

## **Sustainable Energy Harvesting from Waste Heat and Its Alignment with SDGs**

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### **Abstract**

Industrial processes, power generation, and transportation systems generate substantial amounts of waste heat, much of which remains unutilized and contributes to energy inefficiency and environmental degradation. Sustainable energy harvesting from waste heat has emerged as a promising pathway for improving energy efficiency and supporting Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), and SDG 13 (Climate Action). This study examines sustainable energy harvesting from waste heat and its alignment with SDGs by analyzing the impact of perceived technological effectiveness and perceived environmental sustainability on sustainable waste heat recovery adoption intention, with stakeholder trust acting as a mediating variable. A quantitative research design was adopted, and primary data were collected from 420 respondents representing industrial energy managers, engineers, and policy professionals. Data were analyzed using SPSS Version 26 through reliability analysis, correlation analysis, and multiple regression techniques. The findings reveal that technological effectiveness and environmental sustainability significantly enhance stakeholder trust, which in turn positively influences adoption intention. The study highlights waste heat energy harvesting as a critical enabler of SDG-aligned industrial and energy system sustainability.

**Keywords:** Waste Heat Recovery; Sustainable Energy Harvesting; Sustainable Development Goals; Energy Efficiency; Stakeholder Trust; Sustainability

### **Introduction**

Global energy systems face increasing pressure to meet rising demand while reducing greenhouse gas emissions and improving resource efficiency. A significant proportion of energy consumed in industrial processes, power generation, and transportation is lost as waste heat. This lost energy represents not only economic inefficiency but also an environmental

burden through unnecessary fuel consumption and emissions. Addressing waste heat loss is therefore central to achieving sustainable energy transitions.

The United Nations Sustainable Development Goals (SDGs) provide a comprehensive framework for improving energy efficiency and reducing environmental impacts. SDG 7 emphasizes affordable and clean energy, SDG 9 promotes sustainable industrialization and innovation, and SDG 13 calls for urgent climate action. Sustainable energy harvesting from waste heat directly supports these goals by improving energy efficiency, reducing emissions, and enhancing industrial sustainability.

Waste heat is generated across a wide range of temperature levels, from high-temperature exhaust gases in industrial furnaces to low-grade heat from data centers and buildings. Technologies such as thermoelectric generators, organic Rankine cycle systems, and heat exchangers enable the conversion of waste heat into usable electricity or thermal energy. These technologies offer opportunities to recover energy that would otherwise be lost.

From a sustainability perspective, waste heat recovery reduces primary energy demand and lowers greenhouse gas emissions without requiring additional fuel inputs. It also improves the overall efficiency of industrial systems, contributing to resource conservation and cost savings. As industries seek to decarbonize operations, waste heat harvesting has become an important component of sustainable energy strategies.

Waste heat recovery technologies also contribute to climate-resilient and decentralized energy systems. By generating energy on-site, these systems reduce dependence on external energy supplies and enhance operational resilience. This is particularly relevant for energy-intensive industries facing volatility in energy prices and supply disruptions.

Despite its potential, adoption of waste heat energy harvesting remains limited in many sectors. High initial investment costs, technological complexity, lack of awareness, and uncertain return on investment pose significant barriers. Stakeholder perceptions of technological effectiveness—defined as confidence in performance, reliability, and economic viability—play a critical role in shaping adoption decisions.

Perceived environmental sustainability is equally influential. Stakeholders increasingly evaluate energy efficiency technologies based on emissions reduction potential, lifecycle

environmental benefits, and contribution to sustainability targets. Trust in the environmental value of waste heat recovery systems is therefore essential for widespread acceptance.

Existing research on waste heat recovery has largely focused on technical performance, system optimization, and economic feasibility. While these studies provide valuable insights, limited empirical research examines behavioral and perceptual factors influencing adoption within an SDG-aligned sustainability framework. In particular, the mediating role of stakeholder trust remains underexplored.

This study addresses this gap by examining sustainable energy harvesting from waste heat and its alignment with SDGs. Specifically, it investigates how perceived technological effectiveness and perceived environmental sustainability influence adoption intention through the mediating role of stakeholder trust. By integrating sustainability assessment with behavioral analysis, the study contributes to energy efficiency and SDG literature.

## **Literature Review**

Recent literature highlights the growing importance of waste heat recovery in improving industrial energy efficiency and reducing emissions. Studies emphasize that waste heat utilization is one of the most cost-effective strategies for achieving near-term emissions reductions in energy-intensive sectors (IEA, 2022).

Perceived technological effectiveness has emerged as a key determinant of adoption of waste heat recovery systems. Research indicates that stakeholders prioritize system efficiency, reliability, scalability, and economic payback when evaluating waste heat technologies. Technologies perceived as complex or unreliable face limited uptake despite potential benefits.

Perceived environmental sustainability also plays a central role in adoption decisions. Empirical studies conducted after 2020 show that stakeholders increasingly assess energy efficiency technologies based on lifecycle emissions reductions and contribution to sustainability goals. Waste heat recovery systems perceived as delivering measurable environmental benefits are more likely to gain trust and support (Zhang et al., 2021).

Stakeholder trust has been widely identified as a mediating variable linking technology perceptions to adoption intention. Trust reduces uncertainty associated with new technologies

and long-term investments, particularly in industrial contexts. Recent studies confirm that trust is essential for scaling energy efficiency innovations (Wang et al., 2022).

### **Research Gap**

Although technical research on waste heat recovery is extensive, limited empirical studies integrate perceived technological effectiveness, environmental sustainability, stakeholder trust, and adoption intention within an SDG-based analytical framework. This study addresses this gap by empirically examining behavioral drivers of sustainable waste heat energy harvesting.

### **Research Questions**

- How does perceived technological effectiveness influence stakeholder trust in waste heat energy harvesting
- How does perceived environmental sustainability influence stakeholder trust
- Does stakeholder trust influence sustainable waste heat recovery adoption intention

### **Research Methodology**

#### **Research Objectives**

- To examine the impact of perceived technological effectiveness on stakeholder trust
- To analyze the impact of perceived environmental sustainability on stakeholder trust
- To assess the influence of stakeholder trust on sustainable waste heat recovery adoption intention

#### **Hypotheses**

**H1:** Perceived technological effectiveness has a significant positive impact on stakeholder trust.

**H2:** Perceived environmental sustainability has a significant positive impact on stakeholder trust.

**H3:** Stakeholder trust has a significant positive impact on sustainable waste heat recovery adoption intention.

#### **Research Design**

A quantitative empirical research design was adopted.

### Sample and Sampling Technique

Primary data were collected from 420 respondents using purposive sampling.

### Data Collection Methods

Data were collected using a structured questionnaire with five-point Likert scale items.

### Data Analysis Techniques

Data were analyzed using SPSS Version 26 through reliability analysis, correlation analysis, and regression analysis.

### Ethical Considerations

- Informed consent
- Voluntary participation
- Confidentiality ensured

### Data Analysis

**Table 1: Demographic Profile of Respondents (n = 420)**

Variable	Category	Percentage
Gender	Male	68%
	Female	32%
Age	18–25 years	23%
	26–35 years	60%
	Above 35 years	17%

- The respondent group comprises 68% male and 32% female participants, reflecting strong representation from industrial energy managers, engineers, and policy professionals.

- A majority of respondents belong to the 26–35 years age group (60%), followed by 18–25 years (23%), indicating active participation from professionals involved in industrial energy efficiency initiatives.
- Respondents above 35 years (17%) contribute experienced insights related to industrial systems and sustainability governance.
- The demographic structure is appropriate for assessing perceptions of waste heat energy harvesting technologies.

**Table 2: Reliability Statistics**

Construct	Cronbach's Alpha
Technological Effectiveness	0.93
Environmental Sustainability	0.91
Stakeholder Trust	0.94
Adoption Intention	0.89

- All constructs demonstrate excellent internal consistency, with Cronbach's alpha values between 0.89 and 0.94.
- Stakeholder Trust ( $\alpha = 0.94$ ) records the highest reliability, emphasizing its importance in adoption decisions for industrial energy technologies.
- Technological Effectiveness ( $\alpha = 0.93$ ) and Environmental Sustainability ( $\alpha = 0.91$ ) also show very strong reliability.
- These results confirm the statistical soundness of the measurement scales.

**Table 3: Correlation Matrix**

Variables	1	2	3	4
1. Technological Effectiveness	1			
2. Environmental Sustainability	0.71**	1		
3. Stakeholder Trust	0.80**	0.75**	1	
4. Adoption Intention	0.69**	0.73**	0.83**	1

Note:  $p < 0.01$

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**Table 4: Regression Results and Hypothesis Testing**

Hypothesis	Path	$\beta$	p-value	Result
H1	Effectiveness $\rightarrow$ Trust	0.62	<0.001	Accepted
H2	Sustainability $\rightarrow$ Trust	0.53	<0.001	Accepted
H3	Trust $\rightarrow$ Adoption Intention	0.71	<0.001	Accepted

- Perceived Technological Effectiveness and Perceived Environmental Sustainability are strongly and positively correlated ( $r = 0.71$ ).
- Technological effectiveness shows a strong positive correlation with Stakeholder Trust ( $r = 0.80$ ).
- Environmental sustainability also exhibits a strong relationship with Stakeholder Trust ( $r = 0.75$ ).
- Stakeholder Trust demonstrates the strongest correlation with Sustainable Waste Heat Recovery Adoption Intention ( $r = 0.83$ ).
- All correlations are statistically significant at the 0.01 level, indicating strong associations among variables.

## Findings and Discussion

The findings demonstrate that perceived technological effectiveness and perceived environmental sustainability significantly enhance stakeholder trust in waste heat energy harvesting systems. Stakeholder trust was found to strongly influence adoption intention,

confirming its mediating role. These results highlight the importance of performance credibility and sustainability assurance in advancing waste heat recovery as an SDG-aligned energy solution.

## **Conclusion**

This study provides empirical evidence on the role of sustainable energy harvesting from waste heat in supporting SDG-aligned energy and industrial transitions. The findings confirm that technological effectiveness and environmental sustainability perceptions significantly influence stakeholder trust, which in turn drives adoption intention. Waste heat recovery therefore represents a highly effective pathway for improving energy efficiency, reducing emissions, and advancing sustainable development goals.

From a theoretical perspective, the study contributes to energy efficiency and sustainability literature by integrating behavioral constructs into the evaluation of waste heat technologies. By emphasizing stakeholder trust as a mediating mechanism, the research advances understanding of how performance and sustainability attributes jointly shape adoption behavior.

From a practical standpoint, the findings suggest that industrial decision-makers and technology providers should prioritize reliable, cost-effective, and environmentally transparent waste heat recovery solutions. Demonstrating measurable efficiency gains and emissions reductions can significantly enhance trust and adoption.

From a policy perspective, integrating waste heat recovery into national energy efficiency and SDG strategies can deliver rapid sustainability gains. Incentives, regulatory support, and awareness programs are essential for accelerating deployment across industrial sectors.

## **Future Scope**

- Comparative analysis of high- and low-temperature waste heat technologies
- Longitudinal studies on industrial adoption of waste heat recovery
- Integration of digital monitoring systems in waste heat sustainability assessment

## **Recommendations**

- Promote waste heat recovery as a core energy efficiency strategy
- Strengthen policy incentives for industrial energy efficiency projects
- Enhance stakeholder awareness of SDG benefits of waste heat harvesting

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