et al. (2021) showed that HRM practices in the form of fair task distribution and employee input boosted job satisfaction in their longitudinal study spanning 4 years, involving 6,000 employees across 104 industries. They found that overtime investments into creating balanced workload systems improved both morale and productivity. This aligns with the ASTEP results, where investments in improved work package allocation and fairer distribution of working hours were associated with a rise in satisfaction over the decade as seen in Figure 28.

Next, Figure 29 illustrates the probabilistic satisfaction scores for PD over the same 10-year period following an incremental 5% investment increase per annum.

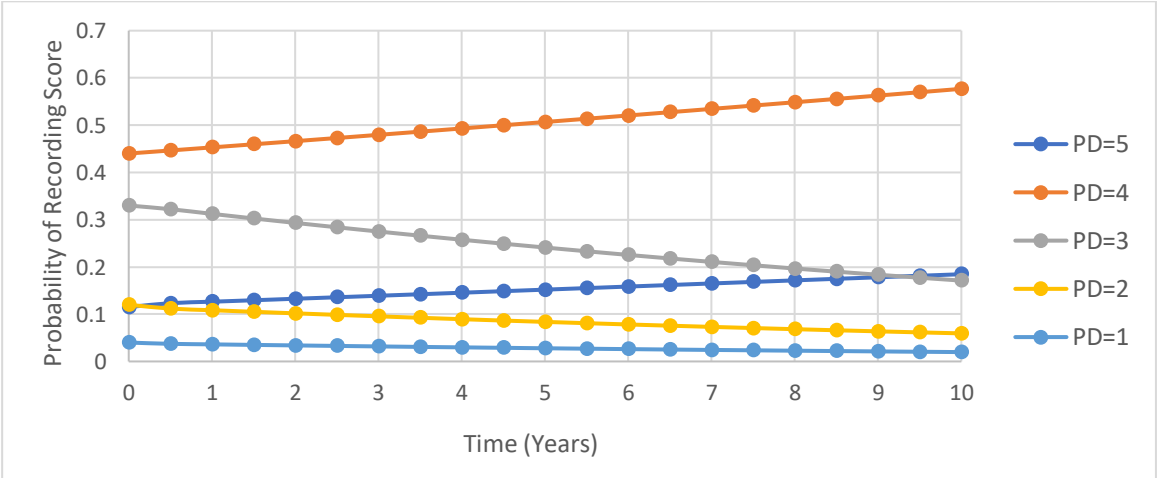


Figure 29: Projected Probabilistic PD Scores Over 10 Years Time from Investment in PPD & EE

Figure 29 shows that the probabilistic satisfaction scores for PD over a 10-year period improved across positive satisfaction rankings due to an incremental +5% investment into PPD. This association was found to be due to a correlation coefficient of 0.81 at a high statistical significance of  $p < 0.05$ . It was observed that the probability of employees achieving the highest satisfaction score (PD = 5) increased from 0.20 to 0.50. Similarly, the probability of a score of 4 increased from 0.30 to 0.45. Meanwhile, the probability of the lowest satisfaction score (PD = 1) decreased slightly, from 0.10 to 0.05. The probability for PD = 2 dropped from 0.20 to 0.10, and the score of PD = 3 likewise also dropped from 0.40 to 0.25.

These findings in the PD category align with those found in the literature. For example, Silvester et al. (2024), found a strong correlation between increased investment in professional development resources and improved satisfaction among educators, with targeted training leading to better teaching performance and higher job satisfaction over a 7-year time frame. Parboteeah et al. (2005) elaborated on these resources in their study consisting of 949 R&D engineers, which included certification programs for employees, career support in the form of CV building workshops and mentoring schemes. Their findings showed that sustained investment in these resources enhanced employee satisfaction over a 5-year period, supporting the trends observed in Figure 29 of the ASTEP study where similar investments in PPD covering these exact resources influenced positive employee satisfaction. Furthermore, Lerche et al. (2025) found in their 4-year longitudinal analysis involving 3,028 academic employees that investments into professional development schemes for academic employees, such as in teaching workshops, participation in grant-writing seminars, collaboration in other research projects, and engagement in international conferences, improved employee satisfaction. These findings are further substantiated by Pignata et al. (2016), who revealed in their multi-year longitudinal study that access to professional development opportunities such as grant writing and collaborative research with other institutes enhanced academic staff's job satisfaction. These trends verify the ASTEP study, as incremental investment into professional development resources for ASTEP's academic staff influenced stronger employee satisfaction as evidenced in Figure 29.

## 8.2 Future Predictions of Industrial Acceptance

Figure 30 shows the future predictions of industrial acceptance for the TC category considering all 318 responses from the industry, which is sufficient data as per Memon et al. (2020).

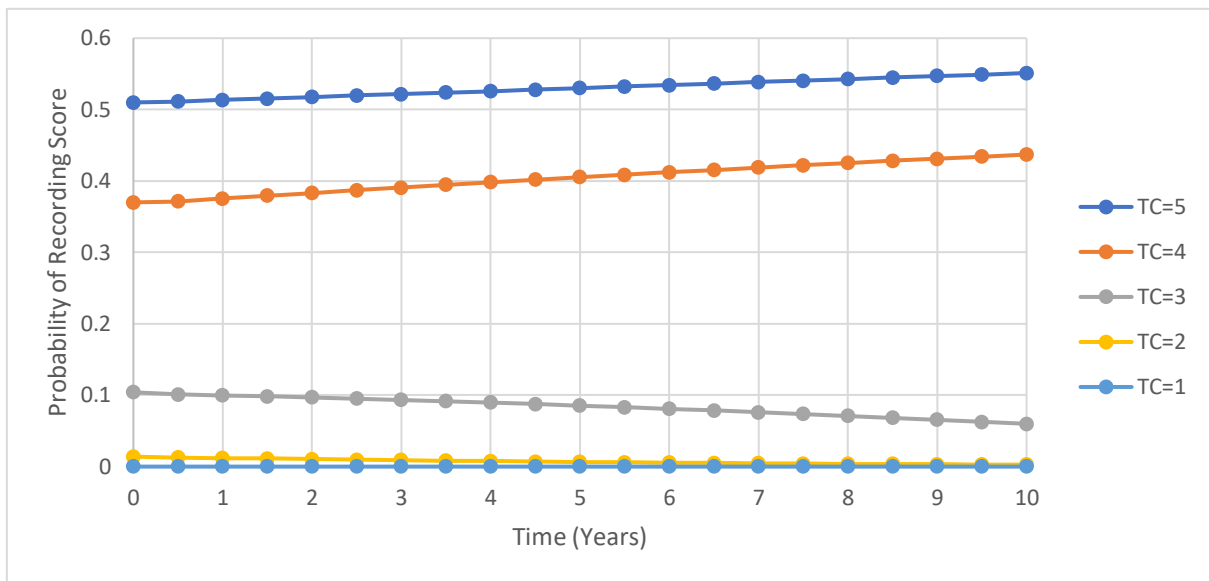


Figure 30: Projected Probabilistic TC Scores Over 10 years Time from Investment in TE & SO

Figure 30 shows that the probabilistic satisfaction scores for TC over a 10-year period marginally improved across positive satisfaction rankings due to an incremental +5% investment per annum into TE and SO. Both of these influencing investments were found to be statistically significant; TE was associated with a correlation coefficient of 0.72 ( $p < 0.05$ ) and EE with a coefficient of 0.66 ( $p < 0.05$ ), validating that both had a statistically significant influence on future predictions in TC. It can be observed that the probability of the highest acceptance score (TC = 5) marginally increased across all industries from 0.51 and to 0.55 by Year 10. Similarly, the next highest score (TC = 4) saw a modest probabilistic rise from 0.37 to 0.44 over the same period, indicating marginal gains in industrial acceptance over the next 10 years for ASTEP’s technical compatibility. Meanwhile, the lower acceptance scores (TC = 3) declined from 0.10 to 0.06, and the lowest scores, TC = 2 and TC = 1, diminished to negligible levels indicating that negative acceptance diminishes over the decade.

A more detailed analysis for the TC category indicated an increase in the probability of achieving a high acceptance score (TC = 4 or 5) among small and micro-sized companies. This probability was derived by aggregating the probabilistic outcomes for TC = 4 and TC = 5 for each company size and simulating these values over time, as illustrated in Figure 31.

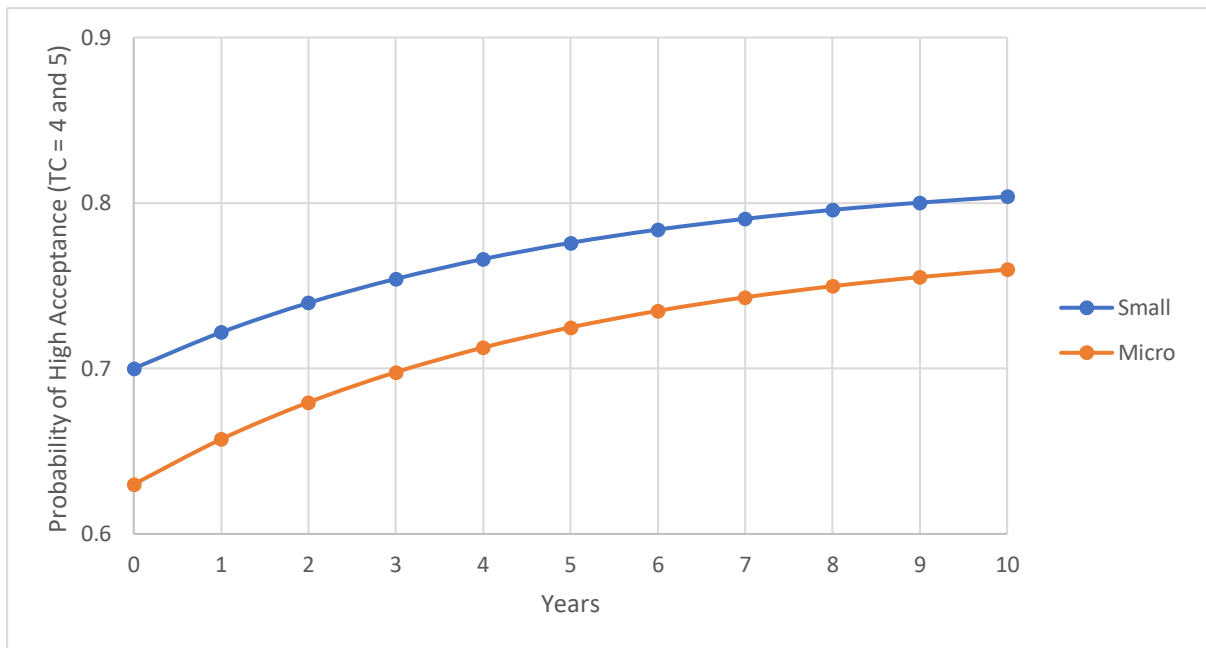


Figure 31: Projected High Acceptance Probabilities over 10 Years for TC Among Small & Micro-Sized Companies

Figure 31 presents the projected probability of achieving a high acceptance score (TC = 4 or 5) for small and micro-sized companies in the TC category. For small companies, this probability increased from 0.70 at Year 0 to 0.80 by Year 10, while micro companies increase from 0.63 to 0.76 over the same timeframe. These increases associate with better perceived technical compatibility of the ASTEP system amongst small and micro sized companies, which were found to be influenced by targeted investments aimed at enhancing ASTEP's thermal output and expanding its operational temperature range. Supporting works from the literature identified the exact types of such influencing investments. Ali et al. (2022) observed that allocating investments directed toward technological diffusion to increase the thermal output of STE technologies, similar to ASTEP, substantially increased industrial acceptance particularly amongst small and micro-sized companies. Popp et al. (2024), expanded by stating that these investments were specifically tailored to train and upskill employees involved in the development of STE systems, ensuring that employee technical knowledge and innovation are effectively enhanced. Such investments explain the upward trend in future industrial acceptance of STE's thermal compatibility observed in the ASTEP study, as industries are more likely to adopt more technologically advanced STE systems that deliver higher thermal output and expanded operating temperature ranges. Voznyak et al. (2023), further highlighted additional types of investments that influence increased industrial acceptance of STE systems, particularly those involving supplementary technical components for enhancing thermal efficiency. These components include high-absorption surface coatings and advanced piping insulation, while Rosales-Pérez et al. (2023) found that the use of hybrid solar-thermal and photovoltaic systems further enhanced industrial acceptance. Such investments that improve

STE efficiency support increase in future industrial acceptance identified in the ASTEP study due to how the system will be seen as more reliable for industrial processes.

Next, Figure 32 shows ASTEP’s future probabilistic industrial acceptance for the next category, AC, considering all industrial participants.

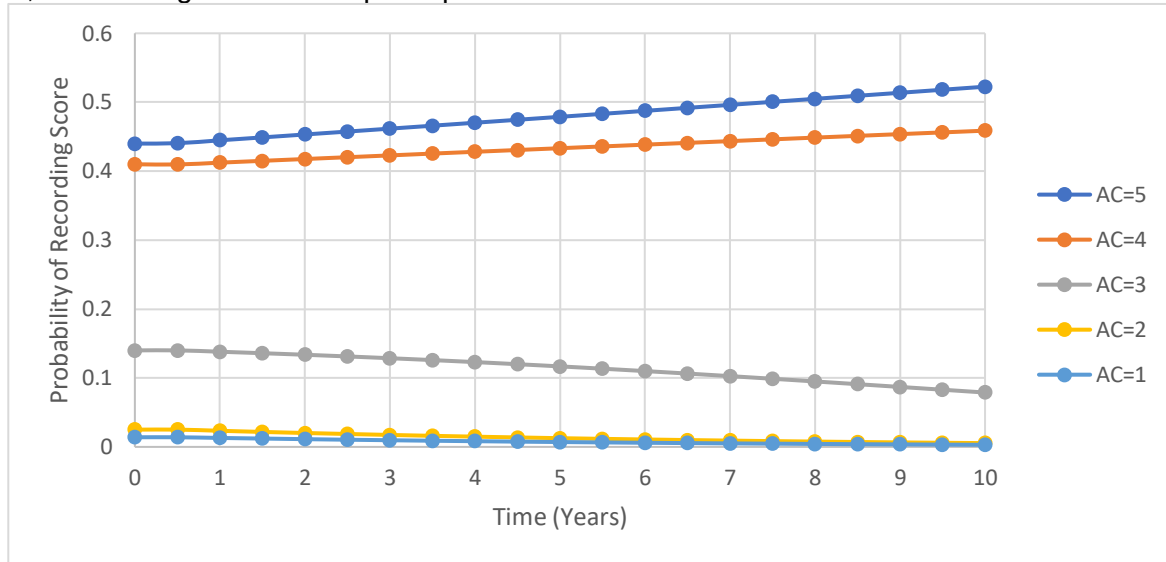


Figure 32: Projected Probabilistic AC Scores Over 10 Years Time from Investment in CS & LS

Figure 32 shows that the probabilistic satisfaction scores for AC over a 10-year period modestly improved across positive satisfaction rankings due to an incremental +5% investment per annum into CS and LS. Both of these influencing investments were found to be statistically significant; CS was associated with a correlation coefficient of 0.68 ( $p < 0.05$ ) and LS with a coefficient of 0.45 ( $p < 0.05$ ), validating that both had a statistically significant influence on future predictions in AC. It can be observed that the probability of the highest acceptance score (AC = 5) increased from 0.44 to 0.52 by Year 10. Similarly, the second-highest score (AC = 4) also increased from 0.41 to 0.46. In contrast, the probability of achieving a mid-tier satisfaction (AC = 3) dropped from 0.14 to 0.079, and lower scores reduced further: AC = 2 dropped from 0.025 to 0.006, AC = 1 dropped from 0.014 to 0.003. Further analysis revealed increases in industrial acceptance amongst small and micro-sized companies for the AC category. This was determined by aggregating the probabilities of achieving AC = 4 and AC = 5 for each both sizes and simulating these combined probabilities over time, as presented in Figure 33.

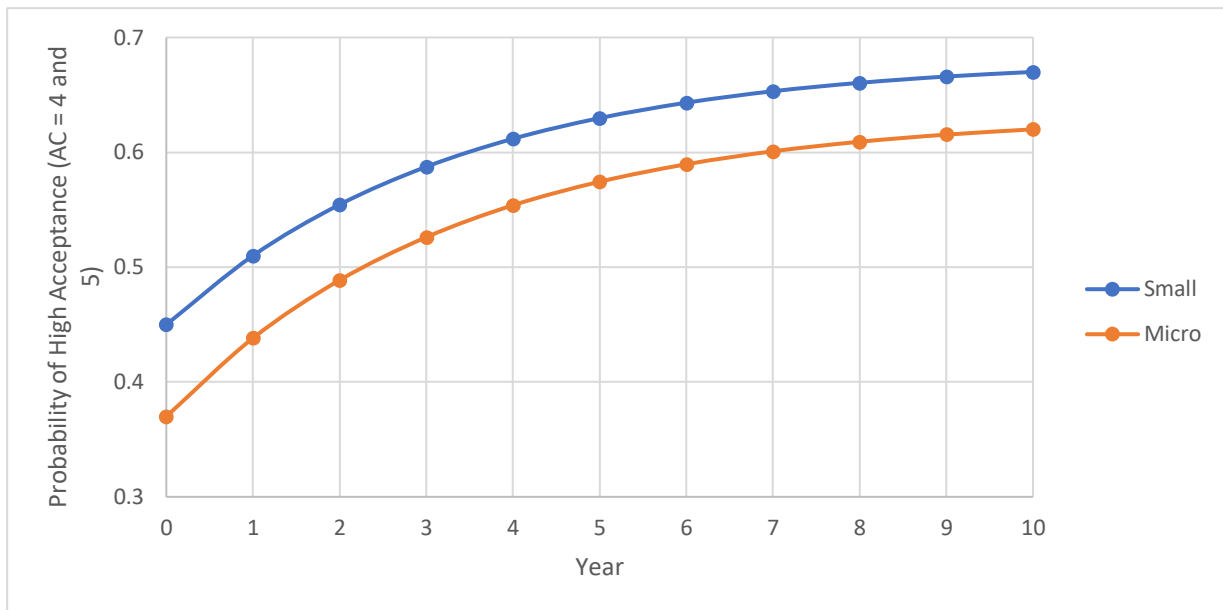


Figure 33: Projected High Acceptance Probabilities Over 10 Yrs for AC Among Small & Micro-Sized Companies

Figure 33 presents the projected probability of achieving a high acceptance score (AC = 4 and 5) for small and micro-sized companies in the AC category, showing an increasing trend over the 10-year period. For small companies, this probability increased from 0.45 at Year 0 to 0.67 by Year 10, while micro companies increased from 0.37 to 0.62 over the same timeframe. These increases are associated with better perceived costs of adopting the ASTEP system amongst smaller companies, which were found to be influenced by increased investment into enhancing ASTEP's financial viability and reducing its upfront costs as further detailed in the literature. Magu (2019) had found that investment into providing financial incentives in the form of cost subsidies and concessional loans for small companies greatly increased the acceptance and adoption of similar STE systems to the ASTEP. Building on this, Xu et al. (2020) reported that targeted low-interest concessional loans for small companies, designed with reduced interest rates and extended repayment terms to ease the operating and maintenance costs of newly developed STE systems, led to over a 40% increase in STE adoption over a 5-year period particularly amongst small companies. This finding corroborates with the improvements in industrial acceptance of small and micro-sized companies found in the ASTEP study, climbing to 35% by 5 years and up to 50% over 10 years. Ali et al. (2022) and Asante et al. (2021) elaborated that investments into governmental subsidies, which are lump-sum payments issued upfront under transition schemes towards STE systems, considerably improved the industrial acceptance of small and micro-sized companies by directly offsetting initial installation expenditure. Such future trends in increasing industrial acceptance amongst small and micro-sized companies explain the findings made in the ASTEP study in Figure 36, supporting that targeted investments into low-interest loans and subsidies for small and micro-sized companies influence better industrial acceptance.

### 8.3 Empirical Groundings and Assumption of the Model

The empirical grounding of the dynamic model is based on statistically validated ( $p < 0.05$ ) correlation coefficients linking investment in HRM resources to empirically observed social impact data (Section 3.5), and investment in the technical and financial performance of the STE system to empirically observed industrial acceptance data (Section 3.6). These correlation coefficients are incorporated into the OLR model, adapted from Poston et al. (2023), to further develop a probabilistic model appropriate for social data as performed in section 3.8. To initialise the model, the empirical data presented in Sections 3.5 and 3.6 are used as baseline conditions to generate the initial probability distributions. The model is then extended into a temporal domain by applying the same coefficients at successive time steps over a 10-year horizon, subject to an annual investment increase of 5%, with time represented through a time-step-based independent variable. This extrapolation is performed by applying the incremental 5% increase in investment at each time step and recomputing the probability distributions using the correlation coefficients and the initial empirical dataset. The resulting probabilities from one time step then inform the next iteration, establishing a feedback loop in which successive predictions evolve as a function of prior scores and progressively increasing investment inputs. Thus, the model generates the numerical likelihood of observing scores from 1 to 5 for social impact and industrial acceptance at each time step, outputting the evolving distribution of low, medium, and high scores as investment levels increase over the decade.

The core assumption of this model is that estimated relationships remain stable over time and that the selected incremental investment pathways are sustained, excluding variations in organisational behaviour, economic conditions, competition from other renewable energy systems, and employee turnover. This assumption is justified in the statistically significant relationships identified from the present-day dataset, which accurately capture the influence of targeted investments pathways on social impact and industrial acceptance outcomes. By holding these coefficients constant, the model isolates the effect of incremental investment pathways and enables a controlled evaluation of how such interventions influence probability transitions over time. Such justification is corroborated by longitudinal and regression-based studies by Shazadi et al. (2017), who also applied fixed empirical relationships to evaluate social impact over time under controlled conditions. Louie and Pearce (2016) similarly employed stable relationships between targeted investments and employee satisfaction within a solar energy system context to assess how incremental investments influence satisfaction outcomes over multiple years.

This assumption may weaken if the underlying relationships deviate due to external influences not captured within the model framework, such as economic fluctuations, employee turnover,

and competition from alternative renewable technologies. Xu et al. (2020) further discussed that economic and policy fluctuations can disrupt projected performance trajectories in dynamic energy models, leading to deviations from expected growth patterns and increased variability in outcomes. Similarly, Ali et al. (2022) highlighted that organisational factors such as workforce changes and disruptions in project funding can delay planned investments, prolonging the expected positive social impact shown through forecast models. Asante et al. (2021) further highlighted that competition from alternative renewable energy technologies can negatively impact projected adoption industrial by diverting investment, shifting industrial preference, and reducing the relative attractiveness of STE systems.

Sensitivity to these external influences is evidenced in the literature, where Solinger et al. (2021) and Çetin & Eğrican (2011) varied correlation coefficients of longitudinal extrapolations by  $\pm 5\%$  to assess the stability of predicted social impact outcomes. Their findings showed that the correlative relationships between HRM resources and employee satisfaction remained stable and statistically significant over a decade. They elaborated that sustained investments in HRM continued to generate improvements in social impact over 10 years, validating that the overall trends observed in the ASTEP study still stand after sensitivity consideration. Kumar et al. (2022) further demonstrated the stability of industrial acceptance outcomes over a 10-year period under sustained technological and financial investment, reporting substantial positive growth despite fluctuating market conditions and competition from alternative renewable technologies. Hence, the core assumption underpinning the dynamic model in the ASTEP study remains valid, indicating that the model is robust in predicting future social impact and industrial acceptance outcomes.

#### 8.4 Uncertainty of the Dynamic Model

A compounding effect of uncertainty was observed within the dynamic model, whereby the uncertainty associated with predicted probabilities increased progressively over the temporal domain. This is reflected by progressively widening uncertainty intervals, with deviations increasing from 1.0% at Year 1, to 1.2% at Year 2, 1.5% at Year 3, 2.0% at Year 4, 2.2% at Year 5, 2.5% at Year 6, 3.0% at Year 7, 3.5% at Year 8, 4.0% at Year 9, and reaching 5.0% at Year 10. The uncertainty originates from the estimation error inherent in the correlation coefficients defined in Eqn. 9 (Section 3.8), which, when iteratively applied across annual time steps, propagate through successive probability transitions, leading to a cumulative and compounding effect over the temporal domain. This results in progressively wider uncertainty intervals and a reduction in predictive accuracy in later years of the forecast in the dynamic models of the ASTEP study. Such compounding uncertainty patterns are consistent with established findings in longitudinal and predictive modelling studies (Louie & Pearce 2016;

Shazadi et al. 2017), reinforcing the observed widening of uncertainty intervals, as the model extrapolates further into the future.

The same authors explain that the increasing magnitude and progression of uncertainty over the 10-year horizon remains within acceptable bounds of  $\pm 7\%$  relative to the baseline predictions, suggesting that the model retains reasonable stability over this period. This bounded uncertainty justifies that the ASTEP findings made from the dynamic model remain robust and provide reliable guidance for forecasting strategic resource allocation.

## 8.5 Chapter Summary

In summary, this chapter assessed the future social impact and industrial acceptance of the ASTEP system over a 10-year temporal domain using a developed dynamic model, revealing progressive improvements in employee satisfaction and industrial acceptance under sustained investment pathways. The findings showed that incremental investment in HRM resources positively influenced the probability of achieving higher employee satisfaction with their training, while technical enhancements and financial support for STE adoption increased the acceptance of micro and small sized companies in the industry. Strong alignment with longitudinal studies in the literature further validated the observed trends in social impact and industrial acceptance. The chapter also clarified the model's empirical grounding, discussed and justified assumptions, and outlined the uncertainty of the model.

## Chapter 9: Conclusion

This thesis investigated the social sustainability of the ASTEP system by using a S-LCA framework to collect and assess data for social impact across the product life cycle. Further evaluation of the influencing factors of social impact was performed. The industrial & social acceptance of the ASTEP system was then subsequently assessed. A new dynamic model was then developed to make future predictions of ASTEP's social impact and industrial acceptance within a 10-year time frame.

**1<sup>st</sup> Objective:** *Review the scientific literature on the application of Social Life Cycle Assessment (S-LCA) to STE systems identifying methodological approaches and existing research gaps.*

The 1<sup>st</sup> objective this thesis was met through a comprehensive review of the existing literature on the application of S-LCA to STE systems. The review identified key methodologies employed by S-LCA practitioners, which included data collection methods to measure social impact through the use of SHDB platforms and surveys for data on employee satisfaction surveys. Data collection methods through the use of surveys were also identified for industrial & social acceptance of STE systems. The review also highlighted knowledge gaps in current S-LCA methodologies due to the lack of critical analysis needed to uncover the influencing factors of observed social impact. While social impacts and industrial acceptance of STE systems were often identified, more emphasis is placed on exploring the factors influencing these outcomes so that interventions can be made to rectify gaps in social sustainability. Moreover, it was found that current S-LCA methodologies need to extend beyond static assessments of social impact and include long-term scenarios of social impact and industrial acceptance over a temporal domain, inclusive of dynamic changes.

**2<sup>nd</sup> Objective:** *Conduct an S-LCA of the newly developed STE system through assessing social risks on employees engaged with the technology's production in order to evaluate its social sustainability.*

The 2<sup>nd</sup> objective of this thesis was met by conducting an S-LCA involving the employee stakeholder groups involved in the Production phase of ASTEP. Inventory data for the S-LCA on social risk related to H&S, fair payment, excessive working hours, gender inequality, and local employment were collected using an SHDB. An impact assessment revealed that H&S during the manufacturing of aluminium inserts for the PCM Storage Tank was found to represent a noteworthy concern for employee stakeholders, as represented by 0.038 risk hours in the H&S category, of which 0.029 risk hours were classified as high risk. Further evaluation revealed that result was linked with high risk levels of non-compliance with H&S policies in the

regional non-ferrous mining sector from which the components were sourced, measured to be 0.039 risk hours of which 0.03 were classed as high-risk hours. These findings aligned with those from related literature on STE systems.

**3<sup>rd</sup> Objective: Assess the social impact of the STE system through survey-based data collection involving employees engaged with the technology's product development.**

The 3<sup>rd</sup> objective of this thesis was fulfilled by conducting surveys involving 56 employees during the Product Development phase which assessed imposing social impact. Positive social impact was observed in PD (+1) and WI (+0.6) categories as collected by employee surveys. Further evaluation revealed that effective allocation and distribution of work tasks across ASTEP's subdivisions had a substantial positive influence on WI satisfaction scores, as demonstrated by a strong correlation coefficient of 0.63 at a high statistical significance ( $p < 0.05$ ) and further verified by the literature. Additionally, the provision of opportunities for professional development (PD) was found to positively influence employee satisfaction, particularly academic employees, with a strong correlation coefficient of 0.8 at a high statistical significance ( $p < 0.05$ ). The study also uniquely identified that engaging employees in R&D development activities was correlated with strong PD satisfaction levels. However, the TS category showed a negative impact score (-0.5), indicating a gap in training opportunities for employees engaged in engineering design. Further evaluation of this gap revealed that improving the allocation of specific R&D and training resources influences strong TS, evidenced by a strong correlation coefficient of 0.54 at a high statistical significance ( $p < 0.05$ ) and supported by the literature. These novel insights into the exact types of training programs for STE development and R&D engagements needed to influence better employee training guide managerial practices within STE projects.

**4<sup>th</sup> Objective: Assess global industrial acceptance of the STE system by analysing international perceptions of the technology's economic savings, contributions to greenhouse gas (GHG) reductions, and potential for adoption across different industries.**

The 4<sup>th</sup> objective of this thesis was fulfilled by assessing global industrial acceptance of the ASTEP system using a survey involving 318 international industries. SPIRE and Non-SPIRE industries operating at low to high temperatures were recruited across Europe, North America, and Asian regions. International industrial acceptance was revealed to be very strong, with 82% of industries perceiving ASTEP as both cost-viable and technically compatible with their thermal processes. Positive acceptance rate was strongest in the aerospace (92 %), metallic (89 %), and automotive (86 %) industries. Large (84%) and medium (87%) showed strong acceptance rates, while lower rates were found amongst small (45%) and micro sized companies (37%). Participants accepted ASTEP's high thermal output and operational

efficiency due to its potential to reduce carbon emissions and enhance compliance with standards ISO 14001 and ISO 50001.

**5<sup>th</sup> Objective:** *Assess worldwide social acceptance of the STE system by examining public perceptions of its environmental benefits for communities, impact on consumer preferences, and continual government support.*

The 5<sup>th</sup> objective of this thesis was fulfilled by assessing social acceptance across 279 members from the international general public based in the UK, European, North American, and Asian regions. Social acceptance was found to be very strong, with the study revealing that 86% of the general public agreed with ASTEP's environmental benefits and its contribution to cleaner air for the community. Additionally, 69 % of the general public were willing to consume products manufactured in supply chains applying ASTEP due to its clean energy. Participant comments also advocated ASTEP's continued integration into the industry due to its contribution to providing cleaner and continued government investment in similar STE technologies.

**6<sup>th</sup> Objective:** *Develop a dynamic model to forecast potential applications of the newly developed STE system over the next decade and identify technological improvements needed to improve its overall sustainability and industrial relevance.*

The 6<sup>th</sup> objective of this thesis was fulfilled by developing a dynamic model that predicts the future trajectory of ASTEP's social impact and industrial acceptance over the next decade, identifying the technological improvements and monetary supports required to enhance its overall sustainability and industrial relevance. It was found that a +5% annual incremental investment in specialised engineering training for STE systems and R&D engagement, through laboratory activities and participation in scientific publications, was associated with better social impact on employees over the decade by increasing the probability of observing a top-tier TS score. TS = 5 rose from 0.10 to 0.30 and TS = 4 from 0.35 to 0.60, while the probability of observing lower satisfactions decrease simultaneously. Similarly, it was found that investment into better task allocations enhanced WI = 5 from 0.15 to over 0.50 and WI = 4 from 0.25 to 0.50, while investment into career support boosted the probability of PD = 5 from 0.20 to 0.50 and PD = 4 from 0.30 to 0.45. These trends, supported by the literature, highlight that monetary improvements into targeted training, professional, and fair workload distribution for newly developed STE systems influence better social sustainability.

Similarly, it was found that an annual incremental investment of 5% to increase the STE system's thermal output, operating temperature, and system efficiency through integrating components such as high-absorption coatings, insulation, and hybrid integration of photovoltaic cells increased the probability of observing TC = 5 from 0.51 to 0.55 and TC = 4

from 0.37 to 0.44 over the decade, while the probability of achieving lower scores reduced. Acceptance among small and micro-sized companies also improved, as the probability of observing a high acceptance rate for small companies increased from 0.70 to 0.80 and 0.63 to 0.76 for micro companies. Additionally, an annual investment of 5% into providing subsidies and loan support to reduce the STE system's upfront costs increased the probability of observing AC = 5 from 0.44 to 0.52, and AC = 4 from 0.41 to 0.46 over the decade, while the probability of achieving lower scores reduced. The acceptance rate, particularly amongst small companies, increased more substantially from 0.45 to 0.67, and 0.37 to 0.62 for micro-sized companies. These future trends, as supported by the literature, demonstrate that investment into increasing technological capacity and as well as monetary assistance is associated with better industrial acceptance, hence making the STE system more relevant for the industry.

### 9.1 Advancements, Implications, and Limitations of This Thesis

This thesis advances the scientific literature by addressing several important unknowns in the literature, as the thesis provides validated primary evidence on critical indicators that have received limited empirical attention, including the social impact of employee training and professional development of newly developed STE systems. It also improves the understanding of how industrial acceptance of STE systems, across different industries and company sizes, is influenced by technical compatibility and costs. Moreover, the thesis provides a deeper examination of the factors influencing its social sustainability, including the effect of policy compliance on social risk during the production phase and the quantified influence of HRM resources on employee social impact during the product development phase of STE systems using statistically validated relationships. This advancement provides an evidence-based understanding of how workforce, technical, and financial interventions influence employee social impact and industrial acceptance in emerging STE systems, advancing the literature from identifying outcomes to critically explaining the mechanisms that drive them.

Building on this explanatory foundation, the thesis further advances scientific theory through the development of the future predictions which extrapolate social impact and industrial acceptance outcomes over a 10-year horizon. This advances beyond existing studies bounded in single-point timeframes by integrating statistically validated relationships between observed social impact, industrial acceptance, and investment levels onto a multi-point temporal domain, allowing future potential changes in employee satisfaction and industrial acceptance to be forecasted. It is a nuanced shift in social sustainability assessment of emerging STE systems from static assessment towards predictive, scenario-based evaluation. Hence, the thesis

provides a novel foundation for future research on predictive social impact assessment of newly developed STE systems.

The findings of this thesis have important implications for the development of policies and management practices affecting employee and industrial stakeholder groups. For employees, the findings reveal the critical role of targeted investment in training, professional development, and workload management in improving social impact, providing guidance for human resource management as to which training programmes to prioritise, such as those focused on STE system design, data analytics, and career development. Extrapolating this analysis over the next decade provides valuable guidance for labour policy development by identifying when and where investment interventions are most effective. This enables timely, targeted, and strategically phased actions to maximise positive social impact over a 10-year timeframe in employee satisfaction. For the industry, the findings reveal strong demand and willingness to adopt emerging STE systems among large aerospace, automotive, metallic, and food and beverage industries, driven by their high thermal compatibility with industrial processes, affordable costs, and enhancement of standard compliance, indicating substantial market potential for the widespread deployment of such technologies. Additional findings also revealed that sustained investment forecasted over the decade into technical enhancements and financial support in the form of subsidies and loans improves industrial acceptance of small and micro-sized companies. This guides operational and treasury directors in the industry to design investment strategies that optimise resource allocation for sustained investments over a 10-year timeframe, supporting the progressive adoption of emerging STE systems among these companies. Lastly, the findings revealed strong public support for continued government funding, subsidies, and educational initiatives for emerging STE systems, providing guidance for the expansion of long-term government investment into public awareness programmes supporting STE deployment.

This thesis is subject to several limitations that may influence the interpretation and generalisability of the findings. First, the S-LCA analysis relies on secondary, aggregated data from the SHDB, which may not fully capture site-specific variations in organisational practices and working conditions, potentially leading to discrepancies between estimated and actual social impact. Second, the assessment of employee-related social impact was limited to training, working intensity, and professional development, restricting the comprehensiveness of the analysis by excluding other important factors such as wages and fair payment. Third, industrial and public acceptance were evaluated based on pre-implementation data, meaning the findings reflect anticipated perceptions rather than real-world behaviour, which may differ once practical and operational challenges are encountered. Additionally, the demographic composition of the public sample was regionally concentrated and skewed towards well-

educated individuals, limiting the global representativeness and generalisability of the results. Finally, the dynamic model does not account for external influences such as economic changes, policy shifts, workforce dynamics, or competition from alternative technologies, which may affect the accuracy of long-term forecasts, particularly later in the decade.

## 9.2 Recommendations for Future Works

The following recommendations are made to further improve social sustainability assessment methods for newly developed STE systems.

- Improve social risk analysis in the production phase by integrating first-hand data sources beyond SHDB from industry-specific publications including company disclosure reports, industry audits, government databases.
- Assess more employee-related issues such as wages, job performance, and productivity during the product development phase.
- Expand the geographical and demographic scope of future social acceptance studies to include more diverse populations, encompassing wider age ranges and non-academic groups, while improving representation from regions beyond Europe to enhance the global representativeness of the findings. Conduct post-implementation studies on industrial and social acceptance of newly developed STE system by engaging stakeholders after real-world deployment, to assess how perceptions and adoption behaviour evolve based on actual system performance, cost savings, and environmental benefits.
- Extend the dynamic model by integrating external drivers such as labour market fluctuations, policy reforms, and industrial perception of competitive renewable technologies to produce more realistic and adaptive long-term forecasts of social sustainability and industrial relevance.

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## Declarations

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## Dissemination

### Publications:

- Zafar, I., Stojceska, V. & Tassou, S. 2022. Review of a Social Life Cycle Assessment of Solar Thermal Energy Systems used in Industrial Supply Chain. Renewable and Sustainable Energy Reviews. In press
- Zafar, I., Stojceska, V., Tassou, S., Rovira, A., Abbas, R. Solano, J.P., Camara, J.M., Naplocha, K. A Social Sustainability Assessment of a Newly Developed Solar Thermal System to be Integrated into Industrial Processes. Submitted to Thermal Science and Engineering Progress
- Zafar, I., Stojceska, V., Tassou, S., Rovira, A., Barbero, R., Montes, M.J., Abbas, R. Solano, J.P., Naplocha, K., Nardini, S., Androutsopoulos, A., Aristotelis, B.V., Vassiliki, D. An Assessment of Social Performance of a Solar Thermal System Applied to Industrial Processes. Thermal Science and Engineering Progress. Under Review.
- Zafar, I., Stojceska, V., Tassou, S., Enriquez, J., Torres Gordo, L., Androutsopoulos, A. An Assessment of Social & Industrial Acceptance of a Newly Developed Solar Thermal System Applied to Processes.

#### **Conference Papers:**

- Zafar, I., Stojceska, V. & Tassou, S. 2022. Review of a Social Life Cycle Assessment of Solar Thermal Energy Systems used in Industrial Supply Chain. Energy and Climate Transformations: 3rd International Conference on Energy Research & Social Science.
- Zafar, I., Stojceska, V. & Tassou, S. 2023. Social Life Cycle Assessment of a Newly Developed Solar Thermal Energy System for Industrial Processes. The 11th International Conference on Life Cycle Management. LCM 2023. September 6-7-8, 2023 – Lille, France.
- Zafar, I., Stojceska, V., Enriquez, J. Torres Gordo, L. Tassou, S. Industrial Acceptance of a Newly Developed Solar Thermal Energy System Applied to Industrial Processes. Proceedings of the International Conference on Green Energy and Environmental Technology , Philadelphia, Pennsylvania, USA 3rd Jun 2025. Accepted.

## Appendices

### Appendix 1 – Material data for ASTEP system

#### Appendix 1.1: Material Data for SunDial

<b>Components</b>	<b>Location of Supplier of Components</b> (Town/City, Country) <b>E.g. Milan, Italy</b>	<b>Destination of Components</b> (City, Country) <b>E.g. UPM-Madrid, Spain</b>	<b>Distance</b> e.g. km	<b>Weight of Component</b>	<b>Transportation distance (kgkm)</b>
Mirrors	Madrid	UPM-Madrid	< 50km (40km)	3562.5kg	3562.6x40km =142,504kgkm
Rotating Platform	San Martin de la Vega, Madrid	UPM-Madrid	< 50km (25km)	2.5tonnes (2500kg)	2500kg x 25km = 62,500kgkm
Receiver Tubes	Castellion, Spain	UPM-Madrid	415km	233.32kg	233.32 x 415km = 96,827.8kgkm
Concentrator	Madrid	UPM-Madrid	< 50km (45km)	1964.75 kg	1964.75x45km =88,413.75kgkm
Pipping	< 50km (35km)	UPM-Madrid	< 50km (40km)	107kg	107x40km = 4,280kgkm
Foundation Base	< 50km (35km)	UPM-Madrid	< 50km (35km)	2.41 tonnes -cement (2410kg)	2410x35km=84,350k gkm
Total from suppliers to UPM, Madrid				10,778.57 kg	478,875.55 kgkm
Total	From Madrid	Corinth, Greece	3169km	10778.57kg x 3169 = 34,157,288. 33 kgkm	

<b>Component s</b>	<b>Location of Supplier of Component s</b> (Town/City, Country)  <b>E.g. Milan, Italy</b>	<b>Destination of Component s</b> (City, Country)  <b>E.g. UPM-Madrid, Spain</b>	<b>Distance</b>  e.g. km	<b>Weight of Component</b>	<b>Transportation distance (kgkm)</b>
Mirrors	Madrid	UPM-Madrid	< 50km (40km)	3562.5kg	3562.6x40km =142,504kgkm
Rotating Platform	San Martin de la Vega, Madrid	UPM-Madrid	< 50km (25km)	2.5tonnes (2500kg)	2500kg x 25km = 62,500k gkm
Receiver Tubes	Castellion, Spain	UPM-Madrid	415km	233.32kg	233.32 x 415km = 96,827.8kgkm
Concentrator	Madrid	UPM-Madrid	< 50km (45km)	1639.64 kg	1639.64x45km =73,783.8kgkm
Pipping	< 50km (35km)	UPM-Madrid	< 50km (40km)	107kg	107x40km = 4,280kgkm
Foundation Base	< 50km (35km)	UPM-Madrid	< 50km (35km)	2410kg cement	2410x35km = 84,350kgkm
Total from suppliers to UPM, Madrid				10,452.46 kg	464,245.6 kgkm
Total	From Madrid	Iasi, Romania	3457.3km	10,452.46kg x 3457.3 = 36,137,289.9 6 kgkm	

## Appendix 1.2: PCM Storage Tank

Components	Materials		Processes used to make the components (e.g. welding, injection moulding, etc)	Total amount of each component (e.g. number of shell-side inserts)		Amount of materials used (e.g. amount of aluminium alloy used in the manufacturing of the shell-side inserts for the thermal energy storage).	
	MAND	AMTP		MAND	AMTP	MAND	AMTP
Storage Tanks	Tank: AISI 316L	Tank: AISI 316L	Drilling, milling, welding	2 units	2 units	1000 kg / unit	1000 kg / unit
	Sealing gasket: Graphite & insert of stainless steel (novaphit SSTC)	Sealing gasket: Graphite & insert of stainless steel (novaphit SSTC)	Punching/ Water jet cutting/ Cutting with scissors	2 units	2 units	0,01 kg/unit	0,01 kg/unit
	Wheel support: Stainless steel	Wheel support: Stainless steel	Mechano-welding	8 units (4 units/tank)	8 units (4 units/tank)	6.4 kg/unit	6.4 kg/unit
	Wheel rim: resin	Wheel rims: resin	Moulding	8 units (4units/tank)	8 units (4 units/tank)	1.7 kg/unit	1.7 kg/unit

Foundation Base for storage tank	Steel	Steel	-	2 units	2 units	-	-
Phase Change Materials	NaNO <sub>3</sub>	NaNO <sub>3</sub>	Grinding, mixing	2 batches	2 batches	505 kg/batch	505 kg/batch
	KNO <sub>3</sub>	KNO <sub>3</sub>	Grinding, mixing	2 batches	2 batches	600 kg/batch	600 kg/batch
Tubes	Stainless steel AISI 316L	Stainless steel AISI 316L	Bending, expanding, welding.	122 units (61 units/tank)	122 units (61 units/tank)	1.5 kg/unit	1.5 kg/unit
	Raised-face flange: ASTM A105	Raised-face flange: ASTM A105	Drilling, machining, welding	2 units	2 units	2,4 kg/unit	2,4 kg/unit
Shell-side inserts	Aluminium alloy (Al-Si)	Aluminium alloy (Al-Si)	Moulding	610 units (305 units/tank)	610 units (305 units/tank)	4.8 kg/unit	4.8 kg/unit
Insulation of the tank walls	Rockwool	Rockwool	Sewing	2 units	2 units	310 kg/unit	310 kg/unit
Electrical heater *	Shell: Steel ASTM A106		Forging, welding, metal processes	1 unit		160 kg/unit	
	Raised-face flange: Steel ASTM A105		Drilling, machining, welding	2 units		2.4 kg/unit	
Heat Exchanger (pls)	Battery : Carbon steel		Hot-rolled steel	1 unit		35 kg/unit	
	Ventilating base: Fe 306 B		Metal processes	1 unit		26 kg/unit	

include all the materials) *	Support structure: Iron profiles		Hot rolled steel, welding	1 unit		85 kg/unit	
	Raised-face flange: Carbon steel		Drilling, machining, welding	2 units		2.4 kg/unit	
Hydraulic connections*	Tubes: Carbon steel ASTM A106		Hot-rolled steel	10 m		1.7 kg/m	
	Raised-face flange: Carbon Steel		Drilling, machining, welding	13 units		2.4 kg/unit	
	Globe valve, manually actuated: Stainless		Machining, forging	11 units		2 kg/unit	
	Flanged T DN20: Carbon Steel		Drilling, machining	9 units		5 kg/unit	
	Blind flange DN20: Carbon steel		Drilling, machining, welding	6 units		1 kg/unit	
	Gasket flange: Stainless steel AISI 304L & graphite filler		Punching/ Water jet cutting/ Cutting with scissors	1 unit/flange		5 g/unit	
Tank expansion (Please include all the materials)	Tank: Stainless steel	Tank: Stainless steel	X	1 unit	1 unit	15 kg/unit	15 kg/unit
	Support frame: Steel SJ275	Support frame: SJ275	Hot rolled steel, welding	1 unit	1 unit	40 kg/unit	40 kg/unit

	Ball valve, manually actuated: Steel	Ball valve, manually actuated: Steel	Machining, forging/foundry	5 units	5 units	3.2 kg/unit	3.2 kg/unit
	Relief valve: Steel	Relief valve: Steel	Machining, forging/foundry	1 unit	1 unit	2.5 kg/unit	2.5 kg/unit
	Pressure control valve: Steel	Pressure control valve: Steel	Machining, forging/foundry	1 unit	1 unit	1 kg/unit	1 kg/unit

### Appendix 1.3: Material for Control Unit

Components	Materials (e.g. steel, plastic, etc)		Processes used to make the components (e.g. welding, moulding, etc)	Total number of each component (e.g. number of temperature sensors)	
	MAND	AMTP		MAND	AMTP
PTC 100 (temperature sensors)	Steel and plastic	Steel and plastic	Weld, mount, connect, fix, couple	9	8
Oil Flow meters	Steel and plastic	Steel and plastic	Weld, mount, connect, fix, couple	3	3
Pressure transducer	Steel and plastic	Steel and plastic	Weld, mount, connect, fix, couple	3	3
Wind speed meter	Steel and plastic	Steel and plastic	Weld, mount, connect, fix, couple	1	1
Speed pumps	Steel and plastic	Steel and plastic	Weld, mount, connect, fix, couple	4	3
Solar tracking system	Steel and plastic	Steel and plastic	Weld, mount, connect, fix, couple	1	1
Mirror tracking motors	Steel and plastic	Steel and plastic	Weld, mount, connect, fix, couple	0	6
Platform tracking motors	Steel and plastic	Steel and plastic	Weld, mount, connect, fix, couple	2	2
TOTAL other consumables:	Copper, Tin, Lithium, Iron, Ink, Plastic	Copper, Tin, Lithium, Iron, Ink, Plastic Tape,	-	Terminals, Multicore Cable Ends,	Terminals, Multicore Cable Ends,

	Tape, Paper, Aluminium	Paper, Aluminium		Thermore, Heat Shrink Tubing, Welding material, Cables, Rubber	Thermore, Heat Shrink Tubing, Welding material, Cables, Rubber
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<b>Components</b>	Location of Supplier of Components (Town/City, Country)	Destination of Components	Distance from Suppliers to Madrid	Weight of components	Transportation distance (kgkm)
PTC 100 (temperature sensors)	Velbert, Germany	Madrid	1,811 km	300g (x9)	4,889.7kgkm
Oil Flow meters	Velbert, Germany	Madrid	1,811 km	760g (x3)	4,129.1 kgkm
Pressure transducer	Velbert, Germany	Madrid	1,811 km	94g (x3)	510.7 kgkm
Wind speed	Velbert, Germany	Madrid	1,811km	3.5kg	6,338.5 kgkm
Speed pumps	Velbert, Germany	Madrid	1,811 km	16.2 kg (x4)	117,352.8 kgkm
Solar tracking system	Velbert, Germany	Madrid	1,811 km	90kg	162,990 kgkm
Platform tracking motors	Barcelona	Madrid	695 km	3kg (x2)	4,170 kgkm
Total weight & transportation distance from Suppliers to Madrid				169.56kg	300,380.8 kgkm
Transportation distance from Madrid to MAND	Madrid	Corinth, Greece	3,307km	169.56kg	3307km x 169.56kg = 560,741.53 kgkm

<b>Components</b>	Location of Supplier of Components (Town/City, Country)	Destination of Components	Distance from Suppliers to Madrid	Weight of components	Transportation distance (kgkm)
PTC 100 (temperature sensors)	Velbert, Germany	Madrid	1,811 km	300g (x8)	4,346.4 kgkm
Oil Flow meters	Velbert, Germany	Madrid	1,811 km	760g (x3)	4,129.1 kgkm
Pressure transducer	Velbert, Germany	Madrid	1,811 km	94g (x3)	510.7 kgkm
Wind speed	Velbert, Germany	Madrid	1,811km	3.5kg	6,338.5 kgkm
Speed pumps	Velbert, Germany	Madrid	1,811 km	16.2 kg (x3)	88,014.6 kgkm
Solar tracking system	Velbert, Germany	Madrid	1,811 km	90kg	162,990 kgkm
Mirror tracking motors	Barcelona	Madrid	695 km	17kg (x6)	70,890 kgkm
Platform tracking motors	Barcelona	Madrid	695 km	3kg (x2)	4,170 kgkm
Total weight of components & transportation distance from Suppliers to Madrid				255.06 kg	341,389.3 kgkm
Transportation distance from Madrid to AMTP in Iasi, Romania	Madrid	AMTP - Iasi, Romania	3,566km	255.06 kg	3,566km x 255.06kg = 909,551.09 kgkm

# Appendix 2: Blank Samples and Results of Employee Surveys and Management Questionnaires

## Appendix 2.1: Employee Survey

30/01/2023, 14:16

Employee Social Benefit Survey

### Employee Social Benefit Survey

**Introduction of Questionnaire:** You are being invited to complete this survey, which will evaluate your perception on your employment situation exclusively regarding your involvement for the ASTEP project. The survey includes describing your perspective on your working hours, fair payment, Health and Safety (H&S), career development, and awareness of sustainable issues regarding solar energy. Please answer the following questions to the best of your ability and knowledge, giving your own honest opinion and judgement.

Questions grade your qualitative opinion on either how satisfied you are, how much you agree with, or how much importance you give to the question's subject detailed in the survey.

As detailed within the Participant Information Sheet, please be assured that your identity will be kept anonymous and your responses will be kept confidential from any party involved with your employment.

\* Required

### Consent Form

This section asks you to either agree or disagree to terms listed below. This form is mandatory to fill out before starting the survey. Please tick 'Yes' or 'No' to indicate your response to each of the terms. The participant (or their legal representative) should provide their response to every term on this form, and provide their signature at the end of this form if they agree to participate in this study. If the participant refuses,

1. Have you read the Participant Information Sheet that was provided to you via email? \*

Yes

No

2. Have you been given the opportunity to ask questions and discuss this study (via email/phone for electronic surveys)? \*

- Yes
- No

3. Have you received satisfactory answers to all your questions, if applicable (via email/phone for electronic surveys)? If you did not ask any questions, please tick 'Not Applicable to Me'. \*

- Yes
- No
- Not Applicable to Me

4. Has anyone spoken to you about this study? \*

- Yes
- No

5. If your response to Q4 was 'Yes', please type their **job function** (e.g. my line manager, supervisor). Otherwise, leave this question blank.

6. Do you understand that you will not be referred to by name in any report concerning this study? \*

Yes

No

7. Do you understand that you are free to withdraw from this study at any time? \*

Yes

No

8. Do you understand that you don't have to give any reason for withdrawing? \*

Yes

No

9. Do you understand that choosing not to participate or withdrawing will not affect your employment status? \*

Yes

No

10. Do you understand that all inputted data and responses cannot be withdrawn after submission? \*

Yes

No

11. I agree to my responses being stored as data on the Brunel University Network. \*

- Agree
- Disagree

12. I agree to the use of non-attributable quotes when the study is written up or published. \*

- Agree
- Disagree

13. The procedures regarding confidentiality have been explained to me (as detailed in the cover emails). \*

- Agree
- Disagree

14. I agree that my anonymised data can be stored and shared with other researchers for use in future projects. \*

- Agree
- Disagree

15. I agree to take part in this study. \*

- Agree
- Disagree

16. Please provide your signature in this box to indicate that you have given consent to partaking in this survey.

**Signature of participant: \***

17. Please print today's date below, in the form DD/MM/YY: \*

## Your Occupation and Working Hours

This section asks about your general field of work and how you feel

18. Please provide your field of work (e.g Mechanical Engineering, Project Management, etc...):

19. Please provide your previous field of work if applicable:

20. Please provide the approximate combined number of years you have worked and/or studied within your current field of work/study to date:

21. Please tick what is your type of work:

- Part-Time
- Full-Time
- Temporal/Fixed Term
- Permanent

22. Please tick the circle which best describes how satisfied do you currently feel about the number of hours you have to commit to working on ASTEP per week?

Very Satisfied	Satisfied	Slightly Satisfied	Unsatisfied	Very Unsatisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

23. Please tick the circle which best describes how satisfied do you feel about the intensity of your current workload?

Very Satisfied	Satisfied	Slightly Satisfied	Unsatisfied	Very Unsatisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

24. Please tick the circle which best describes your perception on how evenly have your work assignments been distributed over your work schedule?

Very Satisfied	Satisfied	Slightly Satisfied	Unsatisfied	Very Unsatisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

25. If you have any additional comments regarding this section, please **provide** them here:

## Your Occupational Health and Safety

This section asks about your satisfaction if you Health and Safety at Work. **Only answer** this section if you conduct any lab or field work where Health and Safety (H&S) guidelines are applicable on you. Otherwise

26. Please tick the circle which best describes how secure do you feel about your own safety within your working environment?

Very Secure	Secure	Slightly Secure	Unsecure	Very Unsecure
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

27. Please tick the circle which best describes how satisfied do you feel about the overall Health and Safety training that is given to you?

Very Satisfied	Satisfied	Slightly Satisfied	Unsatisfied	Very Unsatisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

28. Please tick the circle which best describes how satisfied are you with the amount of Personal Protection Equipment (PPE) provided for your field of work?

Very Satisfied	Satisfied	Slightly Satisfied	Unsatisfied	Very Unsatisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

29. If you have any additional comments regarding this section, please **provide** them here:

## Your Contribution to ASTEP

This section asks about ASTEP work packages which you contribute to, and what sort of technical work do you carry out for this project.

30. Please tick **all of the** ASTEP Work Packages (WP) which you are currently assigned with and/or actively contribute to:

- WP 1
- WP 2
- WP 3
- WP 4
- WP 5
- WP 6
- WP 7
- WP 8
- WP 9

31. What is was your approximate start date and end date for your contribution to your assigned ASTEP work packages?

32. Please tick roughly how many hours per week on average do you allocate to working on the ASTEP project:

- 5-10 hrs
- 10-15 hrs
- 15-20 hrs
- 20-25 hrs
- 25-30 hrs
- 30+ hrs

33. If they vary considerably, please give more details in this section about how they varied over the last week, giving approximate daily averages:

34. The ASTEP system is composed of three core components: a SunDial for solar collection, a Thermal Storage Unit, and an electronic Control Unit.

Throughout your personal contribution to the ASTEP project, please tick **all** of the following activities which you have engaged with, both as part of your work packages and any extra contribution you may have made:

- The Conceptual Design of the SunDial
- The Conceptual Design of the Thermal Storage Unit
- The Conceptual Design of the Control Unit
- The Conceptual Design of the Overall System
- The Manufacturing and Assembly of the SunDial
- The Manufacturing and Assembly of the Thermal Storage Unit
- The Manufacturing and Assembly of the Control Unit
- The Manufacturing and Assembly of the Overall System
- Laboratory Testing and Validation of the ASTEP Concept
- Installation of the System at the MAND and AMTP Sites
- Software Simulation of System Components
- Sustainability and Lifecycle Assessment
- Other

35. If you have indicated 'Other' in Q34, please list those topics here:

36. Please tick the circle which best describes how heavily you have been involved in either designing, installing, or maintaining either of the three components listed in Q34 for the project?

Very Heavily	Heavily	Somewhat	Very Little	Not at All
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

37. Please tick the circle which best describes how strongly do you agree that the work you have done is directly contributing to project progression?

Strongly Agree	Agree	Somewhat Agree	Disagree	Strongly Disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

38. If you have any additional comments regarding this section, please **provide** them here:

## Your Employee Training for Your Work Assignments

This section asks about how you feel about the level of training given to

39. Please tick the circle which best describes how strongly do you agree that the training that you have undertaken during your employment is positively contributing to your ability to complete ASTEP work assignments?

Please note, training in this case refers to undertaking overall workshops, seminars, classes, and lectures during your employment.

Strongly Agree	Agree	Somewhat Agree	Disagree	Strongly Disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

40. Please tick the circle which best describes your perception on how much you have progressed in developing your skillset needed to work on your assigned ASTEP work assignments?

Very Developed	Developed	Somewhat Developed	Currently Developing	Need to Develop More
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

41. Please tick the circle which best describes how strongly do you agree that project resources and material are accessible to you which can aid your work assignments for ASTEP?

Strongly Agree	Agree	Somewhat Agree	Disagree	Strongly Disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

42. Please tick the circle which best describes how important do you think working collaboratively with other colleagues and project partners is to your ASTEP work assignments? If you don't carry out the majority of your ASTEP work assignments in teams, please tick 'Not Applicable'.

Very Important	Important	Somewhat Important	Little Importance	Not Important	Not Applicable
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

43. Please tick the circle which best describes how strongly do you agree that working independently on your individual ASTEP work assignments suits you? If you don't carry out the majority of your ASTEP work assignments independently, please tick 'Not Applicable'.

Strongly Agree	Agree	Somewhat Agree	Disagree	Strongly Disagree	Not Applicable
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

44. Please tick whether independently working **or** collaborating with others contributes more to your ASTEP work assignments?

- Working with Others Helps
- Both are Equally Important
- Working Independently

45. The ASTEP system is designed to fulfil both thermal and cooling demands for various industrial processes hosted by both of it's end users (AMTP and MAND).

Please tick the circle which best describes how well do you understand the overall ASTEP system's function in fulfilling their thermal and/or cooling demands?

- |  |                       |                       |                       |                       |                       |
|--|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|  | Very Well             | Quite Well            | Somewhat              | Little Bit            | Not Well at All       |
|  | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

46. If you have any additional comments regarding this section, please **provide** them here:

## Your Career Opportunities and Professional Development

This section asks about your perception on how well working on the ASTEP project as an employee/student is benefiting your career/professional development. This may include how you feel about the current and future opportunities that are being given by your

47. Please tick the circle which best describes how strongly do you feel that working on the ASTEP project is contributing to your professional development?

Please note, professional development in this case can include improvement of your skillset, increase in job prospects, and obtaining higher qualifications.

Strongly      Adequately      Somewhat      Little Bit      Not at All

48. Please tick the circle which best describes your perception on how relevant your involvement in the ASTEP project is to your desired field of study/work? This field of study/work may form the career path which you wish to pursue.

Very Relevant      Relevant      Slightly Relevant      Irrelevant      Very Irrelevant

49. Please tick the circle which best describes your perception on how much you have progressed in developing your skillset needed to work in your desired field of work/study?

Very Developed	Developed	Somewhat Developed	Currently Developing	Need to Develop More
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

50. Please tick the circle which best describes how satisfied are you with the current level of support for your career development?

Please note, examples can include CV development, soft skill workshops, and of job opportunities provided to you by your institution.

Very Satisfied	Satisfied	Somewhat Satisfied	Unsatisfied	Very Unsatisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

51. Please tick whether you have at any point during your employment/studentship discussed potential positions or promotion opportunities with your line manager or head?

Yes	No
<input type="radio"/>	<input type="radio"/>

52. If you have any additional comments regarding this section, please **provide** them here:

## Your Awareness of Sustainable Impact

This section asks about your awareness of environmental impact, and your perception on how important developing solar energy systems is for

53. Please tick the circle which best describes how aware are you about the long term sustainable impact of using solar energy for industrial applications?

Very Aware	Aware	Somewhat Aware	Little Aware	Not Aware
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

54. Please tick the circle which best describes how important do you think it is for EU manufacturers to reduce their carbon footprint?

Very important	Important	Somewhat Important	Little Importance	No Importance
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

55. Please tick the circle which best describes how important do you think it is to develop existing solar technologies that will contribute towards future green energy?

Very important	Important	Somewhat Important	Little Importance	No Importance
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

56. If you have any additional comments regarding this section, please **provide** them here:

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## Appendix 2.2: Employee Survey Results

Participant ID	Category		
	TS	WI	PD
	Score		
1	-0.5	2	1.5
2	1	2	1.5
3	-1	2	1.5
4	-1	-1.5	-1.5
5	-1	-0.5	0
6	-0.5	-0.5	-1.5
7	-0.5	-0.5	1.5
8	-2	-0.5	2
9	-0.5	-1	-1.5
10	-1	1	1
11	1	1	2
12	-1	1	1
13	2	1	2
14	1	1	1
15	1	1	1
16	-1	-0.5	-0.5
17	-2	1	1
18	-1.5	-0.5	0.5
19	-0.5	1	1.5
20	-1	0.5	2
21	-2	-0.5	-0.5
22	1	0.5	0
23	-0.5	-1.5	-1.5
24	1	0.5	0
25	1	2	1.5
26	-2	2	2
27	0.5	0	1
28	-2	0.5	2
29	-2	1	-0.5
30	1	2	2
31	-1.5	1	2
32	-2	0	2
33	-1	0.5	1
34	-1.5	2	2
35	-2	0	1
36	0.5	1	2

37	-2	2	1.5
38	0	2	2
39	-2	2	2
40	1	2	1.5
41	-2	2	2
<b>Avg</b>	<b>-0.5</b>	<b>+0.75</b>	<b>+1</b>

Appendix 2.3: Employee Survey Participant Information Sheet

## **PARTICIPANT INFORMATION SHEET- Employee Survey**

### **Study title**

Social assessment of impacts of using solar thermal energy.

### **Invitation Paragraph**

Upon invitation to partaking in this study, please carefully read all of the following information regarding the purpose of this research in this form before making a decision.

### **What is the purpose of the study?**

This study aims to assess the social impact on stakeholders involved in the integration of solar thermal energy, as part of an internal research assignment. It is designed to create an opinion based model of current social welfare and wellbeing in relation to the solar thermal energy project, based on the current perception of involved employees. Employee perception will be collected using online 1 to 5 scale based surveys.

Social welfare in this context could refer to either your employment, health and safety at work, work relations with other project partners, or education and awareness of sustainable/climate change issues.

### **Why have you been invited to participate?**

You have been invited because you as an employee, who is either directly or indirectly involved in solar thermal energy integration, hold valuable insights and perception as to how satisfied are you with your current social welfare at work.

We kindly ask for your participation due to the value that your opinion will hold towards accurately improving your social welfare within your work environment.

### **Do I have to take part?**

No. Your participation is entirely voluntary and you can decide whether to take part or not. You have been given the option to look over the survey questions by scrolling through the pages. Please have a careful think before signing the consent form. You can simply reject this email and close the survey link if you wish to not take part. You may also leave the survey midway by simply exiting

out, and all of your filled response up to that point will be immediately deleted. There will be no negative consequence imposed by the research team or your employers if you wish to not take part.

If you want to contact the Research Ethics Committee of Brunel University for more concerns, please email them at [res-ethics@brunel.ac.uk](mailto:res-ethics@brunel.ac.uk).

#### **What do I have to do in this study?**

You are being invited to take part in an online employee survey that consists of 6 sections total. The names of the sections are: a) Your Pay and Working Hours, b) Your Occupational Health and Safety, c) Your Contribution to ASTEP, d) Your Employee Training for Your Work Assignments, e) Your Career Opportunities and Professional Development, f) Your Awareness of Sustainable Impact

This online survey has been sent out to all employees via email, as administrated via your line manager. Here is the step by step procedure as to how to complete and submit your survey results:

- 1) Read this participation sheet and sign the attached consent form before partaking in the survey.
- 2) Click the Microsoft Forms link in the email
- 3) Read the introduction paragraph at the start of survey for further instructions.
- 4) Answer all questions accompanied with empty boxes by typing your response.
- 5) Otherwise tick the appropriate number on the scale.
- 6) At the end of the survey click 'Submit' and close the window.

The estimated completion time for all sections of this survey is approximately **15 minutes**.

#### **What are the possible disadvantages and risks of taking part?**

Some questions that will be asked could be highly sensitive regarding your employment or your training. You will be asked to list your field of work and amount of work experience in relation to the ASTEP project.

However, please be assured that all responses will be kept strictly confidential from any managerial party involved with your employment.

**Will there be any benefits to participants taking part?**

There will be no direct benefit to any participants from taking part in the survey.

**Will my personal information in this study be kept confidential?**

All your information collected in this survey, including all results, typed responses and opinions, will be kept strictly confidential from anyone in your department. Your identity will be kept anonymous and you will never be asked to provide your name or any other personal details. The only details which you will provide are your field of work and years of work experience.

Rest assured, these details will not be shared with your employer or any other party, and will only be accessed by the researcher for data analysis and processing. The data is protected by 2 factor authorisation, in an account solely handled by the researcher.

**What will happen to the results of the research study?**

After pressing 'Submit', your responses will be saved and sent directly to a 2 factor protected account handled solely and exclusively by the researcher. Please be aware, these responses will be stored and you would not be able to withdraw them at any time after submission.

You can however withdraw all your responses midway while filling out the survey. Simply exiting out of the survey midway will cancel the survey submission and all responses given will be instantly deleted.

All your responses on a 1 to 5 scale will be used to generate employee satisfaction scores, which will be further processed to determine the social performance of the solar thermal energy project. All other forms of typed out or selected responses will be qualitatively considered to give more insight as to how the project's social performance can be improved, without further presentation or direct quotation.

Rest assured, the final results which will be published for viewing by other parties will be in the form of generic percentages, averaged out across the entire project. They will not include the responses nor the job details of any individual or group of employees. Rather, the aim is to take a general view of employee welfare across all 16 partners in the project.

The final results, which only include the numerated employee satisfaction scores, will be presented at conferences and meetings at Brunel university

London and other institutions. The numerated scores will be published in research papers for further communication.

**Who has reviewed the study?**

The Research Ethics Committee of Brunel University and Dr Valentina Stojceska (the principal supervisor of Social Assessment) have reviewed the study.

**Research Integrity**

Brunel University London is committed to comply with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from our researchers during their research.

**Contact for further information and complaints**

You are free to contact the researcher of this study for more details at [Imaad.Zafar@brunel.ac.uk](mailto:Imaad.Zafar@brunel.ac.uk).

Additionally, please contact to Professor Simon Taylor (Chairman of Research Ethics Committee) for complaints at [Simon.Taylor@brunel.ac.uk](mailto:Simon.Taylor@brunel.ac.uk).

You will be given a copy of the information sheet.

# Principal Investigator Questionnaire

**Introduction of Questionnaire:** You are being invited to complete this questionnaire, with the aim of gaining an insight into how the production and application phases of the ASTEP system are directly affecting employment within the participating affiliations, as part of a Social Sustainability Assessment task under Work Package (WP) 8.3. These questions address employee training, job creation, employee development opportunities, fair payment, fair working hours, and gender equality at work. These social indicators will be used to numerate the project's current social performance, and the results will be used to aid future decision making to improve sustainability. Please answer each question in a brief manner to the best of your ability, and fill all numerical data as accurately as possible according to your most updated records.

As detailed within the Participant Information Sheet, please be assured that your identity will be kept anonymous and your responses will be kept confidential from any party employed under you or within the ASTEP consortium. This includes the protection of any data regarding

## Consent Form

This section asks you to either agree or disagree to terms listed below. This form is mandatory to fill out before starting the survey. Please tick 'Yes' or 'No' to indicate your response to each of the terms. The participant (or their legal representative) should provide their response to every term on this form, and provide their signature at the end of this form if they agree to participate in this study. If the participant refuses,

1. Have you read the Participant Information Sheet that was provided to you via email? \*

Yes

No

2. Have you been given the opportunity to ask questions and discuss this study (via email/phone for electronic surveys)? \*

Yes

No

3. Have you received satisfactory answers to all your questions, if applicable (via email/phone for electronic surveys)? If you did not ask any questions, please tick 'Not Applicable to Me'. \*

Yes

No

Not Applicable to Me

4. Have you spoken to anyone about the study? \*

Yes

No

5. If your response to Q4 was 'Yes', please type their **job function** (e.g. my line manager, supervisor). Otherwise, leave this question blank.

6. Do you understand that you will not be referred to by name in any report concerning this study? \*

Yes

No

7. Do you understand that you are free to withdraw from this study at any time? \*

Yes

No

8. Do you understand that you don't have to give any reason for withdrawing? \*

Yes

No

9. Do you understand that choosing not to participate or withdrawing will not affect your employment status? \*

Yes

No

10. Do you understand that all inputted data and responses cannot be withdrawn after submission? \*

Yes

No

11. I agree to my responses being stored as data on the Brunel University Network. \*

- Agree
- Disagree

12. I agree to the use of non-attributable quotes when the study is written up or published. \*

- Agree
- Disagree

13. The procedures regarding confidentiality have been explained to me (as detailed in the cover emails). \*

- Agree
- Disagree

14. I agree that my anonymised data can be stored and shared with other researchers for use in future projects. \*

- Agree
- Disagree

15. I agree to take part in this study. \*

- Agree
- Disagree

16. Please provide your signature in this box to indicate that you have given consent to partaking in this survey.

**Signature of participant: \***

17. Please print today's date below, in the form DD/MM/YY: \*

## Intake of Employees for the Project

This section asks about the employee and/or student numbers in your current team, who are actively engaged with the ASTEP project. It will also ask about the number of vacancies in your organisation which will be

18. What is the size of your current team who are directly involved with the ASTEP project within your affiliated institute?

19. How many jobs in total have been created in your institutional organisation to serve the purpose of ASTEP project since the starting date of your team's contribution?

20. How many roles are currently vacant within your organisation that have a contribution to the ASTEP project?

## Employee Training

This section asks about the type of training and exposure that employees and/or students in your team receive, as well as how much has been

21. Can you please tick the following general subject areas which your employees and/or students have the opportunity to engage with, specifically through courses (e.g through workshops, seminars, classes, lectures) during their employment:

- Mechanical and Energy Engineering
- Software Simulation
- Electrical and Control Systems
- Manufacturing and Production Engineering
- Sustainability and LifeCycle Assessment
- Human Resources (HR)
- Finance
- Social Sciences
- Other

22. From Q21, if you selected the other option, please specify subject area of the course/workshop:

23. Can you please tick the following general **professional skills** which your employees and/or students have the opportunity to engage with, specifically through courses (e.g through workshops, seminars, classes, lectures) during their employment:

- Project Management
- Leadership and Team Coordination
- Time Management and Organisation
- Data Analytics
- Presentation and Communication Skills
- Other

24. From Q23, if you selected the other option, please specify subject area of the course/workshop:

25. Please report how much of the project budget has been invested on employee and/or student training in accordance with the following ranges:

- 0 – 2,500 €
- 2,501 – 5,000 €
- 7,501 – 10,000 €
- 10,001 – 12,500 €
- 12,500 € +

26. Please tick all of the following events that employees and/or students can **attend** in the broader technological community:

- International Conferences
- Lectures Given by Researchers
- End User Site Visits
- Joint Collaborative Events with other Universities
- Other

27. If there are any other events from Q26, please list them below:

28. Please report how much of the project budget has been invested on facilitating employee and/or student travel expenses for the events listed in Q26:

- 0 – 2,500 €
- 2,501 – 5,000 €
- 7,501 – 10,000 €
- 10,001 – 12,500 €
- 12,500 € +

## Impact on Research and Development

This section asks about ongoing activities in terms of research and development in your organisation, exclusively in relation to ASTEP.

29. Please list the number of peer-reviewed papers and/or project reports related to the ASTEP project that have been published by your institution to date. Please provide the journals that they have been published in and paper titles:

30. If there are other types of publications that have been presented to external parties, please detail them below:

31. If there are other types of publications that are currently being written, please detail them below:

32. To the best of your knowledge, please list the number of peer-reviewed papers and/or project reports related to the ASTEP project which are currently unpublished and are being actively written:

33. Please tick the following general research skills areas which your employees and/or students have the opportunity **to develop** as part of their ASTEP work assignment:

- Conducting Scientific Literature Review
- Publishing and Disseminating Research
- Teaching and Presenting Research
- Devising Methodological Procedures
- Manufacturing and Testing of Test Rigs
- Other

34. If there are any other research related subjects from Q33 please list below:

## Engagement with the Consortium

This section asks about whether employees and/or students in your team are engaged with the wider ASTEP consortium.

35. Are your employees/students engaged with ASTEP's end users: AMTP and MAND (*eg. through regular communication*)?

Yes

No

36. Are your employees/students engaged with ASTEP's material suppliers (*eg. through email, MS Teams, video calls*)?

Yes

No

## Available Social Benefits

This section asks about what social benefits and privileges that employees and/or students in your team are entitled to due to being employed in

37. Please tick the following benefits which **employees** in your team contributing to the ASTEP project are entitled to:

- Bereavement Leave
- Salary Bonuses
- Gym/Fitness Privileges
- Outdoor Employee Events
- Sick Pay
- Health Care Insurance
- Pension Schemes
- Flexible Working Hours
- Other

38. If you have indicated 'Other' in Q37, please list them below:

39. Please tick the following benefits which **students** in your team contributing to the ASTEP project are entitled to:

- Bereavement Leave
- Salary Bonuses
- Gym/Fitness Privileges
- Extracurricular Student Events
- Sick Pay
- Health Care Insurance
- Student Fee Sponsorships
- Student Fee Sponsorships
- Flexible Working Hours
- Other

40. If you have indicated other in Q39, please list them below:

## Appendix 2.5: Management Questionnaire Results

PT	PPD	AT	EE	TA
-1.5	2	-1	-1.5	0
-0.5	0	0	0	0.5
-1.5	-1.5	-2	-2	1
1	-1	1	2	0
-1.5	-1	-1.5	-1.5	1
-0.5	-0.5	-0.5	0	0.5
2	0	2	1.5	1.5
-1	-1	-0.5	0	-1
0	-1.5	0	0.5	0



## **PARTICIPANT INFORMATION SHEET – Principal Investigator**

### **Study title**

Social assessment of impacts of using solar thermal energy.

### **Invitation Paragraph**

Upon invitation to partaking in this study, please carefully read all of the following information regarding the purpose of this research in this form before making a decision.

### **What is the purpose of the study?**

This study aims to assess the social impact on the employees affected by the integration solar thermal energy, as part of an internal research assignment. It is designed to create a model of current social welfare and wellbeing in relation to the solar thermal energy project. This will require the collection of the salary ranges, work experience, and genders of your employees that work under the ASTEP project.

### **Why have you been invited to participate?**

For this questionnaire, the level of employee benefit will be assessed with regards to the ASTEP project. You, as the employer of employees assigned with related project work packages, are being invited to give your input on what you as an employer is providing for those particular employees.

We kindly ask for your participation due to the value that your input will provide towards evaluating the level of social welfare among your employees.

### **Do I have to take part?**

No. Your participation is entirely voluntary and you can decide whether to take part or not. You have been given the option to look over the questionnaire and attached excel sheet by scrolling through the pages. Please have a careful think before signing the consent form. You can simply reject this email and close the questionnaire link if you wish to not take part. You may also leave the survey midway by simply exiting out, and all of your filled response up to that point will be immediately deleted. There will be no negative consequence imposed by the research team or your employers if you wish to not take part.

If you want to contact the Research Ethics Committee of Brunel University for more concerns, please email them at [res-ethics@brunel.ac.uk](mailto:res-ethics@brunel.ac.uk).

#### **What do I have to do in this study?**

You are being invited to take part in an online questionnaire that consists of 4 sections and 21 questions. Here is the step by step procedure as to how to complete and submit your survey results:

- 1) Read this participation sheet and sign the attached consent form before partaking in the survey.
- 2) Click the Microsoft Forms link in the email for the questionnaire
- 3) Read the introduction paragraph at the start of survey for further instructions.
- 4) Tick the appropriate answers which best describes your assessment.
- 5) For Question 6, please fill in the attached excel sheet
- 6) Please upload the completed excel sheet in the appropriate question.
- 7) At the end of the survey click 'Submit' and close the window.

The estimated completion time for all sections of this survey is approximately 25 minutes.

#### **What are the possible disadvantages and risks of taking part?**

None. It is an objective assessment of employee welfare in relation to the solar thermal energy project. No personal details will be asked, and your responses will be kept confidential.

#### **Will there be any benefits to participants taking part?**

There will be no direct benefit to any participants from taking part in the survey.

#### **Will my personal information in this study be kept confidential?**

All your information collected in this survey, including all results, typed responses and opinions, will be kept strictly confidential from anyone in your department. Your identity will be kept anonymous and you will never be asked to provide your name or any other personal details.

As can be seen in the survey questions, the only details which you will provide are your employee's field of work, broad salary ranges, and gender. Rest

assured, these details will not be shared with any other party. The data is protected by 2 factor authorisation, in an account solely handled by the researcher. There is no need for any third party in the project or from any related department to get involved in viewing the raw data. It will only be accessed by the researcher for data analysis and processing once you have filled out the excel sheet and question forms.

#### **What will happen to the results of the research study?**

After pressing 'Submit', your responses will be saved and sent directly to a 2 factor protected account handled solely and exclusively by the researcher. Please be aware, these responses will be stored and you will not be able to withdraw them at any time after submission.

All your responses will be used to generate **employee satisfaction scores**, which will be further processed to determine the social performance of the solar thermal energy project. All other forms of typed out or selected responses will be qualitatively considered to give more insight as to how the project's social performance can be improved, without further presentation or direct quotation.

Rest assured, the final results which will be published for viewing by other parties will be in the form of highly generic percentages, averaged out across the entire project. They will not include the responses nor the job details, salary figures, or gender of any individual or group of employees. Rather, the aim is to take a general view of the project.

The final results, which only include the numerated employee satisfaction scores, will be presented at conferences and meetings at Brunel University London and other institutions. The numerated scores will be published in research papers for further communication.

#### **Who has reviewed the study?**

The Research Ethics Committee of Brunel University and Dr Valentina Stojceska (the principal investigator of Social Assessment) have reviewed the study.

#### **Research Integrity**

Brunel University London is committed to comply with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from our researchers during their research.

#### **Contact for further information and complaints**

You are free to contact the researcher of this study for more details at [Imaad.Zafar@brunel.ac.uk](mailto:Imaad.Zafar@brunel.ac.uk).

## Appendix 3: Blank Samples and Results of Industrial & Social Acceptance Surveys

### Appendix 3.1: Industrial Acceptance Survey

## Industrial Acceptance Survey of Solar Thermal Energy (STE) Systems

Introduction: This research activity is designed to gauge your industry's perspective towards the adoption of novel solar energy technologies, specifically regarding the Application of Solar Thermal Energy to Industrial Processes (ASTEP) system. ASTEP is a newly developed modular STE system designed to meet high-temperature requirements in industrial settings, capable of supplying up to 400°C and 120 MWh of thermal energy annually. It offers a robust solution that enhances energy efficiency, significantly reduces CO<sub>2</sub> emissions, and partially eliminates energy costs. Please see our project website for more details.

ASTEP Website: <https://asteproject.eu/about/>

By participating in this study, you will help provide insights into your industry's interest in adopting ASTEP. We respectfully request that a representative holding strategic roles in your company: a Managing Director, Project Manager, or Technical Lead, to complete this survey. They should possess the authority and knowledge to discuss and make decisions regarding technology adoption and sustainability initiatives for your industry.

The survey consists of 20 questions divided into 3 sections:

- Section 1: General information about You and the Industry
- Section 2: Your Company's Current Energy Sources, Sustainable Practices, and In- House Processes
- Section 3: Your Company's Perspective on ASTEP's adoption.

The estimated time to complete is 15 minutes, and there is no time limit. Please note that participation is completely voluntary and you can opt out at any time during the study.

Please read the Participant Information Sheet (PIS) below for additional information and queries about the survey, attached here: [PIS Industrial Acceptance](#)

## Section 1: General Information

I have read and agreed to participate in this study according to the terms outlined in the Participant Information Sheet (PIS) attached with this survey.

Yes  No

I confirm that I am above the age of 18.

Yes  No

I agree to take part in this study.

Yes  No

Please select the applicability of your industry:

- Aerospace  Automotive  
 Chemical & Petrochemical  Metallic  
 Non-Metallic Materials  Food and Beverage  
 Dairy  Textile  
 Paper and Pulp  
 Mining & Quarrying  
 None of the Above

Please tick the approximate size of the company you are employed under:

- Micro (1-9 employees)  
 Small (10-49 employees)  
 Medium (50-249 employees)  
 Large (250+ employees)

Please select your position/s within your company.

- Managing Director  Technical Lead  
 Project Manager  HR Representative  None of the Above

Please select the country where your industry is based.

- United Kingdom  Germany
- France  Spain
- Czech Republic  Greece
- Sweden  Austria  Poland  Romania  Canada
- United States  China
- India
- Australia
- None of the Above

## Section 2: Your Industry's Current Energy Sources, Sustainable Practices, and In-House Processes

Please select your current primary sources of energy for your industrial facility which are used to power your in-house processes. Please tick all that are relevant:

- Electricity via the Grid  Electric Generators  Gas/Fuel  
 Renewable Energy Sources  Other

If you have selected the 'Renewable Energy Sources' option, please specify the sources here:

If you have selected 'Other', please specify here:

Does your industrial facility in any capacity currently use solar energy?

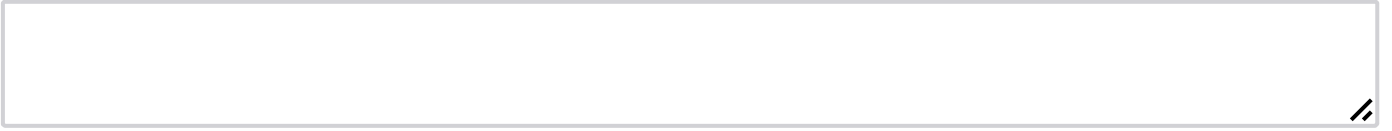
- Yes  No

If you ticked 'Yes', please specify which type of solar collectors that your industrial facility currently uses. Please tick all which are relevant.

- Evacuated Tube Thermal Collectors  Flat Plate Thermal Collectors  
 Concentrating Solar Power (CSP)  Photovoltaic (PV) Cells  
 Other

If you have selected 'Other', please specify here:

Please provide roughly how long your industrial facility has been using the solar collectors which you specified in Q9:



Does your industrial facility have any environmental management standards in place to enhance energy efficiency, reduce greenhouse gas emissions, and/or promote the use of renewable energy?

Yes  No

If you have selected 'Yes', please list them here:

Please tick all of the following temperature ranges in which your in-house industrial processes operate at:

Yes

No

Low ( $T < 150^{\circ}\text{C}$ )

Medium ( $150^{\circ}\text{C} > T > 400^{\circ}\text{C}$ )

High ( $T > 400^{\circ}\text{C}$ )

Please select all processes that are used in your industry:

Heat Treatment  Metal Curing  Metal Casting  Distillation

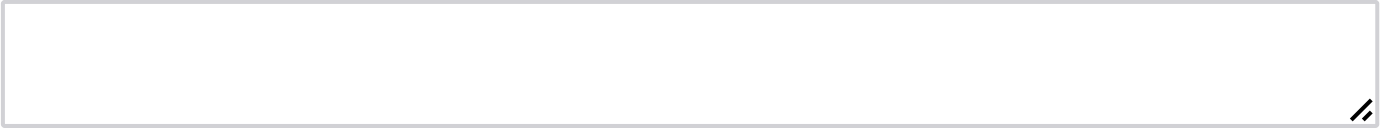
Smelting

Pasteurisation  Dyeing

Pulp Drying  Food Drying  Annealing  Sterilisation  Baking

Other

If you have selected 'Other', please specify those processes as well as their operating temperature ranges below:



### Section 3: Introduction to the ASTEP System

The Application of Solar Thermal Energy to Industrial Processes (ASTEP) system is novel, modular STE system that has been designed to produce large quantities of thermal energy for high-temperature industrial processes, supplying temperatures up to and above 400°C and 120 MWh of thermal energy annually when applied to industries in both low and high-latitude regions.

Based on ASTEP's current performance in those industries, it was demonstrated that both industrial energy consumption and CO<sub>2</sub> emissions were reduced by 20% annually, meaning that nearly €25,000 in net annual energy costs were saved by the consuming industries. The estimated payback period of the system is 3 years with a life expectancy of 30 years. The price of the system is €100,000.

To evidence its environmental sustainability, nearly 45 tonnes of CO<sub>2</sub> emissions were eliminated from those industries annually, meaning that the consuming industries saved

€18,000 in carbon tax under the European Union Emissions Trading System (EU ETS). The ASTEP module comprises of three main components:

Multi-Axis rotary Fresnel Solar Collectors mounted on a square 8x8 metre by 5 metre high metal frame.

A supplementary Phase Change Material (PCM) metallic Thermal Storage Tank, with a shell diameter of 1 metre and height of 2 metres.

An Electronic Systems Control Unit.

Is there a similar STE system currently installed and operational in your industrial facility?

Yes  No

If you have selected 'Yes', please briefly describe the type of STE system, the technologies that it uses, and its operating temperature range:

Please list all of your industry's in-house thermal processes which fall in ASTEP's operating temperature range of 150-400°C.

If ASTEP was implemented and operating within your facility, how financially viable would it be for your industrial facility?

- Very Viable  Viable  
 Somewhat Viable  Minimally Viable  Not Viable

Could you please elaborate on how the implementation of ASTEP would financially benefit your industrial facility? For instance, consider aspects such as energy savings, reduction in carbon taxes, or increased production volumes.

Considering the environmental benefits of ASTEP in the form of reduced carbon emissions, how much will implementing ASTEP enhance your facility's compliance with and reputation regarding environmental management standards, such as ISO 14001 and ISO50001?

- Greatly Enhance  Enhance  
 Somewhat Enhance  Enhance a little  
 Not Enhance

Considering the insights you have provided in this survey about ASTEP's compatibility with the thermal processes in your industry, how applicable do you find ASTEP for your industrial facility?

- Very Applicable  Applicable  
 Somewhat Applicable  Little Applicable  
 Not Applicable

Could you please elaborate on how ASTEP's design and technical performance align with the specific needs of your industrial facility? Consider aspects such as compatibility with current industrial processes and anticipated improvements in energy efficiency.

If you have any final comments or remarks for concluding the survey, please type them here:

## Appendix 3.2: Industrial Acceptance Results

[https://brunel365-my.sharepoint.com/personal/1619580\\_brunel\\_ac\\_uk/Documents/Social%20Acceptance%20Task/Final%20Industrial%20Acc%20n318%20Analysi/Industrial%20Acceptance%20Final%20Results%20n318.xlsx](https://brunel365-my.sharepoint.com/personal/1619580_brunel_ac_uk/Documents/Social%20Acceptance%20Task/Final%20Industrial%20Acc%20n318%20Analysi/Industrial%20Acceptance%20Final%20Results%20n318.xlsx)

## Appendix 3.3: Industrial Acceptance Survey Participant Information Sheet



### **Participant Information Sheet (PIS) – Industrial Acceptance Survey**

#### **Study title**

Assessment of Public Acceptance of Solar Thermal Energy (STE) Systems for Industrial Processes

#### **Invitation Paragraph**

Upon invitation to partaking in this study, please carefully read all of the following information regarding the purpose of this research in this form before making a decision.

#### **What is the purpose of the study?**

This study aims to assess the acceptance demonstrated by external industrial representatives and associative regarding the integration STE into industrial processes, as part of an internal research assignment.

#### **Why have you been invited to participate?**

You have been invited due to the valuable technical and managerial insights you can provide as an external industrial representative regarding the implementation of STE technology into broader industrial settings, particularly for high-temperature manufacturing processes.

#### **Do I have to take part?**

No. Your participation is entirely voluntary and you can decide whether to take part or not. You can simply reject this email and close the survey link if you wish to not take part. You may also leave the survey midway by simply exiting out, and all of your filled response up to that point will be immediately deleted. There will be no negative consequence imposed by the research team or any university academics if you wish to not take part.

If you wish to contact the Research Ethics Committee of Brunel University for more concerns, please email them at [res-ethics@brunel.ac.uk](mailto:res-ethics@brunel.ac.uk)

### **What do I have to do in this study?**

You are being invited to take part in an online Industrial Acceptance study, comprising of **30 questions** as enclosed within a survey link sent with the introduction email. Please read the instructions on how to fill the survey:

- 1) Read this participation sheet .
- 2) Read the introduction paragraph at the start of the survey for details on the activity on the solar thermal energy research project.
- 3) Please indicate whether you have read this document, confirm you are above the age of 18, and if you agree to take part in the survey (Q1-Q4)
- 4) Please input details about the company that you are representing in Q5-Q11. Please note that this is optional, and you leave it blank if you wish.
- 5) Answer Q12-Q30 by ticking the circle which best describes your response to the question's subject.
- 6) At the end of the survey click 'Submit' and close the window.

The estimated completion time for the survey is **10 minutes**.

### **What are the possible disadvantages and risks of taking part?**

There are no risks or disadvantages.

### **Will there be any benefits to participants taking part?**

There will be no direct benefit to any participants from taking part in the survey.

### **Will my personal information in this study be kept confidential?**

All your information collected in this survey including all results will be kept **strictly** confidential from any third academic or industrial party. Your affiliated organisation(s) and its profile will be kept anonymous and you will never be asked to provide your name or any other personal details.

The data is protected by 2 factor authorisation, in an account solely handled by the researcher.

### **What will happen to the results of the research study?**

After submitting your survey responses, they will be securely saved to a protected account accessed only by the researcher. Once submitted, these responses cannot be withdrawn. If you choose to exit the survey before completion, all partially entered responses will be automatically deleted. Your finalized responses will contribute to generating scores that will be averaged with those from other participants to assess industrial perceptions. The aggregated results will be published in the form of generic percentages and presented at conferences and meetings at Brunel University London and other institutions, without disclosing any individual organisations which have responded.

### **Who has reviewed the study?**

The Research Ethics Committee of Brunel University and Dr Valentina Stojceska (the principal supervisor of Social Assessment) have reviewed the study.

### **Research Integrity**

Brunel University London is committed to comply with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from our researchers during their research.

### **Contact for further information and complaints**

You are free to contact the researcher of this study for more details at [Imaad.Zafar@brunel.ac.uk](mailto:Imaad.Zafar@brunel.ac.uk).

Additionally, please contact to Professor Simon Taylor (Chairman of Research Ethics Committee) for complaints at [Simon.Taylor@brunel.ac.uk](mailto:Simon.Taylor@brunel.ac.uk).

You will be given a copy of the information sheet.

## Appendix 3.4: Social Acceptance Survey

### **1. Social Acceptance Survey of ASTEP**

**Introduction to the Survey:** We invite you to complete this brief 4-minute survey to gather your insights on the benefits of industry-wide application of a new solar technology being developed by the European Union (EU), known as the Application of Solar Thermal Energy to Industrial Processes (ASTEP) system.

This project aims to provide clean thermal energy for various manufacturing sectors including metals, food produce, clothing, chemicals, amongst many more. Current results of ASTEP's performance demonstrate its ability to supply temperatures of **up to and**

**above 400°C and 600 MWh** of thermal energy annually when applied to industries in both low and high-latitude regions. An annual reduction in industrial energy consumption and CO<sub>2</sub> emissions of **20%** was seen as a result of application, creating **€78,000** in annual savings in energy costs and carbon tax for the industry. For more information on this project, please feel free to visit our website: <https://asteproject.eu/>

Feel free to provide your honest insight by ticking the appropriate circles for each of the 15 questions. Note that there is no time limit to answering these questions, and participation is voluntary.

Before starting the survey, please fill the **Consent Form** below:

\*Required

1. I am over the age of 18: \*

Yes

No

2. I understand that no personal identifying data is collected in this study, therefore I know that once I have submitted my answers I am unable to withdraw my data from the study. \*

Yes

No

3. I agree that my data can be anonymised, stored and used in future research in line with Brunel University's data retention policies. \*

Yes

No

4. I agree to take part in this study \*

Yes

No

5. Please provide your signature in this box to indicate that you have given your consent to partaking in this study before proceeding to the survey questions. You can provide by providing ur initials.

**Signature of Participant: \***

6. Print today's date below, in the form DD/MM/YY, then press '**Next**' to proceed'. \*

\*\*\*

7. How strongly do you agree that ASTEP reduces Greenhouse Gas (GHG) emissions and benefits the environment?

- Strongly Agree
- Agree
- Somewhat Agree
- Disagree
- Strongly Disagree

8. How strongly do you agree that ASTEP contributes to cleaner air and better air quality in communities surrounding industrial zones?

- Strongly Agree
- Agree
- Somewhat Agree
- Disagree
- Strongly Disagree

9. How aware are you of the integration of Solar Thermal Energy (STE) systems similar to ASTEP in industries, which can include food, textile, metal, and ceramic?

- Very Aware
- Aware
- Somewhat Aware
- Little Aware
- Not Aware

10. How strongly do you agree in applying ASTEP to supply clean thermal energy for high-temperature processes in the industry?

- Strongly Agree
- Agree
- Somewhat Agree
- Disagree
- Strongly Disagree

11. How strongly do you agree with consuming daily food commodities such as milk and yoghurt which were produced using clean energy from ASTEP?

- Strongly Agree
- Agree
- Somewhat Agree
- Disagree
- Strongly Disagree

12. How strongly do you agree that consumers will change their buying behaviour if they knew that products are made with clean energy supplied by ASTEP?

- Strongly Agree
- Agree
- Somewhat Agree
- Disagree
- Strongly Disagree

13. How strongly do you agree with government initiatives in educating the general public about the environmental benefits of ASTEP?

- Strongly Agree
- Agree
- Somewhat Agree
- Disagree
- Strongly Disagree

14. A critical aim of the EU is to achieve a carbon-neutral economy by 2050 with net-zero greenhouse gas emissions, in line with the European Green Deal. For more information, please feel free to visit their website: [https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal\\_en](https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en)

Do you agree that engineering novel, high-temperature solar technologies similar to ASTEP for industrial applications heavily contributes towards achieving a carbon-neutral economy by 2050?

Yes  No

15. How strongly do you agree that governing bodies should increase investment and devote more resources towards advancing STE systems such as ASTEP in light of the EU's ambitions to achieve net-zero emissions by 2050?

Strongly Agree

Agree

Somewhat Agree

Disagree

Strongly Disagree

16. If you have any comments, suggestions, or feedback, please briefly type them in the box below. Thank you for taking the survey.

---

This content is neither created nor endorsed by Microsoft. The data you submit will be sent to the form owner.

 Microsoft Forms

## Appendix 3.5: Social Acceptance Results

[https://brunel365-my.sharepoint.com/personal/1619580\\_brunel\\_ac\\_uk/Documents/Survey%20Results/Final%20results/Public%20Acceptance/Public%20Acceptance%20n279.xlsx](https://brunel365-my.sharepoint.com/personal/1619580_brunel_ac_uk/Documents/Survey%20Results/Final%20results/Public%20Acceptance/Public%20Acceptance%20n279.xlsx)



## **PARTICIPANT INFORMATION SHEET (PIS) – LOCAL COMMUNITY**

### **Study title**

Assessment of Public Acceptance of Solar Thermal Energy (STE) Systems for Industrial Processes

### **Invitation Paragraph**

Upon invitation to partaking in this study, please carefully read all of the following information regarding the purpose of this research in this form before making a decision.

### **What is the purpose of the study?**

This study aims to assess the acceptance demonstrated by the external local community regarding the integration STE into industrial processes, as part of an internal research assignment. It is designed to collect perceptions from the general public on the environmental benefits of STE technology and their satisfaction of buying products from industrial supply chains, such as food, clothing, chemicals, etc, utilising clean heat energy from STE systems.

### **Why have you been invited to participate?**

You have been invited because you, who is indirectly affected by solar thermal energy integration, hold valuable insights and perceptions as to how satisfied are you as the consumer of product supply chains utilising STE technology

We kindly ask for your participation due to the value that your opinion will hold towards accurately improving your social welfare within your local community.

### **Do I have to take part?**

No. Your participation is entirely voluntary and you can decide whether to take part or not.

If you want to contact the Research Ethics Committee of Brunel University for more concerns, please email them at [res-ethics@brunel.ac.uk](mailto:res-ethics@brunel.ac.uk).

### **What do I have to do in this study?**

You are being invited to take part in an online student questionnaire that consists of only 1 section, and 12 questions. This online survey has been sent out to all students via email, as administrated via your academic department. Here is the step-by-step procedure as to how to complete and submit your survey results:

- 1) Read this participation sheet and sign the attached consent form before partaking in the survey.
- 2) Click the Microsoft Forms link in the email
- 3) Read the introduction paragraph at the start of the survey for further instructions.
- 4) Tick the appropriate answer on the scale which best describes your opinion.
- 5) At the end of the survey click 'Submit' and close the window.

The estimated completion time for all sections of this survey is approximately **10 minutes**.

### **What are the possible disadvantages and risks of taking part?**

None. It is completely your thoughts on the integration of solar thermal energy. Your responses will be kept confidential.

### **Will my personal information in this study be kept confidential?**

All your information collected in this survey, including all results, typed responses and opinions, will be kept **strictly** confidential from anyone in your department.

### **What will happen to the results of the research study?**

All your responses will be used to generate community awareness scores, which will be further processed to determine the social performance of the solar thermal energy project. All

The final results, which only include numerated scores, will be presented at conferences and meetings at Brunel University London and other institutions. The enumerated scores will be published in research papers for further communication.

**Who has reviewed the study?**

The Research Ethics Committee of Brunel University and Dr Valentina Stojceska (the principal supervisor of Social Assessment) have reviewed the study.

**Research Integrity**

Brunel University London is committed to comply with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from our researchers during their research.

**Contact for further information and complaints**

You are free to contact the researcher of this study for more details at [Imaad.Zafar@brunel.ac.uk](mailto:Imaad.Zafar@brunel.ac.uk).

Additionally, please contact to Professor Simon Taylor (Chairman of Research Ethics Committee) for complaints at

[Simon.Taylor@brunel.ac.uk](mailto:Simon.Taylor@brunel.ac.uk).

You will be given a copy of the information sheet.

# Appendix 4 – Letters of Ethical Approval

## Appendix 4.1: Ethical Approval for Employee Survey and Management Questionnaire



College of Engineering, Design and Physical Sciences Research Ethics Committee  
Brunel University London  
Kingston Lane  
Uxbridge  
UB8 3PH  
United Kingdom  
[www.brunel.ac.uk](http://www.brunel.ac.uk)

21 September 2022

### LETTER OF APPROVAL

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 03/10/2022 AND 01/05/2024

Applicant (s): Mr Imaad Zafar

Project Title: Assessment of Social Impacts of using a Solar Thermal Energy System for Industrial Processes

Reference: 37581-LR-Aug/2022- 41337-2

Dear Mr Imaad Zafar,

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- **The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.**
- **Please ensure that you monitor and adhere to all up-to-date local and national Government health advice for the duration of your project.**

#### Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- If your project has been approved to run for a duration longer than 12 months, you will be required to submit an annual progress report to the Research Ethics Committee. You will be contacted about submission of this report before it becomes due.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Kind regards,

Professor Simon Taylor

Chair of the College of Engineering, Design and Physical Sciences Research Ethics Committee

Brunel University London

## Appendix 4.2: Ethical Approval for Industrial & Social Acceptance

### LETTER OF APPROVAL

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 17/03/2025 AND 25/03/2025

Applicant (s): Mr Imaad Zafar

Project Title: Assessment of Public Acceptance of Solar Thermal Energy System for Industrial Processes

Reference: 44195-A-Mar/2025- 53999-1

Dear Mr Imaad Zafar

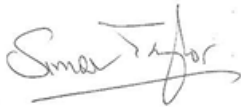
The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- **The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.**

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to any conditions that may appear above.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- If your project has been approved to run for a duration longer than 12 months, you will be required to submit an annual progress report to the Research Ethics Committee. You will be contacted about submission of this report before it becomes due.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.



Professor Simon Taylor

## Appendix 5: Coding Schedule for Dynamic Model

```
# Import libraries

import pandas as pd # For handling datasets

import numpy as np # For numerical calculations

from sklearn.linear_model import LogisticRegression # For OLR model

from scipy.optimize import minimize # For optimization

from scipy import stats # For statistical analysis

import statsmodels.api as sm # For AIC and log-likelihood

# Load dataset

data = pd.read_csv('social_impact_TS_data.csv') # CSV file for Training Satisfaction data

X = data[['Training_Programs', 'R&D_Engagement', 'Workshops', 'Managerial_Interventions']] #
Predictor variables

y = data['TS_Satisfaction'] # Target variable (Training Satisfaction)

result = model.fit(method='bfgs')

# Add intercept

X = sm.add_constant(X)

# Fit the Ordinal Logistic Regression (OLR) model

model = sm.MNLogit(y, X)

result = model.fit(method='bfgs')

# Extract alpha ( $\alpha$ ) values (thresholds) from the fitted model

alpha_values = result.params[0] # The intercepts are the alpha values

# Display alpha values

print("Alpha ( $\alpha$ ) values (thresholds between ordinal categories):")

print(alpha_values)

# Define the objective function (e.g., maximizing Training Satisfaction)

def objective(investment):

    # Modify investment scenario by 5%

    new_investment = np.array([1.05, 1.10, 1.15]) * investment
```

```

# Predict probabilities with updated investments
predicted_probabilities = result.predict(new_investment)

# Objective: maximize satisfaction at TS=4 or 5
return -np.sum(predicted_probabilities[:, [4, 5]]) # Minimizing negative probabilities

# Initial guess for investment (in thousands of EUR)
initial_guess = [10000, 15000, 12000]

# Optimize using 'minimize' from SciPy
optimal_result = minimize(objective, initial_guess, method='COBYLA')
optimal_investment = optimal_result.x # Optimal investment to avoid diminishing returns

# Use the optimized investment to generate satisfaction predictions
optimal_probabilities = result.predict(optimal_investment)

# Display results
print(f"Optimal Investment: {optimal_investment}")
print("Predicted Probabilities for Training Satisfaction:")
print(optimal_probabilities)

# Calculate AIC for the model
aic = result.aic
print(f"AIC: {aic}")

# Calculate log-likelihood for the model
log_likelihood = result.llf
print(f"Log-Likelihood: {log_likelihood}")

```

