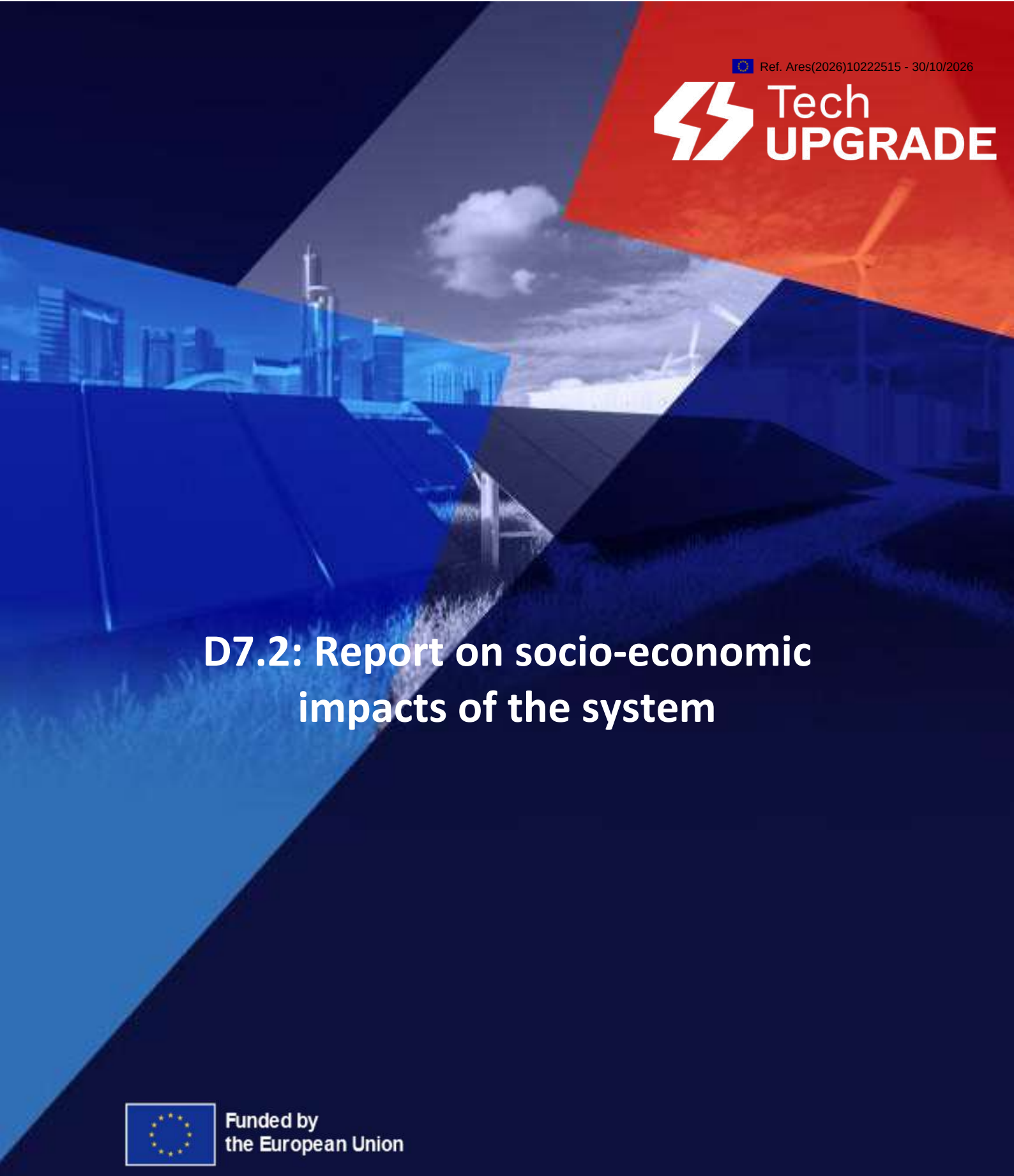
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Tech UPGRADE



D7.2: Report on socio-economic impacts of the system

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Abbreviations

Abbreviation	Meaning
CAPEX / OPEX	Capital / operational expenditure
CCUS	Carbon capture, utilisation and storage
CINEA	European Climate, Infrastructure and Environment Executive Agency
COP / COPh	Coefficient of performance (electrical) / thermal coefficient of performance
CRF	Capital recovery factor
DEA	Danish Energy Agency
DH	District heating
EC / EU	European Commission / European Union
EIC	European Innovation Council
GDPR	General Data Protection Regulation
HTHP	High-temperature heat pump
IDA	Danish Society of Engineers (employment factors used in REWARDHeat)
IO / SIOT	Input-output / symmetric input-output table
IRR / NPV	Internal rate of return / net present value
KPI	Key performance indicator
LCA / TEA	Life cycle assessment / techno-economic assessment
LCOH	Levelised cost of heat
MVR	Mechanical vapour recompression
NACE / CPA	EU statistical classification of economic activities / products
NG	Natural gas
OSH	Occupational safety and health
SCB	Statistics Sweden (Statistiska centralbyrån)
SDG	UN Sustainable Development Goal
SIA	Social impact assessment
SME	Small and medium-sized enterprise
SWOT	Strengths, weaknesses, opportunities, threats
THT / TCHT	Thermochemical heat transformer
TRL	Technology readiness level
VCHP / TAHP	Vapour-compression heat pump / thermally activated heat pump

1 Summary

This report presents the results of Task 7.2 "Socio-economic impact analysis" of the TechUPGRADE project and constitutes Deliverable D7.2 "Report on socio-economic impacts of the system". It assesses the environmental, economic and societal impacts of TechUPGRADE's thermochemical heat upgrade technology, which lifts low-grade heat from industrial waste heat, solar thermal collectors or district heating to process heat at 150-250 °C using very little electricity and with built-in heat storage. The assessment combines a quantitative impact analysis with a social impact assessment based on stakeholder questionnaires and semi-structured interviews.

The quantitative analysis builds on the use-case analyses and benchmarking of WP4 (D4.3), updated with the common assumptions agreed for the financial analysis in D7.4, and on an input-output analysis of the employment structure of the TechUPGRADE value chain based on Swedish national accounts. The stakeholder analysis covers 104 questionnaire responses from four stakeholder groups in 18 countries and eight semi-structured interviews, two per stakeholder group.

Storyline. The report is organised around one question: what needs to be in place for the technical potential of TechUPGRADE to turn into adoption by industry? The evidence points to four conditions, which structure the findings and the recommendations: proof (performance, durability and cost demonstrated at industrial scale), price (a cost advantage over fossil heat, which depends on access to low-cost heat sources and on carbon prices), permission (clear rules for recovering, upgrading and selling excess heat) and people (the skills to integrate and operate the systems, and informed and supportive communities). Section 10.9 brings the evidence on these four conditions together.

Environmental and economic impacts. Compared with an existing natural gas boiler, which emits about 280 kg CO_2 per MWh of delivered process heat, TechUPGRADE emits about 2.1 kg CO_2/MWh when upgrading waste heat and 5.4 kg CO_2/MWh when coupled with solar heat. These are operational emissions, calculated as in D4.3 and D7.4 by dividing the emission factor of the energy used by the efficiency of the technology: 204.46 kg CO_2 per MWh of natural gas divided by the 73% efficiency of the existing boiler gives 280 kg CO_2/MWh, and the Danish electricity emission factor of 31.02 kg CO_2/MWh divided by the electrical COP of TechUPGRADE of 14.5 gives 2.1 kg CO_2/MWh; the value for the solar configuration is taken from D4.3. They exclude emissions from materials, manufacturing, construction and end-of-life, which are covered by the life cycle assessment in D7.3. On this basis, TechUPGRADE saves about 278 and 275 kg CO_2 per MWh of process heat, the highest savings among the technologies benchmarked. The levelised cost of heat (LCOH) is about 35 €/MWh for TechUPGRADE with free waste heat and 58 €/MWh with solar heat, compared with 72 €/MWh for the existing natural gas boiler, 61-67 €/MWh for biomass boilers, 89-178 €/MWh for high-temperature heat pumps and 208-211 €/MWh for electric boilers. TechUPGRADE with waste heat is therefore the only option assessed that reduces both emissions and heat costs substantially; its payback time is about 4.3 years. Reaching the market ambition of the proposal, 5 TWh of decarbonised process heat per year, would avoid about 1.4 Mt of operational CO_2 emissions per year.

Employment and macro-economic impacts. The ten Swedish sectors that form the TechUPGRADE value chain produce SEK 3.17 trillion of output and employ 755,015 people, with construction (28.5% of output) and machinery manufacturing (13.3%) as the largest components. The output-weighted cost per job is €569,960, slightly more capital-intensive than the biomass-boiler (€566,610) and electric-boiler (€519,410) value chains; per million euro of annual system cost, the three technologies

support between 1.76 and 1.93 jobs. Because the fossil fuels displaced are largely imported, the main transition risk is a skills mismatch rather than job loss.

Stakeholder perspectives. Academic and research stakeholders (n = 64) rate the scientific and socio-economic impact potential of TechUPGRADE at 4.27 out of 5; 54 of 64 consider the heat-upgrade challenge very or highly relevant and 37 of 64 see scale-up demonstration as the post-project priority. Industrial stakeholders (n = 11, mostly SMEs) unanimously name energy-cost reduction as the main adoption driver, and 6 of 11 identify demonstration under realistic conditions and material reliability as preconditions for scale-up. Civil-society stakeholders (n = 27) place air pollution and public health at the top of community concerns (25 of 27 respondents) and consider communities poorly informed (24 of 27). The two public-authority respondents (Denmark) report that regulatory uncertainty and poor coordination between authorities have hindered previous excess-heat projects. The eight interviews, two per group and including two Italian policymakers, corroborated these findings. The samples are not representative in a statistical sense: the academic sample is large, but the industrial sample is small and dominated by energy-service SMEs, the civil-society sample consists mainly of professionals, and the public-authority evidence rests on four people. Findings for the latter groups are therefore treated as indicative (Section 5.8).

Recommendations. Each recommendation in Chapter 3 is linked to the results that support it and to the strength of that evidence (Table 3.1). The best-supported recommendations concern proof: taking the technology to TRL 6 through an engineering-scale prototype at a site with free waste heat, which is supported by the WP4 benchmarking (35 €/MWh and a payback of about 4.3 years with waste heat), by 37 of 64 academic respondents and by 6 of 11 industrial respondents; and publishing verified performance and cost data, which 41 of 64 academic respondents would use and whose absence 5 of 11 industrial respondents cite as a barrier. Recommendations on people, namely green skills and early community engagement, are supported by consistent evidence from the industrial, academic and civil-society surveys. Recommendations on price (carbon pricing and de-risking finance) and permission (clarifying the regulatory status of excess heat) are plausible and consistent with D7.4, but rest on smaller samples, in particular four public-authority respondents, and should be tested further in D7.5. These recommendations feed into D7.4, D7.5 and Task 8.3.

2 Introduction

2.1 The TechUPGRADE project

TechUPGRADE is a Horizon Europe project (grant agreement No. 101103966, call HORIZON-CL5-2022-D4-01-04) that develops and demonstrates a thermochemical heat upgrade system, referred to as a Hydration Heat Transformer, to upgrade low-temperature heat to 150-250 °C. The system is based on reversible hydration and dehydration reactions of salt hydrates. During dehydration, low-grade heat drives an endothermic reaction that removes water from the salt at low water-vapour partial pressure; during hydration, water vapour at elevated partial pressure triggers an exothermic reaction that releases heat at a higher temperature. Because the equilibrium temperature is governed by the water-vapour partial pressure, the temperature is lifted without mechanical compression, and electricity is needed only for pumps, fans and similar auxiliaries (D4.3).

The technology can upgrade industrial waste heat (for example from data centres), solar thermal heat and district heating, and offers inherent heat storage. The consortium of 14 partners, coordinated by DTU, aims to validate the concept at TRL 5 at laboratory and pilot scale at DLR and at Absolicon in Sweden, where the system is coupled to concentrating solar collectors, and targets a levelised cost of heat of 3-6 c€/kWh.

2.2 Policy and market context

Process heat is the largest industrial energy need in Europe. According to Heat Roadmap Europe, the demand for process heating amounts to about 1,952 TWh per year (2019), about 78% of which is covered by fossil fuels. Process heat at 100-200 °C represents about 26% of this demand, is 67% fossil-based and accounts for about 102 Mt of CO_2 per year (D7.4). At the same time, EU industry discharges about 304 TWh of waste heat per year, over 100 TWh of which is available at 100-200 °C (project proposal). Converting this waste heat into usable process heat is the market opportunity that TechUPGRADE addresses; the proposal targets 5 TWh of decarbonised process heat per year within five years of commercialisation.

The technology contributes to the European Green Deal, to the REPowerEU objective of reducing fossil gas imports, to energy-efficiency and waste-heat recovery objectives, and to UN Sustainable Development Goal 7. Its social dimension is equally important. The Just Transition Mechanism aims to ensure that the shift to climate neutrality is fair for regions, sectors and workers dependent on fossil fuels, and Horizon Europe calls for people-centred innovation. This is why Task 7.2 was included in the TechUPGRADE work plan.

2.3 Objectives of Task 7.2

Task 7.2 "Socio-economic impact analysis" is led by MG Sustainable Engineering (MGS) with the participation of DTU, GRL and COWI, and runs from month 23 to month 42. The task develops a Social Impact Assessment that measures TechUPGRADE's impact on the communities and industrial sites where the technology will be installed, combining questionnaires and semi-structured interviews to acquire quantitative and qualitative data on environmental, economic and social impacts. It also assesses the economic dimension for the public in terms of jobs and economic benefits, as opposed to the fossil fuels that are phased out, so that positive impacts can be maximised and drawbacks mitigated in line with Just Transition principles. The specific objectives of this report are:

- To define energy, environmental, economic and societal KPIs for assessing TechUPGRADE.
- To quantify these KPIs on the basis of the WP4 use cases and benchmarking, and to indicate their order of magnitude at the market scale targeted in the proposal.
- To estimate the employment structure and labour intensity of the TechUPGRADE value chain using national input-output data, and to compare it with other energy technologies.
- To collect and analyse the views of academia, industry, civil society and public authorities on the expected benefits, risks and conditions for uptake.
- To integrate the quantitative and stakeholder evidence into a consolidated assessment of benefits and drawbacks, with recommendations.

2.4 Research gaps and research questions

Research on energy transitions has been dominated by technical and economic perspectives, while social inclusion, equality and public acceptance remain comparatively under-researched (Urban et al., 2025). The green and digital transitions are reshaping work: around one million new green jobs are expected in the EU, but many will require upskilling and lifelong learning (CEDEFOP, 2021, 2024; OECD, 2023; Abrahamsson, K., Ennals, R., Harlin, U., & Mathieu, C., 2025). Significant gaps also persist in how job creation is estimated (Hanna et al., 2024): gross employment counts jobs created directly and indirectly, whereas net employment also accounts for jobs displaced elsewhere, and output-based input-output methods, which describe the structural labour intensity of existing sectors, are rarely distinguished from investment-based methods, which estimate incremental jobs from new spending (Cameron and van der Zwaan, 2015). Few studies combine such estimates with structured evidence from the stakeholders who will adopt, regulate or live alongside a new industrial technology. This report addresses these gaps through the following research questions:

- What are the environmental and economic impacts of TechUPGRADE compared with conventional and alternative low-carbon heat-supply options?
- How can input-output methods estimate job creation from TechUPGRADE in a specific national context, and how many people are employed in each relevant sector of its value chain?
- How do different estimation approaches and types of energy projects influence employment estimates?
- How do academic, industrial, civil-society and public-authority stakeholders perceive the benefits, risks and conditions for uptake of the technology?
- What are the implications for labour-market, energy and industrial policy?

2.5 Relation to other work packages and deliverables

The quantitative analysis builds on the use-case analyses and benchmarking of WP4 (D4.3) and uses the same techno-economic assumptions as the financial analysis and go-to-market strategy (D7.4, COWI). The CO_2 emissions reported in this report are operational emissions per MWh of delivered process heat, calculated with the same method as in D4.3 and D7.4: the emission factor of the fuel or electricity used divided by the efficiency or coefficient of performance of the technology (Section 5.2). They cover only the energy used to operate each heat-supply option and exclude the emissions associated with raw materials, manufacturing, construction, transport and end-of-life. Their scope therefore differs from that of the life cycle assessment carried out by RISE in D7.1 and D7.3, which

covers all life-cycle stages. For the CO_2 emissions of the TechUPGRADE system integrated with industry over its whole life cycle, the reader is referred to D7.3. The policy guidelines and replicability report (D7.5, IED) builds on the regulatory challenges and policy instruments identified here, and the KPIs proposed in this report feed the impact-monitoring framework of Task 8.3.

2.6 Structure of the report

The report follows the structure of the other WP7 deliverables. Chapter 1 summarises the main findings, Chapter 2 introduces the study task, and Chapter 3 presents the recommendations. Chapter 4 defines the key performance indicators and Chapter 5 the methodology. Chapter 6 presents the environmental and economic impacts based on the WP4 use cases and benchmarking, and Chapter 7 the employment and macro-economic analysis. Chapter 8 reports the results of the stakeholder questionnaires and Chapter 9 the semi-structured interviews. Chapter 10 integrates the evidence across stakeholder groups and concludes with a synthesis of four conditions for adoption, Chapter 11 discusses the findings and Chapter 12 concludes. Chapter 13 contains the bibliography and Chapter 14 the appendices.

3 Recommendations

The recommendations below follow from the evidence in Chapters 6-11 and are grouped by the actor best placed to act. Table 3.1 links each recommendation to the specific results that support it and rates the strength of that evidence. The rating is high when the recommendation is supported by consistent results from at least two sources, including the techno-economic analysis or a large sample; medium when it is supported by consistent results from smaller or non-representative samples; and low when it rests on very few respondents. Recommendations with low evidence strength are presented as issues to be tested further rather than as firm conclusions.

3.1 The TechUPGRADE consortium

TechUPGRADE will reach TRL 5 in pilot systems. The next step, as identified in D7.4, is to develop the product to TRL 6, the demonstration of an engineering-scale prototype in a relevant environment that verifies its performance, reliability and durability under realistic conditions. All stakeholder groups point in this direction: scale-up demonstration is the first post-project priority for 57.8% of academic respondents, and realistic demonstration together with material and reactor reliability are the most cited requirements of industrial respondents (6 of 11 respondents each). The WP4 results show that the prototype should preferably be hosted at a site with free waste heat, where TechUPGRADE achieves the lowest cost of heat (35 €/MWh) and a payback time of about 4.3 years.

Alongside the demonstration, the consortium should publish performance, durability and cost data in a documented, reusable form, as open data wherever confidentiality permits: 64.1% of academic respondents want to use project data, and 45.5% of industrial respondents cite the lack of cost data at prototype stage as a barrier. Communication should be tailored to each audience: energy-cost savings and energy security for SMEs, local air quality and health for communities, and local jobs and economic development for public authorities. Occupational safety and health should be designed into reactors and plants from the outset, with clear procedures for handling salt hydrates and high-temperature components.

3.2 Policymakers and public authorities

Policy should first remove regulatory uncertainty. Public-authority respondents report that unclear rules and the need to coordinate several institutions have already hindered excess-heat projects, and simpler permitting is the second most requested policy change in industry (3 of 11). Because this evidence rests on few respondents, the recommendation should be tested with energy regulators in D7.5. Within these limits, the legal and fiscal status of recovered and upgraded excess heat should be clarified, including its sale across company boundaries and its delivery to district heating networks, and a coordinating authority or one-stop shop should support developers. Price signals should reward CO_2 savings: carbon pricing or stricter emission targets is the policy change most requested by industrial respondents (4 of 11). First-of-a-kind installations need de-risking instruments; as noted in D7.4, SMEs can seek EIC Accelerator funding to move the technology from TRL 6 to TRL 9, and large demonstrations can later be supported by the EU Innovation Fund.

3.3 Industry and industrial clusters

Industrial companies can prepare for adoption by mapping waste-heat sources and heat sinks across co-located firms. The WP4 data-centre case at GreenLab, where 80 MW of waste heat at 70 °C is available next to a biogas plant needing heat at 150 °C, shows the potential of industrial symbiosis, and one industrial respondent described a complex where some companies pay to cool exhaust fumes while their neighbours burn LPG to heat water. Companies should also invest early in skills for process integration, thermal systems engineering and digital monitoring, in partnership with universities and vocational training providers.

3.4 Academia and education

With 60.9% of academic respondents seeing high potential for curriculum integration, thermochemical heat upgrading should be introduced into energy and process engineering programmes, supported by the project's training material, design documentation and simulation models. Industrial PhD programmes would connect research with application, and the joint research agenda identified by respondents (material stability, reactor heat and mass transfer, system integration, digital twins, and combined techno-economic and life-cycle assessment) provides a basis for follow-up projects.

3.5 Civil society and local communities

Public acceptance depends less on overcoming opposition than on closing an information gap: 88.9% of civil-society respondents consider communities poorly informed. Engagement around demonstration sites should start early and be transparent, combining community education sessions with published plans and risks, the two measures preferred by 70.4% of respondents. Civil-society organisations should be involved as independent sources of information and as monitors of local impacts, and local benefits should be made visible.

Table 3.1. Summary of recommendations, supporting evidence and strength of evidence.

Recommendation	Supporting evidence	Strength of evidence	Addressed to	Taken forward in
Develop TechUPGRADE to TRL 6 with an engineering-scale prototype, preferably at a site with free waste heat	D4.3: LCOH 35 €/MWh and payback about 4.3 years with waste heat, against 58 €/MWh and about 10 years with solar heat; scale-up demonstration is the top academic priority (37 of 64); demonstration and material reliability are the top industrial requirements (6 of 11 each); interviews confirm; D7.4	High	Consortium, industry	D7.4, Task 8.3
Publish performance, durability and cost data	41 of 64 academic respondents would use project data (21 more might); 5 of 11 industrial respondents cite the lack of cost data at prototype stage; cost is the most frequent academic barrier (27 of 54 coded answers)	High	Consortium	WP8, data management plan
Tailor communication to each audience and integrate occupational safety and health	Benefits valued differently: energy cost by all industrial respondents, air quality and health by 25 of 27 civil-society respondents; safety concerns currently low (4 of 27) but sensitive to incidents; OSH literature (Chapter 7)	Medium	Consortium	WP8

Recommendation	Supporting evidence	Strength of evidence	Addressed to	Taken forward in
Clarify the status of upgraded excess heat; one-stop shop; simpler permits	One public-authority questionnaire respondent and two interviews with Italian policymakers; simpler permitting requested by 3 of 11 industrial respondents	Low: to be tested in D7.5	Policymakers	D7.5
Carbon pricing and de-risking finance (EIC Accelerator, Innovation Fund)	Carbon pricing is the policy change most requested by industry (4 of 11); cost and funding are frequent academic barriers; funding instruments identified in D7.4	Medium	Policymakers, consortium	D7.4, D7.5
Map heat sources and sinks across firms and invest in skills	D4.3 GreenLab case (80 MW of waste heat at 70 °C next to a heat user at 150 °C); 7 of 11 industrial respondents expect new jobs or skills; engineering services are the most labour-intensive sector of the value chain (Section 7.10)	Medium	Industry, clusters	Task 8.3
Curricula, industrial PhDs and a joint research agenda	High curriculum potential (39 of 64); integration with industrial processes (43 of 64) and material stability (38 of 64) are the top research areas	High within academia	Academia	WP8
Early, transparent engagement; civil society as independent monitor	24 of 27 civil-society respondents consider communities not or only slightly informed; lack of awareness is the main barrier (22 of 27); education sessions and transparent sharing of plans preferred (19 of 27 each); sample of professionals rather than residents	Medium	Consortium, authorities, civil society	D7.5, WP8

4 Key performance indicators

4.1 Definition of key performance indicators

A key performance indicator (KPI) is a metric that shows how effectively a system achieves its objectives. In this report, KPIs are used to evaluate and compare the impacts of TechUPGRADE against alternative heat-supply technologies. The environmental and economic KPIs are those used for the benchmarking in WP4 (D4.3), so that results are consistent across deliverables; they are complemented by societal and stakeholder-acceptance KPIs.

4.2 Energy and environmental indicators

Efficiency. For TechUPGRADE, the thermal coefficient of performance (COPh, the ratio of upgraded heat to low-grade heat input) and the electrical COP (the ratio of delivered heat to electricity consumed); for boilers and heat pumps, the conversion efficiency or COP.

CO_2 for delivered process heat (kg/MWh). The emissions per MWh of process heat, obtained from the emission factor of the fuel or electricity used and the efficiency of the technology. Embedded emissions are not included.

CO_2 savings compared with natural gas (kg/MWh). The difference between the emissions of the existing natural gas boiler and those of the alternative technology per MWh of process heat.

4.3 Economic indicators

Levelised cost of heat (LCOH, €/MWh). The annualised lifetime cost of the system, including capital expenditure, fixed and variable operating costs and fuel or electricity, divided by the heat delivered.

Additional cost compared with natural gas (€/MWh) and cost per kg CO_2 avoided (€/kg). The difference in LCOH compared with the natural gas reference and this difference divided by the CO_2 savings. Negative values indicate that the technology both saves money and avoids emissions.

Payback time, net present value (NPV) and internal rate of return (IRR). Financial indicators of the investment compared with continued use of the existing natural gas boiler.

4.4 Societal indicators

Employment intensity of the value chain (k€ per job; jobs per M€). The labour intensity of the sectors that supply, install and operate the technology, derived from national input-output and employment statistics.

Investment-phase and operation-phase employment. The job-years created during manufacturing and installation and the jobs supported each year during operation.

Skills, health and safety. Qualitative indicators of the occupational profile required by the technology and of its effects on workers' health and safety.

4.5 Stakeholder and acceptance indicators

The SIA adds indicators of how the technology is perceived by those who will develop, adopt, regulate or live alongside it: perceived relevance and impact potential (share of respondents and 1-5 rating),

familiarity with thermochemical heat upgrade, expected socio-economic effects, barriers to adoption and acceptance, and information and engagement levels.

Table 4.1. Overview of key performance indicators used in this report.

Domain	Indicator	Unit	Source of data
Energy	Efficiency (COPh, COP, boiler efficiency)	-	D4.3; COWI assumptions
Environment	CO_2 for delivered process heat	kg/MWh	D4.3; updated CO_2 calculation
Environment	CO_2 savings compared with natural gas	kg/MWh	D4.3; updated CO_2 calculation
Economy	Levelised cost of heat	€/MWh	D4.3; updated LCOH calculation
Economy	Additional cost vs natural gas; cost per kg CO_2 avoided	€/MWh; €/kg	D4.3; updated calculation
Economy	Payback time, NPV, IRR	years; €; %	D4.3
Society	Employment intensity	k€ per job; jobs per M€	Input-output analysis (Sweden)
Society	Investment-phase and operation-phase jobs	job-years; jobs/yr	Input-output analysis; IDA factor
Society	Skills, health and safety	qualitative	Literature; stakeholders
Acceptance	Relevance, familiarity, expected effects, barriers, information	% of respondents; 1-5 rating	Questionnaires; interviews

5 Methodology

The assessment combines a quantitative impact analysis with a Social Impact Assessment based on stakeholder questionnaires and semi-structured interviews. Table 5.1 summarises the analytical framework.

Table 5.1. Analytical framework of the assessment.

Strand	Method	Data sources	Main outputs
Environmental and economic impacts	Use-case analysis and benchmarking against reference and alternative technologies	D4.3 (WP4); COWI assumptions (December 2025); updated LCOH and CO_2 calculations; DEA technology data for industrial process heat	CO_2 per MWh of heat, CO_2 savings, LCOH, payback, NPV, IRR
Market-scale indication	Scaling of unit results to the market target of the proposal	Project proposal; D4.3 unit results	Order of magnitude of CO_2 savings, cost savings, capacity and investment
Employment analysis	Output-based input-output allocation	Statistics Sweden SIOT 2022; SCB employment statistics 2022	Allocated jobs, employment intensity, cost per job, comparison with other energy projects
Social impact assessment	Four stakeholder questionnaires; semi-structured interviews	104 questionnaire responses from 18 countries; 8 interviews	Perceptions of benefits, risks, barriers and conditions for uptake
Integrated assessment	Cross-stakeholder synthesis, impact register, SWOT, risk register	All of the above	Benefits to maximise, drawbacks to mitigate, recommendations

5.1 Use cases and benchmarking

The environmental and economic analysis uses the use cases defined in WP4 (D4.3) in cooperation with GreenLab Skive and Absolicon. Four configurations of TechUPGRADE are analysed: upgrading surplus heat from a data centre at GreenLab for a biogas plant (Case 1), two solar-driven configurations for food-processing plants (Cases 2 and 3), and a cascade of a high-temperature heat pump and TechUPGRADE (Case 4). Following D4.3, these configurations are benchmarked against the reference scenario of an existing natural gas boiler and against three alternative technologies: high-temperature heat pumps (HTHP, with a mechanical vapour recompression stage for 250 °C), electric boilers and biomass boilers fuelled with wood chips or wood pellets.

D7.4 additionally describes further cases under development (waste cardboard processing and furniture production at GreenLab, a glycosaminoglycan plant, heat recovery at a snack-fryer plant, steam for green hydrogen production, amine regeneration for carbon capture, a topping cycle for high-temperature heat pumps, and solar-integrated upgrade with storage). Their assumptions are being updated in D7.4, and they are therefore not quantified in this report.

5.2 Environmental method

In line with D4.3, the CO_2 emissions per MWh of delivered process heat are calculated from the emission factor of the energy carrier and the efficiency of the technology:

$$CO_{2,heat} = \frac{EF_{fuel}}{\eta}$$
$$\Delta CO_2 = CO^{NG}_{2,heat} - CO^{tech}_{2,heat}$$

where EF is the CO_2 emission factor of the fuel or electricity (kg/MWh) and η the efficiency or COP of the technology. The CO_2 savings of each technology are its emissions subtracted from those of the existing natural gas boiler. The emission factors are 204.46 kg/MWh for natural gas, 4.92 kg/MWh for wood chips, 4.12 kg/MWh for wood pellets and 31.02 kg/MWh for electricity (DEA 2026 forecast for Denmark); the EU electricity mix (213.73 kg/MWh, EMBER 2024) is defined as a sensitivity in the COWI assumptions. For example, the existing gas boiler emits 204.46 / 0.73 = 280.08 kg CO_2 per MWh of process heat, while TechUPGRADE with waste heat, whose only energy input that causes emissions is electricity for auxiliaries, emits 31.02 / 14.5 = 2.14 kg CO_2/MWh. These are operational emissions only: upstream and embedded emissions from materials, manufacturing, construction and end-of-life are excluded here and are covered by the life cycle assessment in D7.3.

5.3 Economic method

The levelised cost of heat is calculated as in D4.3 and the updated LCOH calculation:

$$LCOH = \frac{CAPEX \cdot CRF + OPEX_{fixed} + OPEX_{var} + C_{fuel}}{Q}$$
$$CRF = \frac{r(1+r)^N}{(1+r)^N - 1}$$

where CAPEX is the capital cost, CRF the capital recovery factor, OPEX the fixed and variable operating costs, C_fuel the cost of fuel or electricity and Q the annual heat delivered. The main assumptions are those of D4.3 and of the common assumptions prepared by COWI for D7.4 (Table 5.2). Costs exclude VAT and taxes. Payback time, NPV and IRR are taken from D4.3.

Table 5.2. Main techno-economic assumptions (D4.3; COWI assumptions, December 2025).

Parameter	Value	Source
Interest rate; economic lifetime	4%; 20 years (sensitivity 3% and 7%; 7, 10 and 15 years)	D4.3; COWI
Operating time	4,000 h/yr (two shifts on workdays, incl. start-up)	D4.3; COWI
Natural gas price	50.5 €/MWh (2026 forecast)	COWI
Electricity price	194.1 €/MWh (EU non-household, Eurostat 2024); sensitivity 108.6 €/MWh (DEA forecast)	COWI
Wood chips; wood pellets	33.8 €/MWh; 40.3 €/MWh	COWI (DEA)
Surplus waste heat	0 €/MWh (sensitivity 20 and 40 €/MWh)	COWI
Existing natural gas boiler	Efficiency 73% (range 56-86% depending on age and location)	D4.3; COWI
TechUPGRADE	CAPEX 0.9 M€/MW; fixed OPEX 45.63 k€/MW/yr; variable OPEX 7.4 €/MWh; COPh 0.55-0.6; electrical COP 14.5	D4.3
Alternative technologies	CAPEX, OPEX and efficiencies of HTHP, electric and biomass boilers	DEA technology data for industrial process heat; D4.3

5.4 Employment and macro-economic method

Input-output (IO) models assess how economic activities are interconnected across sectors and are widely used to estimate the employment effects of energy technologies (Hanna et al., 2024). IO analysis is based on national accounts describing the structure of an economy (Leontief, 1951) and traces how spending in one sector generates indirect and induced employment through supply chains (Cameron and van der Zwaan, 2015; Stamopoulos et al., 2021). The analysis uses the Swedish symmetric input-output table (SIOT) for 2022, published by Statistics Sweden in September 2024, together with SCB employment statistics by industry (annual mean of the four quarters of 2022). Rather than estimating project-specific jobs directly, it identifies the sectors linked to TechUPGRADE and analyses their employment and output. The method consists of four steps. First, the relevant sectors are selected. Second, the output share of each sector is calculated:

$$Output\ share\ _i = \frac{Output_i}{\sum_{i=1}^{n} Output_i}$$

Third, allocated jobs are obtained by distributing the total employment of the selected sectors according to these shares, and the employment intensity and the output required per job are calculated for each sector:

$$Allocated\ Jobs_i = Output\ share\ _i \times \sum_{i=1}^{n} Employees\ _i$$

$$Employment\ Intensity_i = \frac{Employees\ _i}{Output\ _i}$$

$$Output\ per\ job\ _i = \frac{1}{Employment\ Intensity\ _i}$$

The output required per job is converted into euros at EUR/SEK = 0.0935. Fourth, an output-weighted average cost per job is calculated for the value chain and used to estimate the number of jobs supported by the annual cost of a project:

$$\underline{C} = \sum_{i=1}^{n} Output\ Share\ _i \times k€\ per\ job_i$$

$$Estimated\ jobs = \frac{Total\ Annual\ Cost}{\underline{C}}$$

5.5 Social impact assessment: stakeholder questionnaires

The SIA follows the quadruple-helix model, which distinguishes academia, industry, government and civil society. A dedicated questionnaire was developed for each group, structured around the environmental, economic and social themes of the Description of Action (Table 5.3).

Table 5.3. Structure of the stakeholder questionnaires.

Stakeholder group	Items	Main themes
Academia and research	15	Profile; relevance of upgrading low-grade heat to 150-250 °C; research areas for collaboration; curricula; useful outputs; contribution to decarbonisation, the Green Deal and SDG 7; post-project priorities; joint research; data access; academic-industry collaboration; barriers; overall impact rating (1-5)
Industrial stakeholders	21	Profile; adoption drivers; heat source, temperatures and waste-heat share; heat recovery; familiarity; benefits; scale-up requirements; recovery potential; competitiveness; CO_2 reduction; environmental benefits; jobs and skills; socio-economic performance; policy needs; stakeholders; long-term change
Civil society	13	Profile; familiarity; community concerns; attitude to the transition; expected social impacts; involvement of civil society; information; barriers to acceptance; role of civil society; good practice; economic risks
Public authorities	17	Profile; familiarity; regulatory challenges; effect of regulation; permits; policy instruments; importance of socio-economic impacts; community concerns; public perception; existing initiatives; support needed by industry

The questionnaires combined single-choice, multiple-choice, Likert-type and open questions and were administered online through Google Forms, distributed through partner networks, project events, universities, industry clusters and public bodies. Each opened with an information and consent statement in accordance with the GDPR, and all respondents gave their consent. E-mail addresses collected by the form were removed before analysis.

Table 5.4. Sample of the stakeholder questionnaires.

Group	Responses	Collection period	Countries	Profile
Academia and research	64	13 Feb - 20 Jun 2026	17 (+1 not stated)	80% universities; 36 students and 28 researchers and staff; Greece 47%, Sweden 14%
Industrial stakeholders	11	25 Nov 2025 - 24 Apr 2026	5 (+1 not stated)	10 SMEs, 1 technology provider; Sweden 45%
Civil society	27	12 Feb - 12 Jun 2026	5	Project managers, managers, engineers, researchers, students; Sweden 48%, Greece 37%
Public authorities	2	9 Apr 2026	1	Danish municipality and business development council
Total	**104**	**Nov 2025 - Jun 2026**	**18**	

Responses were cleaned before analysis. Country names were harmonised, and free-text job titles were standardised: typing errors were corrected (for example “Proejct coordinator”) and variants of the same role, such as “Project manager” and “Project Manager”, were grouped together so that each role is counted accurately. In multiple-choice questions, respondents could select several options. In Chapter 8 and its charts, the percentages for these questions therefore represent the share of each option in the total number of mentions across all responses, while the bars show how many respondents selected each option; elsewhere in the report, multiple-choice results are expressed as numbers or shares of respondents. Open answers were analysed thematically, with each answer coded to one or more themes; non-substantive answers were excluded from the denominator.

5.6 Semi-structured interviews

Semi-structured interviews complement the questionnaires by exploring the reasoning behind the survey patterns. Four stakeholder-specific interview scripts were developed by MGS and shared with the consortium. They mirror the themes of the questionnaires and use guiding prompts that partners can adapt to the interviewee's role. Eight interviews were conducted, two with each stakeholder category; the two public-authority interviews were held with Italian policymakers. Interviews were planned to last 25-35 minutes, and are reported anonymously in line with the GDPR.

5.7 Integration of quantitative and stakeholder data

Indicators measured in comparable ways across stakeholder groups (familiarity, expected effects, barriers, need for demonstration, employment expectations) are compared side by side, and stakeholder expectations are confronted with the quantitative results. The combined evidence is summarised in a social impact register, a SWOT analysis and a risk register.

5.8 Sample representativeness and limitations

The stakeholder samples were recruited through the networks of the project partners and are non-probabilistic. Respondents chose to take part, so they are likely to be more interested in, and more favourable to, clean industrial heat than the average member of each group. The results are therefore descriptive: they show which views exist and how they are distributed in each sample, but they cannot be generalised statistically to the populations of researchers, companies, citizens or public authorities in Europe. Table 5.5 summarises the composition of each sample, its main biases and how these affect the interpretation of the results.

Table 5.5. Representativeness and main biases of the stakeholder samples.

Group	Sample	Composition and possible bias	Implication for interpretation
Academia and research	64 questionnaires; 2 interviews	17 countries, but Greece (47%) and Sweden (14%) dominate; 36 of 64 are students; most respondents work on energy systems rather than thermochemistry	The most robust sample. Students may judge with less experience, but senior respondents rate the impact potential slightly higher (4.43) than students (4.14), so the student share does not inflate the results
Industry	11 questionnaires; 2 interviews	10 SMEs; 7 of 11 work in energy systems or renewable energy integration and are potential suppliers or integrators rather than heat users; large energy-intensive companies are absent	Indicative only: one respondent equals about 9 percentage points. Views of heat-consuming manufacturers and large industry need to be confirmed
Civil society	27 questionnaires; 2 interviews	Sweden (48%) and Greece (37%); mostly professionals working in or with organisations (project managers, engineers, managers), not residents living near industrial sites	Reflects informed civil-society professionals rather than the general public. The information gap among the general public is probably larger than measured here
Public authorities	2 questionnaires (Denmark); 2 interviews (Italy)	Economic and business development officers; no energy or environmental regulators	Qualitative signals only. Findings on regulation and permitting should be tested with regulators in D7.5
Interviews (all groups)	8 interviews, 2 per group	Selected through partner networks; scripts mirror the questionnaires; reported in aggregate to protect anonymity	Corroborate and help explain the survey results, but too few to reach thematic saturation or to identify new themes systematically

To limit the effect of these biases, the analysis triangulates the results across stakeholder groups and methods, reports counts rather than percentages for the small samples, distinguishes between shares of respondents and shares of mentions for multiple-choice questions (Section 5.5), and qualifies the strength of the evidence behind each recommendation (Table 3.1). Three further limitations concern the quantitative analysis. The environmental and economic results rely on the cost and performance estimates of a technology at TRL 5, as defined in D4.3, and will be updated in D7.4 and with the results of the pilot demonstrations. The CO_2 emissions are operational emissions only (Section 2.5). The input-output allocation describes the structural labour intensity of existing Swedish sectors rather than the net effect of new investment.

6 Environmental and economic impact analysis

This chapter presents the environmental and economic impacts of TechUPGRADE on the basis of the use-case analyses and benchmarking carried out in WP4 (D4.3). The benchmarking results are reported with the updated LCOH and CO_2 calculations prepared for D7.4, which use the common assumptions of Table 5.2.

6.1 Use cases analysed in WP4

Table 6.1 summarises the four use cases of D4.3.

Table 6.1. TechUPGRADE use cases analysed in WP4 (D4.3).

Case	Description	Heat source	Process heat	Capacity	CAPEX (M€)	LCOH (c€/kWh)	CO_2 for delivered heat (kg/MWh)
Case 1	Surplus heat from a data centre upgraded for the GreenLab Biogas Plant	Waste heat 70 °C	150 °C	1 MW	0.9	3.53	2.14
Case 2	Solar heat for a food production plant	Solar heat 80 °C	160 °C	4 MW	8.48	5.8	5.43
Case 3	Solar heat for a snack-processing plant	Solar heat 200 °C	212 °C (20 bar steam)	11.5 MW	24.4	5.8	5.43
Case 4	Cascade of HTHP (70-180 °C) and TechUPGRADE (180-250 °C)	Low-temperature heat 70 °C	250 °C	1 MW	4.7	33.2	36.9

Case 1 - data centre surplus heat at GreenLab. GreenLab Skive is a 60-hectare green industrial park whose companies share energy and resources through the SymbiosisNET. A planned 100 MW data centre could provide about 80 MW of waste heat at 70 °C. The GreenLab Biogas Plant needs 5 MW of heat, currently covered by natural gas, of which 1 MW is required at 150 °C to regenerate the amine solution in its biogas upgrading unit, which runs continuously. TechUPGRADE upgrades the data-centre heat from 70 °C to 150 °C at an LCOH of 3.53 c€/kWh and with 2.14 kg CO_2 per MWh of process heat.

Cases 2 and 3 - solar-driven upgrading. Provided by Absolicon, Case 2 concerns a food production plant that uses steam at about 159 °C mainly for sterilisation and plans to need 170-175 °C in the future; Case 3 concerns a snack-processing plant with 11.5 MW of steam demand at 20 bar (about 212 °C). In both cases the system is driven by solar heat, at an LCOH of 5.8 c€/kWh. The snack plant also releases about 8,054 MWh per year of vapour at about 130 °C from its fryers, which is currently not recovered.

Case 4 - cascade with a high-temperature heat pump. A high-temperature heat pump lifts heat from 70 °C to 180 °C and TechUPGRADE from 180 °C to 250 °C. The cascade achieves a temperature lift of about 180 K but at a high cost (33.2 c€/kWh) and with higher emissions (36.9 kg CO_2/MWh), because of the electricity demand of the heat pump.

6.2 Benchmarking against alternative technologies

Table 6.2 and Figures 6.1 and 6.2 compare the three TechUPGRADE configurations with the existing natural gas boiler and the alternative technologies, using the updated calculations.

Table 6.2. Techno-economic and CO_2 performance of heat-supply technologies (updated D4.3 benchmarking).

Technology	Fuel	CO_2 in fuel (kg/MWh)	CO_2 for delivered heat (kg/MWh)	CO_2 savings vs natural gas (kg/MWh)	LCOH (€/MWh)	Additional cost vs natural gas (€/MWh)	Cost per kg CO_2 avoided (€/kg)
Natural gas boiler (existing)	Natural gas	204.46	280.08	0	72	0	0
HTHP up to 150 °C	Electricity DK	31.02	10.17	269.91	89	17	0.06
HTHP + MVR 250 °C	Electricity DK	31.02	20.96	269.91	178	106	0.39
Electric boiler up to 150 °C	Electricity DK	31.02	32.83	247.26	208	136	0.55
Electric boiler up to 250 °C	Electricity DK	31.02	32.83	247.26	211	139	0.56
Biomass boiler, wood chips, up to 150 °C	Wood chips	4.92	5.59	274.49	61	-11	-0.04
Biomass boiler, wood chips, up to 250 °C	Wood chips	4.92	5.53	274.55	63	-9	-0.03
Biomass boiler, wood pellets, up to 150 °C	Wood pellets	4.92	5.47	274.62	65	-7	-0.03
Biomass boiler, wood pellets, up to 250 °C	Wood pellets	4.92	5.47	274.62	67	-5	-0.02
TechUPGRADE Basic (waste heat)	Electricity DK	31	2.14	277.94	35	-37	-0.13
TechUPGRADE + Solar	Electricity DK	31	5.43	274.66	58	-14	-0.05
TechUPGRADE + HTHP integrated	Electricity DK	31	36.90	243.18	332	260	1.07

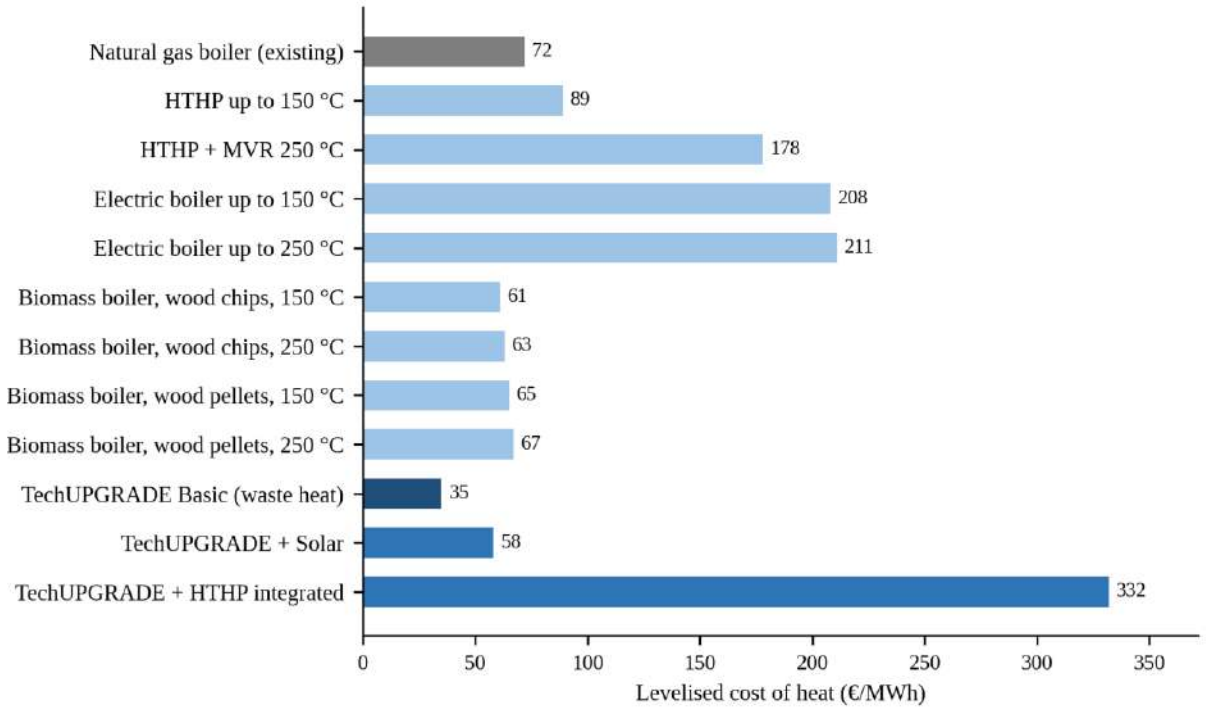


Figure 6.1. Levelised cost of heat of the benchmarked heat-supply technologies (updated D4.3 benchmarking).

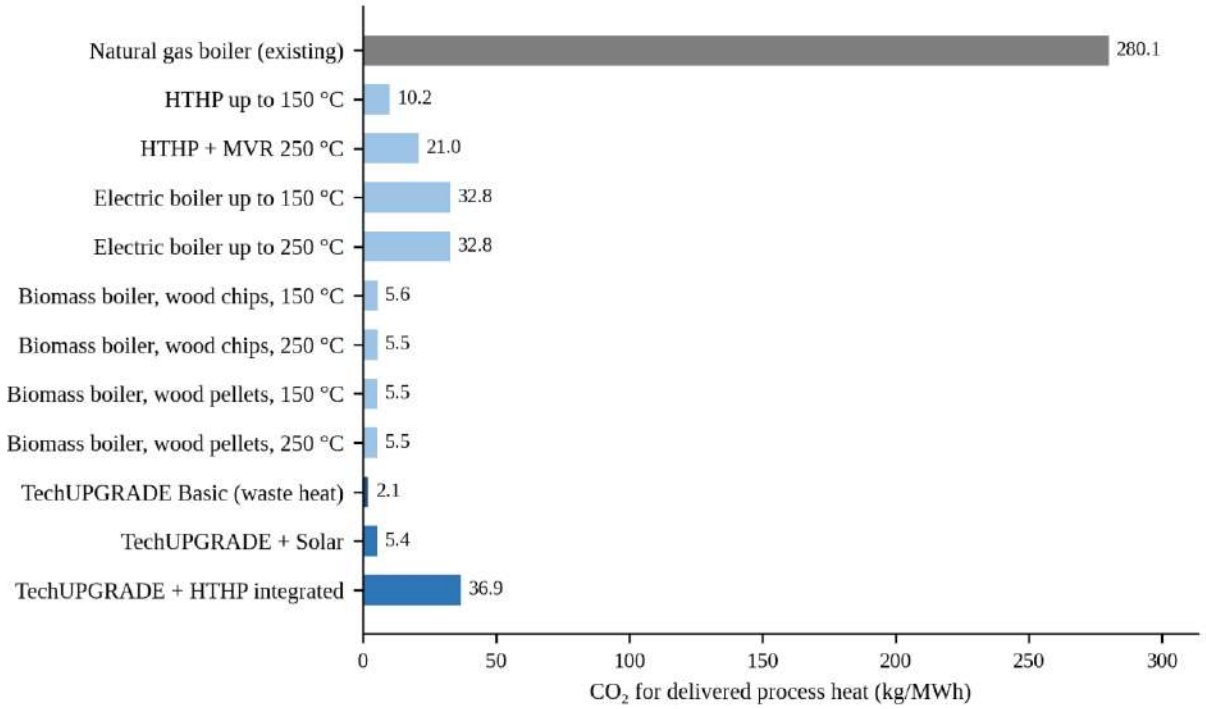


Figure 6.2. CO_2 emissions per MWh of delivered process heat of the benchmarked technologies (updated D4.3 benchmarking).

The benchmarking leads to four conclusions. First, TechUPGRADE Basic, which upgrades free waste heat, has the lowest emissions (2.14 kg CO_2/MWh, a saving of 277.94 kg/MWh or about 99% compared with the existing gas boiler) and the lowest cost of heat (35 €/MWh, about half that of natural gas). It is the only technology that both avoids almost all emissions and reduces the cost of heat substantially, with a negative abatement cost of -0.13 €/kg CO_2. Second, TechUPGRADE with solar heat is also cheaper than natural gas (58 €/MWh) with near-zero emissions. Third, biomass boilers are competitive in cost and emissions but depend on a limited biomass resource, whereas high-temperature heat pumps and electric boilers reduce emissions at a higher cost of heat because of the electricity price assumed (194.1 €/MWh). Fourth, the cascade of TechUPGRADE with a high-temperature heat pump is not economically competitive under the current assumptions.

6.3 Financial indicators

Table 6.3 presents the payback time, NPV and IRR of selected technologies compared with the existing natural gas boiler, as calculated in D4.3.

Table 6.3. Payback time, NPV and IRR of selected heat-supply technologies compared with the existing natural gas boiler (D4.3).

Technology	CAPEX (€)	Cash flow (€/yr)	NPV (€)	IRR	Payback (years)
Electric boiler	108,000	-542,871	-7,430,790	n/a	n/a
HTHP	1,428,000	12,831	-1,198,618	n/a	111.3
Biomass boiler (wood)	726,000	75,448	354,367	10.99%	9.6
TechUPGRADE + waste heat	900,000	209,102	1,996,769	24.67%	4.3
TechUPGRADE + solar	2,120,000	209,102	776,769	8.55%	10.1

TechUPGRADE with waste heat provides the strongest financial performance, with an NPV of about €2.0 million, an IRR of 24.7% and a payback time of about 4.3 years. TechUPGRADE with solar heat also improves the annual cash flow compared with natural gas but requires a larger investment, giving a payback time of about 10 years. The electric boiler has a negative cash flow and the HTHP only a marginal improvement under the assumed electricity price.

6.4 Sensitivity to economic lifetime

Table 6.4 shows the sensitivity of the LCOH to the economic lifetime. Capital-intensive technologies benefit most from a longer lifetime: the LCOH of TechUPGRADE Basic falls from 56 €/MWh at 7 years to 35 €/MWh at 20 years, and that of TechUPGRADE with solar from 107 to 58 €/MWh. Even with a lifetime of only 10 years, TechUPGRADE Basic (46 €/MWh) remains cheaper than the natural gas boiler (72 €/MWh).

Table 6.4. Sensitivity of the LCOH (€/MWh) to the economic lifetime (updated calculation).

Technology	7 years	10 years	15 years	20 years
Natural gas boiler (existing)	73	72	72	72
HTHP up to 150 °C	116	103	94	89
HTHP + MVR 250 °C	232	207	188	178
Electric boiler up to 150 °C	210	209	208	208
Electric boiler up to 250 °C	218	215	213	212
Biomass boiler, wood chips, up to 150 °C	75	68	63	61
Biomass boiler, wood chips, up to 250 °C	81	73	66	63
Biomass boiler, wood pellets, up to 150 °C	76	71	67	65
Biomass boiler, wood pellets, up to 250 °C	82	75	70	67
TechUPGRADE Basic	56	46	39	35
TechUPGRADE + Solar	107	84	66	58
TechUPGRADE + HTHP integrated	442	391	351	332

6.5 Indicative impacts at the market scale targeted in the proposal

To give an order of magnitude of the impacts at market scale, the unit results of TechUPGRADE Basic are applied to the market ambition of the proposal: 5 TWh of decarbonised process heat per year within five years of commercialisation, replacing heat from existing natural gas boilers. The results in Table 6.5 are indicative and use only the D4.3 unit values and the operating time of 4,000 hours per year.

Table 6.5. Indicative impacts of supplying 5 TWh/yr of process heat with TechUPGRADE Basic instead of existing natural gas boilers.

Indicator	Value	Basis
Installed capacity	about 1,250 MW	5 TWh / 4,000 h
Investment	about €1.1 billion	0.9 M€/MW (D4.3)
CO_2 emissions avoided	about 1.4 Mt/yr	277.94 kg CO_2/MWh (D4.3)
Heat-supply cost savings	about €185 million/yr	72 - 35 €/MWh (updated LCOH)

Indicator	Value	Basis
Investment-phase employment	about 8,000 job-years	€140,000 per job-year (IDA factor)
Operation-phase employment	about 300 jobs/yr	Annual cost of 35 €/MWh × 5 TWh and 1.76 jobs per M€ (Chapter 7)

6.6 Implications for the socio-economic assessment

The environmental and economic results have three main socio-economic implications. First, the climate benefit of TechUPGRADE is large at every site where it replaces fossil heat, and because the technology needs very little electricity, it does not compete for scarce renewable electricity and grid capacity. Replacing on-site combustion also removes local emissions of air pollutants, which addresses the main concern of civil-society respondents, although these were not quantified in D4.3. Second, the economic case is strongest where free waste heat is available, as in the GreenLab data-centre case, which makes industrial symbiosis and heat mapping key enablers of uptake. Third, the economic results depend on the cost and performance estimates of a technology at TRL 5, which confirms that demonstration and verified cost data, the main conditions set by industrial and academic stakeholders, are decisive for converting the potential into adoption.

7 Employment and macro-economic impact analysis

The TechUPGRADE value chain draws on ten Swedish sectors that together produce SEK 3.17 trillion of output and employ 755,015 people; on average, each job in this value chain is backed by about €570,000 of annual output. This places TechUPGRADE at the capital-intensive end of the clean heat technologies compared here, although the differences per euro spent are small. This section explains how these figures are derived, what they mean for the labour market, how they compare with other energy projects and with the investment-based approach of REWARDHeat, and what they imply for job creation, job destruction and the Just Transition.

7.1 Mapping the value chain onto national accounts

The first step translates the physical value chain of a thermochemical heat upgrade system into the product classification of the Swedish input-output tables. The selection follows the life cycle of a plant, from materials through equipment and installation to knowledge services and operation.

Upstream material inputs are represented by chemicals and chemical products (C20), which covers the salt hydrates and heat-transfer fluids that form the reactive core of the system, and by fabricated metal products (C25), which covers reactor vessels, storage tanks, piping and heat exchangers. Equipment manufacturing is represented by computer, electronic and optical products (C26) for sensors, control units and monitoring hardware; electrical equipment (C27) for pumps, motors and power electronics; and machinery and equipment n.e.c. (C28) for heat exchangers, conveyors and particle-handling systems. Deployment and physical integration at an industrial site are captured by construction (F) and by repair and installation of machinery and equipment (C33), which together reflect the on-site labour of mounting, connecting and commissioning the units.

The energy sector itself (D35) is included because the technology interfaces directly with heat and electricity supply, including district heating networks and on-site utilities. Knowledge-intensive services are represented by architectural and engineering services and technical testing (M71), which covers process integration, design, testing and certification, and by scientific research and development (M72), which reflects the strong research content of a technology still at TRL 5. Together, these sectors encompass both the tangible production of equipment and the service-based expertise required to design, install and operate industrial heat upgrade systems. The two comparator projects share this core and add sectors that reflect their specific characteristics: InterFlex adds IT and consultancy services (J62-J63) for digital control and flexibility, and WeDistrict adds wood and wood products (C16) for its biomass supply chain.

Table 7.1. Sectors selected for each project (Statistics Sweden, SIOT 2022).

SIOT	CPA code	Sector	TechUPGRADE	InterFlex (electric boiler)	WeDistrict (biomass boiler)
SIOT 7	C16	Wood and products of wood and cork	-	-	✓
SIOT 11	C20	Chemicals and chemical products	✓	✓	✓
SIOT 16	C25	Fabricated metal products	✓	✓	✓
SIOT 17	C26	Computer, electronic and optical products	✓	✓	✓

SIOT	CPA code	Sector	TechUPGRADE	InterFlex (electric boiler)	WeDistrict (biomass boiler)
SIOT 18	C27	Electrical equipment	✓	✓	✓
SIOT 19	C28	Machinery and equipment n.e.c.	✓	✓	✓
SIOT 23	C33	Repair and installation of machinery and equipment	✓	✓	✓
SIOT 24	D35	Electricity, gas, steam and air conditioning	✓	✓	✓
SIOT 27	F	Constructions and construction works	✓	✓	✓
SIOT 40	J62-J63	Computer programming, consultancy and information services	-	✓	-
SIOT 47	M71	Architectural and engineering services; technical testing	✓	✓	✓
SIOT 48	M72	Scientific research and development services	✓	✓	✓

7.2 Output structure of the TechUPGRADE value chain

Construction dominates the economic structure underlying TechUPGRADE, accounting for 28.5% of the combined output of the selected sectors, followed by machinery manufacturing (13.3%) and a group of sectors each contributing 8-9%: electronics (8.8%), chemicals (8.8%), R&D (8.5%) and engineering services (8.2%). Fabricated metals (7.7%), energy supply (7.2%), electrical equipment (6.2%) and repair and installation services (2.8%) complete the picture. These weights show that system deployment and equipment manufacturing are the two pillars of the industrial heat upgrade economy, with knowledge services as a substantial third pillar. For a technology that must be designed and integrated case by case into existing process lines, this third pillar is likely to be more important in early markets than the national averages suggest.

Table 7.2. TechUPGRADE: allocated jobs and labour intensity by sector.

Sector (CPA)	Output 2022 (SEK M)	Employees 2022	Output share	Allocated jobs	Jobs per SEK M	SEK M per job	€ k per job
Chemicals (C20)	277,763	33,405	8.77%	66,187	0.120	8.32	777.5
Fabricated metal products (C25)	245,226	67,673	7.74%	58,434	0.276	3.62	338.8
Computer, electronic and optical (C26)	278,524	19,819	8.79%	66,369	0.071	14.05	1,314.0
Electrical equipment (C27)	197,019	23,254	6.22%	46,947	0.118	8.47	792.2
Machinery and equipment (C28)	421,273	74,382	13.30%	100,384	0.177	5.66	529.6
Repair and installation (C33)	90,154	19,716	2.85%	21,482	0.219	4.57	427.5
Electricity, gas, steam (D35)	226,912	29,691	7.16%	54,070	0.131	7.64	714.6
Construction (F)	903,980	348,872	28.53%	215,406	0.386	2.59	242.3
Architecture and engineering (M71)	259,627	114,811	8.19%	61,866	0.442	2.26	211.4
Scientific R&D (M72)	268,038	23,392	8.46%	63,870	0.087	11.46	1,071.4

Sector (CPA)	Output 2022 (SEK M)	Employees 2022	Output share	Allocated jobs	Jobs per SEK M	SEK M per job	€ k per job
Total / weighted average	**3,168,516**	**755,015**	**100%**	**755,015**	**0.238**	**4.20**	**570.0**

Note: employment is the 2022 annual mean of quarterly SCB data; € values at EUR/SEK = 0.0935. Allocated jobs represent the share of national sector employment attributable to each sector, using output shares as weights.

7.3 Allocated jobs across the value chain

Applying the output shares to the combined workforce of the ten sectors gives the allocated employment profile shown in Figure 7.1. Construction accounts for about 215,406 allocated jobs, reflecting the workforce associated with deploying systems and integrating them into industrial infrastructure. Machinery and equipment manufacturing follows with about 100,384 jobs, underlining the importance of domestic equipment production. Knowledge- and technology-intensive sectors also account for a large share: computer, electronic and optical products (66,369), chemicals (66,187), scientific R&D (63,870) and architectural and engineering services (61,866). Fabricated metals (58,434), energy supply (54,070), electrical equipment (46,947) and repair and installation (21,482) complete the value chain.

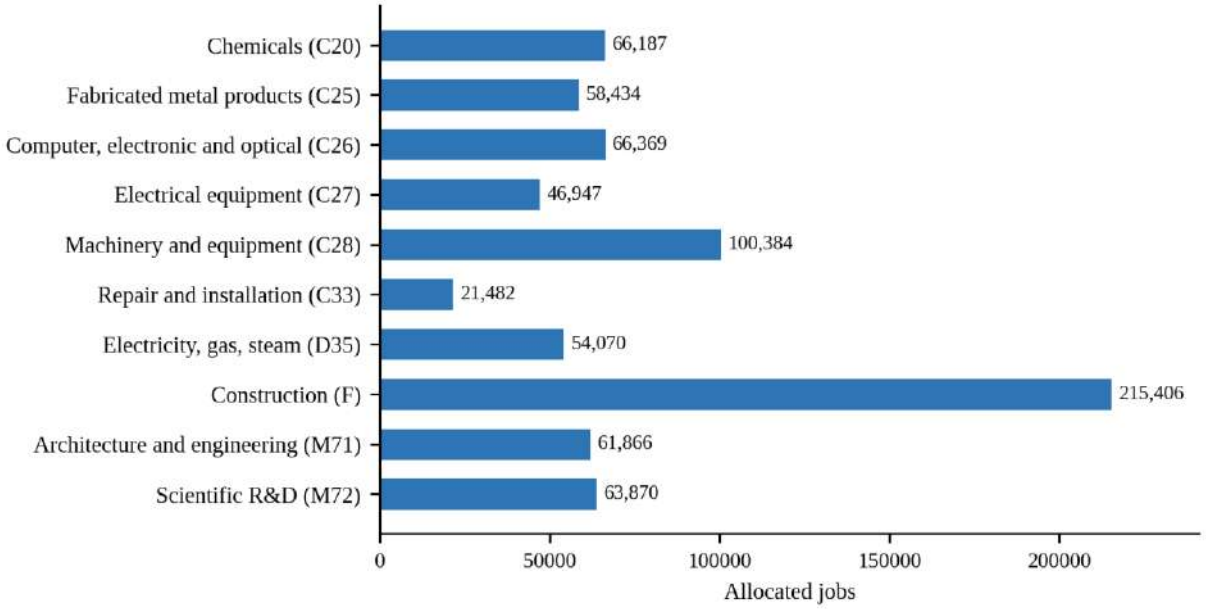


Figure 7.1. Allocated jobs per relevant sector in the TechUPGRADE value chain (Sweden, 2022).

The allocation reweights employment towards high-output sectors, which matters for interpretation. Construction actually employs 348,872 people but receives 215,406 allocated jobs, and engineering services employ 114,811 but receive 61,866. Electronics, by contrast, employs only 19,819 people but receives 66,369 allocated jobs because of its high output. The allocated figures should therefore be read as the economic weight of each sector in the TechUPGRADE value chain, not as headcounts that the project would create.

Read in this way, the profile is consistent with recent international evidence that the construction and installation phases of renewable energy projects generate more jobs per unit of investment than fossil-fuel technologies, largely because these activities are more labour-intensive and often take

place locally (Hanna et al., 2024). Studies of low-carbon heating transitions similarly show that construction, installation and manufacturing are generally more employment-intensive than conventional fossil-fuel heating systems (Ram et al., 2022). The outcome nevertheless depends on the extent to which labour and supply-chain services are sourced domestically rather than imported.

7.4 Capital intensity: the cost of supporting one job

The inverse of employment intensity gives the output needed to sustain one job, shown in SEK million in Figure 7.2 and in thousand euros in Figure 7.3. Three groups of sectors emerge. High-technology manufacturing and research are the most capital-intensive: electronics requires SEK 14.1 million (€1.31 million) of output per job and R&D SEK 11.5 million (€1.07 million). These sectors rely on advanced production equipment, specialised facilities and highly skilled staff, so employment growth there is closely tied to substantial capital expenditure. This pattern is consistent with wider evidence that employment outcomes per unit of investment depend on the balance between labour and capital inputs, on wage levels and on supply-chain structures (Hanna et al., 2024).

Industrial production and utilities form a middle group with moderate requirements: chemicals (SEK 8.3 million), electrical equipment (SEK 8.5 million), energy supply (SEK 7.6 million) and machinery (SEK 5.7 million). The most labour-intensive group comprises repair and installation (SEK 4.6 million), fabricated metals (SEK 3.6 million), construction (SEK 2.6 million) and engineering services (SEK 2.3 million), equivalent to roughly €210,000-430,000 per job, because a larger share of their expenditure flows directly to labour rather than to equipment or high-value technological inputs. Similar patterns are widely observed in studies of low-carbon investments, where construction and installation show higher employment intensity than more capital-intensive energy supply technologies (Ram et al., 2022).

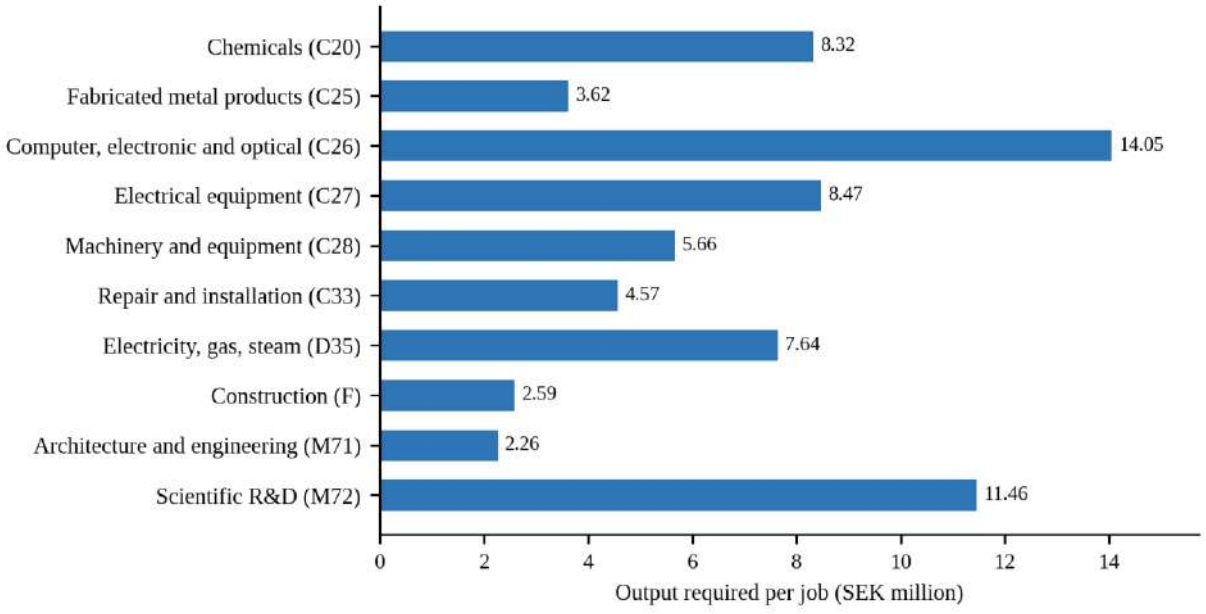


Figure 7.2. Output (investment) required per job, SEK million.

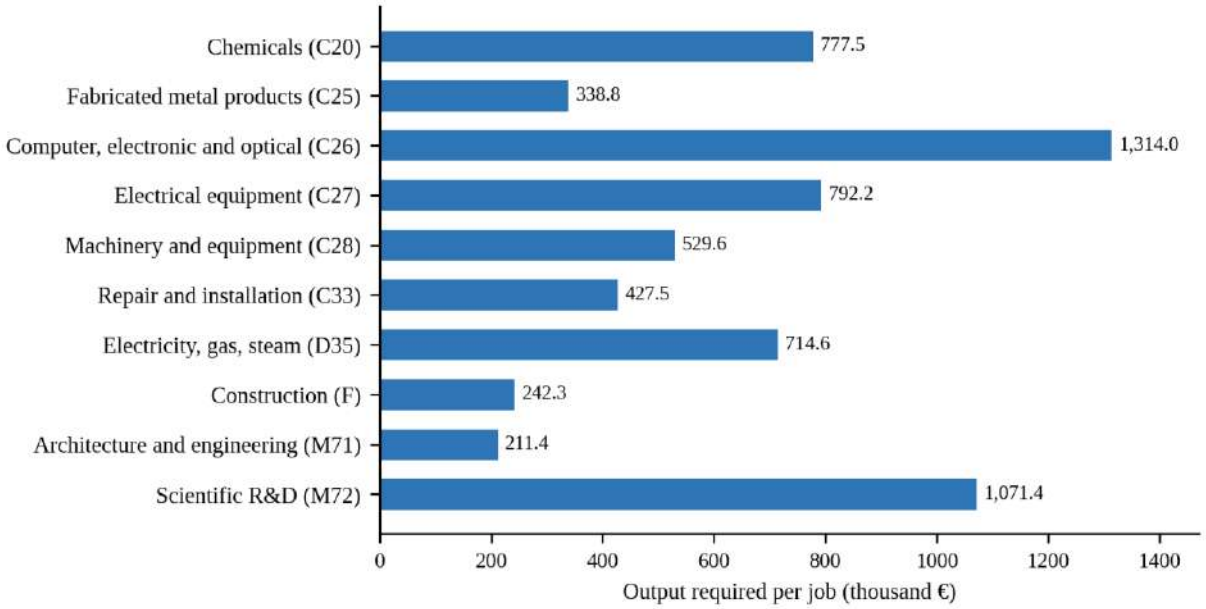


Figure 7.3. Output (investment) required per job, thousand euros.

The result is a value chain in which capital-intensive, innovation-driven segments coexist with labour-intensive technical and deployment activities. Variation in jobs per unit of investment therefore reflects differences in capital-labour composition and value-chain structure rather than differences in the importance of a sector to the technology (Ram et al., 2022). Weighting each sector's cost per job by its output share gives an average of €569,960 per job for the TechUPGRADE value chain. Comparisons of jobs per unit of investment show that renewable energy and energy-efficiency measures generally create more employment than fossil-fuel or nuclear generation (Ram et al., 2020, 2022), largely because mature fossil technologies have more capital-intensive production structures (Hanna et al., 2024). Overall, employment outcomes in the energy transition are shaped by capital intensity, labour requirements, technology maturity and supply-chain localisation, factors consistent with the sectoral differences observed for TechUPGRADE.

7.5 Comparison with other energy projects

To place TechUPGRADE in context, the same procedure was applied to InterFlex, representing electricity-based heat from electric boilers, and WeDistrict, representing biomass-based heat from biomass boilers. The full sector tables are given in Appendix 14.2. Estimated jobs are obtained by dividing the total annual cost of each system by the weighted average cost per job of its value chain.

Table 7.3. Comparison of estimated jobs for different heat-supply technologies.

Project (heat technology)	Sectors	Output (SEK M)	Allocated jobs	Weighted € k per job	Annual cost (M€/yr)	Estimated jobs	Jobs per M€
TechUPGRADE (thermochemical heat upgrade)	10	3,168,516	755,015	569.96	18.42	32.4	1.76
WeDistrict (biomass boiler)	11	3,339,681	786,739	566.61	25.04	44.2	1.76
InterFlex (electric boiler)	11	3,677,399	987,531	519.41	84.29	162.3	1.93

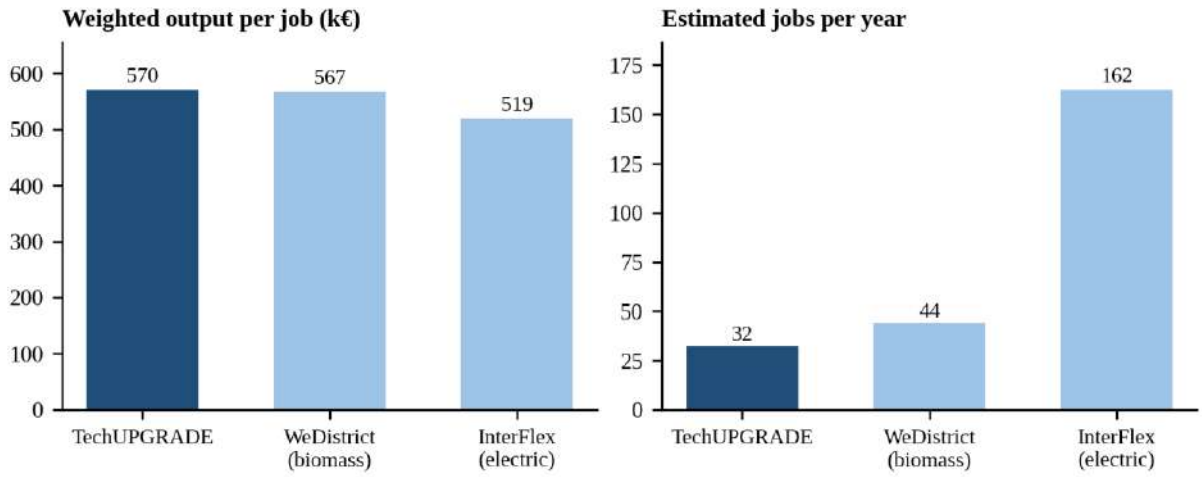


Figure 7.4. Weighted output per job and estimated jobs per year for the three heat-supply technologies.

InterFlex shows the strongest labour intensity, with the broadest sector mix (987,531 allocated jobs) and the lowest weighted cost per job (€519,410), driven by the labour-intensive IT services sector that electrification and system integration require. TechUPGRADE is the most capital-intensive (€569,960 per job) with the smallest employment pool, reflecting a value chain concentrated in construction and heavy machinery and a stronger capital-expenditure profile. WeDistrict lies close to TechUPGRADE (€566,610 per job), with a distinct forestry-based supply chain. These patterns are consistent with Hanna et al. (2024), who find that biomass- and electricity-based energy systems tend to generate relatively more employment.

The scale of spending dominates the absolute number of jobs. The electric boiler scenario has the highest annual cost (€84.29 million) and the highest job estimate (162 jobs); the biomass scenario follows (€25.04 million; 44 jobs); TechUPGRADE has the lowest cost (€18.42 million) and the lowest estimate (32 jobs). Per euro spent, however, the three technologies are close, at 1.76-1.93 jobs per million euro. This is an important message for policy. TechUPGRADE's lower job count is mainly the result of its lower cost, which is the purpose of the technology; a cheaper heat supply that releases resources for other productive uses is a net economic benefit, not a loss. Conversely, a natural gas boiler scenario was costed at €144.95 million per year, but a large part of that cost is imported fuel, which supports jobs abroad rather than in the domestic value chain. Fuel-based scenarios should therefore not be read as job-rich in a cost-based calculation.

7.6 Benchmark against the investment-based approach of REWARDHeat

The REWARDHeat project estimated job creation with employment factors from the Danish Society of Engineers (IDA), which are based on a national input-output demand-shock model linking investment in specific technologies to direct and indirect jobs across supply chains. REWARDHeat derived technology-specific investment-to-job ratios from this study, applied them as standardised coefficients to the capital expenditure of each technology obtained from EnergyPLAN scenarios (baseline, 2050 and 2050 with 100% REWARDHeat solutions), and summed the results across technologies for each demonstration site. Technologies involving significant infrastructure and equipment deployment, such as district heating networks and heat pumps, show relatively high employment intensity in this framework. The results represent mainly temporary employment associated with the investment phase over about ten years, including equipment manufacturing, construction, installation and supply-chain activities.

The two approaches measure different things. The TechUPGRADE analysis reflects the employment supported by ongoing sectoral output, that is, the structural labour intensity of the economy, whereas REWARDHeat measures the incremental job-years generated by additional investment. The IDA factors imply that about €140,000 of investment generates one job-year. Because industrial and infrastructure jobs typically last several years, the investment per job increases proportionally: about €280,000 for two years, €700,000 for five years and €1.4 million for ten years. TechUPGRADE's sector-based range of €210,000 to €1.31 million per job, with a weighted average of €570,000, corresponds to roughly four job-years at IDA rates and lies well within this range. The two methods are not directly comparable, but together they give a consistent order of magnitude and complementary insights into the employment implications of industrial and energy-system investments. This is why both are used for the indicative market-scale estimate in Section 6.5.

7.7 Job destruction, reallocation and the Just Transition

The energy transition involves simultaneous job losses and job creation, with overall employment effects that remain strongly positive (Ram et al., 2022). Employment declines are concentrated in fossil fuel extraction and supply, while gains arise in renewable generation, storage, grid infrastructure and related value chains. The transition therefore reflects a structural reallocation of labour from fuel-based industries towards technology- and infrastructure-oriented sectors, with future employment increasingly linked to electrification, renewable deployment and system integration. Similarly, Li et al. (2023) find that employment declines are concentrated in pollution-intensive and labour-intensive industries, whereas growth occurs in cleaner, more capital- and skill-intensive sectors. Capital upgrading and technological change contribute to labour substitution but also increase demand for higher-skilled workers, resulting in structural reallocation rather than a uniform decline.

For TechUPGRADE, the displaced activity is mainly the supply and combustion of natural gas, oil and LPG for process heat. In Sweden, Denmark and most EU countries these fuels are largely imported, so the domestic job loss from replacing them is small compared with the domestic activity created in equipment manufacturing, installation, engineering and maintenance. The more relevant risk is a skills mismatch: boiler operators and fuel-handling staff will need to be retrained in thermochemical systems, process integration and digital monitoring. This finding is supported by the stakeholder evidence in Sections 8 and 10: industrial respondents anticipate demand for process integration experts, thermal systems engineers and monitoring specialists, and civil-society respondents are more concerned about disruption during the transition than about job losses caused by the technology itself.

7.8 Health, safety and environmental co-benefits for workers

All energy sources have some negative impacts, but their magnitude varies considerably. Fossil fuels remain the most polluting and hazardous, whereas modern renewable energy sources are significantly safer and cleaner (Ritchie, 2021) and can eliminate the risks associated with fossil-based heat systems (Albin et al., 2025). Waste heat recovery systems can substantially reduce emissions from fossil fuel-based processes; industrial waste heat is a major source of recoverable energy, and its use contributes to lower emissions of fine particulate matter. By substituting recovered heat for combustion, TechUPGRADE can reduce workers' exposure to harmful emissions, improve air quality in industrial environments, especially in high-impact sectors, and promote cleaner and more energy-efficient operations.

The transition to fossil-free and circular economies can reduce traditional occupational risks, but it also introduces new hazards, such as chemical exposure and ergonomic strain (Kenneth et al., 2025; Albin et al., 2025). For TechUPGRADE these include the handling of salt hydrates and hot particles, pressurised steam and surfaces at up to 250 °C. Several studies emphasise the need for proactive strategies to promote safe and healthy green jobs, so that the environmental transition does not compromise workers' safety or health. Occupational safety and health management should therefore be integrated into green transformation plans and into the design of TechUPGRADE installations from the outset, supported by research on workplace innovation and risk prevention (Sanne et al., 2025; Albin et al., 2025).

7.9 Implications for SMEs, value chains and digitalisation

With rapid technological progress, the growing use of artificial intelligence in the green transition, which is also relevant for TechUPGRADE's digital twin and control systems, can improve the efficiency and quality of many tasks but may also displace some manual work (Alexander et al., 2024). Overall, TechUPGRADE has the potential to influence industrial value chains and SMEs positively by accelerating the shift towards cleaner, more efficient and digitally enabled heat technologies. More than 90% of EU SMEs already implement resource-efficiency measures and increasingly use renewable energy; TechUPGRADE can support this progress by reducing energy consumption, minimising heat waste and improving operational efficiency. By integrating advanced digital technologies and real-time monitoring, the project aligns with broader trends in digitalisation and new digital infrastructure, which are reshaping industrial value chains and enabling firms to move into low-carbon activities. This opens opportunities for SMEs to expand into emerging markets such as smart energy services, critical raw material recycling, component manufacturing, installation and maintenance of advanced heat systems, and circular-economy activities.

The project can also support labour-market transformation by contributing to new green jobs in manufacturing, installation, safety and monitoring technologies, while helping existing workers develop the green skills required for digital industrial systems. However, SMEs still face barriers such as high upfront capital costs, complex regulations and vulnerabilities linked to critical raw material supply chains, and in less developed regions limited digital capacity may further constrain adoption. The full impact of TechUPGRADE is therefore likely to depend on supportive regional policies, strong digital infrastructure and targeted assistance to SMEs, so that they can participate fully in evolving industrial value chains.

7.10 Which job categories benefit most?

The input-output results describe the economic weight of each sector in the TechUPGRADE value chain; combined with the stakeholder evidence, they show which categories of jobs are most likely to benefit from deployment (Table 7.4). In absolute numbers, construction and installation workers benefit most, because construction accounts for 28.5% of the output of the value chain and installation work is carried out on site. Per euro spent, engineering services and installation are the most labour-intensive activities, at €211,000 and €428,000 of output per job respectively. In terms of new skills, the clearest gains are in process integration and digital monitoring: these are the roles industrial respondents expect most often, and process integration is also the research area the academic community considers most important.

Table 7.4. Job categories expected to benefit from TechUPGRADE: input-output and stakeholder evidence.

Job category	Value-chain sectors (allocated jobs; output per job)	Stakeholder evidence	Expected effect
Construction, installation and commissioning workers	Construction F (215,406; €242k); repair and installation C33 (21,482; €428k)	Integration with existing process lines is a key scale-up requirement (4 of 11 industrial respondents)	Largest number of jobs; labour-intensive and mostly local; recurring as long as deployment continues
Engineers for process integration, design and testing	Architecture and engineering services M71 (61,866; €211k, the most labour-intensive sector)	Process integration experts and process engineers are the roles most often expected by industry (Q17); integration with industrial processes is the top research area for academia (43 of 64)	Strongest demand for new skills; the clearest match between the input-output results and stakeholder expectations
Equipment manufacturing (reactors, heat exchangers, pumps, conveyors)	Machinery C28 (100,384; €530k); fabricated metals C25 (58,434; €339k); electrical equipment C27 (46,947; €792k)	Reliability of materials and reactors is a key scale-up requirement (6 of 11 industrial respondents)	Substantial manufacturing employment; its location depends on where equipment is produced
Digital monitoring, control and electronics specialists	Computer, electronic and optical products C26 (66,369; €1,314k)	Digital monitoring specialists expected by industry (Q17); digital twins among the most useful outputs for academia (15 of 64)	Fewer, highly skilled and capital-intensive jobs
Researchers and materials specialists	Scientific R&D M72 (63,870; €1,071k); chemicals C20 (66,187; €777k)	Material stability is a key research area (38 of 64); high curriculum potential (39 of 64); interest in industrial PhDs	High-skill jobs and an education pipeline for the workforce needed at deployment
Operators and maintenance staff of existing heat systems	Electricity, gas and steam D35 (54,070; €715k)	Maintenance staff and technicians expected by industry (Q17); civil society worried about job loss in traditional sectors (12 of 27) and disruption during the transition (14 of 27)	Transition rather than creation: boiler operators need retraining in thermochemical systems and digital monitoring

The comparison also identifies who needs support. Operators and maintenance staff of fossil-fuelled boilers are not expected to lose their jobs in large numbers, because the fossil fuels displaced are largely imported, but their work will change. This is consistent with the civil-society results: respondents rarely associate TechUPGRADE itself with job losses (2 of 27), but many worry about disruption during the transition as a whole (14 of 27). Retraining programmes for existing heat-system staff are therefore the main Just Transition measure for this technology.

8 Social impact assessment: stakeholder consultation results

This section presents the results of the four stakeholder questionnaires. For each group, the profile of respondents is described first, followed by the results on each theme, illustrated with the response charts and with representative quotations from the open answers. Cross-group comparisons are reserved for the integrated analysis in Chapter 10. For multiple-choice questions, the percentages in this chapter are shares of all mentions, as explained in Section 5.5.

8.1 Academia and research stakeholders

The academic community sees TechUPGRADE as scientifically relevant and as a strong platform for teaching and collaboration: respondents rate its overall scientific and socio-economic impact potential at 4.27 out of 5, and 91% give it a 4 or 5. Their support is conditional, however. They want the technology proven at scale and its data made openly available, and they identify capital cost and the gap between laboratory and market as the factors most likely to limit impact. With 64 responses, this is the largest and most robust of the four samples.

8.1.1 Respondent profile

Responses came from 17 countries, with Greece (30; 46.9%) and Sweden (9; 14.1%) the largest groups, followed by Denmark (5), Spain (3), Portugal, Italy and Cyprus (2 each), and single responses from Austria, Belgium and the Netherlands, Czechia, Germany, Hungary, Romania, Slovakia, Slovenia, Türkiye and the United Kingdom. The concentration in Greece and Sweden reflects the networks of the partners that distributed the survey. Universities account for 51 respondents (79.7%), research centres for 5, technical institutes for 2, and SMEs, a private company and a knowledge platform for the remainder.

The sample deliberately combines the current and the next generation of researchers. Students form the largest group (36; 56.3%), of whom 23 are bachelor or undergraduate students, 12 PhD candidates and one a master's student. Senior respondents include 13 researchers or scientists, 10 professors or lecturers, 4 project managers or group leaders and one engineer. The dominant fields of expertise are renewable energy integration and energy system modelling (25.2% and 24.4%, respectively), followed by process engineering (10.1%), industrial decarbonisation (8.4%), thermochemical energy storage (7.6%) and materials science (4.2%), with single mentions of fluid dynamics, LCA and techno-economic assessment, geothermal energy, marine and naval engineering, and operational research.

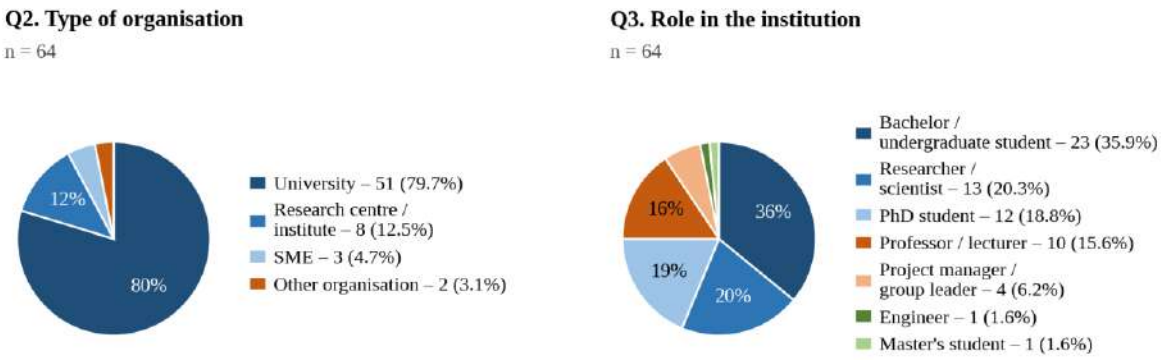


Figure 8.1. Academia: type of academic or research organisation (Q2) and role in the institution (Q3).

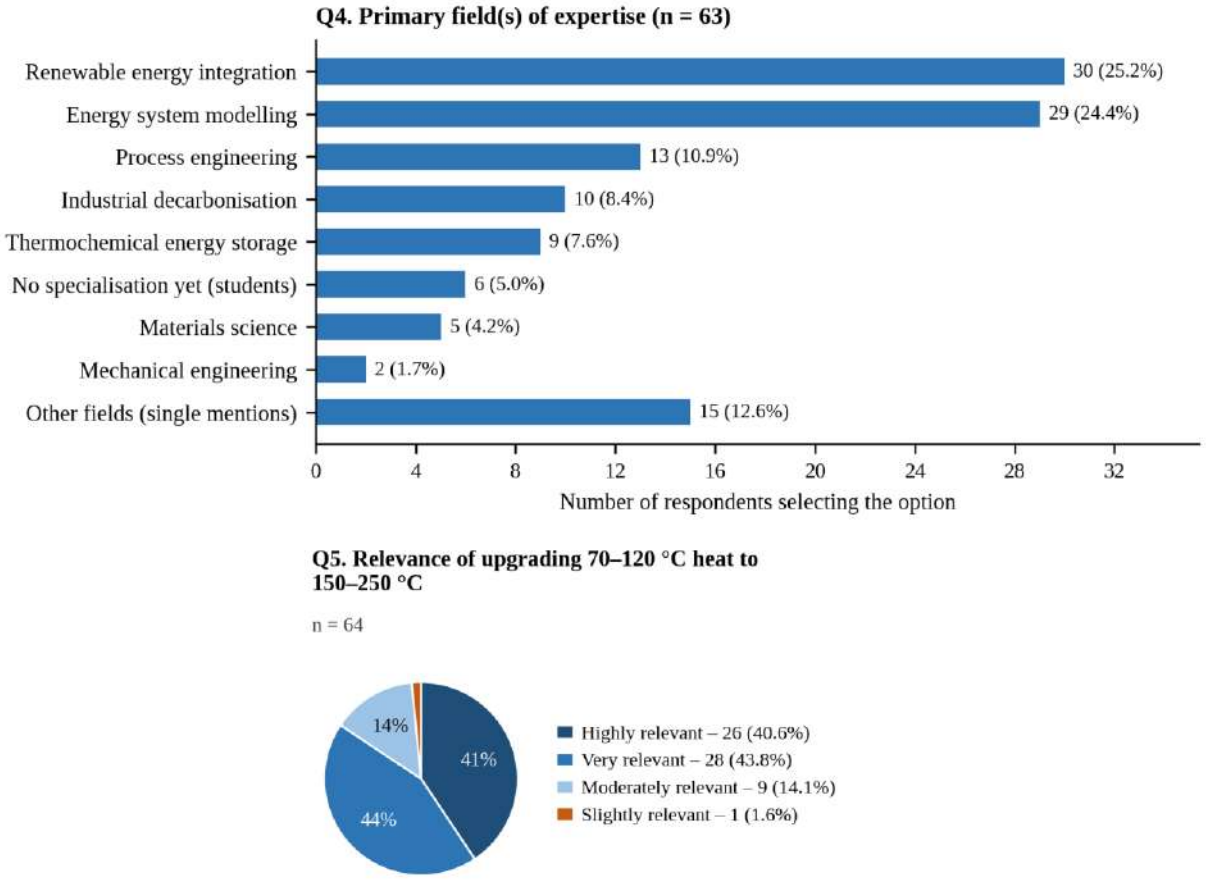


Figure 8.2. Academia: primary fields of expertise (Q4) and relevance of upgrading low-grade heat to 150–250 °C (Q5).

8.1.2 Relevance of the scientific challenge

Upgrading low-grade heat at 70-120 °C to 150-250 °C is considered very relevant by 43.8% and highly relevant by 40.6% of respondents, so that 84.4% place it in the top two categories. A further 14.1% find it moderately relevant and only one respondent slightly relevant; nobody considers it irrelevant. This is a strong endorsement of the project's core premise, coming from a community whose expertise lies mainly in energy systems rather than in thermochemistry itself.

8.1.3 Research collaboration, education and useful outputs

Integration with industrial processes is the research area expected to benefit most from collaboration within TechUPGRADE (24.6%), ahead of thermochemical material stability and cyclability (21.7%), heat and mass transfer in reactors (18.9%) and techno-economic modelling (18.3%). Reaction kinetics and particle behaviour (9.7%) and control and automation algorithms (5.7%) follow. The ranking is revealing: the academic community places the system-integration question, how a novel reactor fits into a real plant, on a par with the fundamental materials question that the project addresses in WP3.

The educational potential is high. 60.9% see high and 35.9% moderate potential to integrate project outcomes into higher-education curricula or training programmes, and only 3.1% see low potential. Asked which output would be most useful, respondents favour open-access datasets (31.3%), digital twins or simulation models (23.4%), lab-scale reactor design documentation (20.3%) and training material and lectures (18.8%); techno-economic results were chosen by only 4.7%, perhaps because respondents expect these to be published in any case.

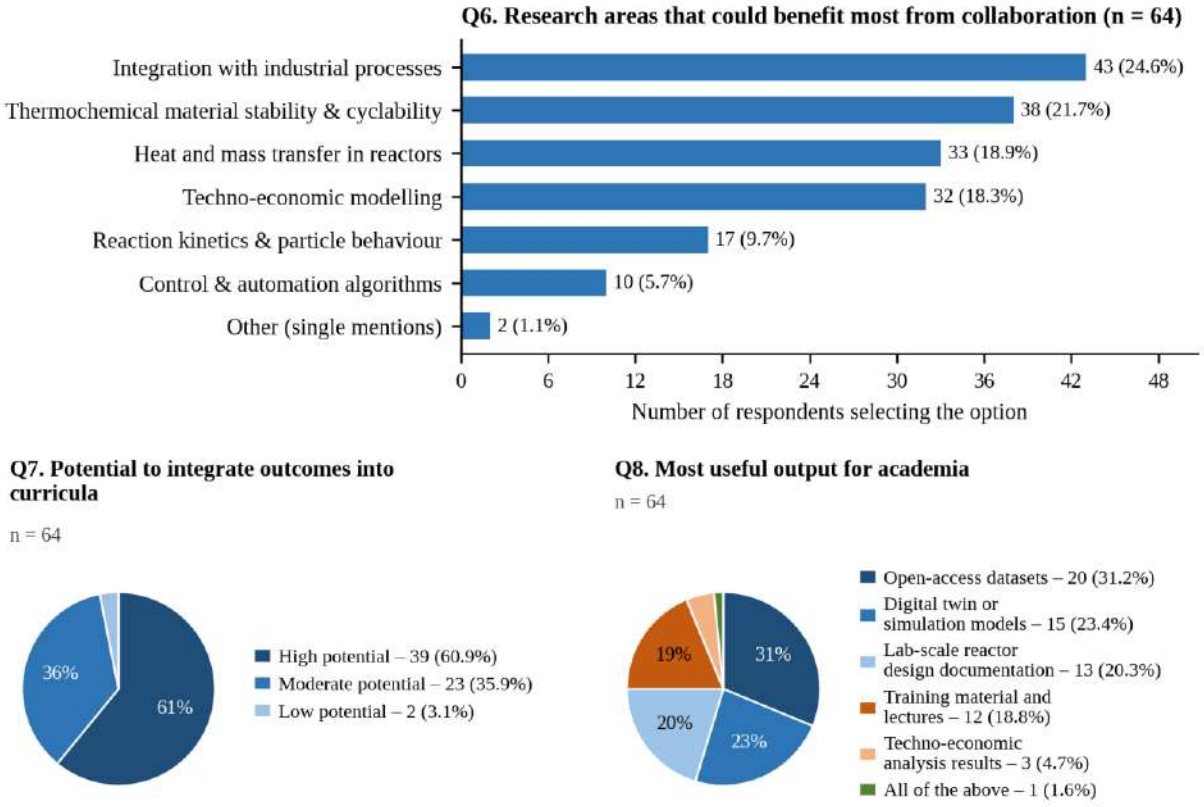


Figure 8.3. Academia: research areas benefiting from collaboration (Q6), curriculum integration potential (Q7) and most useful outputs (Q8).

8.1.4 Expected contribution to decarbonisation, the Green Deal and SDG 7

The 64 open answers on TechUPGRADE's expected contribution converge on a clear causal chain. Recovering and upgrading waste heat raises industrial energy efficiency; this displaces the fossil fuels that dominate heat supply at 150-250 °C; and this cuts Scope 1 CO_2 emissions. Respondents link this chain to the Green Deal objectives of climate neutrality and a circular, energy-efficient economy, and to SDG targets 7.2 and 7.3. Several highlighted the technology's specific advantages over vapour-compression heat pumps, namely low electricity demand and therefore low grid impact, and chemical heat storage that decouples heat recovery from demand. One respondent cited the target levelised cost of heat of 4-6 c€/kWh as the condition for competitiveness.

A minority offered more critical perspectives that are valuable for positioning the technology. One respondent noted that about half of industrial heat demand is above 400 °C, so that TechUPGRADE addresses an important segment but is "a step but not a holy grail solution". Another stressed that the project's most important contribution may be the experimental data and preliminary techno-economic results needed to judge whether development beyond TRL 5 is justified. Others saw indirect contributions through educating future industrial decision-makers and through enabling endothermic processes for carbon-free fuels such as hydrogen and ammonia.

> *"It sits at the intersection of all three frameworks: it provides a concrete technological pathway for industrial decarbonisation, operationalises Green Deal ambitions at the plant level, and advances SDG 7 by making clean industrial energy more efficient, affordable and scalable." (Academic respondent)*

8.1.5 Priorities for the post-project phase

A scale-up demonstration is the clear priority for the next phase (57.8%), followed by open access to data and models (21.9%) and joint academic-industrial PhD programmes (17.2%); policy dialogue was chosen by only 3.1%. The emphasis on demonstration echoes the industrial survey, in which demonstration under realistic conditions is the most frequently cited scale-up requirement.

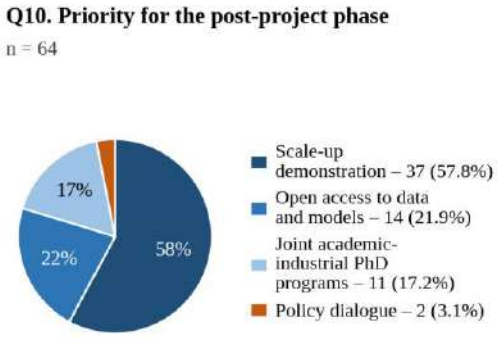


Figure 8.4. Academia: post-project priorities (Q10).

8.1.6 Joint research opportunities and data access

The open answers on joint research identify a broad and coherent research agenda. The most frequently named areas are thermochemical materials (stability, cyclability, degradation, corrosion and novel salt hydrates), reactor engineering and heat and mass transfer, system integration including pinch and exergy analysis, digital twins with AI-based and model-predictive control, and techno-economic assessment combined with LCA. Several respondents proposed hybrid systems that combine thermochemical units with high-temperature heat pumps, storage and renewables, and applications in district and campus energy systems, geothermal fluids and carbon capture. The preferred vehicles are PhD theses, including industrial PhDs, post-doctoral programmes, publications, and follow-up Horizon Europe or Clean Energy Transition Partnership projects.

Interest in project data is strong: 64.1% would use TechUPGRADE data, materials or pilot results for independent work and 32.8% might do so, while only 3.1% would not. This supports the open-data approach of the project's data management plan and suggests that a curated, documented release of pilot data would be widely used.

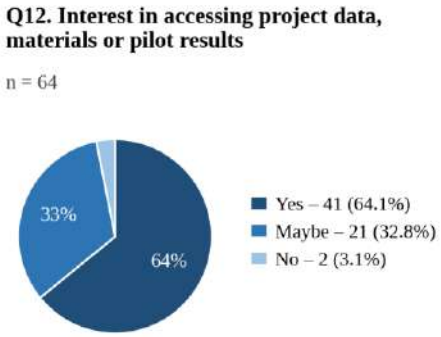


Figure 8.5. Academia: interest in accessing data, materials or pilot results (Q12).

8.1.7 Academic-industry collaboration and barriers to impact

76.6% of respondents consider it likely (54.7%) or very likely (21.9%) that TechUPGRADE will promote new academic-industry collaborations in their field; 14.1% are neutral and 9.4% sceptical. The 54 substantive answers on barriers were coded thematically, with each answer allowed to carry several themes (Table 8.1).

Table 8.1. Barriers to socio-economic impact named by academic respondents (n = 54 substantive answers; multiple coding).

Barrier theme	Answers	Share
High capital and investment costs, financing risk	27	50%
Scale-up and demonstration gap (TRL, "valley of death", market entry)	20	37%
Industrial conservatism and resistance to change	15	28%
Technical complexity, efficiency and performance	14	26%
Integration into existing (legacy) processes and customisation	13	24%
Policy, regulation and insufficient carbon pricing	11	20%
Low awareness, weak dissemination, limited trust	10	19%
Material stability, degradation, corrosion, lifetime	8	15%
Skills and workforce shortages	6	11%
Competing technologies (heat pumps, hydrogen, other projects)	6	11%
Discontinuity of research funding	5	9%
Safety of chemical reactions	1	2%

Cost and scale-up dominate, and respondents often linked the two: until a demonstrator proves performance at a relevant scale, investors perceive high risk, which keeps the cost of capital high. Several answers stressed that the greatest socio-economic impact is delivered only when a technology reaches markets of scale, and that each step from TRL 5 to the market is a barrier in itself. Others pointed to the communication challenge: general knowledge of thermochemical systems in the process industry is limited, and one respondent suggested developing a common terminology, as the energy storage sector has done. One answer warned that an uncontrolled reaction or accident could cause a severe social backlash, underlining the importance of safety engineering and communication.

> *"Even a perfectly performing thermochemical system can fail to deliver impact if capital costs remain high, payback periods exceed industry tolerance, regulatory signals are weak, and the workforce lacks the skills to deploy it." (Academic respondent)*

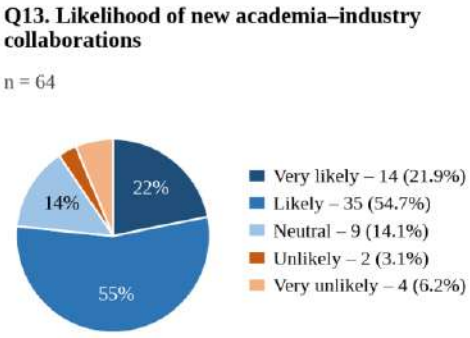


Figure 8.6. Academia: likelihood of new academic-industry collaborations (Q13).

8.1.8 Overall assessment

The overall impact rating averages 4.27 (standard deviation 0.67; median 4): 34 respondents give a 4 (53.1%), 24 a 5 (37.5%), 5 a 3 (7.8%) and one a 2; nobody gives a 1. Senior researchers and staff rate the project slightly higher (4.43, n = 28) than students (4.14, n = 36), and Swedish respondents (4.56, n = 9) higher than Greek respondents (4.13, n = 30) and respondents from other countries (4.32, n = 25). Those closest to the field are therefore the most positive, which strengthens confidence in the result.

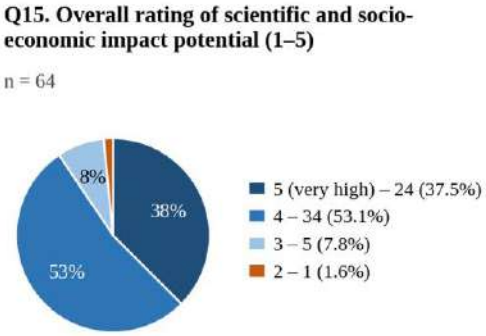


Figure 8.7. Academia: overall rating of scientific and socio-economic impact potential, 1 (low) to 5 (very high) (Q15).

The academic findings point to three actions: securing a credible scale-up pathway, releasing well-documented open data and models, and anchoring the technology in curricula and industrial PhD programmes, so that the skills needed for deployment exist when the market develops.

8.1.9 Interpretation and implications for deployment

The academic results matter for deployment in two ways. First, support is strong but conditional. The community does not question the relevance of the technology (54 of 64 consider it very or highly relevant), but it locates the main risks in cost and in the step from laboratory to market, the same barriers that industrial respondents raise. The fact that integration with industrial processes is ranked above material stability as a research priority is significant: academics expect the bottleneck to lie in fitting the reactor into real plants rather than in the chemistry itself. A demonstrator should therefore be designed as an integration test in an operating plant, not only as a materials test.

Second, academia is a supplier of the evidence and the skills that adoption requires. The strong demand for open data (41 of 64 would use it) and the high potential for integration into curricula (39 of 64) mean that the project can create a pipeline of engineers trained in thermochemical systems,

which addresses the skills needs identified by industry. The over-representation of Greek and Swedish respondents and of students does not appear to inflate the results, since senior staff rate the impact potential higher than students.

8.2 Industrial stakeholders

Industrial respondents see TechUPGRADE primarily as an energy-cost solution with climate benefits attached, and they will adopt it only once it has been proven under real operating conditions. All respondents who answered the question named lower energy costs as their main adoption driver, and the most frequently cited scale-up requirements are demonstration in realistic industrial settings and the reliability of materials and reactors. Most expect a moderately positive effect on competitiveness and a CO_2 reduction of 5-15% in their sector. The sample is small (11 organisations), so the results are indicative, but they come from the type of companies most likely to be early adopters and integrators.

8.2.1 Respondent profile

Ten of the eleven respondents are SMEs and one is a technology provider. Five are headquartered in Sweden, two in Romania and one each in the Netherlands, Spain and Portugal; one did not state a country. Seven work in energy systems and renewable energy integration, and the other four represent metals and minerals (porcelain), the non-ferrous metal industry, food and beverage, and waste heat recovery and energy services. The sample therefore over-represents energy-service and solar companies, which are potential integrators and suppliers of the technology, relative to heat-consuming manufacturers.

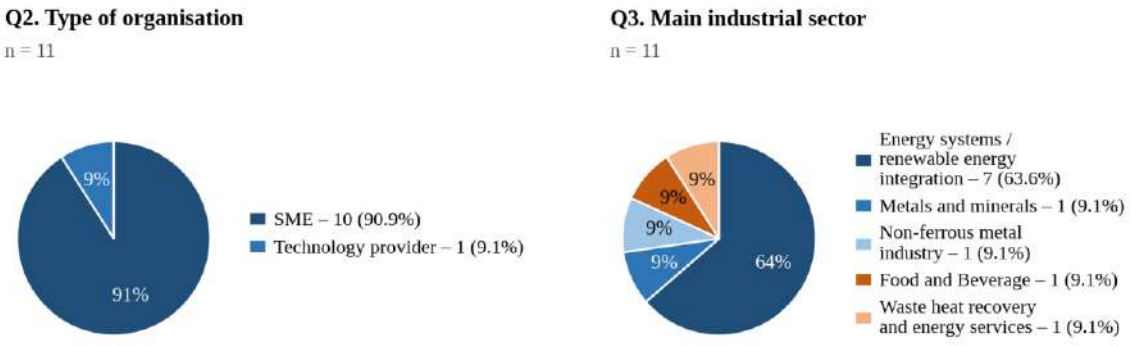


Figure 8.8. Industry: type of organisation (Q2) and main industrial sector (Q3).

8.2.2 Adoption drivers and current heat profile

Energy-cost reduction is the universal driver (10 of 10 respondents), followed by lower CO_2 emissions and environmental impact (7 of 10 respondents), improved efficiency and waste heat recovery (5 of 10 respondents), energy security and reduced dependence on external supply (3 of 10 respondents), and regulatory compliance (2 of 10 respondents). For SMEs, climate benefits strengthen the business case but do not replace it. Regulation is not yet a significant driver, which suggests that current policy signals for industrial heat remain weak.

The current heat supply is diverse: electricity (27.3%), natural gas (18.2%), solar thermal (18.2%), and geothermal, biomass, LPG and recovered waste heat (9.1% each). Fossil fuels (natural gas and LPG) therefore supply 27.3% of respondents, a lower share than in EU industry as a whole, reflecting the energy-sector bias of the sample. Process temperatures are evenly spread: 27.3% operate below 100

°C, 27.3% at 100-150 °C, 27.3% at 150-250 °C and 18.2% above 250 °C, so that close to half of respondents (45.5%) operate in or above the target range of TechUPGRADE.

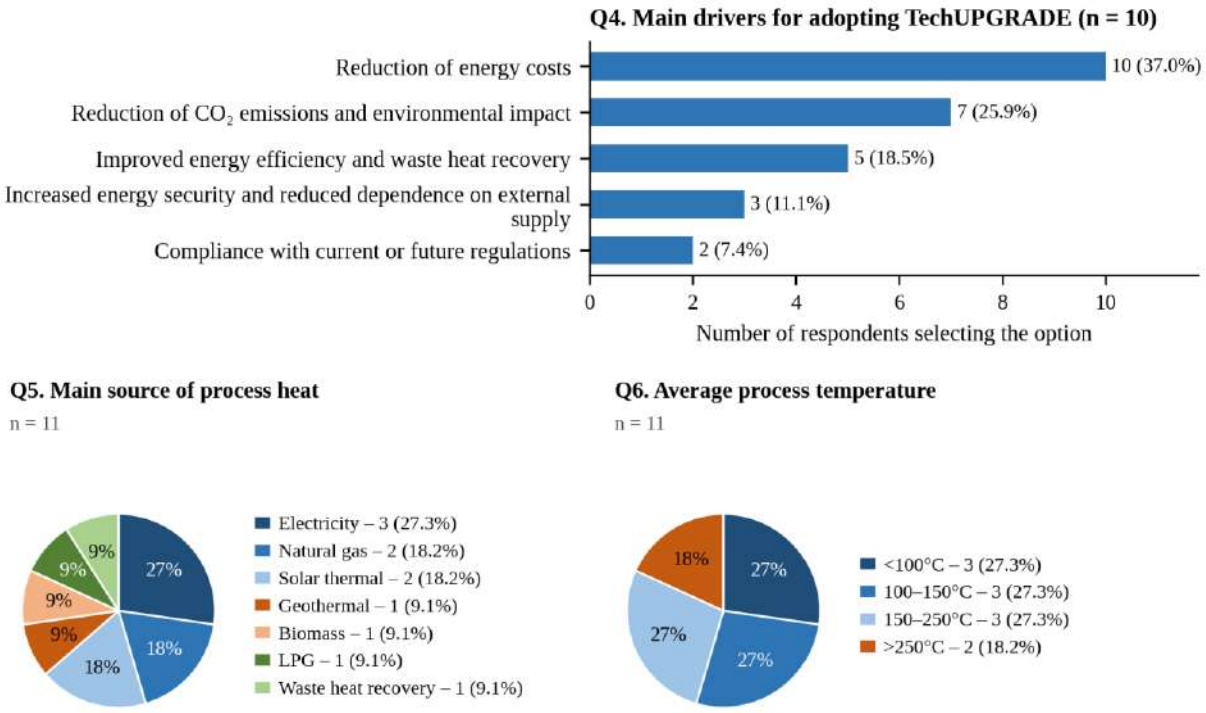


Figure 8.9. Industry: main adoption drivers (Q4), current source of process heat (Q5) and average process temperature (Q6).

8.2.3 Waste heat availability and familiarity with the technology

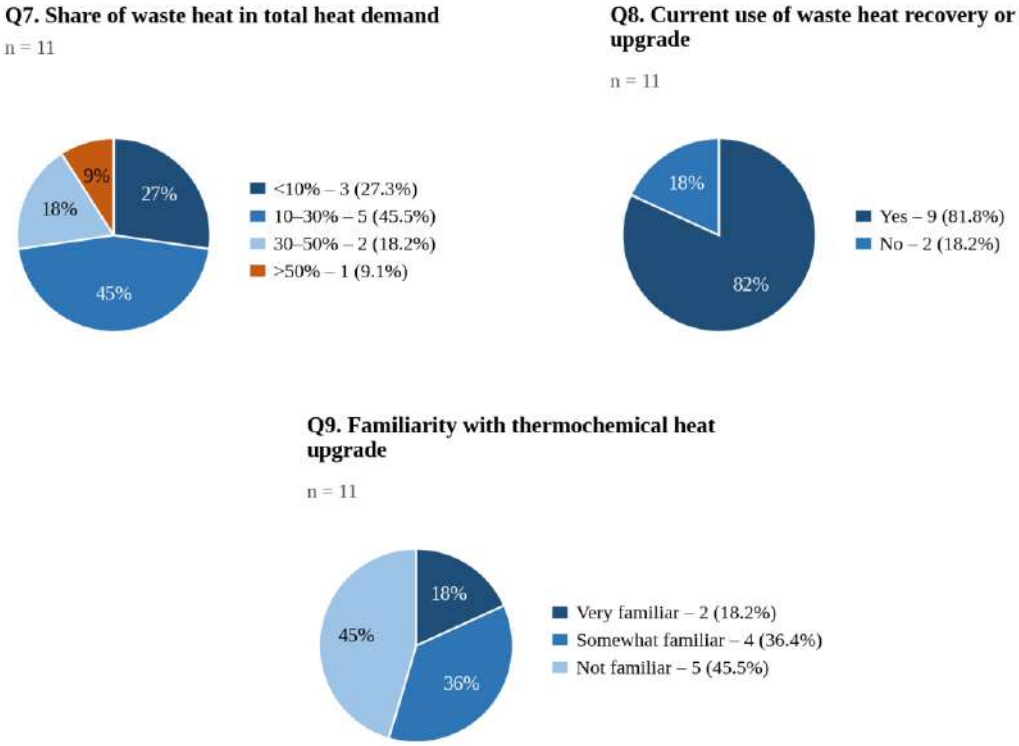


Figure 8.10. Industry: share of waste heat in heat demand (Q7), use of waste heat recovery (Q8) and familiarity with thermochemical heat upgrade (Q9).

8.2.4 Perceived benefits and scale-up requirements

Respondents perceive the benefits broadly: reduced fossil fuel dependence (27.6%), integration with solar or district heating (24.1%), lower CO_2 emissions (24.1%) and improved energy efficiency (24.1%). That integration with solar and district heating scores as high as CO_2 reduction confirms the value of the project's multi-source design.

Table 8.2. Challenges and requirements for scaling up 150-250 °C heat upgrade technology (n = 11; multiple answers).

Requirement	Respondents	Share of mentions
Demonstration under realistic industrial conditions	6	18.2%
Technical performance and reliability of materials and reactors	6	18.2%
Limited data on cost-effectiveness at prototype stage	5	15.2%
Integration with existing process lines	4	12.1%
Operational stability and safety at high temperatures	4	12.1%
Compatibility with current heat supply infrastructure	3	9.1%
Standardised performance metrics and certification	2	6.1%
Uncertainty about maintenance or operation	2	6.1%
Cost of investment	1	3.0%

The requirements form a coherent sequence. Industry first needs proof that materials and reactors work reliably at temperature, then evidence from a realistic demonstration, then credible cost data,

and finally solutions for integration into existing lines and infrastructure. Certification and standardised performance metrics would make this evidence comparable across suppliers and are a natural topic for D7.5.

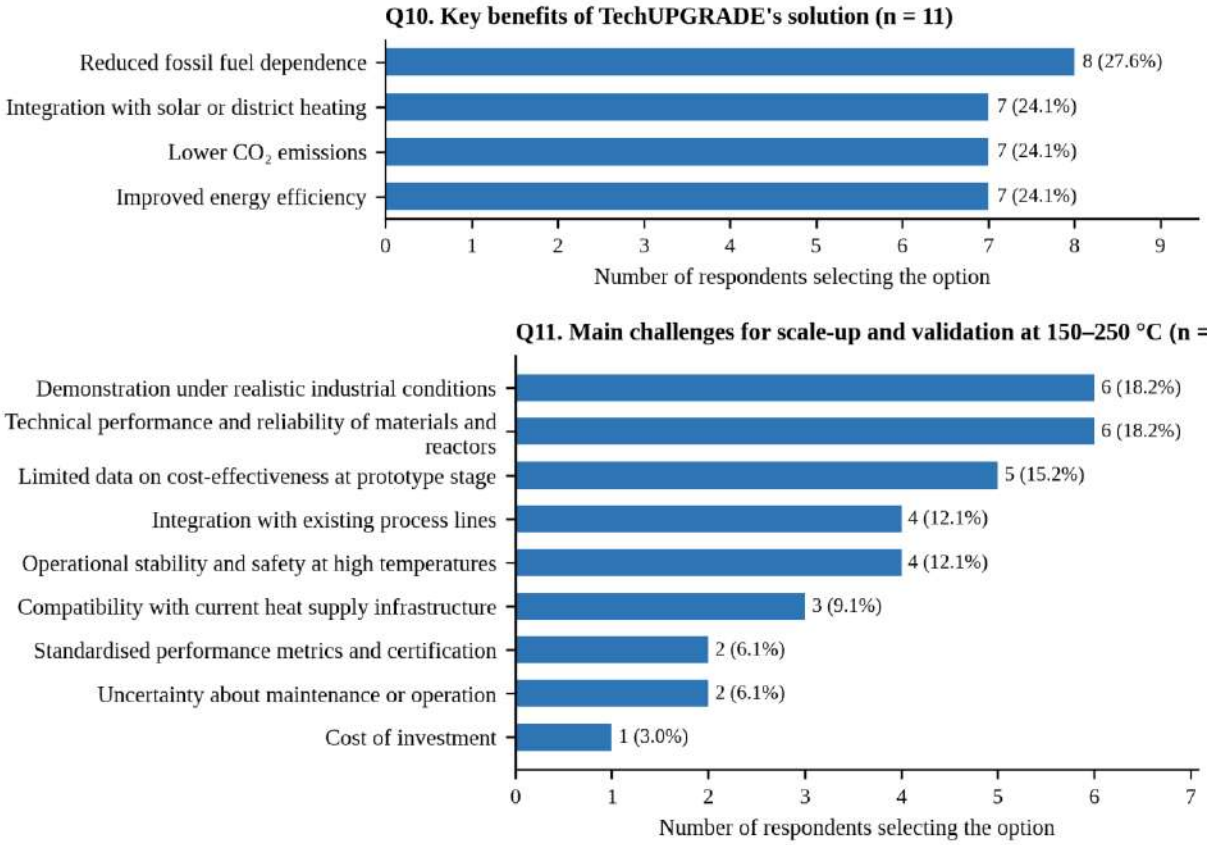


Figure 8.11. Industry: key benefits of TechUPGRADE's solution (Q10) and main challenges for scale-up and validation (Q11).

8.2.5 Recovery potential

Most available waste heat is at low temperature: 36.4% report waste heat at 80-120 °C, 27.3% below 80 °C and 9.1% at 120-180 °C, while 18.2% are not sure. This profile matches the design input range of TechUPGRADE closely. Respondents also see a meaningful recovery potential: 20% each estimate that 5-10%, 20-30% or more than 30% of their waste energy could be recovered and reused, and 30% estimate 10-20%. In total, 70% of respondents who answered see a recoverable potential above 10% of their waste energy.

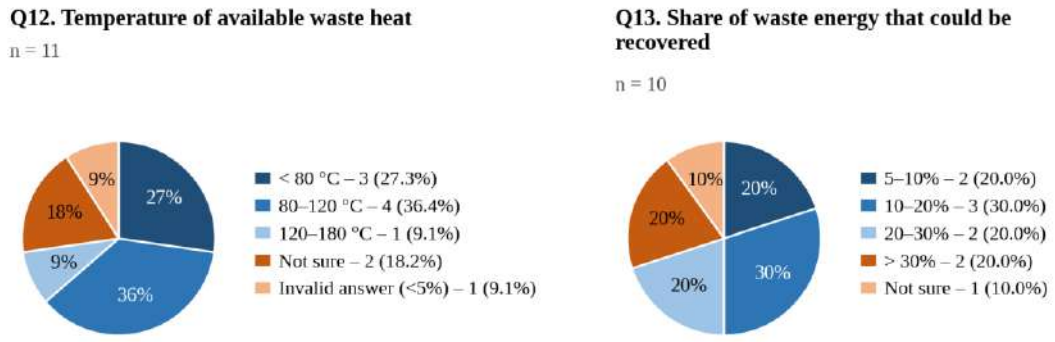


Figure 8.12. Industry: temperature of available waste heat (Q12) and potentially recoverable waste energy (Q13).

8.2.6 Competitiveness, business opportunities and CO_2 reduction

Views on competitiveness are mostly positive but grounded in cost. Eight respondents expect benefits, citing green branding, ESG reporting and new energy services. A Spanish solar energy company explained that it could supply more energy to its clients with only a small additional investment. A food and beverage company operating within a multi-company industrial complex described a situation that illustrates the opportunity well: two of the four companies in the complex pay to cool exhaust fumes, while the other two burn LPG to heat water, and the complex also plans new businesses that will require additional energy.

> *"We are at an absurd situation of spending money to cool down fumes, and then burning LPG to heat up water for the other processes." (Industrial respondent)*

Two respondents were sceptical. A Swedish manufacturer in the non-ferrous metals sector argued that green branding does not currently increase business, while heavy investments in circularity raise production costs that customers are unwilling to pay for, a reminder that the business case cannot rely on green premiums. Another respondent saw potential synergies with carbon capture, where clean heat for solvent regeneration is a growing need. On CO_2, 45.5% expect a moderate reduction of 5-15% in their sector, 18.2% a significant reduction above 15% and 27.3% a slight reduction below 5%; 9.1% need more data. These sector-level expectations are more modest than the savings per MWh of heat calculated in Chapter 6 (about 99% compared with an existing gas boiler), which is consistent with partial market penetration and with the respondents' low current fossil share.

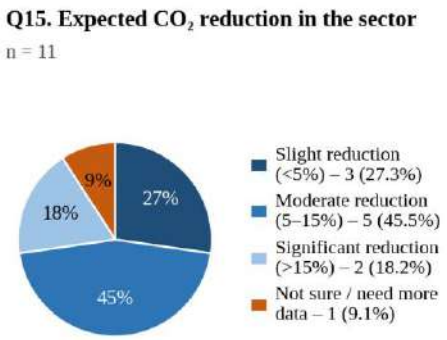


Figure 8.13. Industry: expected CO_2 reduction in the sector (Q15).

8.2.7 Environmental benefits, jobs and skills

The most valued environmental benefit is better use of waste heat and circularity (34.5%), followed by improved local energy efficiency and integration with renewable sources (20.7% each), reduced fossil fuel consumption (17.2%) and lower air pollution (6.9%). Seven of the eleven respondents expect new jobs or skills in their sector. They most often name process integration experts and process engineers, followed by digital monitoring specialists, thermal systems engineers, technicians, maintenance staff and, in one geothermal company, geothermal process engineers. One respondent expects no change and three do not know.

> *"It will drive demand for specialised roles such as thermal systems engineers, process integration experts and digital monitoring specialists to manage complex heat recovery and storage infrastructures." (Industrial respondent)*

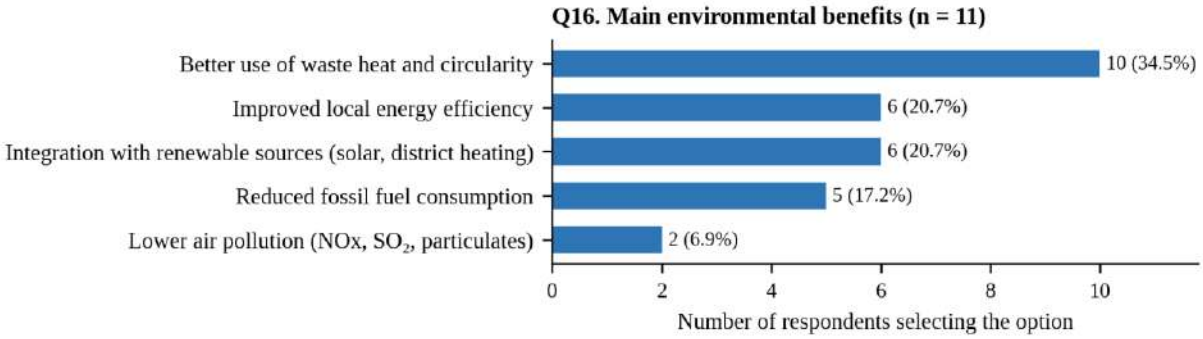


Figure 8.14. Industry: main environmental benefits (Q16).

8.2.8 Socio-economic performance, policy and stakeholders

Eight respondents (72.7%) expect a moderately positive effect on their organisation's socio-economic performance, one is neutral, one uncertain and one negative for cost reasons. Carbon pricing or stricter emission targets is the policy change most often cited (36.4%), ahead of simplified permitting and certification (27.3%), support for waste heat utilisation (18.2%), and R&D and pilot grants and investment support (9.1% each). Industrial end-users are seen as the stakeholders who must be most involved in scaling up (63.6%), followed by technology developers (18.2%), regional authorities and research institutions (9.1% each).

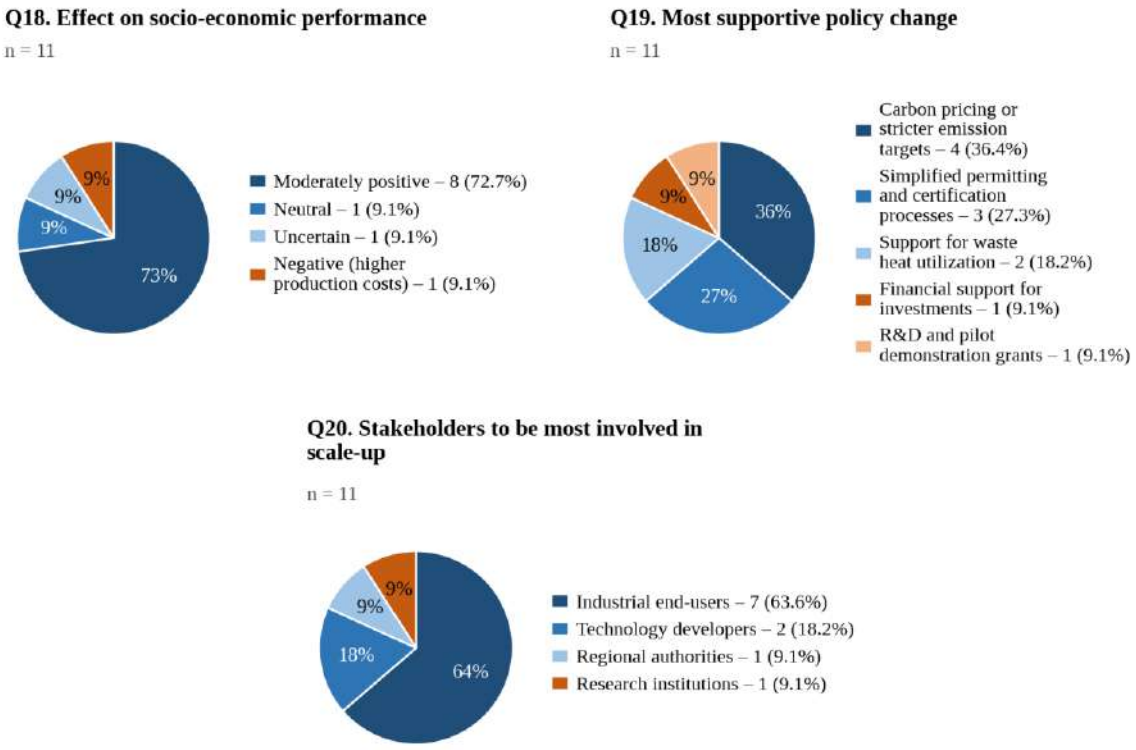


Figure 8.15. Industry: effect on socio-economic performance (Q18), supportive policy changes (Q19) and key stakeholders for scale-up (Q20).

8.2.9 Long-term changes to the industrial ecosystem

Asked about long-term changes, respondents mention stronger local supply chains (three answers), a broader green transition (two), employment creation, and independence from external suppliers and price shocks. One respondent described a virtuous circle in which more predictable energy costs

improve planning and profitability, which in turn enables investment and new jobs. Another saw a change of mindset as the main legacy: as fossil fuels are phased out, energy engineering becomes more complex, flexibility and storage become critical, and technologies like TechUPGRADE demonstrate the value of these complex clean systems.

Industry's message is pragmatic: prove it, price it and integrate it. A credible demonstration with transparent cost data, combined with carbon pricing that rewards the CO_2 savings, would convert a broadly favourable attitude into adoption.

8.2.10 Interpretation and implications for deployment

The industrial results describe a clear decision logic: cost first, proof second, climate third. Energy-cost reduction is the only driver named by every respondent, and climate benefits strengthen but do not replace the business case; one manufacturer stated explicitly that customers do not pay for lower-carbon products. For deployment, this means that TechUPGRADE will be adopted where it lowers heat costs, which according to D4.3 is the case with free waste heat (35 €/MWh against 72 €/MWh for gas), and that carbon pricing is needed to widen the advantage in less favourable configurations.

A second finding is a familiarity paradox. Most respondents already recover waste heat (9 of 11), yet almost half are not familiar with thermochemical heat upgrading (5 of 11). The gap is therefore not general awareness of waste heat, but knowledge of this specific technology and of its performance. Generic awareness campaigns will not close it; site visits, performance data from the pilots and peer examples will. The temperature profile of the available waste heat (7 of 11 respondents have waste heat below 120 °C) also confirms a good technical fit with the input range of the technology.

Finally, the composition of the sample shapes the interpretation. Seven of eleven respondents are energy-service, solar or renewable-integration companies, which are potential integrators and sales channels rather than end-users. Their positive view suggests that a go-to-market strategy through energy-service companies and integrators, as explored in D7.4, is promising, but the views of large heat-consuming manufacturers remain to be confirmed.

8.3 Civil society stakeholders

Civil society supports the move away from fossil heat but sees an information deficit as the main obstacle to public acceptance. Air pollution and public health is the community concern named by almost all respondents (25 of 27), and nearly nine in ten (88.9%) say communities are not at all or only slightly informed about new industrial heat technologies. Respondents associate TechUPGRADE far more with new jobs and cleaner air than with job losses, but they are concerned about economic disruption during the transition and call for transparent sharing of plans and risks.

8.3.1 Respondent profile

The 27 respondents come from Sweden (13; 48.1%), Greece (10; 37.0%), Germany (2), the Netherlands and Portugal (1 each). They hold a wide range of roles in civil-society, community and professional organisations: project managers and coordinators (9), managers and business roles such as chief operating officer, co-founder, technical manager, head of HR and business developer (6), researchers (3), engineers (3), students (3), a public relations officer and a planning architect. This mix provides the view of engaged citizens and organisations working at the interface between communities and industry, rather than of the general public.

Familiarity is moderate for heat pumps but low for the specific technology. Two thirds (66.7%) are somewhat familiar with industrial heat pumps, 25.9% not familiar and 7.4% very familiar. For thermochemical heat upgrade, 55.6% are not familiar, 40.7% somewhat familiar and only one respondent very familiar.

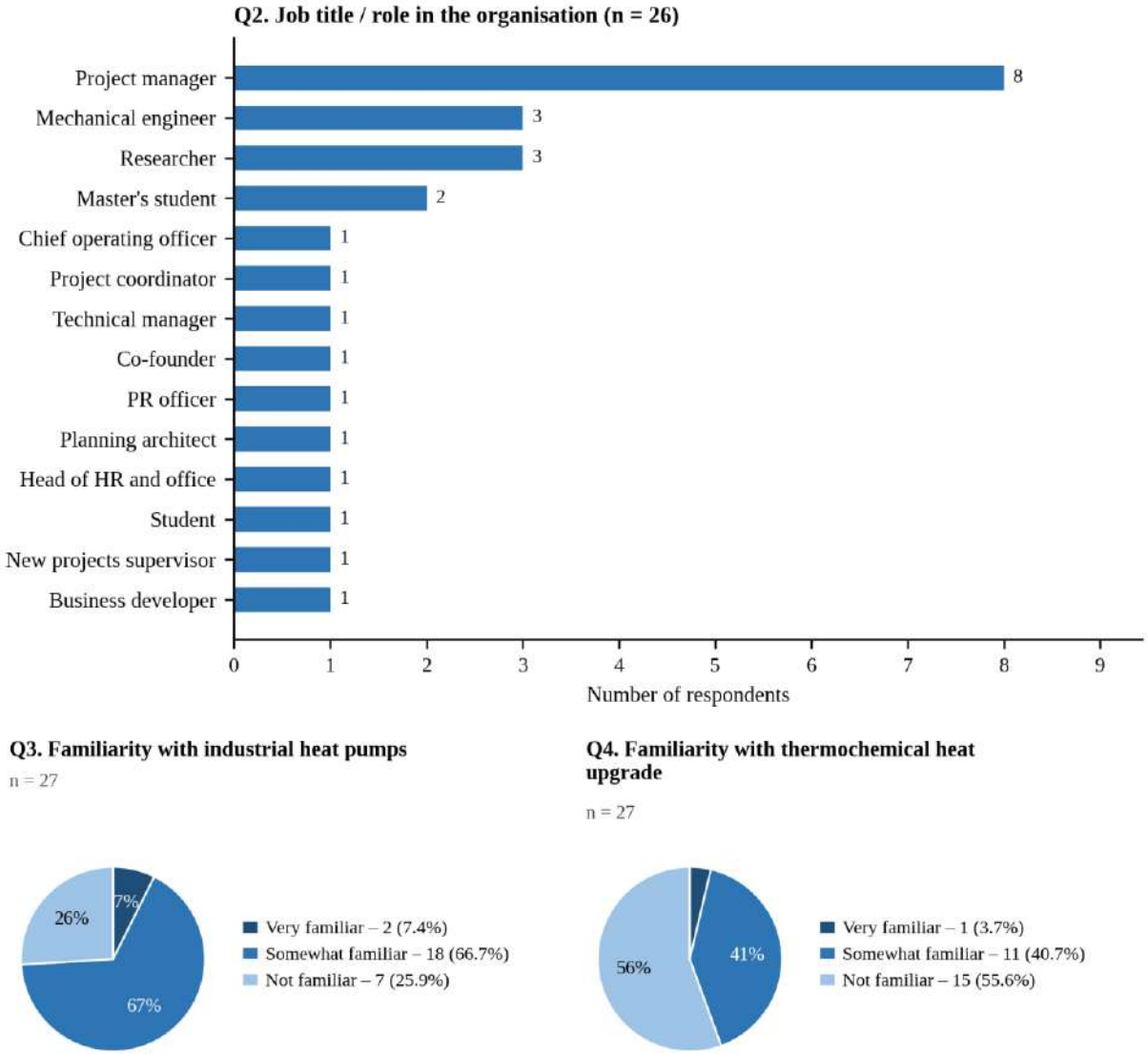


Figure 8.16. Civil society: role in the organisation (Q2), familiarity with industrial heat pumps (Q3) and with thermochemical heat upgrade (Q4).

8.3.2 Community concerns and attitudes to the transition

Air pollution and public health dominate community concerns (32.9%), well ahead of environmental sustainability (18.4%), local economic impact (17.1%), worker safety in new technologies (14.5%) and job stability and security (14.5%). This ranking matters for communication: the most compelling message for communities is the local health and air-quality benefit of replacing on-site combustion with recovered heat, rather than the global climate benefit.

Asked how concerned they are about the transition from fossil fuels to clean industrial heat, 51.9% answered very concerned, 29.6% somewhat concerned and 11.1% neutral. The question proved ambiguous: one respondent noted that if "concerned" means being afraid of the transition they are

not concerned at all, but if it means looking forward to it they are very concerned. Read together with the other answers, which are strongly favourable to clean heat, the high level of concern is best interpreted as strong engagement with the transition rather than opposition to it.

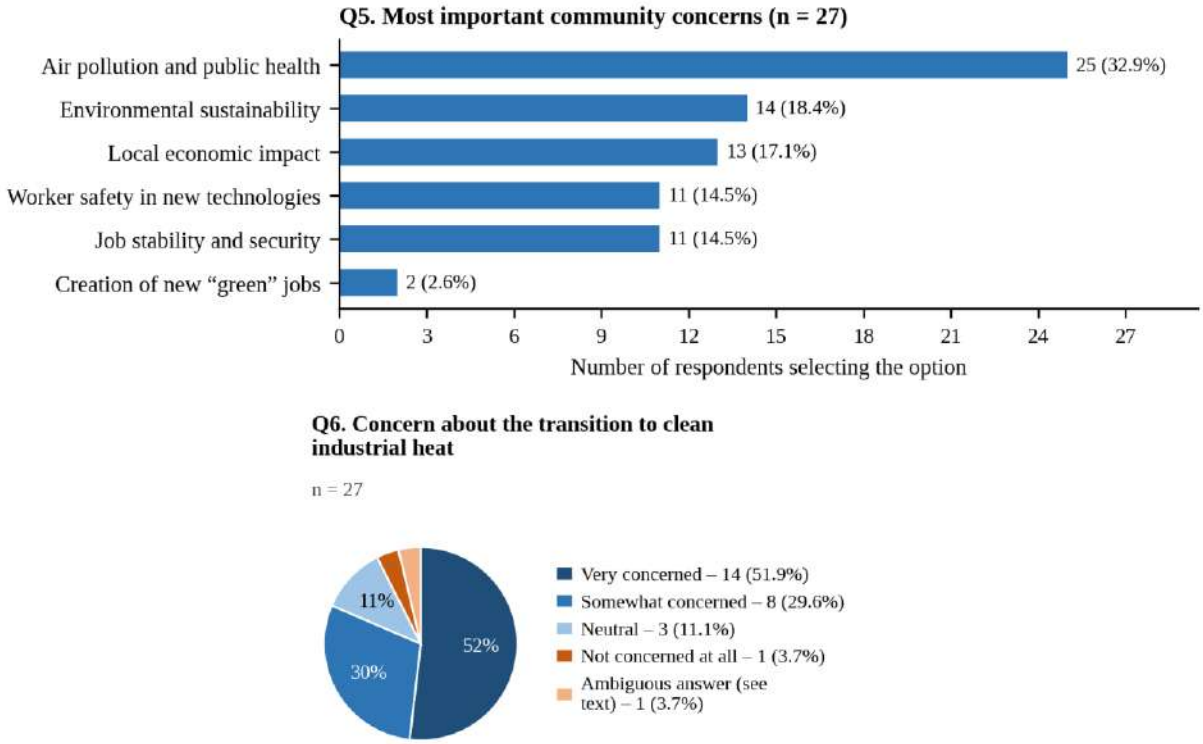


Figure 8.17. Civil society: most important community concerns (Q5) and level of concern about the transition (Q6).

8.3.3 Expected social impacts and involvement of civil society

The social impact most associated with TechUPGRADE is a change in local energy supply (34.6%), followed by new job opportunities (26.9%) and improved air quality (25.0%). Enhanced community reputation (5.8%), risk of job loss (3.8%) and disruption to local industries (3.8%) are rarely mentioned. The balance of expected impacts is therefore clearly positive, with employment seen as an opportunity rather than a threat.

To involve civil society in technology deployment, respondents favour community education sessions and transparent sharing of plans and risks (27.1% each, selected by 19 of 27 respondents), followed by ongoing feedback opportunities (17.1%), involvement in planning or decision boards and public consultations (14.3% each). The preference for education and transparency over formal consultation suggests that communities want to understand the technology before they are asked to decide on it.

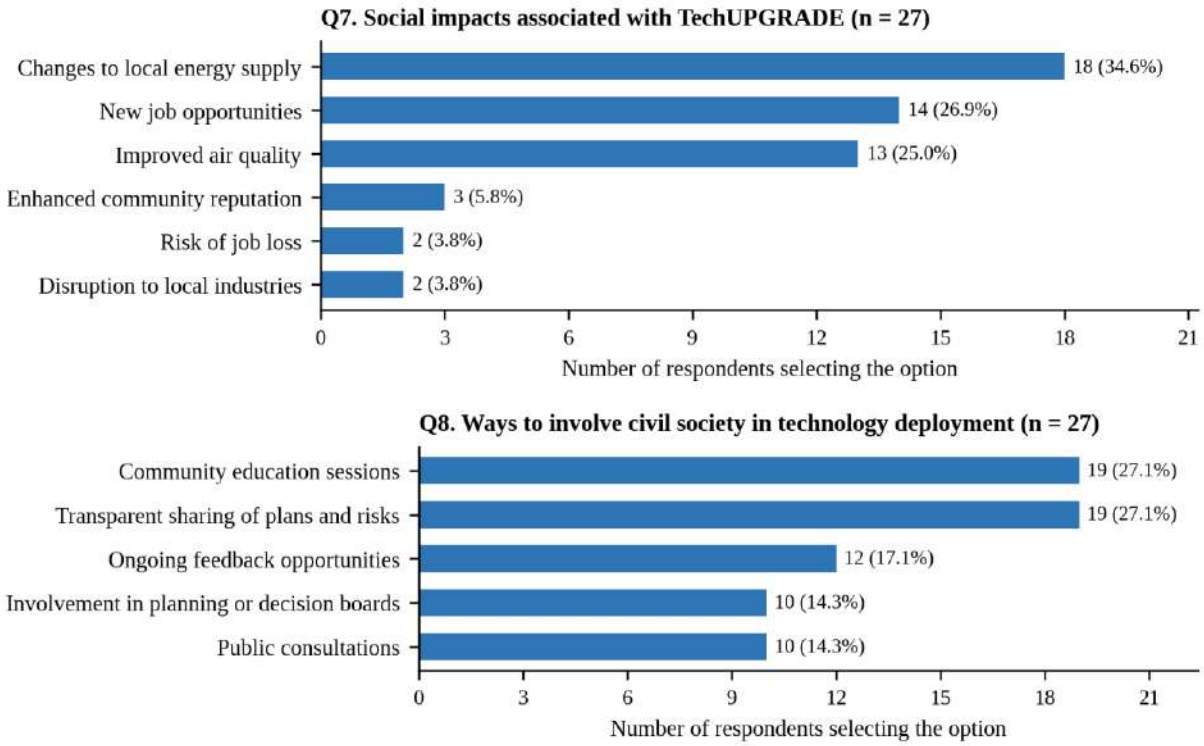


Figure 8.18. Civil society: social impacts associated with TechUPGRADE (Q7) and ways of involving civil society (Q8).

8.3.4 Information levels and barriers to acceptance

No respondent considers communities well informed: 48.1% say not at all informed, 40.7% slightly and 11.1% moderately informed. Consistently, lack of understanding and awareness is the leading barrier to public acceptance (32.8%), followed by financial costs and myths (25.4%) and the absence of visible local benefits (16.4%). Distrust of new technology (11.9%), concerns about job impacts (6.0%), fear of safety or environmental risks (6.0%) and fossil fuel subsidies (one mention) are less frequent.

Table 8.3. Main barriers to public acceptance of technologies like TechUPGRADE (n = 27; multiple answers).

Barrier	Respondents	Share of mentions
Lack of understanding and awareness	22	32.8%
Financial costs and myths	17	25.4%
Absence of visible local benefits	11	16.4%
Distrust of new technology	8	11.9%
Concerns about job impact	4	6.0%
Fear of safety or environmental risks	4	6.0%
Fossil fuel subsidies	1	1.5%

The barriers are mostly informational and economic rather than related to risk. Safety concerns are low at present, but this partly reflects low awareness; experience with other energy technologies shows that safety perceptions can change quickly after an incident. The fact that 11 of 27 respondents miss visible local benefits points to a practical remedy: demonstration sites should show and communicate local benefits, such as cleaner air, local jobs or lower heat costs, in concrete terms.

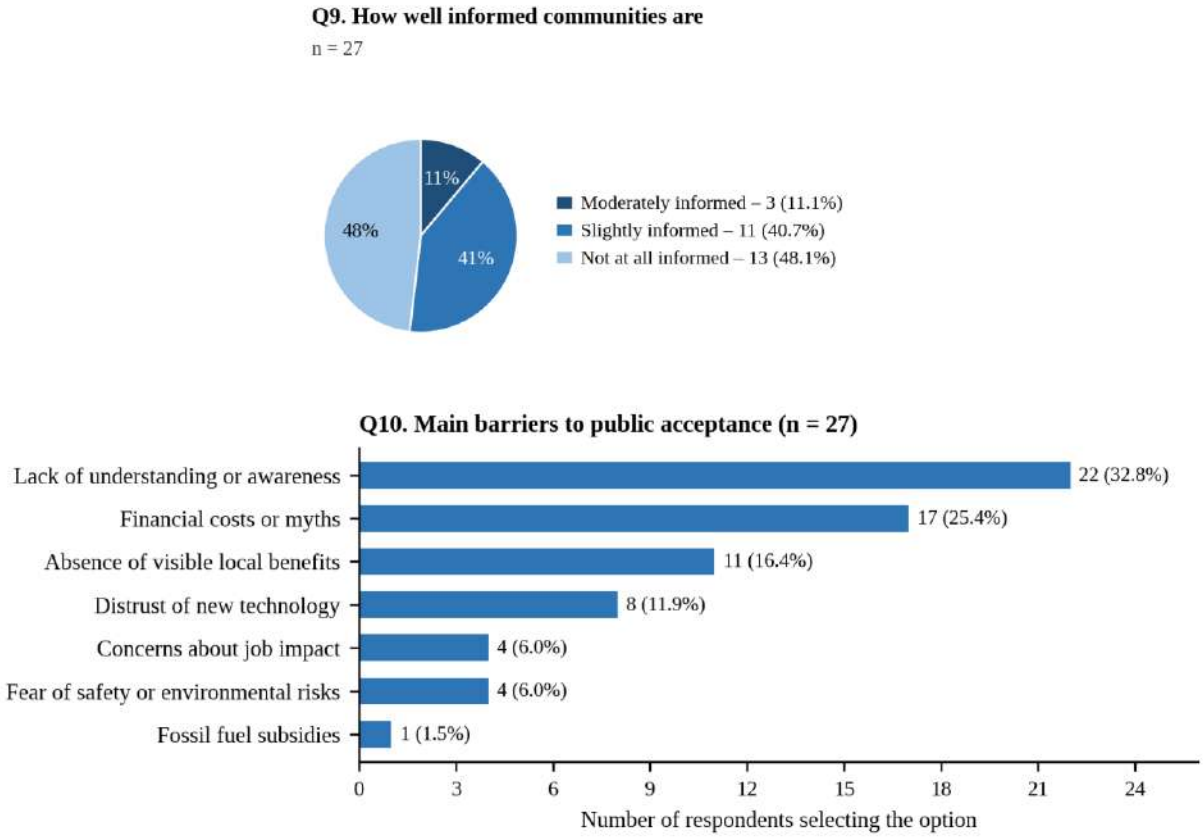


Figure 8.19. Civil society: how well informed communities are (Q9) and barriers to public acceptance (Q10).

8.3.5 The role of civil society in building trust

Civil-society respondents see their own role mainly as an independent source of information (29.6%) and a facilitator of dialogue between stakeholders (24.1%), followed by organising public forums (20.4%), monitoring and reporting on impacts (16.7%) and advocating for vulnerable groups (9.3%). Good practice appears scarce: only 14.8% know of successful examples of public engagement or capacity building in industrial energy transitions, 51.9% do not and 33.3% are not sure. TechUPGRADE and its follow-up demonstrations can therefore fill a gap by creating a visible engagement example.

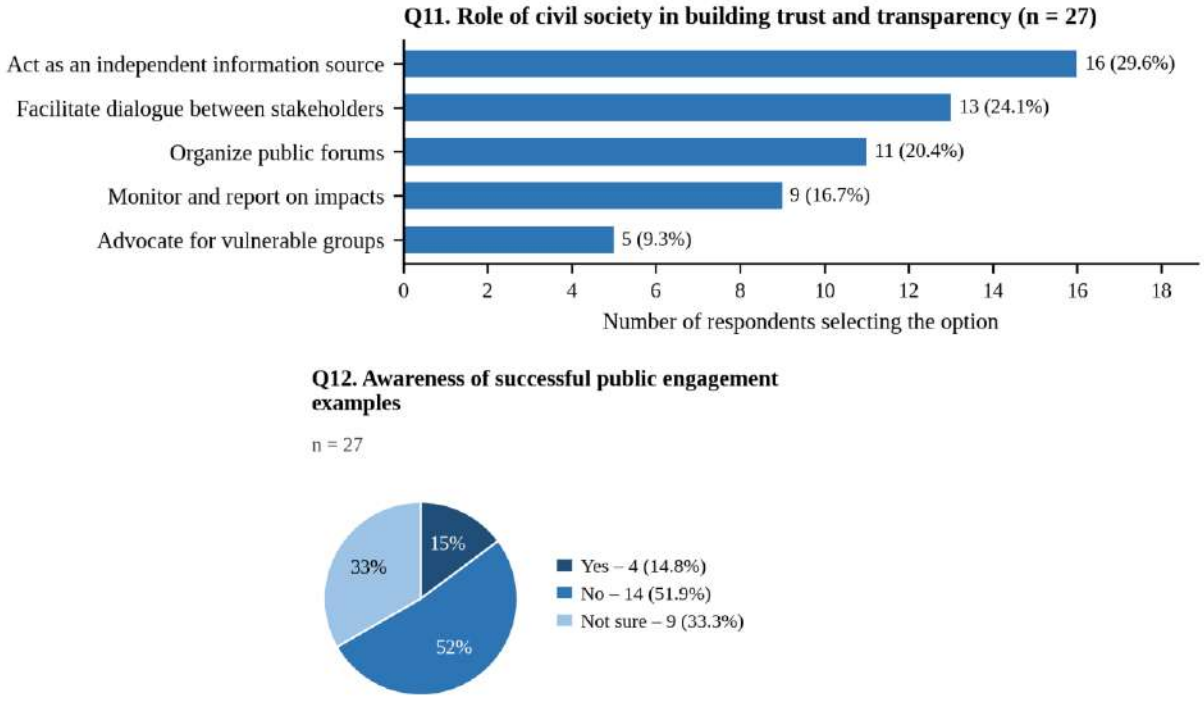


Figure 8.20. Civil society: role in building trust and transparency (Q11) and awareness of successful engagement examples (Q12).

8.3.6 Economic risks

The economic risks that most concern civil society are disruption during the transition (36.8%) and job loss in traditional sectors (31.6%), followed by rising inequality (18.4%) and worker displacement (10.5%). These concerns relate to the transition as a whole rather than to TechUPGRADE specifically: when asked about the technology itself, only 7.4% expected job losses. One respondent summarised the prevailing view that the transition must go ahead and that its problems can be solved along the way.

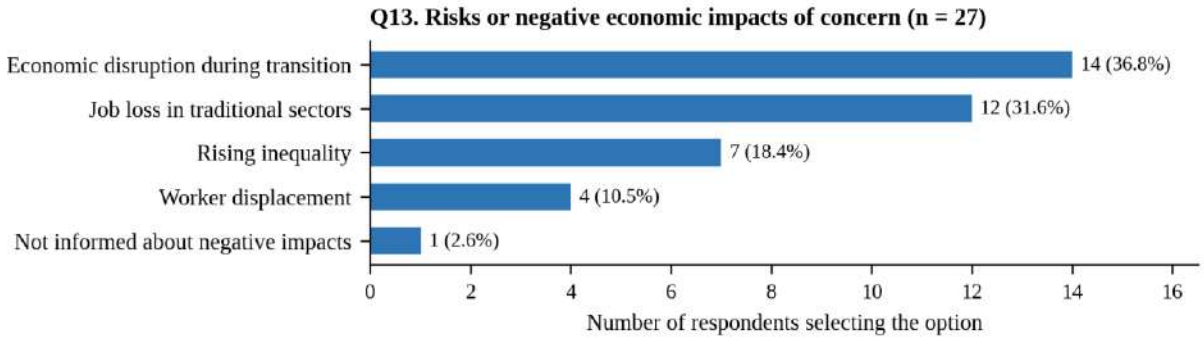


Figure 8.21. Civil society: risks or negative economic impacts of concern (Q13).

The civil-society evidence calls for an engagement strategy built on education and transparency, centred on local health and air-quality benefits, with explicit attention to Just Transition measures, such as retraining and a fair distribution of costs, for workers and communities that depend on fossil-based activities.

8.3.7 Interpretation and implications for deployment

The civil-society results suggest that public acceptance is not a question of opposition but of information. Respondents associate the technology with changes to local energy supply, new jobs and better air quality rather than with risks, and the barriers they name are mainly informational (lack of awareness) and economic (costs and myths). The main implication is that engagement should start early and be framed around local benefits, especially air quality and health, which is the concern named by almost all respondents.

Two qualifications are important. First, safety concerns are low (4 of 27), but this partly reflects low familiarity: experience with other energy technologies shows that acceptance can change quickly after an incident, so safety must be part of the communication from the start. Second, the respondents are mainly professionals working in or with organisations rather than residents living near industrial sites. Since even this informed group considers communities poorly informed, the information gap among the general public is probably larger than measured here.

8.4 Public authorities

The questionnaire evidence from public authorities is limited to two Danish respondents, complemented by interviews with two Italian policymakers (Chapter 9), but it points to the same structural barrier identified by industry and academia: regulatory uncertainty and fragmented responsibility for excess-heat projects. Both respondents work in economic and business development, both are unfamiliar with heat pump and thermochemical technologies, and both ask for clear regulatory frameworks and guidance. Their answers are best read as qualitative signals, to be complemented by the interviews and by the policy analysis of D7.5.

8.4.1 Respondent profile and familiarity

One respondent represents a business development council and the other a municipality; both are project or programme managers in business or economic development. Neither is familiar with industrial heat pumps or thermochemical heat upgrade. This is itself a finding: the public officials who typically broker industrial development projects and local partnerships are not energy specialists, so information aimed at them must translate technical performance into economic and planning terms.

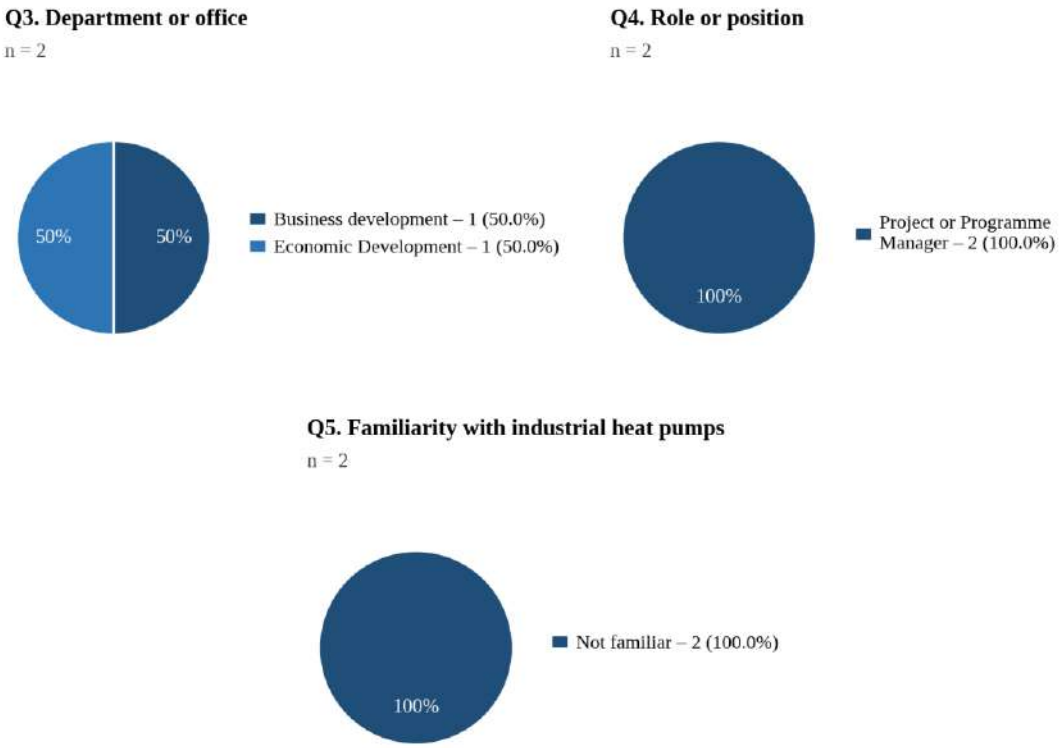


Figure 8.22. Public authorities: department (Q3), role (Q4) and familiarity with industrial heat pumps (Q5).

8.4.2 Regulatory challenges and permits

One respondent identifies the lack of clear regulations or guidelines and coordination challenges between different authorities as the main regulatory obstacles; the other could not answer. The explanation is instructive: although the respondent does not work on heat directly, previous attempts to use excess heat in the region had been hampered by regulatory uncertainty and by the need to coordinate several public institutions and private companies. Neither respondent could judge whether current regulation supports or hinders deployment. The same respondent flags environmental permits and operational licences as permits that might delay similar projects.

> *"Previous efforts to use excess heat have been challenged due in part to regulatory uncertainties and coordination between multiple public institutions and private companies." (Public authority respondent, Denmark)*

This observation fits the Danish experience, where the taxation and price regulation of industrial excess heat have been adjusted repeatedly to unlock its use in district heating. For TechUPGRADE, which can supply heat both to processes and potentially to district heating networks, clarity on the regulatory status of upgraded excess heat is a precondition for business models that cross company boundaries.

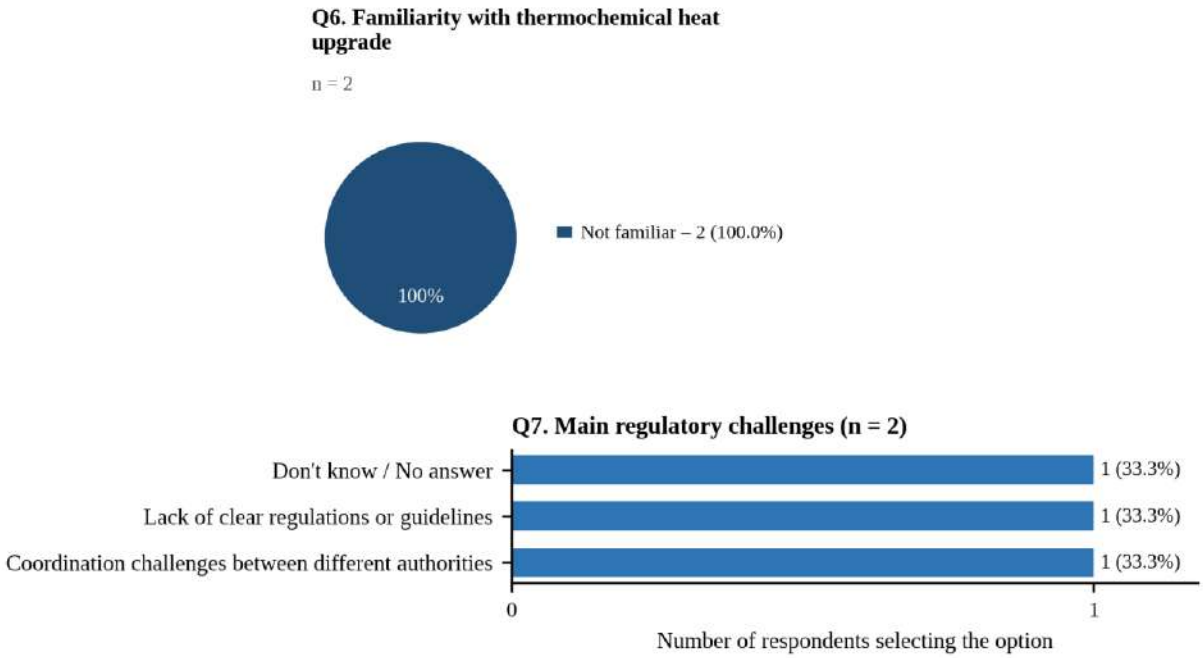


Figure 8.23. Public authorities: familiarity with thermochemical heat upgrade (Q6) and main regulatory challenges (Q7).

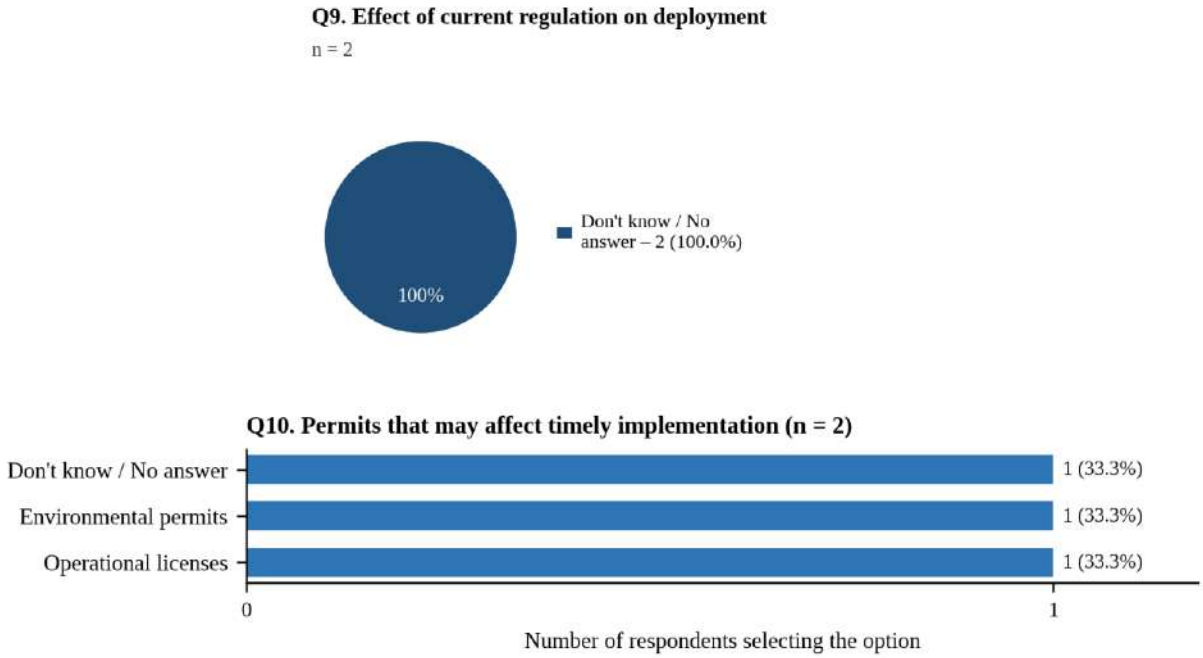


Figure 8.24. Public authorities: effect of current regulation (Q9) and permits that may affect timely implementation (Q10).

8.4.3 Policy instruments and the role of socio-economic impacts

The respondent who answered selected four instruments to accelerate acceptance and scale-up: financial incentives or subsidies, tax rebates or credits, clear regulatory standards, and mandatory emission reduction targets. Socio-economic impacts matter in decision-making: one respondent rates them very important and the other somewhat important. This confirms that the jobs, local value and community benefits documented in this report are relevant evidence for public decision-makers, not only for industry.

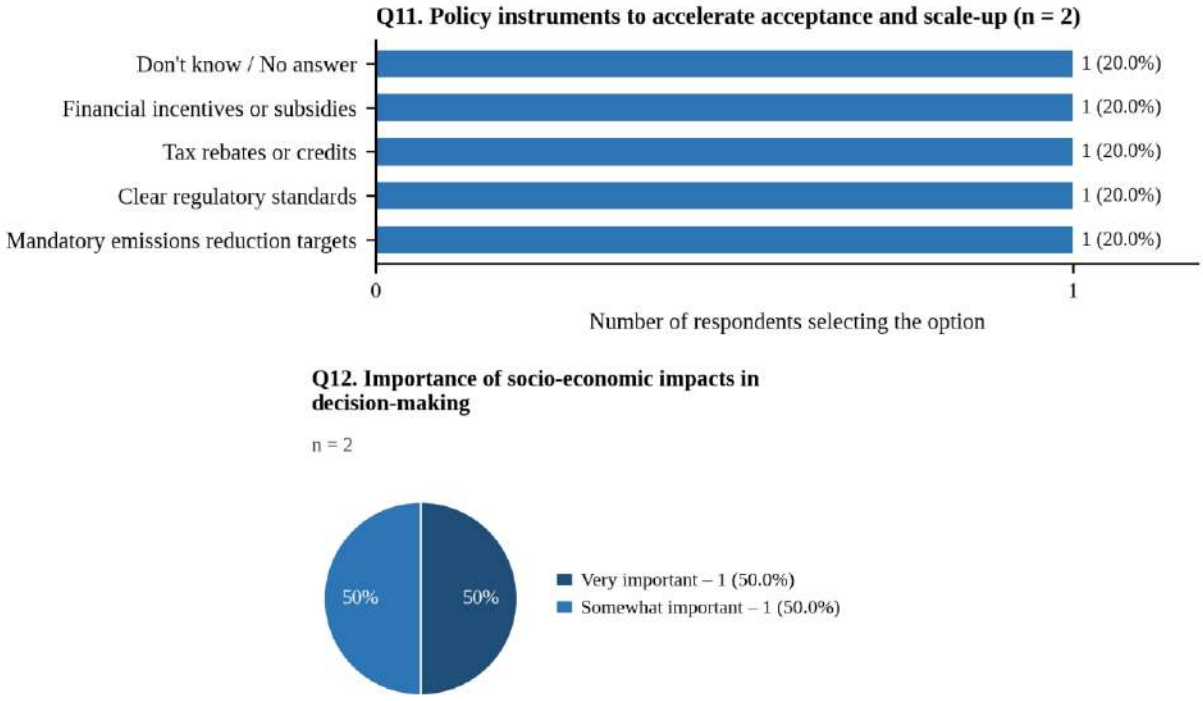


Figure 8.25. Public authorities: policy instruments to accelerate scale-up (Q11) and importance of socio-economic impacts in decision-making (Q12).

8.4.4 Community concerns and public perception

The concerns encountered from local communities are uncertainty or mistrust about new technologies, fear of rising energy costs, and a lack of clear communication and involvement. The respondent described a timing dilemma: innovative projects rarely have all the answers from day one, which makes it difficult to decide when to involve citizens. Citizens also want assurance that renewable-based systems will function when the sun is not shining or the wind is not blowing, and that energy costs will not rise suddenly after a switch.

> *"People are generally sceptical of new technologies and sometimes innovative projects don't have all the answers to their questions from day one; this makes communication and the timing of involvement rather tricky." (Public authority respondent, Denmark)*

These concerns speak directly to TechUPGRADE's strengths: built-in thermochemical storage addresses the intermittency question, and a target cost of heat of 3-6 c€/kWh addresses the cost question, provided both are demonstrated and communicated. On perception, one respondent expects it to remain neutral, while the other expects it to become more positive with a good involvement process and honest communication about complexities.

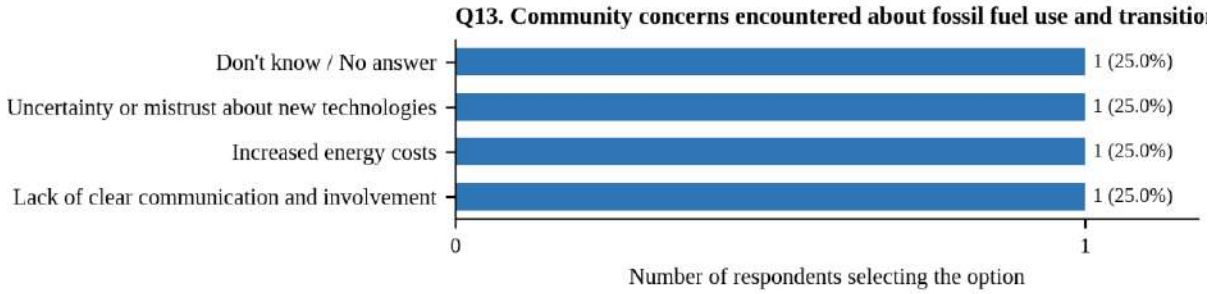


Figure 8.26. Public authorities: community concerns about fossil fuel use and transitions (Q13).

8.4.5 Existing initiatives and support needed by industry

Neither respondent knows of a regional programme that engages citizens on industrial sustainability. One points to two relevant examples outside their region: a Finnish thermal energy storage solution (Elstor) and GreenLab, the Danish green industrial park that is a TechUPGRADE partner. Both respondents see clear regulatory frameworks and guidance as the support industry most needs from government; one also selects financial support or incentives and the facilitation of stakeholder dialogues.

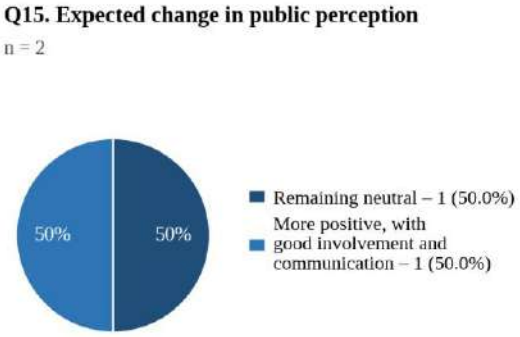


Figure 8.27. Public authorities: expected change in public perception (Q15).

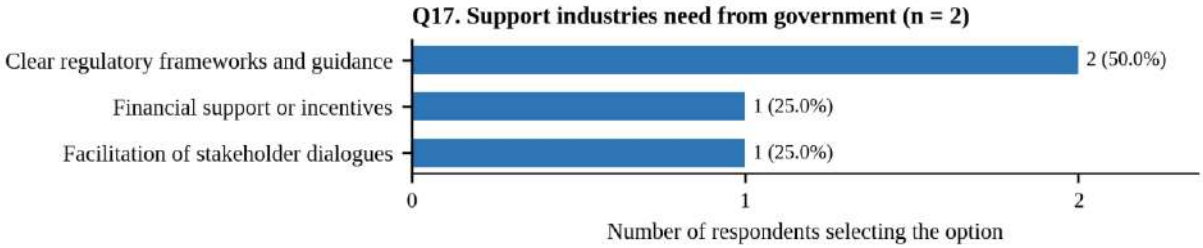


Figure 8.28. Public authorities: support industries need from government (Q17).

The public-authority findings reinforce three messages for D7.5: clarify the regulatory status of upgraded excess heat, assign coordinating responsibility across authorities, and equip local development officers with accessible information on the technology and its socio-economic benefits.

8.4.6 Interpretation and implications for deployment

The public-authority evidence is too limited to support general conclusions, but it points to a risk that matters for deployment: the first TechUPGRADE projects that sell or share upgraded heat across company boundaries may be delayed by unclear rules and by the need to coordinate several institutions. The respondents are economic-development officers rather than energy specialists,

which shows that information aimed at public authorities must translate technical performance into economic, employment and planning terms. These findings should be tested with energy and environmental regulators in D7.5 before firm policy conclusions are drawn.

9 Semi-structured interviews

The semi-structured interviews form the qualitative core of the Social Impact Assessment. Whereas the questionnaires measure how widely views are held across the four stakeholder groups, the interviews explore why stakeholders hold these views, how they weigh benefits against risks, and which conditions they attach to their support. The interview programme was designed by MGS and shared with the consortium as four stakeholder-specific interview scripts, so that partners in different countries could conduct interviews in a consistent way within their own networks. In total, eight interviews were conducted, two with each stakeholder category.

9.1 Interview design and ethical framework

Each script opens with a standardised introduction to TechUPGRADE, adapted to the audience. For industrial stakeholders and public authorities, the technology is presented as a thermochemical Hydration Heat Transformer, developed in two designs and demonstrated at TRL 5, that boosts low-grade heat from waste heat, solar collectors or district heating to 150-250 °C, with very low electricity use compared with vapour-compression and thermally activated heat pumps and with built-in heat storage. For civil society, the same concept is explained in non-technical language: a clean-energy technology driven mostly by heat itself, based on a reversible chemical process using safe and widely available salt hydrates, which can reuse heat that would otherwise be wasted and store energy for later use. For academia, the introduction emphasises the scientific relevance, open research questions and opportunities for collaboration.

The questions were formulated as guiding prompts that partners may adjust to the interviewee's role, expertise and the flow of the conversation. Interviews were planned to last 25-35 minutes. Interviewees were asked for permission to record the conversation. All responses are treated as confidential and anonymous and are reported only in generalised form, in line with the GDPR.

9.2 Structure and themes of the interview scripts

The four scripts mirror the structure of the corresponding questionnaires. This makes it possible to compare the interview results with the survey results theme by theme, while the open, explanatory prompts capture information that a questionnaire cannot.

Table 9.1. Structure of the stakeholder interview scripts.

Stakeholder group	Focus of the script	Question blocks	Main themes
Academia and research	Socio-economic and scientific impact	13	Research context; relevance of the heat-upgrade challenge; scientific and technical challenges (material cyclability, kinetics, heat and mass transfer, integration, scale-up); collaboration areas; education and training; useful outputs; contribution to decarbonisation, the Green Deal and SDG 7; post-project priorities; joint research; data access; academia-industry collaboration; barriers; overall impact rating (1-5)

Stakeholder group	Focus of the script	Question blocks	Main themes
Industrial stakeholders	Socio-economic impact	14	Background; industrial context and heat use; waste-heat availability and use; awareness and perceived benefits; adoption drivers; technical and operational challenges; recovery potential; competitiveness and business opportunities; environmental impact; jobs, skills and workforce; organisational socio-economic impact; policy and support needs; stakeholders and ecosystem; long-term industrial and regional impact
Civil society	Socio-economic impact and public perception	11	Background; awareness of industrial heat technologies; community concerns on health, employment and environment; perceptions of the energy transition; perceived social impacts; barriers to public acceptance; information, transparency and trust; involving civil society in decision-making; role of civil-society organisations; good-practice examples; economic and social risks and just-transition measures
Public authorities	Socio-economic impact and policy framework	12	Institutional context; familiarity and institutional capacity; policy and regulatory context; regulatory and administrative barriers; permits and approval processes; policy instruments; socio-economic impact in decision-making; community concerns and acceptance; public perception and communication; existing programmes; support needed by industry; long-term policy and systemic impact

Compared with the questionnaires, the scripts add several explanatory dimensions. The academic script distinguishes between challenges that require fundamental research and those that are mainly engineering-driven, and asks about the added scientific value of TechUPGRADE. The industrial script asks which drivers matter most to decision-makers, what information would be needed to assess the recovery potential, and how new skills would be obtained. The civil-society script explores whether concerns differ between social groups and regions and what information people feel is missing. The public-authority script asks about institutional capacity, how regulatory barriers manifest in practice, which permits are the most critical bottlenecks, and how TechUPGRADE-type solutions could fit within existing programmes.

9.3 Interview sample

Eight stakeholders were interviewed, two from each of the four categories: academia and research, industry, civil society and public authorities. The balanced design ensures that each group is represented by more than one voice, while keeping the interview programme manageable alongside the questionnaire survey.

Table 9.2. Interview sample.

Stakeholder group	Interviews	Script used	Note on the sample
Academia and research	2	Academia and Research Stakeholders Interview Script	Complements 64 questionnaire responses
Industrial stakeholders	2	Industrial Stakeholders Interview Script	Complements 11 questionnaire responses
Civil society	2	Civil Society Interview Script	Complements 27 questionnaire responses
Public authorities	2	Public Authorities Interview Script	Two Italian policymakers; complements 2 Danish questionnaire responses
Total	**8**		

The public-authority interviews are particularly valuable. The questionnaire received only two responses from public authorities, both in Denmark. The interviews with two Italian policymakers double the evidence base for this group and extend it to a second national policy context, in Southern Europe, with a different industrial structure and regulatory framework.

9.4 Added value of the interviews

The interviews added depth rather than breadth to the evidence. Whereas the questionnaires recorded which options respondents selected, the interviews gave stakeholders the opportunity to explain their answers in their own words, to qualify them, and to describe how different factors interact in practice. This provided three main benefits.

First, the interviews offered **more detailed explanations** of the views measured in the questionnaires. Interviewees could explain why particular benefits or barriers mattered to them, rather than only indicating that they did, which helps interpret the percentages reported in Chapter 8.

Second, they gave a **deeper understanding of stakeholders' perspectives and reasoning**, including how they weigh benefits against risks, which conditions they attach to their support, and how their position (as a researcher, company, community organisation or policymaker) shapes their expectations of the technology.

Third, they allowed a **validation of the questionnaire results** in a different format and, for public authorities, in a different country. Because the scripts follow the same themes as the questionnaires, each interview could be compared directly with the corresponding survey results.

9.5 Interview findings

Overall, the interviews confirmed the findings that had emerged from the questionnaires. No interview contradicted the main survey results. Because only eight interviews were conducted, two per group, and because the interview notes are reported in aggregate to protect the anonymity of the interviewees, the findings are presented at the level of themes rather than individual statements. Their main contribution is to corroborate the survey results and to show how stakeholders reason about them; they are not numerous enough to establish new themes on their own. The findings are summarised below for each stakeholder group.

Academia and research. The academic interviewees confirmed the high scientific relevance of upgrading low-grade heat to 150-250 °C and the positive overall assessment of TechUPGRADE's impact potential found in the questionnaire (average rating 4.27 out of 5). They confirmed the importance of collaboration on thermochemical materials, reactor design and integration with industrial processes, the strong potential for integrating project outcomes into education and training, and the value of open data and models. In line with the survey, they identified scale-up demonstration as the main priority after the project and high investment costs and the gap between laboratory and market as the main barriers to impact.

Industrial stakeholders. The industrial interviewees confirmed that energy-cost reduction is the decisive driver for adoption, with emission reductions an important but secondary benefit. They confirmed that demonstration under realistic industrial conditions, the reliability of materials and reactors, and credible data on performance and cost are preconditions for investment, and that integration with existing process lines is a key technical requirement. Consistent with the questionnaire, they expected new skills to be needed in process integration, thermal systems and digital monitoring, and identified carbon pricing and support for waste-heat utilisation as the most helpful policy measures.

Civil society. The civil-society interviewees confirmed that air pollution and public health are the community concerns most relevant to the technology, and that communities are generally poorly informed about new industrial heat technologies. They confirmed that lack of awareness, rather than fear of risk, is the main barrier to public acceptance, and that transparent sharing of plans, benefits and risks and community education are the most effective ways of building trust. In line with the survey, they associated the technology with new job opportunities rather than job losses, while stressing the importance of managing the transition fairly.

Public authorities. The two Italian policymakers confirmed the findings from the Danish questionnaire respondents. They confirmed that familiarity with thermochemical heat upgrade technologies within public administrations is limited, that regulatory clarity and coordination between authorities are essential for excess-heat and industrial heat projects, and that financial incentives and clear regulatory standards are among the most effective instruments for accelerating uptake. They also confirmed that socio-economic impacts, such as employment and industrial competitiveness, are important in public decision-making, and that clear communication and early involvement of citizens are needed to build public acceptance. The convergence of views between Danish and Italian public authorities suggests that these findings are not specific to one national context.

9.6 Consistency with the questionnaire results

Table 9.3 summarises how the interviews relate to the main propositions derived from the questionnaires. All propositions were confirmed.

Table 9.3. Questionnaire propositions and interview results.

Proposition from the questionnaires	Survey evidence	Interview question	Interview result
Energy cost, not climate, is the decisive adoption driver for SMEs	Industry Q4: 100% cost, 70% CO_2	Industry Q5 (drivers for adoption)	Confirmed

Proposition from the questionnaires	Survey evidence	Interview question	Interview result
A full-scale demonstration with open cost data is the main condition for uptake	Industry Q11 (54.5%); Academia Q10 (57.8%)	Industry Q6-Q7; Academia Q8	Confirmed
Carbon pricing and support for waste-heat use are the key policy levers for industry	Industry Q19 (36.4% carbon pricing)	Industry Q12	Confirmed
New roles centre on process integration, thermal systems and digital monitoring	Industry Q17; Academia Q11	Industry Q10; Academia Q5	Confirmed
Communities value local health benefits	Civil society Q5 (92.6% air pollution)	Civil society Q3, Q5	Confirmed
Low awareness, not risk perception, limits acceptance	Civil society Q9-Q10 (81.5% awareness)	Civil society Q6-Q7	Confirmed
Regulatory clarity and coordination between authorities are needed	Public authorities Q7-Q8	Public authorities Q3-Q5	Confirmed (Italian policymakers)
Incentives, clear standards and early communication support uptake and acceptance	Public authorities Q11, Q13-Q17	Public authorities Q6, Q8-Q9, Q11	Confirmed (Italian policymakers)

9.7 Conclusions from the interviews

The interviews show that the questionnaire results are consistent across methods. Across all four stakeholder groups, the interviewees confirmed the same benefits, barriers and conditions for uptake identified in the surveys, and the two Italian policymakers confirmed the views of the Danish public-authority respondents in a different national context. Their main added value is to show how cost, proven performance, awareness and regulatory clarity interact in stakeholders' reasoning about adoption. Their limits should also be acknowledged: with two interviews per group, recruited through partner networks and following scripts that mirror the questionnaires, they corroborate rather than extend the survey findings. A larger interview programme focused on the groups that are under-represented in the surveys, namely heat-consuming manufacturers, energy regulators and residents near industrial sites, would be needed to explore themes beyond those covered by the questionnaires.

10 Integrated stakeholder and impact analysis

This section integrates the data from the four stakeholder categories with one another and with the quantitative results of Chapters 6 and 7. It shows that the stakeholder groups converge on the main benefits and barriers of TechUPGRADE, that their expectations are consistent with the modelled impacts, and that the remaining differences concern emphasis rather than direction. The integrated evidence is then translated into an impact assessment matrix, a SWOT analysis, a social impact register and a risk register.

10.1 Integrated profile of the 104 respondents

Together, the four questionnaires collected 104 responses from 18 countries. Academia and research account for 61.5% of responses, civil society for 26.0%, industry for 10.6% and public authorities for 1.9%. Greece (40 responses; 38.5%) and Sweden (27; 26.0%) are the largest countries, followed by Denmark (7), Spain and Portugal (4 each), Germany and Romania (3 each), Cyprus, Italy and the Netherlands (2 each), and ten other countries with one response each. The pooled sample therefore combines a broad academic base across Europe with concentrated civil-society and industrial samples in Sweden and Greece, the two countries where the project partners responsible for the SIA and for dissemination are based, and a small public-authority sample in Denmark, the country of the project coordinator and of the use cases.

Table 10.1. Integrated sample by stakeholder group and main countries.

Country	Academia	Industry	Civil society	Public authorities	Total
Greece	30	0	10	0	40
Sweden	9	5	13	0	27
Denmark	5	0	0	2	7
Spain	3	1	0	0	4
Portugal	2	1	1	0	4
Germany	1	0	2	0	3
Romania	1	2	0	0	3
Netherlands	0	1	1	0	2
Other countries or not stated	13	1	0	0	14
Total	**64**	**11**	**27**	**2**	**104**

10.2 Familiarity and awareness across groups

Familiarity with thermochemical heat upgrade technologies was measured in the same way for industry, civil society and public authorities. Across these 40 respondents, 55% are not familiar with the technology, 38% somewhat familiar and only 8% very familiar (Figure 10.1). Even industrial respondents, most of whom already use waste heat recovery, are largely unfamiliar with it (45%), and both public officials are. Among civil-society respondents, familiarity with industrial heat pumps (74% at least somewhat familiar) is much higher than with thermochemical upgrading (44%), which suggests that communication can build on the more familiar concept of heat pumps as an entry point. Academic respondents, who were not asked this question directly, also identify low awareness and weak

dissemination as a barrier (19% of coded answers). Awareness is therefore the most consistent gap across all four groups, and the cheapest to close.

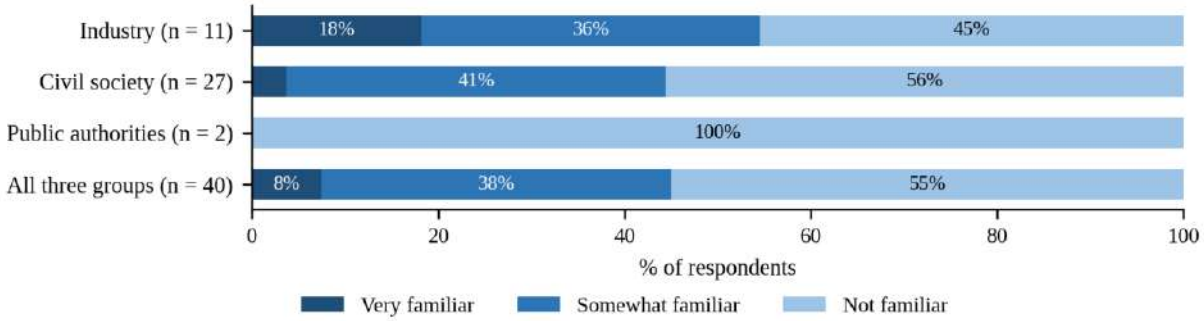


Figure 10.1. Familiarity with thermochemical heat upgrade technologies in industry, civil society and public authorities, and pooled across the three groups.

10.3 Convergence and divergence of key indicators

Figure 10.2 compares five indicators that were measured in comparable ways in at least two groups, and Table 10.2 summarises the main findings of all groups side by side. The indicators are defined as follows: positive overall expectation is an academic rating of 4–5 or an industrial expectation of a moderately positive effect; need for demonstration is the academic post-project priority and the industrial scale-up requirement; cost is the coded academic barrier, the industrial adoption driver and the civil-society acceptance barrier; low awareness combines the coded academic barrier with industrial unfamiliarity and the civil-society information level; and new jobs refers to industrial expectations of new jobs or skills and civil-society expectations of new job opportunities. All values are shares of respondents.

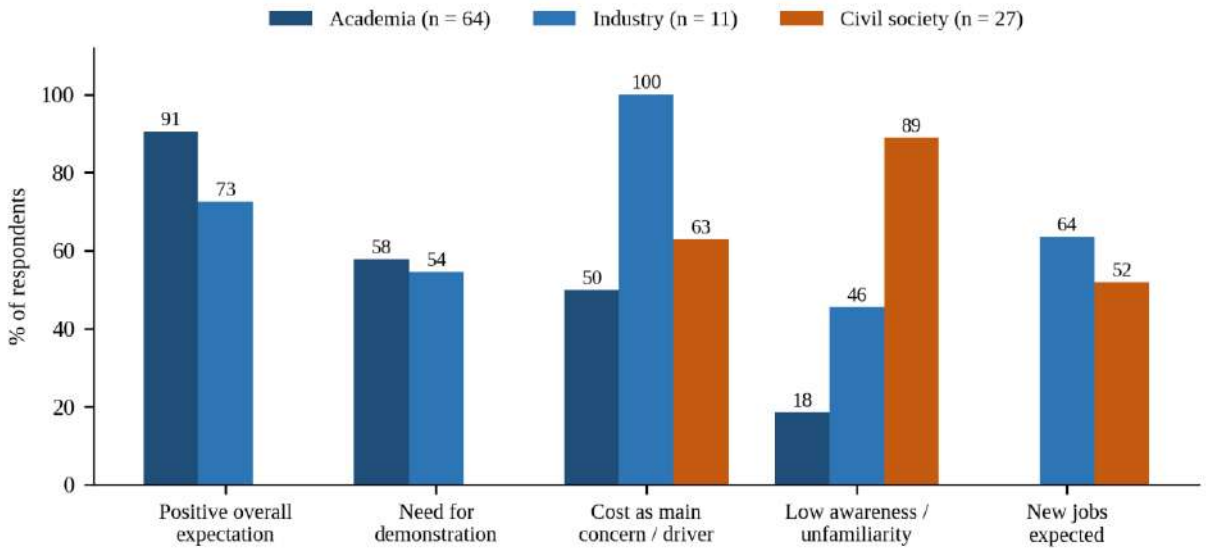


Figure 10.2. Key indicators compared across stakeholder groups (% of respondents).

Table 10.2. Cross-stakeholder comparison of key findings.

Theme	Academia (n = 64)	Industry (n = 11)	Civil society (n = 27)	Public authorities (n = 2)	Quantitative analysis
Relevance and potential	84% find challenge very or highly relevant; rating 4.27/5	73% expect moderately positive effect on competitiveness	Associate it with local energy supply (67%) and new jobs (52%)	Socio-economic impacts very or somewhat important	Over 100 TWh/yr of EU waste heat at 100-200 °C; proposal target 5 TWh/yr
Main benefit	Decarbonisation, efficiency, SDG 7	Lower energy costs (100%), less fossil dependence (73%)	Air quality and public health (93% concern)	Not assessed	CO_2 savings of 278 kg/MWh (about 99%) vs existing gas boiler; LCOH 35 €/MWh vs 72 €/MWh for gas
Main barrier	Capital cost (50%), scale-up gap (37%)	Realistic demonstration, material reliability (55% each)	Lack of awareness (82%), costs and myths (63%)	Unclear regulation, poor coordination	TRL 5; economic case depends on access to low-cost heat sources
Familiarity	High in energy fields	45% not familiar	56% not familiar	Both not familiar	-
Jobs and skills	Industrial PhDs, curricula (61% high potential)	Process integration, monitoring, thermal engineering	New jobs expected (52%); transition disruption feared (52%)	-	1.76 jobs per M€; about 8,000 job-years and 300 jobs/yr at 5 TWh/yr
Policy ask	Scale-up funding, open data	Carbon pricing (36%), simpler permitting (27%)	Education and transparency (70%)	Clear frameworks, incentives, emission targets	Strongest case with free waste heat (payback 4.3 years)

Three points of convergence stand out. First, every group places demonstration and proof at the centre: academics rank scale-up demonstration first among post-project priorities (57.8%), industry ranks realistic demonstration and material reliability first among scale-up requirements (6 of 11

respondents each), and citizens and authorities want answers on reliability and cost before they trust a new technology. Second, cost is decisive for all: it is the universal adoption driver for industry, the most frequently cited barrier for academia (50%), the second barrier to acceptance for civil society (17 of 27 respondents) and a community concern reported by public authorities. Third, awareness is low wherever it was measured.

The groups diverge on what counts as the main benefit. Industry values the technology for energy-cost savings and energy security, academia for decarbonisation and scientific opportunity, and civil society for health and local air quality. They also differ in their view of employment: industry and civil society expect new jobs, while civil society also fears disruption during the transition, and academia focuses on skills and education. These differences call for tailored communication: a single climate-focused message would under-sell the technology to SMEs and to communities.

10.4 Stakeholder expectations compared with modelled impacts

A key purpose of the integrated analysis is to test whether stakeholder expectations are realistic. Table 10.3 confronts the main expectations with the results of the quantitative analysis.

Table 10.3. Stakeholder expectations compared with the quantitative results.

Stakeholder expectation	Quantitative result	Assessment
Energy-cost reduction is the main benefit (industry, 100%)	LCOH 35 €/MWh with free waste heat and 58 €/MWh with solar heat vs 72 €/MWh for the existing gas boiler	Confirmed
Moderate CO_2 reduction of 5-15% at sector level (industry, 45.5%)	About 99% reduction per MWh of heat; about 1.4 Mt/yr at the 5 TWh/yr market target	Consistent: large per site, moderate per sector because of gradual penetration
Air quality and public health are the main community concern (civil society, 92.6%)	On-site combustion is replaced by upgraded waste or solar heat (air pollutants not quantified in D4.3)	Qualitatively confirmed
New jobs rather than job losses (civil society 51.9% vs 7.4%; industry 63.6%)	Positive gross employment; displaced fossil activity largely imported	Confirmed; main risk is skills mismatch
High capital cost is the main barrier (academia, 50%)	CAPEX 0.9 M€/MW; payback 4.3 years with waste heat but about 10 years with solar heat	Partly confirmed: the barrier is investment risk and uncertainty at TRL 5 rather than unattractive returns
Carbon pricing is the key policy lever (industry, 36.4%)	Fossil heat costs 72 €/MWh in the benchmarking; carbon pricing would widen the gap for all low-carbon options	Consistent
Concerns about intermittency of renewable heat (public authorities)	Built-in thermochemical storage; solar coupling demonstrated at ABS pilot	Addressable through demonstration and communication

The comparison shows that stakeholder expectations are broadly realistic and, in some respects, conservative. Industrial respondents underestimate the CO_2 savings at site level, while academic respondents may overestimate the cost barrier in cases with free waste heat, where the payback calculated in D4.3 is about four years. Communicating the quantitative results of this report to stakeholders could therefore strengthen support and correct misperceptions, in particular the "financial costs and myths" cited by 63% of civil-society respondents.

10.5 Integrated impact assessment matrix

Table 10.4 consolidates the evidence by impact domain. For each domain, it rates the expected magnitude of the impact, the strength of the evidence and the degree of stakeholder agreement, on a three-level scale (high, medium, low).

Table 10.4. Integrated impact assessment matrix.

Impact domain	Expected impact	Direction and magnitude	Evidence strength	Stakeholder agreement	Key condition
Climate (CO_2)	Avoided emissions from fossil process heat	Positive, high (about 99% per MWh; about 1.4 Mt/yr at 5 TWh/yr)	High (D4.3 benchmarking)	High (all groups)	Market uptake beyond demonstration
Air quality and health	Avoided combustion emissions near industrial sites	Positive, medium	Low (not quantified)	High (civil society 93%)	Displacement of combustion on site
Energy security	Reduced natural gas use	Positive, medium	Medium	Medium (industry 30%)	Scale of deployment
Industrial competitiveness	Lower and more stable heat costs	Positive, high with free waste heat; medium with solar heat	Medium (TRL 5 cost data)	High (industry 73%)	Verified CAPEX and performance
Employment	Jobs in construction, installation, machinery, engineering	Positive, medium (1.76 jobs per M€)	Medium (structural IO method)	High (industry, civil society)	Domestic sourcing, skills availability
Skills and education	New green skills, curricula, PhDs	Positive, medium	Medium	High (academia 61%)	Training programmes
Innovation and research	New collaborations, open data, research agenda	Positive, high	High (academia)	High (academia 77%)	Open data policy, follow-up projects
Occupational safety	Less combustion exposure; new chemical and thermal hazards	Mixed, low-medium	Low-medium (literature)	Low (rarely mentioned)	OSH integrated in design
Social acceptance	Support conditional on information and visible benefits	Positive but fragile	Medium	High on awareness gap	Early, transparent engagement
Regulation and governance	Clarity on excess heat, permits, coordination	Currently a barrier	Low (two respondents)	Medium	Policy action (D7.5)

10.6 SWOT analysis

The SWOT analysis in Table 10.5 combines the internal characteristics of the technology with the external conditions identified by stakeholders and by the benchmarking in Chapter 6.

Table 10.5. SWOT analysis of TechUPGRADE from a socio-economic perspective.

Strengths	Weaknesses
Very low electricity demand (7% of heat) and low grid impact compared with heat pumps and electric boilers	TRL 5: performance, durability and cost not yet proven at industrial scale

Strengths	Weaknesses
Built-in thermochemical storage that decouples heat recovery from demand	Higher cost and longer payback with solar heat; cascade with HTHP not competitive
LCOH of 35 €/MWh with free waste heat, about half the cost of gas heat	Capital-intensive value chain and case-specific integration
About 99% CO_2 reduction per MWh compared with an existing gas boiler	Low awareness among industry, citizens and authorities
Strong academic support and research agenda (rating 4.27/5)	Small industrial and public-authority evidence base
Opportunities	**Threats**
Large EU market: about 26% of process heat at 100-200 °C (67% fossil) and over 100 TWh/yr of waste heat at 100-200 °C	Low gas prices weakening the business case
Rising carbon prices, REPowerEU, Clean Industrial Deal and Energy Efficiency Directive	Regulatory uncertainty for excess heat and slow permitting
Coupling with solar thermal and district heating; synergies with carbon capture and hydrogen	Competition from high-temperature heat pumps, electric boilers and hydrogen
New SME markets in components, installation, monitoring and energy services	Skills shortages in process integration and thermochemical systems
Industrial symbiosis in parks such as GreenLab	Safety incidents damaging public trust; critical raw material supply risks

10.7 Social impact register: benefits to maximise and drawbacks to mitigate

The Description of Action requires Task 7.2 to document both the societal benefits and the drawbacks of the technology rollout, so that benefits can be maximised and drawbacks limited in line with Just Transition principles. Table 10.6 consolidates the evidence.

Table 10.6. Social impact register for TechUPGRADE.

Impact	Type	Evidence	Who is affected	Strategy
Lower and more predictable heat costs	Benefit	Chapter 6; Industry Q4, Q21	Industrial users, SMEs and their employees	Maximise: publish verified cost data from pilots and demonstrators
Reduced combustion emissions and better local air quality	Benefit	Chapter 6; Civil society Q5, Q7	Workers, nearby communities	Maximise: measure and communicate local air-quality gains
Skilled jobs in installation, machinery, engineering and R&D	Benefit	Chapter 7; Industry Q17	Engineers, technicians, installers	Maximise: training programmes and local sourcing
Research, education and collaboration	Benefit	Academia Q7, Q12, Q13	Universities, students, SMEs	Maximise: open data, curricula, industrial PhDs
Energy security and local supply chains	Benefit	Section 6.5; D4.3 (GreenLab); Industry Q4, Q21	Regions, industrial clusters	Maximise: regional supplier development
Transition-phase disruption and skills mismatch	Drawback	Section 7.7; Civil society Q13	Fossil-fuel and boiler workers	Mitigate: retraining, phased deployment
High upfront capital cost and investment risk	Drawback	Section 6.3; Academia Q14; Industry Q11	SMEs, early adopters	Mitigate: grants, guarantees, carbon pricing

Impact	Type	Evidence	Who is affected	Strategy
New occupational hazards (salt hydrates, high temperatures)	Drawback	Section 7.8; Academia Q14	Plant workers	Mitigate: OSH management, safety standards
Low awareness and potential mistrust	Drawback	Civil society Q9-Q10; Public authorities Q13	Communities	Mitigate: early, transparent engagement
Regulatory uncertainty for excess-heat projects	Drawback	Public authorities Q7-Q8; Industry Q19	Developers, authorities	Mitigate: guidance and coordination (D7.5)

10.8 Risk register

Table 10.7 identifies the main risks to the realisation of TechUPGRADE's socio-economic impacts, their likelihood and impact, and the mitigation measures and responsible actors.

Table 10.7. Risk register for the socio-economic impact of TechUPGRADE.

Risk	Likelihood	Impact	Mitigation	Responsible
Performance or durability below targets at scale	Medium	High	Extended cycling tests, staged scale-up, transparent reporting	Consortium (WP2-WP6)
CAPEX above the D4.3 estimate of 0.9 M€/MW, eroding cost advantage	Medium	Medium	Design-to-cost, standardised modules, early supplier involvement	Consortium, COWI (D7.4)
Low gas prices	Medium	High	Target sites with free waste heat; advocate carbon pricing	Industry, policymakers
Regulatory barriers and slow permitting	Medium	Medium	Guidance on excess heat, one-stop shop	Policymakers (D7.5)
Lack of skilled workforce	Medium	Medium	Curricula, vocational training, industrial PhDs	Academia, industry
Low public awareness and mistrust	High	Medium	Education sessions, open communication, visible local benefits	Consortium (WP8), civil society
Safety incident at a demonstration site	Low	High	OSH by design, risk assessment, emergency procedures	Consortium, operators
Supply risks for materials and components	Low-medium	Medium	Diversified suppliers, recyclable materials	Industry

10.9 Synthesis: four conditions for adoption

Taken together, the quantitative and stakeholder evidence can be read as a set of four conditions that determine whether the technical potential of TechUPGRADE turns into adoption: proof, price, permission and people. Table 10.8 summarises what the evidence shows for each condition, how strong that evidence is, and what it implies for deployment.

Table 10.8. Four conditions for the adoption of TechUPGRADE: evidence, strength of evidence and implications.

Condition	What the evidence shows	Strength of evidence	Implication for deployment
Proof: performance, durability and cost demonstrated at scale	TRL 5 today; demonstration is the top academic priority (37 of 64) and, with material reliability, the top industrial requirement (6 of 11 each); interviews confirm	High: consistent across groups and methods	An engineering-scale demonstrator (TRL 6) in an operating plant is the decisive next step

Condition	What the evidence shows	Strength of evidence	Implication for deployment
Price: a cost advantage over fossil heat	LCOH 35 €/MWh with free waste heat and 58 €/MWh with solar heat against 72 €/MWh for gas; payback about 4.3 and 10 years; energy cost is the driver for every industrial respondent	High for the D4.3 results; medium for stakeholder views (small industrial sample)	First markets are sites with free waste heat; carbon pricing and de-risking finance widen the market
Permission: clear rules for excess heat	Unclear regulation and poor coordination reported by public authorities (one questionnaire respondent, two interviews); simpler permitting requested by 3 of 11 industrial respondents	Low: few respondents	A potential source of delay for projects that cross company boundaries; to be tested with regulators in D7.5
People: skills and public acceptance	Industry expects new roles in process integration and digital monitoring (Q17); input-output analysis confirms engineering and installation as labour-intensive; communities poorly informed (24 of 27) but expect benefits rather than risks	Medium: consistent across sources, but samples not representative of the general public	Training in integration and monitoring, and early engagement framed around local benefits

The synthesis shows that the conditions are not equally well understood. Proof and price are supported by consistent evidence, and they are also the conditions the consortium can influence most directly through demonstration and cost reduction. People is supported by consistent but non-representative evidence. Permission is the least documented condition, although public authorities identify it as a practical obstacle. The recommendations in Chapter 3 follow this hierarchy: they are most specific where the evidence is strongest, and they call for further investigation where it is weakest.

11 Discussion

11.1 Environmental and socio-economic significance

The results show that TechUPGRADE addresses a part of industrial decarbonisation that is both large and difficult. Process heat at 150-250 °C is too hot for most conventional heat pumps and is still dominated by fossil fuels, while waste heat at 70-120 °C is abundant but rarely used. By connecting the two with a technology that needs very little electricity, TechUPGRADE offers a decarbonisation route that does not compete for scarce renewable electricity and grid capacity, a growing constraint in many European regions. Per MWh of process heat, TechUPGRADE with waste heat avoids about 278 kg of CO_2 compared with an existing gas boiler at about half the cost of heat; at the proposal target of 5 TWh per year, this corresponds to about 1.4 Mt of CO_2 and about €185 million of heat-cost savings per year. The environmental benefits are both global (climate) and local (replacement of on-site combustion), and the economic benefits accrue to the industrial users that adopt the technology and to the regions where they are located.

11.2 Just Transition and distributional effects

From a Just Transition perspective, the distribution of benefits and costs is favourable. The benefits, in the form of lower heat costs, cleaner air and skilled jobs, are concentrated in industrial regions and among the workers and communities around industrial sites. The costs fall mainly on fossil fuel supply, which in most European countries is located abroad. The domestic workers most affected are those operating and maintaining fossil-fuelled boilers, whose skills in thermal systems and plant operation are a good basis for retraining. The stakeholder data confirm this picture: civil-society respondents expect new jobs from the technology and worry about the transition in general rather than about TechUPGRADE specifically. The main distributional risk is that SMEs and less developed regions, which face higher capital costs and weaker digital capacity, adopt the technology later, so that the benefits accrue first to large companies and advanced regions. Targeted support for SMEs, and the inclusion of regions with high fossil heat use, would help ensure an inclusive transition.

11.3 Comparison with other impact assessments

The results can be compared with those of other Horizon impact assessments of heat technologies. The REWARDHeat impact scenarios found that low-temperature district heating and cooling solutions reduce non-renewable primary energy use by 17-73% and CO_2 emissions substantially, without increasing the annual total levelised cost in any demonstration site, and that most solutions benefit local economies by creating jobs and by reducing spending on fuels from outside the region, even though some conventional technologies such as individual gas boilers require more local labour. TechUPGRADE shows a similar pattern at industrial level: emission reductions are large, total costs fall where low-cost heat sources are available, and employment shifts from fuel supply to equipment, installation and engineering. The employment intensity found here (€570,000 of output per job, equivalent to about four job-years at the IDA rate of €140,000 per job-year) is consistent with the REWARDHeat factors. Compared with the electric-boiler and biomass-boiler value chains of InterFlex and WeDistrict, TechUPGRADE supports slightly fewer jobs per euro spent but requires much less electricity than electric boilers and no fuel supply chain, unlike biomass, which avoids competition for limited renewable electricity and biomass resources.

11.4 Policy implications

Four policy implications emerge. First, carbon pricing and access to low-cost heat sources matter: the benchmarking shows that the advantage of TechUPGRADE over gas is largest with free waste heat and smaller where solar heat requires additional investment. Second, the regulatory status of excess heat needs clarification, since public authorities report that uncertainty and fragmented responsibilities have already hindered excess-heat projects. Third, de-risking instruments for first-of-a-kind installations are needed to bridge the "valley of death" between TRL 5 and commercial scale identified by academic and industrial respondents. Fourth, skills and awareness policies, through curricula, vocational training and community engagement, are as important as financial instruments, because low familiarity is the most consistent barrier across all stakeholder groups. These implications are developed further in the policy guidelines of D7.5.

11.5 Limitations and future research

The environmental and economic results rely on the D4.3 cost and performance estimates for a technology at TRL 5 and cover operational emissions only; they should be updated with the measured results of the pilot demonstrations, the updated assumptions of D7.4 and, for the full life cycle, the LCA of D7.3. The employment analysis describes the structural labour intensity of the Swedish value chain; future work should apply a demand-driven input-output model with actual project CAPEX and OPEX, include import shares, induced effects and displaced fossil activity to estimate net employment, and extend the analysis to other countries such as Denmark and Greece.

The stakeholder evidence has limitations that differ by group (Section 5.8 and Table 5.5). The academic sample (64 respondents from 17 countries) is large enough for robust descriptive results, although Greek and Swedish respondents and students are over-represented. The industrial sample (11 respondents) is small and dominated by energy-service and renewable-integration SMEs, so the views of heat-consuming manufacturers, the most important future customers, are under-represented; each industrial respondent accounts for about nine percentage points. The civil-society sample (27 respondents) consists mainly of professionals working in or with organisations rather than residents of industrial communities. The public-authority evidence rests on two questionnaire responses from Danish economic-development officers and two interviews with Italian policymakers, which provides qualitative signals but no basis for generalisation. All samples were recruited through partner networks and are likely to be more favourable to clean heat than the wider population.

The eight interviews, two per group, corroborated the survey results and helped explain them, but they followed scripts that mirror the questionnaires and are too few to explore new themes systematically. Future work should therefore extend the interview programme to heat-consuming manufacturers, energy and environmental regulators and residents near demonstration sites, and repeat the questionnaires after the demonstration results become available, so that changes in awareness and acceptance can be measured over time.

12 Conclusions

The evidence indicates that TechUPGRADE can deliver substantial environmental and socio-economic benefits: lower heat costs for industry where low-cost heat sources are available, large reductions of operational CO_2 emissions, the replacement of on-site combustion, skilled jobs in installation, engineering and equipment manufacturing, and a strong research and education agenda. These benefits will materialise only if the four conditions identified in this report are met: proof of performance and cost at industrial scale, a price advantage over fossil heat, clear rules for excess heat, and the skills and public support needed for deployment (Section 10.9). The conclusions are strongest for the techno-economic results and the academic, industrial and civil-society surveys, and weakest for the regulatory dimension, where the evidence rests on few respondents.

12.1 Answers to the research questions

What are the environmental and economic impacts of TechUPGRADE? Compared with an existing natural gas boiler (280 kg CO_2/MWh), TechUPGRADE emits about 2.1 kg CO_2/MWh with waste heat and 5.4 kg CO_2/MWh with solar heat. Its LCOH is about 35 €/MWh with free waste heat and 58 €/MWh with solar heat, against 72 €/MWh for natural gas, and the waste-heat configuration pays back in about 4.3 years. At the proposal target of 5 TWh per year, it would avoid about 1.4 Mt of CO_2 per year.

How can IO methods estimate job creation, and how many people are employed in each relevant sector? An output-based allocation using Swedish SIOT 2022 and SCB employment data maps the technology onto ten sectors employing 755,015 people, with construction (215,406 allocated jobs) and machinery (100,384) the largest. Output per job ranges from €211,000 in engineering services to €1.31 million in electronics, with a weighted average of €570,000.

How do estimation approaches and project types influence employment estimates? Output-based estimates reflect structural labour intensity, while investment-based estimates count incremental job-years; at about €140,000 per job-year, the two are consistent for jobs lasting about four years. Across projects, the number of jobs is driven mainly by the scale of spending (32, 44 and 162 jobs for TechUPGRADE, biomass and electric boilers), while jobs per million euro differ little (1.76-1.93).

How do stakeholders perceive the technology? Academic, industrial and civil-society respondents view TechUPGRADE positively: academics rate its impact potential at 4.27 out of 5, with 58 of 64 giving a rating of 4 or 5; 8 of 11 industrial respondents expect a moderately positive effect on their organisation; and civil-society respondents associate it far more often with new job opportunities (14 of 27) than with job losses (2 of 27). The two public-authority respondents were not familiar with the technology and did not assess it directly, but both consider socio-economic impacts important in decision-making. The main barriers named are cost (27 of 54 coded academic barrier answers; energy cost is the adoption driver for all industrial respondents), the gap between laboratory and market (20 of 54 academic answers; demonstration required by 6 of 11 industrial respondents), low awareness (24 of 27 civil-society respondents consider communities poorly informed; 5 of 11 industrial respondents are not familiar with the technology) and regulatory uncertainty (reported by public authorities, on a limited evidence base). Stakeholder expectations are broadly consistent with the quantitative results; for example, industrial respondents expect sector-level CO_2 reductions of 5–15% (5 of 11), which is compatible with the large savings per MWh calculated in Chapter 6 once partial market penetration is taken into account.

What are the implications for policy? Carbon pricing, de-risking finance for first-of-a-kind installations, and investment in skills and public awareness are the main levers supported by the evidence. Clarity on the regulatory status of excess heat is likely to be important as well, but this conclusion rests on few respondents and should be confirmed in D7.5.

12.2 Socio-economic KPIs for monitoring

Table 12.1 proposes a set of KPIs, with the baseline values established in this report, to monitor the socio-economic impact of TechUPGRADE beyond the project within the framework of Task 8.3.

Table 12.1. Socio-economic KPIs and baselines for monitoring.

KPI	Unit	Baseline (this report)	Source for monitoring
Upgraded heat delivered by installed units	TWh/yr	0 (pilots only)	Exploitation plan, market data
CO_2 savings per MWh of heat vs existing gas boiler	kg/MWh	278 (waste heat); 275 (solar)	Demonstrator measurements
Levelised cost of heat	€/MWh	35 (waste heat); 58 (solar)	Demonstrator cost data; D7.4
Jobs supported per M€ of annual system cost	jobs per M€	1.76	IO update with project data
Weighted output per job in the value chain	k€ per job	570	SIOT and SCB updates
Stakeholder rating of impact potential	1-5	4.27 (academia)	Repeat survey
Industrial unfamiliarity with thermochemical upgrade	% not familiar	45.5%	Repeat industry survey
Community information level	% not or only slightly informed	88.9%	Repeat civil-society survey
Training and curriculum uptake	courses, theses	Monitored from project end	WP8 dissemination records
Demonstration and replication projects initiated	number	Monitored from project end	Exploitation plan (Task 8.3)

12.3 Outlook

The findings of this report feed directly into the financial analysis and go-to-market strategy (D7.4), the policy guidelines and replicability report (D7.5) and the impact-monitoring framework of Task 8.3. As the pilot demonstrations are completed, the use-case and benchmarking results should be updated with measured performance and cost data, the employment analysis extended to a demand-driven model of net effects, and the stakeholder surveys repeated, so that changes in awareness and acceptance can be tracked as TechUPGRADE moves from the laboratory towards the market.

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14 Appendices

14.1 Overview of the techno-economic assumptions of the benchmarked technologies

Table 14.1. Techno-economic assumptions of the benchmarked technologies (D4.3; COWI assumptions, December 2025; DEA technology data). Prices at 2020 level, excluding VAT.

Technology	Process temperature (°C)	CAPEX (M€/MW)	Fixed OPEX (k€/MW/yr)	Variable OPEX (€/MWh)	Efficiency / COP	Fuel
Steam boiler, natural gas, existing	184	0	1.95	1.1	73%	Natural gas
Biomass boiler 6-10 bar	150	0.48 (pellets) - 0.61 (chips)	34.8-36.5	2.1-2.8	88-90%	Wood pellets / chips
Biomass boiler 40 bar	250	0.61 (pellets) - 0.77 (chips)	34.8-36.5	2.1-2.8	89-90%	Wood pellets / chips
High-temperature heat pump	150	1.19	0.92	3.3	COP 3.05	Electricity
High-temperature heat pump + MVR	250	2.03	0.97	4.95	COP 1.48	Electricity
Electrode steam boiler 12 bar	150	0.09	1.08	0.9	94.5%	Electricity
Electrode steam boiler 40 bar	250	0.29	1.08	0.9	94.5%	Electricity
TechUPGRADE	150-250	0.9	45.63	7.4	COPh 0.55-0.6; COP 14.5	Waste, solar or district heat; electricity

14.2 Allocated jobs for comparator projects

Table 14.2. InterFlex (electric boiler): allocated jobs for relevant sectors.

Sector (CPA)	Output 2022 (SEK M)	Employees 2022	Output share	Allocated jobs	€ k per job
Chemicals (C20)	277,763	33,405	7.55%	74,591	777.5
Fabricated metal products (C25)	245,226	67,673	6.67%	65,853	338.8
Computer, electronic and optical (C26)	278,524	19,819	7.57%	74,795	1,314.0
Electrical equipment (C27)	197,019	23,254	5.36%	52,908	792.2
Machinery and equipment (C28)	421,273	74,382	11.46%	113,129	529.6
Repair and installation (C33)	90,154	19,716	2.45%	24,210	427.5
Electricity, gas, steam (D35)	226,912	29,691	6.17%	60,935	714.6
Construction (F)	903,980	348,872	24.58%	242,755	242.3
Computer programming and information services (J62-J63)	508,883	232,516	13.84%	136,656	204.6
Architecture and engineering (M71)	259,627	114,811	7.06%	69,720	211.4
Scientific R&D (M72)	268,038	23,392	7.29%	71,979	1,071.4
Total / weighted average	**3,677,399**	**987,531**	**100%**	**987,531**	**519.4**

Table 14.3. WeDistrict (biomass boiler): allocated jobs for relevant sectors.

Sector (CPA)	Output 2022 (SEK M)	Employees 2022	Output share	Allocated jobs	€ k per job
Wood and wood products (C16)	171,165	31,724	5.13%	40,322	504.5
Chemicals (C20)	277,763	33,405	8.32%	65,433	777.5
Fabricated metal products (C25)	245,226	67,673	7.34%	57,769	338.8
Computer, electronic and optical (C26)	278,524	19,819	8.34%	65,613	1,314.0
Electrical equipment (C27)	197,019	23,254	5.90%	46,412	792.2
Machinery and equipment (C28)	421,273	74,382	12.61%	99,241	529.6
Repair and installation (C33)	90,154	19,716	2.70%	21,238	427.5
Electricity, gas, steam (D35)	226,912	29,691	6.79%	53,454	714.6
Construction (F)	903,980	348,872	27.07%	212,953	242.3
Architecture and engineering (M71)	259,627	114,811	7.77%	61,161	211.4
Scientific R&D (M72)	268,038	23,392	8.03%	63,143	1,071.4
Total / weighted average	**3,339,681**	**786,739**	**100%**	**786,739**	**566.6**