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Evaluating GHG Emissions and Renewable Energy Use in the Italian Energy Sector: Monitoring, Reporting, and Objectives

Stefano Castelluccio *, Silvia Fiore and Claudio Comoglio

DIATI, Department of Engineering for Environment, Land, and Infrastructures, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy; silvia.fiore@polito.it (S.F.); claudio.comoglio@polito.it (C.C.)
* Correspondence: stefano.castelluccio@polito.it

Abstract: This study investigates the greenhouse gas (GHG) and renewable energy use reporting practices among thermal power plants (TPPs), waste incinerators (WIs), and hydropower plants (HPPs) in Italy, as reflected in their EMAS environmental statements. The analysis focuses on GHG emissions (Scope 1, 2, and 3) and renewable energy utilization reporting, and on the objectives set by the companies for reducing emissions and fossil fuels use. TPPs and WIs reported positive Scope 1 emissions extensively but reporting on Scope 2 and Scope 3 resulted inconsistent for all facilities. Negative emissions reporting was generally lacking, except for HPPs. Renewable energy use reporting was also limited, especially in TPPs and WIs, despite some facilities producing energy from renewable sources. The study also evaluated the objectives set by the companies on GHG reduction and renewable energy use increase, finding that GHG reduction was prioritized over renewable energy use. However, both were often a secondary goal integrated into planned operational improvements. The findings highlight that, to ensure transparency of sustainability data and the possibility of performances benchmarking in the energy production sector, there is the need for defining stronger reporting guidelines on GHG emissions, especially regarding Scope 3 emissions, and to prioritize increasing the share of renewable energy among strategic objectives. Future research should investigate factors affecting reporting behavior and the barriers to renewable energy adoption in fossil fuel-reliant sectors.

Keywords: GHG emissions; renewable energy; EMAS; thermal power plants; waste incinerators; hydropower plants; negative emissions; improvement objectives

Academic Editor: Syu-Ruei Jhang

Received: 6 December 2024
Revised: 25 January 2025
Accepted: 4 February 2025
Published: 6 February 2025

Citation: Castelluccio, S.; Fiore, S.; Comoglio, C. Evaluating GHG Emissions and Renewable Energy Use in the Italian Energy Sector: Monitoring, Reporting, and Objectives. *Environments* **2025**, *12*, 55. https://doi.org/10.3390/environments12020055

1. Introduction

The energy sector plays a pivotal role in shaping the global economic and environmental landscapes. Fossil fuels still provided 79% of the global energy supply in 2022 [1] and account for 28% of the greenhouse gas (GHG) emissions worldwide [2]. While renewable energy sources have gained traction in recent years, fossil fuels such as coal, oil, and natural gas still account for a significant portion of energy generation globally, presenting an arduous challenge in transitioning to sustainable energy systems. Italy, as a leading industrialized nation, reflects this global trend. Despite making strides in integrating renewable energy sources into its energy portfolio, the country remains heavily reliant on natural gas, which accounted for 50.5% of its energy mix in 2022 [3], and the energy sector continues to be one of the largest contributors to Italy's GHG emissions. This underscores the urgent need for effective monitoring and reporting, as well as concrete strategies to reduce GHG output.

In alignment with European Union (EU) directives [4] and national commitments under international climate agreements, such as the Paris Agreement [5], Italy set ambitious targets for reducing CO_2 emissions and increasing the share of renewable energy in its energy mix. Italy's National Energy and Climate Plan [6] establishes a framework for achieving these objectives, aiming to reduce GHG emissions by 55% by 2030 compared to 1990 levels while ensuring that 30% of its total energy consumption comes from renewable sources. Achieving these targets requires comprehensive reporting mechanisms to track emissions and energy usage accurately, as well as strategic investments in emissions reduction technologies and renewable energy deployment.

Environmental management systems (EMSs) such as the EU Eco-Management and Audit Scheme (EMAS) [7] can play a crucial role in this context. EMAS is a voluntary framework that enables organizations to improve their environmental performance through rigorous monitoring, reporting, and validation processes. One of its core requirements is the publication of an annual environmental statement (ES), which must meet the minimum requirements established by Annex IV of the EMAS Regulation, including descriptions of organizational activities, significant environmental aspects, objectives, and validated performance data, ensuring transparency and compliance [8]. This statement must be validated by an independent environmental verifier, ensuring that the data, including GHG emissions and renewable energy usage, meet rigorous standards of accuracy and reliability.

The global standards for GHG monitoring and reporting at company level are defined by established frameworks such as International Organization for Standardization (ISO) 14064 [9] and the GHG Protocol [10]. ISO 14064 provides standards for quantifying and reporting GHG emissions, while the GHG Protocol sets guidelines for tracking direct and indirect emissions (Scopes 1, 2, and 3), ensuring consistency and transparency across industries. These frameworks are critical to maintaining uniformity in GHG reporting and emission reduction practices, particularly in sectors like energy production, where emissions are substantial.

Extensive research has assessed the environmental performance of energy-producing facilities [11–15]. Conversely, the body of research focusing on enhancing the accuracy and transparency of GHG emissions reporting is scarcer, although growing. Tanzharikov et al. [16] comprehensively analyzed GHG emission sources in oil and gas production operations, underlining the critical need for accurate measurement and reporting frameworks. Similarly, Turner et al. [17] categorized emission sources in offshore oil and gas facilities and proposed systematic approaches for validating GHG emissions. Bunchuaidee et al. [18] detailed the establishment of a multi-ministry framework for GHG emission reduction monitoring in Thailand, while Comyns [19] found that regulation under the EU emissions trading scheme and adherence to guidelines lead to better quality and more extensive reporting. Their work illustrated how institutional frameworks can facilitate comprehensive GHG mitigation tracking, especially in developing nations. Similarly, Yaman [20] advocated for implementing standardized frameworks such as ISO 14064 and the GHG Protocol and discussed developing action plans for organizations to measure, monitor, and report GHG emissions annually. Several challenges persist in GHG monitoring and reporting, including the complexity of accurately measuring emissions due to technological limitations and data collection difficulties. Petrescu et al. [21] highlighted uncertainties in CO_2 emissions reporting and the importance of reliable quantification processes for effective climate action, while Perugini et al. [22] called for improved methodologies and collaboration among researchers and inventory agencies to enhance inventory quality. Janik et al. [23] found that sustainability reports from energy sector companies focus on GHG issues, but the comprehensiveness and quality of reporting vary. They found a discrepancy between high-level strategic declarations and the description of specific actions or operational indicators. Talbot and Boiral [24] found significant non-compliance with reporting standards in the sustainability reports from the energy sector firms. Hapsari and Hardiyanti [25] identified company size, profitability, and stakeholder pressure among the factors determining carbon emissions voluntary disclosure in Indonesia's energy sector companies.

Studies on carbon accounting in sectors other than energy production underscored that reports often lacked transparency about assumptions, input data, emission factors, and calculation methods, leading to incomplete and non-transparent GHG inventories [26,27] and that reports were often not compliant with reference standards [24]. A study on multinational companies described the quality of reporting on GHG emissions as problematic, and highlighted that the standardization of practices is linked with improved report quality [28]. While some researchers observed improvements in the GHG disclosure practices, for instance in conjunction with reporting guidelines publication [29,30], others found no significant improvements over time [31].

Some researchers have assessed that achieving decarbonization levels consistent with the EU's current emission reduction goals in energy-intensive industries is technically possible but only with a considerable adoption of zero-carbon electricity, heat sources, biomass, and carbon capture technologies [32,33]. Similarly, Wu et al. [34] highlighted that an effective GHG emission reduction requires that each sector contributes appropriately to the overall reduction goal. Significant investments are required, particularly in the power generation sector, to meet the long-term emission reduction goals. However, only a limited number of studies have focused on assessing the actual efforts of energy-producing organizations to reduce GHGs. Some studies analyzed the improvement objectives set by the organizations managing some energy-producing facilities [35–37], but they did not focus specifically on GHG reduction and did not analyze reporting practices.

Significant knowledge gaps remain in understanding how energy companies set and pursue GHG reduction objectives:

- Limited understanding of how energy companies report GHG emissions;
- Insufficient information on how companies report renewable energy use alongside their emissions mitigation efforts;
- Scarcity of studies focusing on the actual implementation of improvement objectives in GHG reduction and renewable energy share increase in energy-producing facilities.

This study addresses these knowledge gaps by examining the environmental statements of Italian energy companies registered under EMAS, which represent a sub-sample of plants highly committed in implementing certified environmental management systems aimed at the continuous improvement of their environmental performances and full transparency in data disclosure. Specifically, it focuses on three key objectives: (i) to analyze GHG monitoring practices, including direct and indirect emissions (Scopes 1, 2, and 3); (ii) to evaluate how energy companies report GHG emissions and renewable energy usage; and (iii) to assess the strategic objectives set by these companies for GHG reduction and the integration of renewable energy within their operations. This study provides a comprehensive overview of GHG emissions and renewable energy reporting practices in the Italian energy sector, contributing valuable insights to the ongoing discourse on sustainable energy management.

This study focused on thermal power plants (TPPs), hydroelectric power plants (HPPs), and waste incinerators (WIs) due to their prominent roles in Italy's energy production and their differing impacts on GHG emissions. Analyzing TPPs is essential for understanding emission sources and evaluating potential reduction strategies, as they dominate Italy's energy sector [3] and given their significant contribution to GHG emissions. HPPs, responsible for 9.28% of total production in Italy [3], are a major renewable energy source, making them ideal for assessing emissions avoidance through renewable energy utilization. WIs, while accounting for only 2.3% of the total Italian energy production [3], serve the dual function of producing energy from waste while mitigating landfill emissions. Their unique contribution to both positive and negative emissions justifies their inclusion. By focusing on these plant types, this study ensures a comprehensive evaluation of emissions across both conventional and renewable sectors.

2. Materials and Methods

This study followed a structured methodology to assess the reporting of GHG emissions and renewable energy usage in the ESs of EMAS-certified energy companies in Italy. The methodology consisted of three main phases: data collection, acquisition of environmental statements, and data analysis focusing on GHG monitoring, reporting practices, and reduction objectives.

2.1. Data Collection

The first step involved compiling a list of energy production companies in Italy certified under EMAS. The data collection focused on companies under the NACE (Statistical Classification of Economic Activities in the European Community) code 35.11 (electricity production) and used as a primary source the Italian National Institute for Environmental Protection and Research (ISPRA) list of EMAS-certified companies operating in the energy sector [38]. Furthermore, the European Commission's EMAS register [39] was cross-referenced to ensure all relevant energy production companies were captured.

Once the list was finalized, the ESs of companies operating TPPs, HPPs, and WIs were collected from the companies' websites or through direct requests to the operators. Only the ESs published after 2020 were included in the analysis to ensure that the data reflected current reporting practices and aligned with recent regulatory frameworks. ESs reporting aggregated data of multiple facilities under a single registration were also excluded, if they did not allow activity-specific analysis.

2.2. Data Analysis

The data analysis involved a thorough review of each ES to ensure correct interpretation of environmental data. This approach avoided relying on keyword searches, which may lead to incomplete or inaccurate conclusions.

Individual datasets were organized in a structured format to ensure consistency and comparability. Specifically, separate workbooks were created for each organization. These workbooks contained raw data extracted from the ESs, including GHG emissions figures, renewable energy usage, and stated environmental objectives. Data fields were standardized to facilitate aggregation and cross-comparison. The data from individual organization workbooks were then consolidated into summary workbooks, categorized by plant type (TTPs, HPPs, and WIs). The aggregated datasets provided a comprehensive view of reporting practices and performance across the sampled facilities.

2.2.1. GHG Reporting

The collected ESs were examined to identify the techniques and methodologies used by each organization to monitor, quantify, and report GHG emissions. The types of emissions reported were evaluated for both positive and negative (avoided) emissions within the 3 different scopes: direct emissions (Scope 1), energy-related emissions (Scope 2), and value chain emissions (Scope 3).

2.2.2. Renewable Energy Use Reporting

The next step was evaluating how organizations reported their use of energy from renewable sources. The analysis investigated purchased and self-produced renewable energy, the energy source, the proportion of total consumed energy derived from renewable sources, and the comprehensiveness of the reports.

2.2.3. GHG Reduction and Renewable Energy Use Improvement Objectives

The final stage of the analysis involved reviewing the objectives set by the organizations in their EMAS environmental program related to GHG reduction and increased renewable energy usage. Objectives were classified based on whether they aimed at these issues as the primary goal or treated them as a secondary goal (e.g., actions aimed at increasing energy efficiency that lead to GHG emission reduction as a secondary effect, or actions for electric mobility increase that raise renewable energy use as a secondary effect). Financial resources allocated to these objectives were also analyzed to determine the level of commitment of the companies.

3. Results and Discussion

3.1. Sample Description

The sample consisted of 293 energy production facilities, with a composition reflecting Italy's energy landscape. The 72 TPPs selected for the study produced 99.1 TWh of electricity in 2020, representing 47.3% of the total energy generated using fossil fuels in Italy. The HPPs chosen included 206 installations across 17 EMAS-registered organizations. They generated a total of 14.1 TWh in 2019, which accounted for 29.3% of all electricity produced by hydropower plants in Italy, offering insight into one of the country's most significant renewable energy contributors. Additionally, 15 WIs were selected from the 37 operational in 2022, representing a substantial portion of Italy's waste-to-energy infrastructure. These plants offer a representative sample of Italy's energy production capacity, allowing for a comprehensive analysis of GHG emissions and renewable energy utilization in the energy production sector.

3.2. GHG Reporting

3.2.1. Thermal Power Plants—GHG

Positive Emissions—TPPs

Most GHG emissions reported under Scope 1 were due to fossil fuel combustion, with 71 out of 72 plants quantifying their emissions and 1 organization only mentioning them (Figure 1). This result aligns with previous findings on the oil and gas and energy industry, where at least 80% of the sample reported quantitative GHG emissions [23,31,40]. Twenty-nine organizations relied on calculations, while forty-three did not specify their quantification method. This lack of transparency, which was consistent across the analyzed organizations, confirms previous findings of the limited disclosure of the methods used to calculate or measure GHG emissions [24,31]. Minor inconsistencies emerged: only seven facilities considered N_2O emissions from combustion, while one facility ambiguously reported its emissions without clarifying which GHGs were included. N_2O, produced during fossil fuel combustion and certain industrial processes, is a potent greenhouse gas with a global warming potential approximately 273 times greater than CO_2 over a 100-year timescale, making even small emissions significant for climate change. Additionally, a plant reported zero emissions due to the exclusive use of biomass.

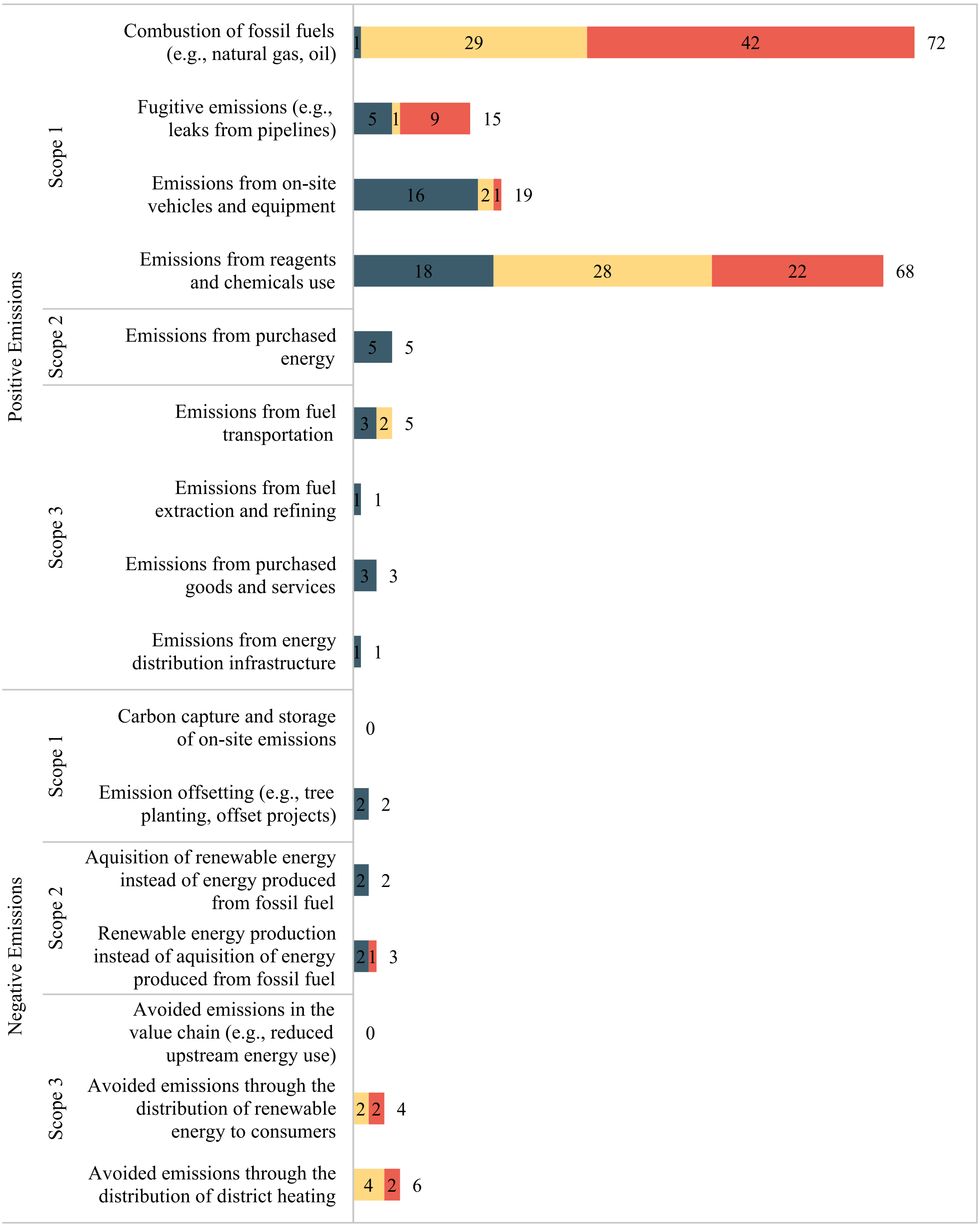

Figure 1. Scope 1, 2, and 3 greenhouse gas (GHG) emissions sources, including both positive and negative (avoided) emissions, reported by thermal power plants. Bar colors indicate the reporting approach: "mentioned" (blue-gray) and "quantified" as measured (teal), calculated (yellow), or unspecified (red). The total counts for each source are shown to the right of each bar.

Fugitive emissions, such as leaks from pipelines, were reported inconsistently: only 15 out of 59 plants using primarily methane quantified (10) or mentioned (5) them, even though several studies have underscored their significance [41,42]. Ten plants considered methane leaks, two plants mentioned fuel storage as a GHG emission source but considered it negligible, and three plants mentioned unspecified fugitive emissions as a GHG source. Moreover, quantification methods were mostly unclear, with only one plant disclosing the method used for calculating methane emissions and only those occurring during startup due to venting. The reporting was generally incomplete, with only five organizations considering the full range of fugitive emissions. The incomplete disclosure in terms of GHG emission sources, which we have identified across the different plant types, has also been observed in previous studies on the energy sector [24].

Scope 1 GHG emissions from on-site vehicles and equipment was considered by 19 organizations, though detailed quantification was rare: only 3 reports quantified emissions, and only 2 disclosed the quantification method based on total kilometers traveled and engine types (for vehicles). Overall, 6 organizations considered emissions from vehicles and 13 from plant equipment. Plant equipment operations were generally broadly acknowledged as GHG sources but specifics, such as a description of the equipment contributing to GHG emissions, were inconsistent. Overall, the reporting for this source category was partial in 17 cases.

Finally, Scope 1 emissions from the use of reagents and chemicals were acknowledged in 68 reports. Refrigerant and insulating gases were cited 62 and 59 times, respectively, being quantified in 50 reports and mentioned in 18. Emissions from chemical reagents were less consistently monitored. Only one facility reported emissions from using calcareous materials but lumped them together with combustion emissions, highlighting a lack of clarity, and one report recognized urea as a GHG emission source. Due to the scarce consideration of reagent usage emissions, only three reports comprehensively represented the emissions from using reagents and chemicals.

Scope 2 emissions were reported with notable inconsistencies. Although 33 stated they bought electricity from the grid, only five organizations mentioned related off-site emissions as a GHG emission source and none provided a quantification (Figure 1).

A small number of organizations reported on Scope 3 emissions. The scarce consideration of Scope 3 emissions, which also apply to HPPs and WIs, confirms the findings of previous studies on the energy sector [24]. Five plants mentioned fuel transportation as a source of emissions, with two providing detailed quantification based on average truck emissions and travel distances. Emissions from fuel extraction and refining were almost entirely overlooked, with only one organization identifying them as a GHG emission source. Similarly, few organizations addressed emissions from purchased goods and services. One organization mentioned the disposal of waste and two the materials used as a GHG source, but no quantification or calculation method was provided (Figure **1**). The reporting of downstream emissions from the energy distribution infrastructure was also almost entirely absent, with only one report mentioning it as a GHG source.

Negative Emissions—TPPs

No organizations reported Scope 1 direct emissions reductions using carbon capture and storage technologies. However, two organizations mentioned tree planting as a GHG reduction strategy, but neither quantified the positive impact of these activities. The minimal implementation of carbon sequestration strategies reflects a missed opportunity for larger-scale emissions reductions in the sector.

Only two organizations reported renewable energy acquisition (Scope 2) out of the thirty-three stating they purchased electricity from the grid, and neither quantified the GHG emissions avoided through this substitution. Renewable energy usage will be discussed in further detail in the subsequent sections. Of the 10 organizations reporting they produced renewable energy in their ES, only 3 mentioned producing energy (solar photovoltaic) for internal use to reduce GHG emissions. Moreover, only one organization quantified the avoided emissions but without mentioning the calculation method used (Figure 1).

The reporting about Scope 3 negative emissions primarily concerned energy distribution to consumers through district heating, which six organizations mentioned as a negative emission source. All six reports quantified the avoided emissions, but only four specified the calculation method which compared plant emissions with those of domestic gas boilers. It must be noted that district heating was implemented by 26 out of the 72 TPPs. Of 10 organizations producing renewable energy, 4 quantified the related avoided emissions from distributing it to consumers (2 from biomass and 2 from solar photovoltaic). Only two provided the calculation method, which utilized the carbon intensity of the Italian energy mix. Avoided emissions through efficiency in the value chain (e.g., reduced upstream energy use) were never considered in the reports.

GHG Reporting Practices and Gaps—TPPs

The above results show considerable variability in the comprehensiveness, accuracy, and transparency of GHG emissions reporting across TPPs, especially for Scope 2 and 3. It must be noted that Scope 2 and 3 emissions have been significantly underreported in various sectors, including energy production [23,31]. While some organizations provide detailed and comprehensive reports, particularly for positive emissions from fuel combustion, there are notable gaps, especially in the fugitive emissions and emissions from chemical reagents. Negative emissions, particularly in the context of renewable energy acquisition and production, are often acknowledged but rarely quantified, limiting the overall transparency. These results, which mostly apply also to HPPs and WIs, substantiate previous research on the energy sector, which highlighted poor completeness, accuracy, and transparency [31,43].

3.2.2. Hydropower Plants—GHG

Positive Emissions—HPPs

Scope 1 emissions from on-site vehicles and equipment were considered by 16 out of 17 HP organizations, with half quantifying these emissions and the other half merely mentioning them (Figure 2). Twelve organizations considered emissions from emergency power generators (six mentioned and six quantified them), and five quantified GHG emissions from combustion in general. Vehicle emissions were only mentioned by three organizations and quantified by four, with three specifying their quantification method based on fuel consumption and kilometers driven. Additionally, heating emissions were recognized by five organizations, with four providing quantified data.

Emissions from using reagents and chemicals were more extensively quantified, with 11 organizations quantifying and 4 mentioning them; 14 facilities reported emissions from insulating and 11 from refrigerant gases. Emissions were calculated from the amount of gas needed for refills. The overall reporting of Scope 1 emissions was mostly partial, with gaps covering all relevant emission sources for most organizations.

Reporting on Scope 2 emissions from purchased electricity was limited. None of the organizations quantified emissions, and only four mentioned acquired electricity consumption as a GHG source (Figure 2). Six organizations said they bought electricity from the grid, although five mentioned doing it only during plant shutdown. This result is in line with previous studies considering other sectors, where at least 71% of organizations disclosed GHG emissions [30,31] but only 15% reported Scope 2 emissions [30].

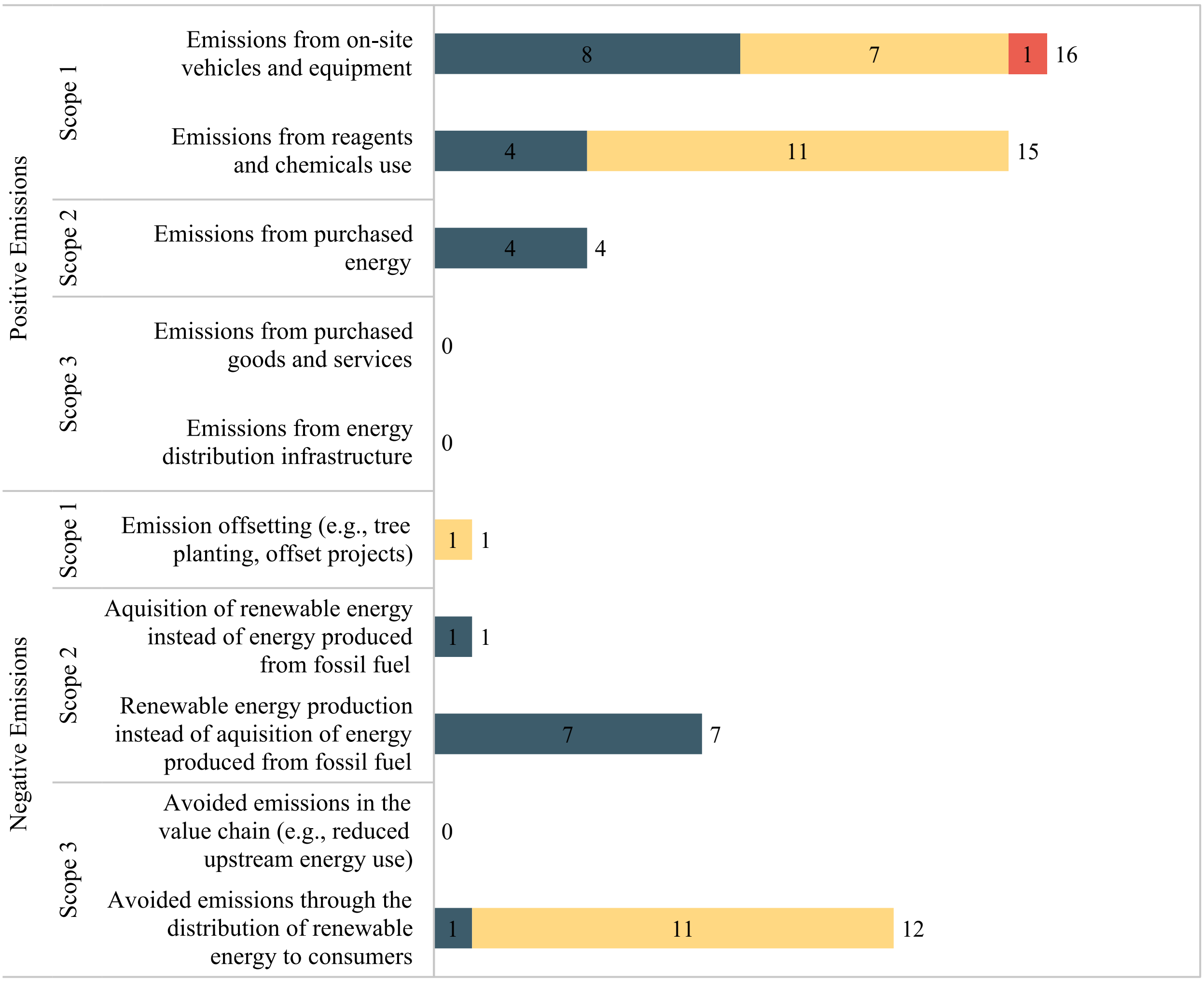

Figure 2. Scope 1, 2, and 3 greenhouse gas (GHG) emissions sources, including both positive and negative emissions, reported by hydropower companies. Bar colors indicate the reporting approach: "mentioned" (blue-gray) and "quantified" as measured (teal), calculated (yellow), or unspecified (red). The total counts for each source are shown to the right of each bar.

Scope 3 emissions were consistently overlooked. No organizations quantified or mentioned purchased goods and services nor the downstream energy distribution infrastructure as a GHG source. This indicates a gap in Scope 3 emissions reporting, limiting the overall transparency and completeness of environmental statements for hydropower plants.

Negative Emissions—HPPs

Regarding Scope 1, only one organization reported CO_2 capture via tree planting. The report estimated the avoided emissions and was considered comprehensive, but the lack of broader adoption of such strategies suggests limited engagement with carbon sequestration methods in the hydropower (HP) sector.

Considering Scope 2 negative emissions, only one organization mentioned the acquisition of renewable energy as a replacement for fossil fuel-based energy without any quantified data. Thirteen organizations referenced the consumption of auto-produced renewable energy, mostly hydropower, though only seven mentioned it as a strategy to reduce emissions, and none quantified those reductions (Figure 2).

As expected from an energy production sector relying on a renewable source, Scope 3 negative emissions were the better-reported categories, but still with only 11 organizations out of 17 quantifying the avoided emissions from renewable energy distribution to consumers. Additionally, one plant mentioned it without providing data (Figure 2). All reports calculated the avoided GHG emissions using the carbon intensity of the Italian energy mix. Notably, some organizations also mentioned using solar photovoltaic (PV) (4) and wind power (3) as supplementary renewable energy sources. This level of reporting in Scope 3 avoided emissions reflects the emphasis of HP organizations on the role of renewable energy in reducing GHG emissions.

GHG Reporting Practices and Gaps—HPPs

The results reveal variability in the comprehensiveness of GHG emissions reporting among HP organizations, especially for Scope 1 and Scope 2 emissions. While many companies quantified emissions from on-site sources like equipment and transformers, gaps remain in providing complete accounts. Scope 2 reporting was sparse, with limited acknowledgment of purchased electricity emissions, and Scope 3 emissions were largely neglected. In contrast, negative emissions reporting showed a stronger focus on renewable energy's role in reducing GHG impacts, particularly through avoided emissions from energy distribution. However, inconsistent quantification and reliance on generalized metrics highlight the need for more rigorous and transparent reporting practices.

3.2.3. Waste Incinerators—GHG

Positive Emissions—WIs

Regarding Scope 1, 13 out of 15 organizations reported GHG emissions from waste combustion, with 12 quantifying them (Figure 3). Of these 12 facilities, 9 used direct measurement techniques, 1 a calculation method, and 2 did not specify their quantification approach. Overall, 13 of the 15 WIs provided comprehensive reports, accounting for all possible emission sources in this category. However, the inclusion of N_2O emissions was less consistent, with only six organizations quantifying them and one describing them as negligible. Methane emissions were also scarcely mentioned, with only one facility including them among GHG sources. A lack of clarity was noted in one report, which provided a single emission value without specifying from which GHG sources.

It must be noted that six facilities explicitly stated that a significant portion of the CO_2 emitted from waste combustion was biogenic, emphasizing the reduced addition of fossil-based CO_2 into the atmosphere compared to fossil fuel-powered facilities. The GHG emissions caused by the non-biogenic fraction of the waste were less frequently reported, with only three organizations quantifying them. None of these reports, however, provided details on the measurement or calculation methods, limiting transparency and comparability.

GHG emissions related to combustion of fuels from on-site vehicles and equipment were reported by six facilities, with three providing a quantification, but none specified the measurement or calculation methods used. The comprehensiveness of reporting was partial, with five out of six reports excluding certain emission sources, such as specific equipment or operations. The sources mentioned varied widely, including vehicles (two facilities), lights (one), motors (one), flue-gas treatment steps (one), and equipment using fuel in general (four). However, one report downplayed the significance of these emissions, stating they were of minimal importance.

The emissions from reagents and chemicals used in waste incineration processes were inconsistently reported. Only one facility quantified these emissions, while five others only mentioned them. Most facilities highlighted refrigerant (five mentioned and one quantified) and insulating gases (four mentioned) as sources, with one report recognizing the use of sodium bicarbonate as a minor contributor (out of the twelve facilities using it as a reagent). However, the overall reporting was partial, with no facility offering a comprehensive breakdown of emissions in this category.

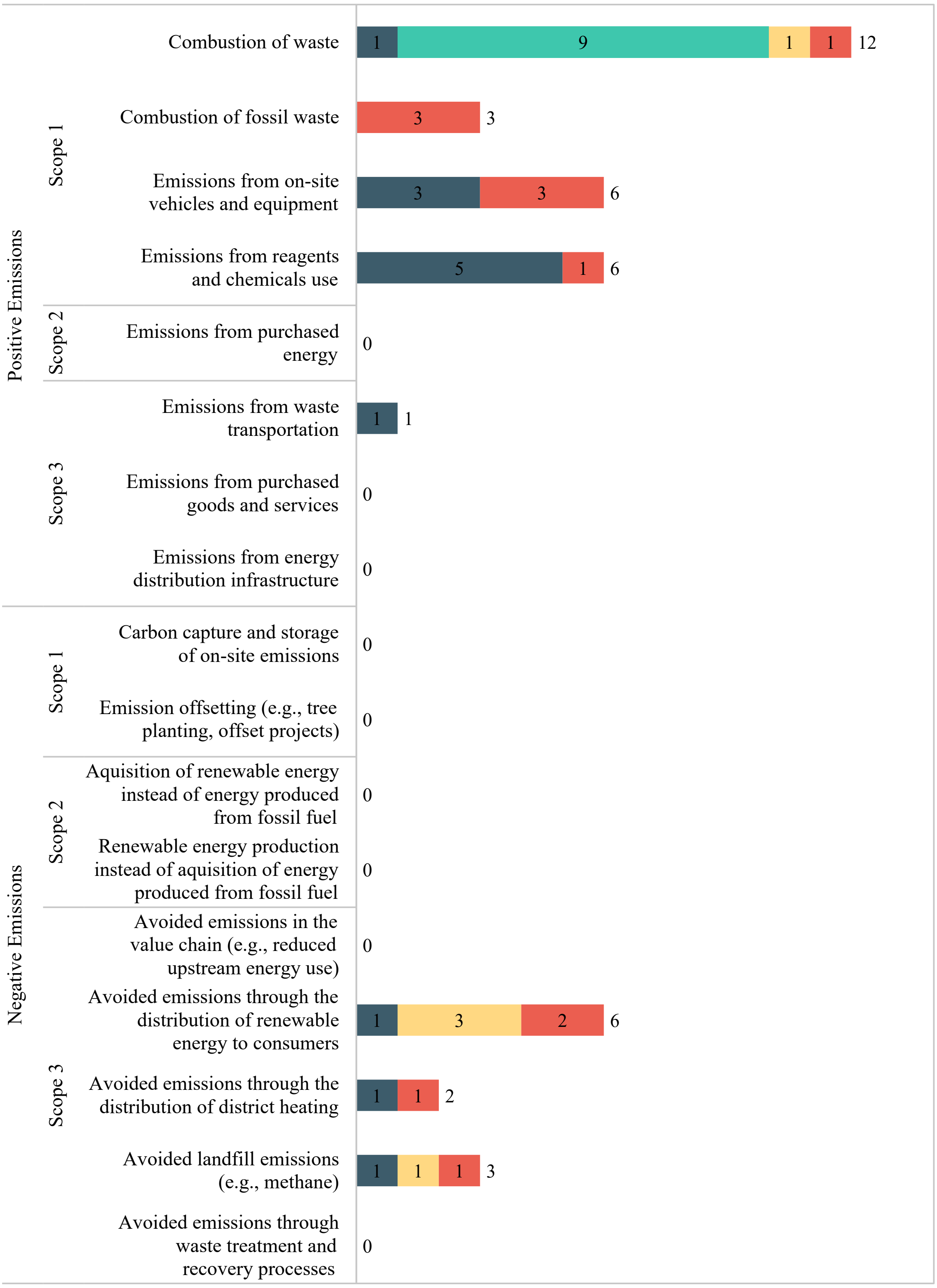

Figure 3. Scope 1, 2, and 3 greenhouse gas (GHG) emissions sources, including both positive and negative emissions, reported by waste incinerators. Bar colors indicate the reporting approach: "mentioned" (blue-gray) and "quantified" as measured (teal), calculated (yellow), or unspecified (red). The total counts for each source are shown to the right of each bar.

Reporting on emissions related to purchased electricity was absent. None of the organizations quantified their Scope 2 emissions, despite nine organizations acknowledging the need to buy energy from the grid. Two facilities stated that they exclusively used auto-produced energy, and one report suggested that purchased electricity was insignificant in quantity (Figure 3).

Only one facility mentioned emissions from waste transportation under Scope 3 but without providing quantified data. Reporting on other Scope 3 sources, such as emissions from purchased goods and services or the downstream energy distribution infrastructure, was entirely absent. This lack of reporting on Scope 3 emissions reflects a significant gap in addressing the entire life cycle of waste incineration operations and their impact on GHG emissions.

Negative Emissions—WIs

Regarding Scope 1, none of the organizations reported capturing or storing CO_2 emissions from combustion processes. Likewise, no facilities mentioned CO_2 sequestration through tree planting, indicating a missed opportunity to mitigate or offset direct emissions.

Across the sector, 51% of the energy produced by waste incinerators was considered renewable, as per national regulations (DM 06/07/2012). Despite this, none of the reports considered the use of purchased or produced renewable energy instead of fossil fuel-derived electricity as a negative GHG emission source (Scope 2). Two facilities also mentioned renewable energy production through solar PV systems but neither linked it to avoided emissions. This lack of detailed reporting on renewable energy use undermines the sector's potential to showcase efforts in reducing Scope 2 emissions.

Several organizations reported avoided emissions under Scope 3, mainly through the distribution of renewable energy (Figure 3). Although 51% of the energy produced by WIs was considered renewable, only five facilities quantified the avoided emissions, with one more mentioning them. Of those, two detailed that the calculation methods used were based on the carbon intensity of the Italian energy mix. Two organizations considered avoided emissions by implementing district heating systems (one quantified and one mentioned), but none disclosed the calculation method used. Only two facilities quantified avoided landfill GHG emissions, one calculating them by considering average methane extraction rates from Italian landfills. A third facility just mentioned avoided landfill GHG emissions. Notably, none of the organizations considered avoided emissions through waste treatment and recovery processes.

GHG Reporting Practices and Gaps—WIs

The above results show that reporting practices in WI environmental statements under EMAS varied significantly in comprehensiveness, accuracy, and transparency. While Scope 1 positive emissions from waste combustion were relatively well covered, non-biogenic waste combustion emissions were rarely quantified, and the acknowledgment of other direct GHG sources, such as on-site equipment, reagents, and chemicals, was less comprehensive. Scope 2 and Scope 3 reporting were particularly lacking, with minimal or no quantification provided for purchased electricity or other indirect emission sources. Furthermore, the partial reporting on avoided emissions, especially regarding renewable energy distribution, suggests a need for more detailed and methodologically robust reporting. Without comprehensive data on these avoided emissions, the sector risks underreporting its contributions to GHG reductions.

3.3. Renewable Energy Use Reporting

3.3.1. Thermal Power Plants—Renewable Energy

Renewable energy use within TPPs was scarcely reported, with only 5 out of 72 facilities acknowledging it. Of these, just two facilities provided quantification, while three others merely mentioned the use of renewable energy. The reported sources included solar PV and biomass (Table 1).

Table 1. Comparison of renewable energy use reporting across thermal power plants, waste incinerators, and hydropower plants. Ment. = mentioned, Quant. = quantified.

		Thermal Power Plants			Hydropower Companies			Waste Incinerators		
		Total	**Ment.**	**Quant.**	**Total**	**Ment.**	**Quant.**	**Total**	**Ment.**	**Quant.**
Considered		5 out of 72	-	-	13 out of 17	-	-	15 out of 15	-	-
Origin	Purchased	2	1	1	1	1	0	0	0	0
	Self-produced	4	2	2	13	7	6	15	2	13
Self-production source	Hydropower	0	0	0	12	6	6	0	0	0
	Solar photovoltaic	3	1	2	5	5	0	0	0	0
	Wind	0	0	0	2	2	0	0	0	0
	Waste-to-Energy	0	0	0	0	0	0	14	2	12
	Biomass	1	1	0	1	1	0	1	0	1

Only one facility explicitly quantified its purchase of renewable energy, while another mentioned it without providing quantification. For self-produced energy, two facilities quantified their solar PV consumption, while two only mentioned consumption from renewable sources (one solar PV and one biomass).

When considering the proportion of total energy consumption from renewable sources, the results varied significantly. Two facilities reported that less than 1% of the used electricity came from renewable sources, while another stated that around 7% of its energy came from purchased renewable and self-produced solar PV energy. The highest figure was reported by a single plant specifying that 35% of its total electricity consumption came from renewable sources.

Notably, six other facilities mentioned producing renewable energy (ten in total) but failed to indicate whether they used it themselves. Of these, four specifically stated selling the generated renewable energy, while five facilities indicated relying on grid electricity for operations. This disconnection between renewable energy generation and internal use highlights a gap in reporting practices and the integration of green energy into the energy mix.

The comprehensiveness of the TPP reports on renewable energy utilization was generally poor. Most facilities failed to mention renewable energy usage altogether or providing vague and incomplete information, substantiating previous findings [43]. While five facilities acknowledged some form of renewable energy use, the details provided were sparse. Of the few facilities that provided numerical data, there were noticeable gaps in how they reported renewable energy usage. For instance, one facility claimed a renewable energy share of 35%, but the lack of supporting data calls the accuracy of this figure into question. Moreover, the fact that several facilities produced renewable energy but did not use it internally suggests that there may be commercial or logistical reasons for this decision, though these aspects were not explored in the reports.

3.3.2. Hydropower Plants—Renewable Energy

Most HP organizations reported using renewable energy, with 13 out of 17 providing some level of information. However, the depth and quality of reporting on this subject varied substantially. Of the 13 companies that acknowledged renewable energy usage, 6 quantified their self-produced energy, while 7 others only mentioned self-produced renewable energy use without specific numerical data (Table 1). One company also mentioned purchasing renewable energy, though it did not quantify this information.

Self-produced energy was predominantly sourced from hydropower, as expected from these companies. Of the 13 HP organizations that reported renewable energy use, 6 provided specific figures regarding their hydropower production, while 6 others merely acknowledged its usage without offering precise data. In terms of other renewable sources, solar PV was mentioned by five companies, although none quantified the energy generated from it. Wind energy and biomass were also scarcely adopted, with only two and one companies mentioning their usage, respectively, but again without providing detailed measurements.

Seven organizations indicated that most of their energy needs were met through self-produced renewable energy, mainly hydropower. These companies stated that nearly 100% of their electricity use was sourced from renewables, except when the hydropower plants were offline, during which electricity was sourced from the grid. Additionally, one company noted that some of its vehicles were powered by solar PV energy harnessed from rooftop installations, though this information was not quantified.

Most HP organizations demonstrated their commitment to renewable energy, although mainly due to self-consumption, with the majority reporting its use. However, this level of detail was not consistent across all companies, as several only mentioned renewable energy use without providing specific figures. This inconsistency highlights an area for improvement in ensuring that all organizations offer clear and detailed information, further enhancing transparency and accountability.

3.3.3. Waste Incinerators—Renewable Energy

All 15 WIs examined in this study reported some form of renewable energy usage in their EMAS environmental statements. However, discrepancies in reporting practices, particularly regarding quantification and transparency, were noted. None of the facilities reported the purchased renewable energy, despite nine organizations acknowledging buying energy from the grid (Table 1).

In contrast, self-produced renewable energy was commonly reported, with 13 facilities providing quantitative data on this source and 2 facilities only mentioning it without further details. Of course, the dominant source of renewable energy was derived from waste-to-energy processes. Of the 15 facilities, 12 quantified the renewable energy portion from waste incineration, while 2 others mentioned it without offering precise figures. One facility also quantified the use of biomass as a renewable energy source, as the facility used waste biomass as fuel. Two facilities mentioned renewable energy production through solar PV systems but did not specify whether it was consumed or sold.

The proportion of electricity generated from renewable sources varied significantly across the facilities. One facility approached 100% renewable electricity usage, primarily due to its reliance on waste biomass. Most facilities (12 out of 15) reported that between 48% and 51% of their electricity came from renewable sources, as Italian normative guidelines consider 51% of energy produced from waste incineration renewable. However, two facilities failed to disclose any data on the proportion of renewable electricity used, contributing to gaps in the reporting process.

The proportion of renewables was more diverse when considering the total energy, including the energy from fuels used in the plants. One facility reported that approximately 75% of its total energy consumption was from renewable sources thanks to waste biomass. Other facilities reported renewable energy contributions ranging from 19% to 45%, with four facilities falling between 41% and 45%, 6 facilities reporting between 33% and 37%, one facility at 28%, and one at 19%. Notably, two facilities failed to disclose their total energy share from renewable sources.

It must be noted that only 6 out of the 13 facilities whose renewable energy consumption was quantifiable explicitly disclosed the figure in the environmental statements. In contrast, for four facilities, it was necessary to rely on the reported statement that 51% of the electricity produced from waste incineration was renewable, as no detailed calculations or specific percentages were provided. The remaining three organizations did not clarify the amount of renewable electricity consumed nor the percentage of renewable energy generated, although the Italian normative reference value (51%) likely applies to these facilities.

While showing some variability, the reporting practices for renewable energy utilization among waste incineration facilities demonstrate a considerable level of commitment to renewable energy usage integration. All facilities reported some degree of renewable energy usage, and the majority provided quantifiable data, allowing for a relatively easy assessment of their renewable energy contributions. However, there remains room for improvement, particularly regarding the reporting of purchased renewable energy, which was neither mentioned nor quantified by any facility. This omission suggests an opportunity to further enhance the completeness of the reports.

3.4. GHG Reduction and Renewable Energy Use Improvement Objectives

3.4.1. Thermal Power Plants—Objectives

Among the 72 analyzed TPPs, objectives with GHG emissions reduction as the primary goal were set by 26 organizations, while 69 TPPs set objectives that included GHG reduction as a secondary goal. Only three organizations did not include any GHG-related objectives, reflecting the high importance given to GHG mitigation and the widespread recognition of the need for action. However, the fact that GHG emissions reduction was more commonly considered as a secondary goal suggests that other aspects, such as operational efficiency or cost control, are often more prioritized (Figure 4).

Out of 569 specific objectives reported by the TPPs, 30 were focused on GHG reduction as the primary goal while 214 treated it as a secondary one.

The most common GHG-related objectives with GHG reduction as the primary goal were:

- Increase energy production from renewable sources by installing photovoltaic systems (15 occurrences);
- Improved emissions monitoring by controlling fugitive methane emissions (4);
- Reduction of diffuse emissions by optimizing methane transport and storage systems (4);
- Increase the area dedicated to nature by tree planting (3).

When GHG reduction was the secondary goal, the most common objectives were:

- Reducing electricity consumption by replacing lighting with LED lamps (33);
- Efficiency improvements by optimizing or replacing equipment (21);
- Reduction of water consumption by installing water recovery systems (13);
- Increase electric mobility by replacing traditional vehicles with electric vehicles (10).

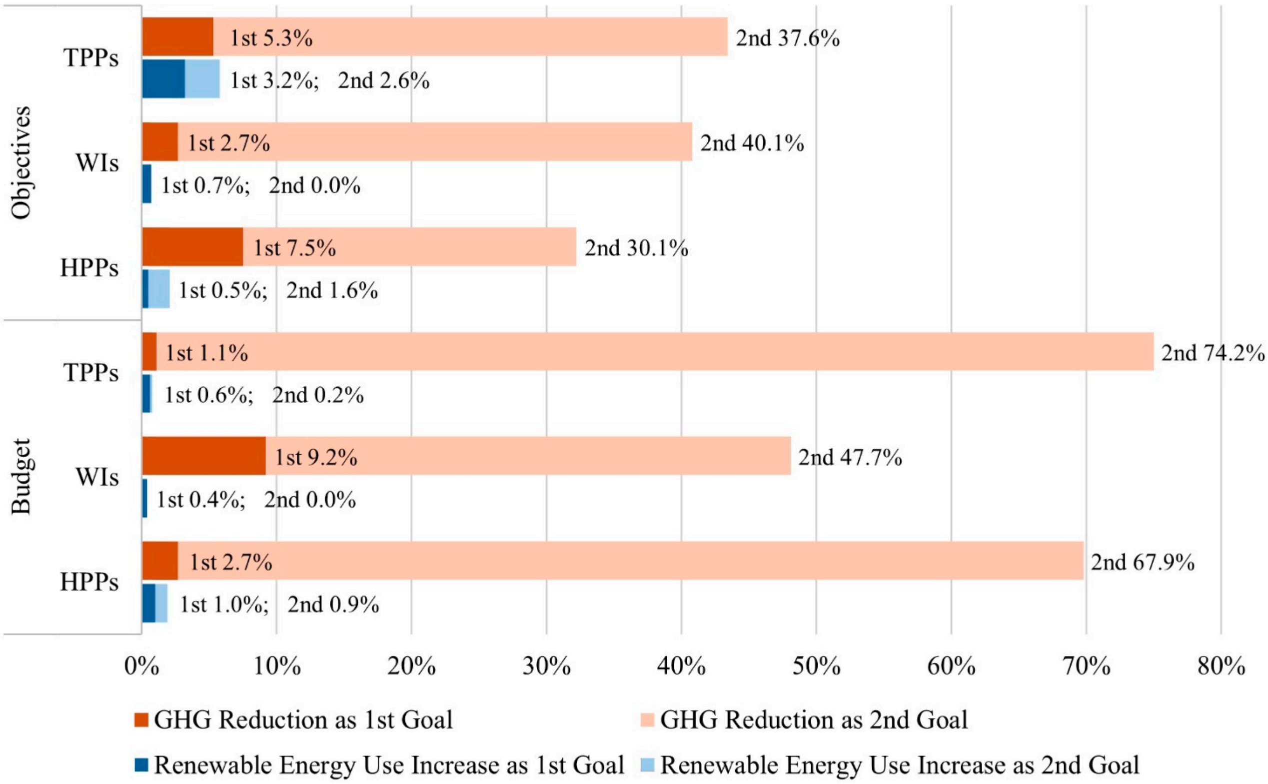

Figure 4. Percentage distribution of total objectives and budget allocations across thermal power plants (TPPs), waste incinerators (WIs), and hydropower plant (HPP) companies with 'GHG reduction' and 'renewable energy use increase' as a goal. '1st' indicates the goal is primary within the objective, while '2nd' that the goal is secondary. Bars represent the percentage of total objectives set or budget allocated, with exact values labeled next to each bar.

The financial investment associated with these objectives varied significantly. For GHG reduction objectives set as a primary goal, the total budget allocated was EUR 6.9 million out of a total of EUR 626.4 million, reflecting a relatively small portion of overall investment for environmental performance improvement (Figure 4). In contrast, objectives with GHG reduction as a secondary goal commanded a much larger share of resources, with EUR 465.0 million being allocated. The most common goals of these objectives were broader operational or technological upgrades that also targeted energy efficiency, which contributes to GHG emission reductions.

Twenty-five TPPs set objectives to increase renewable energy consumption, considerably fewer than those planned to reduce GHG emissions. Eighteen organizations set objectives with this aspect as the primary goal and twelve as a secondary one. This relatively low figure indicates that renewable energy consumption is not as widely prioritized as GHG emission reduction, likely due to the challenges of integrating renewable sources into thermal power production systems that traditionally rely on fossil fuels.

Of the 569 objectives reported, 18 were primarily focused on increasing renewable energy use:

- Increase energy production from renewable sources by installing photovoltaic systems (15);
- Increase electricity consumption from renewable sources by purchasing electricity from renewable sources (3).

On the other hand, 15 objectives listed increasing renewable energy use as a secondary goal:

- Increase electric mobility by replacing traditional vehicles with electric vehicles (10);
- Increase electric mobility by installing charging stations for electric cars (5).

In terms of financial allocation, the total budget for objectives with renewable energy consumption as the primary focus amounted to EUR 3.7 million, a relatively modest figure compared to the overall budget of EUR 626.4 million. Only EUR 1.5 million were allocated for objectives with renewable energy consumption as a secondary goal, further indicating the lower financial prioritization of renewable energy compared to GHG reduction initiatives within the sector (Figure 4).

The ambition and efficacy of these objectives varied significantly across the sector. Objectives with GHG reduction as a primary goal often targeted incremental improvements, such as enhanced monitoring systems or energy efficiency. In contrast, more ambitious initiatives like carbon capture and storage or large-scale shifts toward renewable energy were rare. These results align with previous studies, which highlighted that many companies fail to set GHG reduction goals while others do not report progresses towards their achievement [31]. When renewable energy consumption was addressed, the focus was mainly on adding small-scale solar infrastructure or enhancing electric mobility, suggesting a cautious approach to integrating renewable energy into traditionally fossil-fuel-dependent operations.

3.4.2. Hydropower Plants—Objectives

GHG reduction was a prominent focus, with 9 out of 17 organizations setting objectives where GHG reduction was the primary goal and 14 organizations including objectives with it as a secondary goal. Overall, 15 organizations set at least one objective related to GHG reduction, highlighting the widespread recognition of the need to address this issue.

Of the 186 objectives reported across the HP companies, only 14 (7.5%) focused on GHG emission reduction as the primary goal, while 56 (30.1%) treated GHG reduction as a secondary goal (Figure 4). The smaller number of primary GHG objectives indicates that, similarly to WIs, emissions mitigation is often considered alongside broader operational or efficiency improvements.

When GHG reduction was the primary goal, the most common objectives were:

- Replacement of transport vehicles to reduce emissions (8 occurrences);
- Emissions reduction through improvements in the efficiency of air conditioning systems (4).

When GHG reduction was a secondary goal, the most frequent objectives were:

- Increasing the efficiency of electricity generation by replacing turbines or generators (11);
- Reducing electricity consumption by replacing traditional lighting with LED technology (6);
- Increasing electricity production by constructing new hydroelectric power plants (6).

Only EUR 0.6 million were allocated for objectives with GHG reduction as the primary goal out of a total budget of EUR 22.2 million (2.7%). This reflects a relatively small financial investment in direct GHG reduction measures. However, objectives with GHG reduction as a secondary goal commanded a significantly larger portion of resources, with EUR 15.1 million allocated, representing 68% of the total budget. This allocation underscores the common practice of embedding GHG reduction within larger, more comprehensive operational upgrades.

Renewable energy consumption was far less emphasized compared to GHG reduction. Only one organization set objectives with renewable energy utilization as a primary goal, while three organizations included it as a secondary goal (Figure 4). The limited focus along with the scarce reliance of hydroelectric power plants on non-renewable energy sources likely limits additional renewable energy integration efforts.

Of the 186 objectives, only 1 had renewable energy consumption as the primary focus. This objective involved the installation of photovoltaic panels to reduce electricity consumption. When renewable energy consumption was treated as a secondary goal, objectives included:

- Reducing GHG emissions by replacing diesel and electric machinery (1);
- Reducing suppliers' impact by selecting them based on environmental performance (1);
- Reduce the impact of materials used by identifying more sustainable alternatives (1).

The financial investment in terms of renewable energy consumption was minimal. Only EUR 0.2 million were allocated for both primary and secondary renewable energy consumption objectives, representing a negligible fraction of the total budget. This reinforces the observation that renewable energy utilization, though present, is not a primary driver of strategic planning in the hydroelectric sector.

Overall, while HP organizations set a substantial number of objectives related to GHG reduction, the focus was primarily on embedding emissions reductions within broader operational improvements rather than pursuing GHG mitigation as an independent goal. Renewable energy utilization objectives were significantly less prominent in number and financial commitment, signaling the sector's reliance on existing hydropower capabilities.

3.4.3. Waste Incinerators—Objectives

Of the 15 organizations, 4 set objectives with GHG emissions reduction as the primary goal, while all 15 set objectives that included GHG reduction as a secondary goal. Similarly, only 4 of the 147 total objectives reported across the WI sector were focused primarily on GHG reduction, while 59 treated it as a secondary goal (Figure 4). This indicates that although GHG mitigation is universally recognized as necessary, it is frequently addressed in tandem with other operational objectives, such as efficiency improvements or cost control, rather than being an exclusive focus.

The objectives with GHG emissions as the primary goal were:

- Connection as a supplier to the district heating network (2 occurrences);
- Reduction of CO_2 emissions by replacing traditional vehicles (1);
- Reduction of indirect emissions by improving contractor awareness (1).

The most frequent objectives when GHG emissions were treated as a secondary goal were:

- Reducing electricity consumption by replacing lighting with LED lamps (12);
- Electricity consumption reduction through component replacement (8).

The financial commitment to GHG reduction objectives reveals a clear prioritization gap. For objectives with GHG emissions reduction as the primary goal, a total of EUR 7.3 million was allocated out of a total budget of EUR 79.8 million, constituting a modest 9.1% of the overall financial resources. In contrast, EUR 38.1 million were dedicated to objectives where GHG reduction was a secondary focus, as larger and more expensive projects typically incorporate emissions reductions as one of several intended outcomes.

Renewable energy consumption objectives were notably less prevalent within the waste incineration sector. Only 1 of the 15 organizations set an objective with increasing renewable energy consumption as the primary goal, and none set objectives with renewable energy use as a secondary goal (Figure 4). This indicates a limited focus on integrating renewable energy into waste incineration processes. Consequently, only 1 out of the 147 objectives reported was focused on increasing renewable energy consumption. This objective aimed to reduce electricity withdrawals from the grid by utilizing self-produced electricity for remote heating users. The financial resources allocated to renewable energy consumption objectives were minimal (EUR 0.3 million), representing a mere 0.4% of the total budget of EUR 79.8 million.

In summary, the waste incineration sector prioritizes GHG emissions reduction, though most objectives treat it as a secondary goal. On the other hand, renewable energy consumption was minimally addressed, with only one organization setting a related objective and an even smaller share of the budget dedicated to it. Overall, the sector's objectives reflect incremental progress, with a stronger emphasis on operational efficiency rather than ambitious transitions toward low-carbon technologies.

4. Limitations

While this study provides significant insights into GHG emissions and renewable energy reporting practices among Italian energy production facilities, it is important to acknowledge some limitations.

- The focus on EMAS-certified organizations inherently limits generalizability to non-certified facilities, which may exhibit different practices. However, these facilities represent best-case examples, making the findings especially relevant for policy recommendations and industry benchmarking.
- The reliance on publicly available ESs may have led to data variability due to differences in reporting practices. Some organizations provided highly detailed reports, while others lacked comprehensiveness. This variability reflects the current state of reporting practices rather than a methodological shortcoming.
- A potential limitation is the subjectivity in distinguishing between primary and secondary goals associated with improvement objectives. However, this does not significantly impact the overall trends observed in the data.

5. Conclusions

This study evaluated GHG reduction and renewable energy reporting practices and objectives across TPPs, HPPs, and WIs. Major findings revealed that GHG reporting varied across sectors in key areas. TPPs and WIs performed well in reporting positive Scope 1 emissions but were weaker on Scope 2, with HPPs following a similar pattern but less robust reporting about Scope 1. Scope 3 positive and negative emissions reporting were lacking across all sectors, though HPPs showed notably better transparency in negative emissions. Renewable energy utilization reporting, especially in the TPP and WI sectors, remains limited, reflecting the challenges of integrating renewables into traditional operations.

Objectives aimed at reducing GHG emissions were widely established, particularly as secondary goals integrated into broader operational improvements. TPPs and WIs set a higher number of GHG reduction objectives, though many focused on incremental improvements. HPPs, due to their reliance on renewable energy, had fewer GHG-focused objectives.

Policymakers need to strengthen guidelines around GHG reporting, particularly in standardizing Scope 3 emissions accounting, reporting of parameters outside CO_2, and calculation methods. They should also incentivize integrating renewable energy into sectors reliant on fossil fuels. On the other hand, energy companies should adopt a more standardized approach to GHG reporting, incorporating best practices for monitoring, reporting, and quantifying emissions across all scopes.

Renewable energy integration should be prioritized in their strategic objectives, with clear and measurable goals that align with broader decarbonization targets. Collaboration with suppliers and other stakeholders to reduce upstream and downstream emissions (Scope 3) should also be a core element of GHG reduction strategies.

Future research should investigate the motivations behind energy companies' reporting behaviors, exploring factors influencing their GHG and renewable energy data transparency. Additionally, research could explore the financial and operational barriers that prevent greater integration of renewable energy in sectors like thermal power plants and waste incinerators. Lastly, a longitudinal analysis could track the progress of renewable energy objectives and their real-world impact on emissions reduction over time.

Author Contributions: Conceptualization, S.C., S.F. and C.C.; methodology, S.C., S.F. and C.C.; validation, S.C.; formal analysis, S.C.; investigation, S.C.; data curation, S.C.; writing—original draft preparation, S.C.; writing—review and editing, S.F. and C.C.; visualization, S.C.; supervision, S.F. and C.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found in the environmental statements concerning the analyzed plants, which can be obtained contacting the managing companies or visiting their websites.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

GHG: greenhouse gas; TPP: thermal power plant; HPP: hydropower plant; WI: waste incinerator; EU: European Union; EMS: environmental management system; EMAS: Eco-Management and Audit Scheme; ISO: International Organization for Standardization; ES: environmental statement; NACE: Statistical Classification of Economic Activities in the European Community; ISPRA: National Institute for Environmental Protection and Research; HP: hydropower; PV: photovoltaic.

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