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Linking of Barriers to Energy Efficiency Improvement in Indonesia's Steel Industry

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Abstract: Energy use in Indonesia's steel industry accounts for about 20–35% of total production costs. Consequently, energy end-use efficiency is a crucial measure that is used to reduce energy intensity and decrease production costs. This article aims to investigate the relationships among different barriers to energy efficiency improvement (EEI), using a framework with the following six constructs: government policy, the financial–economic factor, the managerial–organizational factor, the technological factor, workforce, and quality and type of feedstock and fuel used. The data were collected from steel firm practitioners in Indonesia, using a questionnaire to test our framework. The results demonstrate that the applied framework was applicable. We find that EEI is moderately influenced by all constructs but that the managerial–organizational factor has the greatest direct effect on improvements and is the most significant factor.

Keywords: energy efficiency; conceptual framework; barriers; steel industry; Indonesia

1. Introduction

As industrial energy use accounts for about 36–37% or one-third of the world's final energy demand [1], the industrial sector has a large impact on greenhouse gas (GHG) mitigation and is, thus, an important sector in terms of improved energy efficiency [2]. For energy-intensive industries, it is known that energy costs may account for up to and over 30% of total production costs [3], so at the firm level, improving energy efficiency is intended to generate direct economic benefits by decreasing the amount of energy used in production [4,5]. This global industrial sector share consists of 42%, 75%, 44% and 20% of the global electricity generated, coal, natural gas, and oil consumption, respectively [6]. According to [7], there has been increasing concern about energy efficiency improvement (EEI) to overcome issues related to limited energy supply and rising energy demand.

EEI has been acknowledged as an important tool for obtaining competitive advantage and ensuring industrial sustainability [5]. Furthermore, it is estimated that the world manufacturing industry emits 43% of anthropogenic carbon dioxide emissions and specifically accounts for about 25% of global GHG emissions [8,9]. Hence, energy saving is also considered the most cost-effective method of mitigating GHG emissions [10]. Whereas according to [11], there are still requirements to conduct researches that addressed to energy efficiency agility, both in technological aspects and energy efficiency measures, related with combining agile and sustainable manufacturing concepts.

However, even though improved energy efficiency measures have become crucial for manufacturing industries, a number of obstacles still exist, hindering industry involvement in reducing energy enduse [12]. The existence of these barriers leads to differencesbetween the optimal and actual implementation of the potential for improved energy efficiency [13]. This discrepancy is referred to as "the energy efficiency gap" or "energy paradox", which was first defined by [14]. According to [15], the barrier model enables better comprehension of the industrial sector'sefforts to tackle the obstacles for achieving improvedenergy efficiency. To achieve the most effective and successful strategy development and promotion, it is imperative to recognize these barriers to detecting, minimizing, and resolving obstacles [1].

In most countries, the iron and steel industry is one of the basic industrial sectors contributing to national economic development [16]. It is well known that the amount of steel consumption is a key indicator of national economic growth [17]. According to a report by the Agency for the Assessment and Application of Technology [18], the Indonesia's steel industry used energy in the form of electricity (60%), natural gas (38%), and petroleum fuels (2%). Together with the cement, petrochemical, and pulp and paper industries, the steel industry is categorized as one of the most energy-intensive end-using sectors in Indonesia. The steel industry consumes approximately 38% of the total energy end-use of Indonesian industries. The energy end-use in the national steel industry absorbs about 20–35% of total production costs. Because of this situation, these industries can hardly achieve competitive advantages in the international market.

Although some national industries have focused their efforts on improving energy efficiency by implementing energy-saving technologies, the results have not significantly improved energy end-use efficiency [18]. This may be an indication that there are still a number of obstacles hindering the implementation of improved energy efficiency. These difficulties show the existence of barriers to energy use efficiency.

Minimizing existing barriers and creating an advantageous environment for the implementation of cleaner production [19]; obtaining and understanding suitable policies and know-how related to the energy-efficient technologies and practices adopted by the firm [20]; devising cost-efficient policy tactics [21], and designing, assimilating, and enforcing appropriate and effective policies [22] may be possible only through a thorough examination and understanding of these barriers. Numerous studies and reviews have revealed the existence of a wide variety of barriers to the implementation of cost-effective EEI measures, but there are still opportunities for improved energy efficiency [23]. Most of the literature on barriers and the various frameworks for barriers have so far focused solely on the type and importance of each of these barriers, while the interconnections among barriers in linkages perspectives are rarely revealed. Only a few studies review and explain connections and relationships between barriers [24]. There are a few exceptions. Thus, a new framework, that included the most relevant barriers and involved implicit interactions between barriers, is proposed by [25].

Therefore, there is a trend to explore how all barriers are interconnected. Furthermore, there is still very much a need to develop extended conceptual barrier models that explain the relationships between barriers. Meanwhile, the characteristics of these barriers widely, depending on the level of technology or the process being used, the type of industrial sectors, and the regional conditions where the industry is located [26]. For the reasons indicated above, we have conducted a preliminary investigation to identify and analyze the interactions of the barriers to EEI regardingenergy enduse in Indonesia's steel industry. To date, no comprehensive studies have reviewed these barriers to EEI in the steel industry in Indonesia. The uniqueness of this study is in the stipulation of significant knowledge of factors and mechanisms that link, directly or indirectly, the barriers to improved energy efficiency in Indonesia's steel industry.

The remainder of this article is structured as follows: Section 2 presents the research method used in the case study. Section 3 deals with the development of the conceptual frameworks regarding the barriers to adopting industrial energy-saving improvement measures. In Section 4, we propose a conceptual framework model and research hypothesis. In Section 5, an empirical data analysis based on a case study of Indonesia's steel industry is carried out. This analysis is followed by the presentation and discussion of the results. In the final section, the conclusion, limitations, and suggestions for further research are given.

2. Methods

The approach applied in this study was descriptive and exploratory. The descriptive part was used to obtain a systematic depiction of the phenomenon and characteristics of energy end-use in Indonesia's steel industry. The explorative part was motivated as the study explores a novel area, i.e., barriers to energy efficiency in the Indonesia's steel industry. In the regarded study, the paper concerns a case, the steel industry in Indonesia, with a few selected firms, which makes the study suit a case study research design. As outlined by [27], a case study is particularly suitable when studying a contemporary phenomenon. Due to the descriptive and exploratory nature of the study, the initial part of the research was carried out as a multiple-case study inspired by [27], for which the individual cases studied consisted of Indonesian steel mills. Due to the limited number of steel mills in Indonesia, a case study was considered the most suitable methodological approach to the study. The statistical method—structural equation modeling (SEM)—was used to analyze the collected data, in the later part of the research being carried out.

The SEM approach was used to test the hypotheses model. In this research, all SEM analyses were conducted employing the partial least squares (PLS) method. PLS can deal with small sample sizes (20 samples) and does not mandate a normal distributional assumption [28]. The SEM approach to identify the interconnection among key factors related to the diffusion of the Radio Frequency Identification System in the health-care industry, whereas, by integrating SEM and quality function deployment is adopted by [29]. Whilst, the SEM method to develop a systematic framework for service quality improvement is applied by [30]. The SEM applies a two-step procedure that simultaneously examines and constructs the measurement model and then develops and tests the structural model [31]. The two models of SEM should be evaluated separately, even though these models can be interpreted jointly [32]. In SEM-PLS, the measurement model is usually called the outer model, while the structural model is called the inner model. In this study, we used the WarpPLS Version 5.0 software (ScriptWarp Systems, Laredo, TX, USA) program.

This choice of combining case study methodology and statistical analysis was inspired by [13], who also applied a limited statistical analysis in his study of barriers to EEI in the Swedish steel industry, where a limited number of steel mills were also studied. The barrier models that were applied and analyzed were found using a literature study on barriers. It should be noted, as was already outlined in 1994 by [33], that the barrier field is characterized by both a variation in the magnitude of the potential improvement, as well as a variety of definitions of what may or may not be considered a barrier. In our study, we tried to delimit ourselves by these and apply the various outlined barriers of importance that were derived from the review of the scientific literature. This implies that some of the barriers identified as such by previous researchers may not be considered barriers.

The sorting of the firms was based on the industrial company directory that is maintained by the Ministry of Industry, Republic of Indonesia. In order to preserve the homogeneity of the surveyed firms, we selected only the companies in the steel industry that have an EAF or blast furnace. Another reason for choosing this type of steel industry is that the primary production routes in steel making are the BF route and the scrap-based EAF route. Furthermore, because, in some cases, the company's internal conditionsdid not permit access to the site and the undertaking of data collection, from a total of 18 companies, only 12 gave approval for taking part in the case study. In Table 1, we have indicated a few characteristics of the firm respondents involved in the sample.

According to [34], a limitation is the biases of the respondents—that is, participants' tendencies to provide answers even if they have little knowledge about the subject. Furthermore, in many industrial companies, the official energy manager is not completely in charge of energy issues and their related investment costs. For these reasons, we took two to four respondents from each company to minimize this bias. Finally, the total number of respondents who agreed to participate was 38 practitioners from 12 steel firms. The selected respondents were preferred because of their positions on the shop floor, who had responsibility for the energy use issue [20]. Therefore, the questionnaires were mainly directed toward the energy manager, if this position existed. If there was no an energy manager, the questionnaires were pointed to the plant managers (or operation managers or someone in another similar position), the technical director (or middle managers), and the senior engineer who dealt with energy issues. Figure 1 reflects the distribution of therespondents' positions.

Table 1. Company profile.

Company	Age ofthe Firm (Years)	Firm Size (Number of Employees)	Asset (Million $)	Ownership Pattern (Investment)	Type of Final Product	Number of Respondents [1]
A	47	>1000	5–10	Domestic	Billet, semi finished	4
B	30	>1000	>50	Foreign	Bloom, semi finished, flat & long product	3
C	42	100–500	>50	Domestic	Crude steel, long product	3
D	45	100–500	5–10	Domestic	Billet, long product	3
E [2]	46	>1000	>50	Domestic	Slab, billet, semi finished	4
F [3]	6	>1000	>50	Joint venture	Slab, semi finished	3
G	27	500–1000	>50	Domestic	Billet, long product	3
H	11	100–500	>50	Foreign	Long product	4
I	44	>1000	>50	Domestic	Billet, semi finished, long product	2
J	43	100–500	>50	Joint venture	Billet, long product	4
K	40	100–500	>50	Foreign	Billet, semi finished	3
L	46	100–500	>50	Joint venture	Crude steel	2

[1] The total number of respondents = 38 practitioners; [2] The field-survey site; [3] Using the integrated BF production routing.

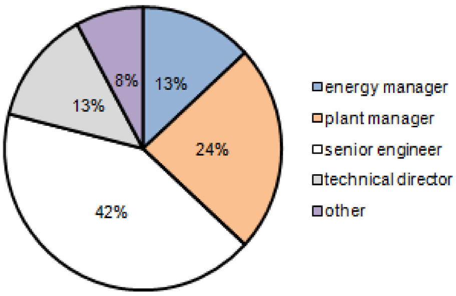

Figure 1. The respondent profiles (in total 38 respondents from Indonesian steel mills participated).

The categories of the selected barriers were developed on the basis of barrier category mapping. The questionnaire design was inspired by [27], and the questions' items related to the barriers' importance were modified from the taxonomy of [26]. In accordance with [35], the survey sought to ascertain perceptions, rather than real impediments, and it may have varied from the real conditions, but it was assumed to be able to clarify behavioral patterns. The design of the questionnaire was verified by three academics in industrial management engineering to strengthen the study's validity. In the questionnaire, we collected data from six categories of barriers—namely policy, the managerial–organizational factor, the financial–economic factor, the technological factor, workforce, and used raw feedstock and fuel. The last category—used raw feedstock and fuel—is a newly proposed construct. Respondents gave scores based on a five-point Likert scale (1—very unimportant/very irrelevant, 2—not important/not relevant, 3—quite important/quite relevant, 4—important/relevant, and 5—very important/very relevant) to assess the level of importance or relevance of the barriers.

Our questionnaire was structured as follows: (i) company profile; (ii) questions associated with patterns of energy enduse and the company's methods of conducting EEI; (iii) barriers to energy efficiency. The questionnaire was sent out by email between February and April 2016, along with the explanation of the study' aims and the confidentiality statement. In addition to the email correspondence, a study visit was conducted at the company site, where respondents were interviewed to further understand the Indonesiaan steel industry's individual site-spesific conditions. Table 2 shows the more technically related details of the study.

Table 2. Research data.

Data collection method	: Structured questionnaire sent out to respondents by email
Time frame	: February–April 2016
Geographical area	: Indonesia
Population under study	: Steel manufacturers with NACE Rev. 2 [1] code CH 24.10 which had an electric arc furnace or blast furnace
Population census	: 18 firms
Sample size	: 12 firms with 38 personnel respondents
A valid response rate	: 67% of firms

[1] Statistical classification of economic activities in the European Community.

3. The Development of Conceptual Framework Regarding Barriers to EEI

A number of previous studies cited in this article, such as [33,35–59], have declared that the barriers are not interrelated and that each obstacle is considered independent from another. These impediments might relate to more than one barrier category due to overlap and the implicit interactions between them [26]. Some research about the barriers to the implementation of energy efficiency measures has shown the relationships between these constraints.

A barrier model is developed by [60] using five barriers: awareness and information barriers, financial–economic barrier, structural-institutional barrier, policy-regulation, behavioral-personal barrier. To analyze the structure of energy efficiency barriers, they used the analytical hierarchy process. The key finding of this research was that obstructions may have multi-structurallevel. In this case, the financial–economic barrier and behavioral–personal barrier arose as the top two constraints to improved energy efficiency.

The link between each barrier to compile a hierarchy of the impediments to energy efficiency in Chinese industrial companies is examined by [61], using interpretive structural modeling. According to this study, an analysis of the connections among the barriers to energy efficiency implementation helped decision makers to formulate pertinent policies. Furthermore, the important barriers to and drivers of energy savings in Thai industries is explored by [62]. The management gave a higher priority to production issues than energy efficiency measures. Their study presented a conceptual framework for decision-making regarding energy efficiency investment that is based on a study of interconnected barriers.

A framework referred to as motivation, capability, implementation, and results is proposed by [24], with classifying 16 key barriers encountered by 16 surveyed companies. The framework interconnected a series of four stages: motivation, capability, implementation, and results. To draw up the series, they adopted a systems thinking approach that could provide a number of advantages, as follows: (i) the framework considered connections among the barriers and different categories of hindrances built upon the series of implemented energy-efficient processes; (ii) the model could be employed to review the stage that still require improvements; and (iii) the framework is flexible because of its capability to exhibit the roles and obligations of stakeholders in energy efficiency implementation. The correlation among obstacles to energy efficiency, is analyzed by [56], for undertaking a preliminary study. The aim of this analysis was to comprehend the dynamics and the relationships among categories of barriers and to provide statistical evidence of the connection level through a correlation coefficient value that might portray the linkages among them.

To emphasize the linkages among obstacles to EEI, a barrier map based on the categorization of the barriers is developed by [57]. This category dealt with barriers such as structural, market interaction, and performance barriers. The mapping could be used to identify the strategic barriers and obtain the potential measures for saving energy. The results of their study showed that among the barriers, the lack of pipes or infrastructure, lack of investment returns, and capital cost were considered the most highly connected hindrances.

According to [25], there were three types of interconnection dynamics among the impediments—namely, causal relationship, composite effect, and hidden effect. By involving all the relevant contributions, they proposed a novel approach related to relationships between barriers. The issues of the research are as follows: (i) in the existing barriers framework, all the factors related to the identified barriers in the literature have not been incorporated; (ii) the emergence of the barrier overlap phenomenon renders an inapposite and disconcerting categorization; (iii) the spectrum of how the barriers' impact affects on the decision-making of the firms; and (iv) the comprehension of the mechanisms and dynamic connections among the barriers have not been fully elaborated.

4. Theory Development

4.1. Proposed Conceptual Framework

According to [13], various studies on barriers have been carried out in order to, among other aims, categorize barriers and provide policy recommendations. Furthermore, the categorization of barriers could provide some potential solutions so that the decision maker could select measures to overcome the obstacles is argued by [57]. Based on a literature review, our study attempts to identify which barriers are frequently encountered (Figure 2). If there are different terms that have the same meanings—for example, staff, personnel, expertise, skill, competence, and human factor—these concepts are considered as one. How often a concept is employed across all the frameworks of barriers is indicated by the number on the right side. From the mapping of barrier categories, the top 10 ranking is presented in descending order, considering how often a barrier category is used acrossall the frameworks, as shownin Table 3. On the basis of the barrier rankings that have been revealed above, we attempt to draw up the barriers' wheel of an energy efficiency conceptual model (Figure 3).

Table 3. Ranking of the barrier categories from the literature study results.

Rank	Barrier Category	Total of Use
1	Financing/Financial/Finance/Capital	16
2	Institutional/Organizational	13
3	Information/Informational	12
4	Economic	11
5	Market structure Technical	8 8
6	Expertise/Skill/Competence/Personnel/Human factor/Staff	7
7	Regulation/Policy/Regulatory Behavioral/Social/Cultural	6 6
8	Market failure Awareness Technological innovation	5 5 5
9	Management/Managerial Cost/Pricing/Prices/Profitability/Relative advantage	4 4
10	Infrastructure/Premises	3

Barriers category	Blumstein et al. (1980)	Gruber and Brand (1991)	Reddy (1991)	Jaffe and Stavins (1994)	Painuly and Reddy (1996)	Weber (1997)	de Almeida et al. (2003)	Cooray (1999)	de Groot et al. (2001)	Harris et al. (2000)	Sorrell et al. (2000)	Brown (2001)	IPCC (2001)	Reddy (2002)	Thiruchelvam et al. (2003)	Anderson and Newell (2004)	Sorrell et al. (2004)	Reddy (2007)	Sardianou (2008)	Schleich and Gruber (2008)	Shi et al. (2008)	Oikonomou et al (2009)	Kostka et al. (2011)	Muthulingam et al. (2011)	Okazaki and Yamaguchi (2011)	Cooremans (2012)	Fleiter et al. (2012)	Trianni and Cagno (2012)	Walsh and Thornley (2012)	Cagno et al. (2013)	Karakaya and Sriwannawit (2015)	Olsthoorn et al. (2015)	Meath et al. (2016)	Total of use
Incentives	√																√																	2
Information/Informational	√	√			√								√	√			√			√	√		√				√	√				√		12
Regulation/Policy/Regulatory	√													√							√	√			√							√		6
Market structure	√						√					√	√						√		√								√	√				8
Financing/Financial/Finance/Capital	√	√	√		√				√				√	√	√	√	√		√	√	√		√								√		√	16
Custom/General	√				√				√																									3
Management/Managerial		√																			√										√		√	4
Consultancy		√																																1
Consumer-related			√																															1
Equipment manufacturer-related			√																															1
Utility-related			√																															1
Government-related/Politics			√																											√				2
Market failure				√		√	√				√	√																						5
Non-market failure				√							√																							2
Technical					√		√	√						√							√				√		√			√				8
Institutional/ Organisational					√	√		√			√		√	√		√			√		√		√							√		√	√	13
Cost/Pricing/Prices/Profitability/Relative adv.					√					√			√														√							4
Behavioural/Social/Cultural						√					√		√	√										√						√		√		6
Awareness							√							√	√													√		√				5
Economic							√	√						√	√	√					√	√			√					√	√	√		11
Internal conflict							√																											1
Systemic								√																										1
Uncertainty									√											√														2
Expertise/Skill/Competence/ Personnel/Human factor/Staff										√				√					√									√		√		√	√	7
Other reason										√															√									2

Figure 2. Mapping of barrier categories.

Barriers category	Blumstein et al. (1980)	Guber and Brand (1991)	Reddy (1991)	Jaffe and Stavins (1994)	Painuly and Reddy (1996)	Weber (1997)	de Almeida et al. (1998, 2003)	Cooray (1999)	Groot et al. (1999, 2001)	Harris et al. (2000)	Sorrell et al. (2000), SPRU (2000)	Brown (2001)	IPCC (2001)	Reddy (2002)	Thiruchelvam et al. (2003)	Anderson and Newell (2004)	Sorrell et al. (2004)	Reddy (2007)	Sardianou (2008)	Schleich and Gruber (2008)	Shi et al. (2008)	Oikonomou et al (2009)	Kostka (2011)	Muthulinggam et al. (2011)	Okazaki and Yamaguchi (2011)	Cooremans (2012)	Fleiter et al. (2012)	Trianni and Cagno (2012)	Walsh and Thornley (2012)	Cagno et al. (2013)	Karakaya and Sriwannawit (2015)	Olsthoorn et al. (2015)	Meath et al. (2016)	Total of use
Technological innovation													√									√			√					√		√		5
Trade													√																					1
Environment/Environmental													√									√												2
Coordination															√																			1
Infrastructure/Premises															√										√								√	3
Hidden cost																	√																	1
Micro barriers																		√																1
Meso barriers																		√																1
Macro barriers																		√																1
Bounded rationality																	√			√														2
Risk																	√			√														2
Investor/User dilemma																				√														1
Public opinion																						√												1
Intellectual property																									√									1
Base barriers																										√								1
Sympton barriers																										√								1
Real barriers																										√								1
Hidden barriers																										√								1
Resources																												√						1
Difficulties																												√						1
Structural																													√					1
Performance																													√					1
Interaction																													√					1
Energy supplier																														√				1
Capital supplier																														√				1
Sociotechnical																															√			1

Figure 2. Mapping of barrier categories (*continued*).

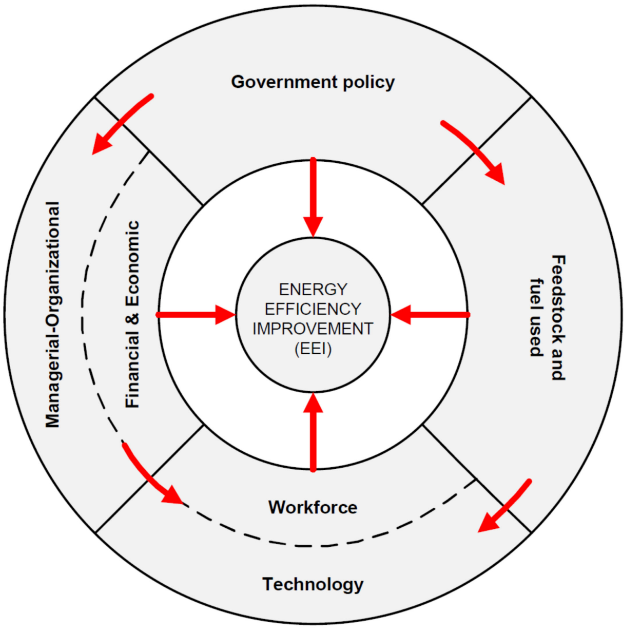

Figure 3. A conceptual model for improved energy efficiency proposed. EEI: energy efficiency improvement.

4.2. Hypotheses Development

The six selected barrier factors may or may not be able to explain the EEI in the Indonesian steel industry. It is worth noting that there may or may not be a connection among these six constructs. To answer our research objective, which we derived based on preceding discussions, the constructs and its indicators are further presented in Table 4, and hypotheses 1 to 7 are conceptually illustrated in Figure 4.

Table 4. Category and indicator of barriers to the implementation of energy use saving.

Category of Barriers	Indicator of Barriers	References
Government policy	(1) Absence of economic incentiveregulation (2) Inadequate of incentive amount (3) Distortion in energy efficiency policy	[19,35,44,50,53]
Financial and economic	(4) Slow rate of investment return (5) High initial capital cost (too expensive initially) (6) Hidden costs	[12,19,25,41–43,46,47,49–51,53,58,59]
Managerial and Organizational	(7) Low status of in-house management program related to energy efficiency measures (8) Resistanceto change (9) Complex decision chain	[19,25,35,40,43,47,49,51,58,59]
Technological	(10) Technologies not available and adequate (11) Lack of the integrated technical capability required for implementing new technologies (12) Long period for adjustment of a new equipment	[19,25,35,43,44,50,55]
Workforce	(13) Lack of skilled technical personnel (14) Lack of staff awareness or motivation (15) Personnel focuses their attention to daily production problems (16) Lack of employee training on energy conservation	[35,41,44,49,55,59]
Quality and type of feedstock and fuel used [1]	(17) Quality of raw material (18) Quantity of scrap (19) Type of energy used (20) Energy prices are subject to fluctuations	[49,55,57,63–65]

[1] The newly proposed category of barrier.

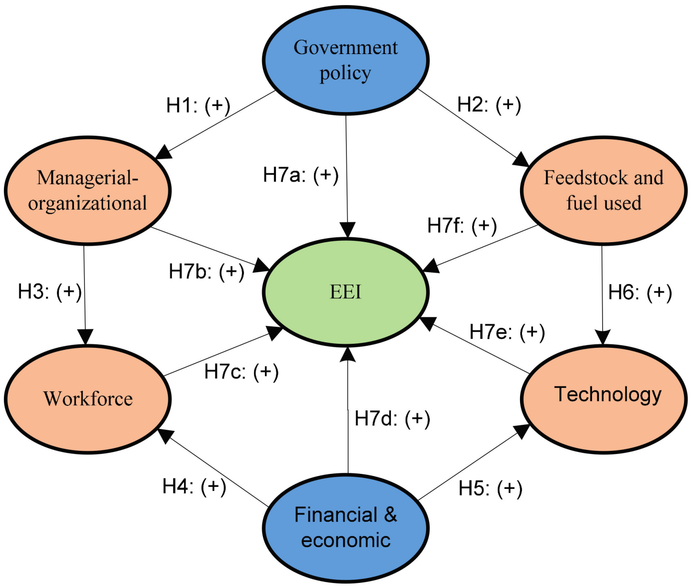

Figure 4. The proposed conceptual framework with hypotheses.

The government policies influence the management of an organization is stated by [66]. This impact is most likely related to the government's position as one of the company's stakeholders. Meanwhile, an important role of government endorsement was to drive the innovation of energy-saving technology was stated by [67]. Based on a study by [19], it was found that an appropriate policy design was required to alleviate internal and external barriers to the adoption of cleaner production. A new technology could not be adopted because there was no policy to suppress energy prices was highlighted by [53]. A policy intervention was crucially required to raise the growth rate of energy productivity, as was done by the government of India with the launching of the National Mission on Enhanced Energy Efficiency under the National Action Plan on Climate Change [68]. The government should establish policies and supporting schemes related to energy efficiency to minimize the existing barriers was declared by [3]. This is further emphasized by the European Energy Efficiency Directive, which has the aim of removing market barriers and imperfections [69]. US legislation and commissions issued the regulation of electricity prices that increase incentives for energy efficiency and market efficiency performance [22]. Thus, it is important to investigate these relationships:

Hypothesis 1 (H1). *The government policy factor has a positive impact on the managerial–organizational factor.*

Hypothesis 2 (H2). *The government policy factor has a positive impact on the used feedstock and fuel.*

From the production perspective, energy efficiency deals with productivity, which eventually has a impact on economic outcome and management [70]. Financial and economic barriers are classified into primary external impediments, together with policy and market barriers. Hence, the effect of these obstacles is very difficult for the company to control [19]. Related toeconomic barriers, [21] stated that the existence of additional or hidden costs can cause the non-adoption of energy efficiency measures. For several companies that lack budget funding, the high initial capital cost becomes an obstaclefor modernization and the upgrading of energy efficiency technology [41,60].

Further, according to [71], more than 90% of the firms are unwilling to expend funds to improve the knowledge and skill their workforces through energy management workshops or training courses, hence, in many companies, there is frequently a lack of skilled technical personnel. This factor can also inhibit the deployment ofenergy efficiency measures [49,72]. Thus, it is important to explore these relationships:

Hypothesis 3 (H3). *The financial–economic factor has a positive impact on the technological factor.*

Hypothesis 4 (H4). *The financial–economic factor has a positive impact on the workforce factor.*

According [73], improved energy efficiency can be achievedviatwo main paths—namely, management and technology. The employment of a full-time energy manager is recommended by [74]. This position is incorporated into the management structure, and the individual has full responsibility for energy enduse, as well as the authority to make decisions regarding energy efficiency measures. When technology requires capital, energy management practices require the knowledge, attention, and awareness of the workforce [75]. According to the personal communication that was analyzed by [76], fewer than 10 employeeshad expertise in the field of energy end-use efficiency related to the management of a large company.

In a study done by [77] in the foundry industry, it was found that the performance of specific energy consumption is affected by both energy management and technological aspects. When photovoltaic technology was implemented in rural areas, unsuitable and inadequate management was one of the major obstacles to the dissemination of this energy-saving system [58]. Therefore, a firm has to define a long-term energy strategy for guiding the implementation of energy efficiency measures [78,79]. Thus, we formulate the following hypothesis:

Hypothesis 5 (H5). *The managerial–organizational factor has a positive impact on the workforce factor.*

During the iron ore concentration and agglomeration steps, energy end-use depends on the implemented process technology and the quality of the iron ore used [80]. In line with this fact, [81] also mentioned that the energy intensity is determined by factors related to the feedstock and material routing. In primary steel production, the substantial energy enduseis due to a process of reducing the iron ore [82]. Meanwhile, the scrap (recycled steel) use is a significant factor for improving energy efficiency [63]. Thus, electric arc furnace (EAF) production routing may be preferable to the integrated blast furnace (BF)/basic oxygen furnace (BOF) technology.

Related to feedstock prices—namely, iron ore, coal, coke scrap, electricity, and natural gas—the changes in the input prices have an impact on energy intensity within each steel production route [65]. Hence, when there is an increase in scrap prices, the BF/BOF technology is more attractive than the EAF method. However, higher electricity prices make the EAF production route more interesting than the primary steel productionroute. In the Thai industry, the energy price increases led to the requirement to improve energy efficiency [62]. Therefore, the following hypothesis is suggested:

Hypothesis 6 (H6). *The used feedstock and fuel has a positive impact on the technological factor.*

Furthermore, also based on the literature studies, we expect a significant impact on energy efficiency adoption for six constructs. Thus, we can postulate the following hypotheses:

Hypothesis 7 (H7a). *The EEI is positively influenced by policy.*

Hypothesis 7 (H7b). *The EEI is positively influenced by the financial–economic factor.*

Hypothesis 7 (H7c). *The EEI is positively influenced by the managerial–organizational factor.*

Hypothesis 7 (H7d). *The EEI is positively influenced by the technological factor.*

Hypothesis 7 (H7e). *The EEI is positively influenced by workforce.*

Hypothesis 7 (H7f). *The EEI is positively influenced by used feedstock and fuel.*

5. Results

5.1. The Measurement Model Evaluation

In order to test the scale validity or reliability of the observed variables, composite reliability and Cronbach's alpha (α) were calculated (Table 5). These indexes reflect the degree of internal consistency of the indicators that represent the common construct. Our results show that composite reliability and Cronbach's alpha coefficients of constructs exceed the value of 0.60, which confirms the degree of internal consistency of the measurement variables. The value is still recommended in an exploratory study [83]. The value of the composite reliability was above the minimum level of 0.60 in all cases [84].

Table 5. Overview of measurement and their criteria.

Construct Variable	Composite Reliability	Cronbach Alpha	AVE	Indicator/Observed Variable	Factor Loadings [2]
Government policy (*X*1)	0.861	0.751	0.678	Incentive regulation (*X*11) Incentive amount (*X*12) Distortion in policy (*X*13)	0.944 0.650 0.848
Financial–economic (*X*2)	0.821	0.673	0.606	Slow rate of return (*X*21) High initial capital cost (*X*22) Hidden costs (*X*23)	0.842 0.731 0.758
Managerial–organizational (*Y*1)	0.793	0.608	0.565	Low status (*Y*11) Resistance (*Y*12) Complex decision chain (*Y*13)	0.781 0.833 0.626
Technological (*Y*2)	0.896	0.825	0.743	Technologies (*Y*21) Technical capability (*Y*22) Long period (*Y*23)	0.864 0.926 0.792
Workforce (*Y*3)	0.773	0.607	0.469	Skilled technical personnel (*Y*31) Staff awareness (*Y*32) Personnel focus (*Y*33) Employee training (*Y*34)	0.729 0.471 0.821 0.670
Used feedstock and fuel (*Y*4)	0.892	0.833	0.679	Quality of feedstock (*Y*41) Quantity of scrap (*Y*42) Type of energy used (*Y*43) Energy prices (*Y*44)	0.890 0.911 0.868 0.583
EEI (*Y*5)	0.738	0.470	0.492	High priority to EEM [1] (*Y*51) Management capability in EEM [1] (*Y*52) Supervision of EEM [1] (*Y*53)	0.524 0.750 0.798

[1] EEM: Energy Efficiency Measures; [2] p-value < 0.001 for all factor loadings.

Furthermore, to establish the convergent validity and divergent (discriminant) validity, confirmatory factor analysis was conducted. The value is examined by three indices: composite reliability is greater 0.6; all standardized factor loadings are more than 0.7 with a significance of p-value; and average variance extracted (AVE) is more than 0.5 [83]. In some cases, the standardized loadings between 0.40 and 0.70 could still be viewed as maintained, mainly for a new questionnaire [85]. In our empirical results (see Table 5), all the constructs meet the three criteria suggested by [83], with the exception of Cronbach's alpha and the AVE value for the EEI factor, which is not fulfilled.

Discriminant validity assesses whether each construct is different from the others [31]. This validity exists if the square root of the AVE for each individual construct is greater than the correlation between each pair of constructs. As shown in Table 6, the square roots of AVEs are denoted on the diagonal. In addition, we have also verified the cross-loading value to evaluate the discriminant validity. If all the cross-loading values of the other constructs are smaller than the construct itself, the measurement of each indicator has demonstrated the divergent validity (see Table 7).

The outer model encounters the relationship between the measurement variables (indicators) and the latent variables (constructs). This model is used to estimate the reliability and validity of the indicators related to its construct. Overall, for this study, the outer analysis confirms that all measures are reliable and valid. Therefore, we can conclude that our barriers to the EEI framework, as presented in Figure 3, are reliable and valid.

Table 6. Correlations (*r*) among constructs with square roots of AVEs.

Constructs	*X*1	*X*2	*Y*1	*Y*2	*Y*3	*Y*4	*Y*5
*X*1	0.823 [1]						
*X*2	0.123	0.779 [1]					
*Y*1	0.327 [4]	0.333	0.752 [1]				
*Y*2	0.507 [2]	0.291 [4]	0.274 [5]	0.862 [1]			
*Y*3	0.517 [2]	0.211	0.413 [3]	0.664 [2]	0.685 [1]		
*Y*4	0.474 [3]	0.139	0.347 [4]	0.567 [2]	0.498 [2]	0.824 [1]	
*Y*5	0.194	0.469 [3]	0.671 [2]	0.212	0.400 [3]	0.262 [5]	0.701 [1]

[1] Diagonal element: $\sqrt{\text{AVE}}$; [2] significant at $p < 0.001$; [3] significant at $p < 0.01$; [4] significant at $p < 0.05$; [5] significant at $p < 0.10$.

Table 7. Standardized factorloadings and cross-loadings.

Constructs	*X*1	*X*2	*Y*1	*Y*2	*Y*3	*Y*4	*Y*5
*X*11	0.944 [1]	−0.029	−0.010	−0.063	−0.077	0.031	0.058
*X*12	0.650 [1]	0.631	−0.107	0.425	−0.100	−0.141	−0.372
*X*13	0.848 [1]	−0.452	0.094	−0.256	0.162	0.073	0.221
*X*21	0.072	0.842 [1]	0.376	0.266	−0.283	−0.199	−0.248
*X*22	−0.260	0.731 [1]	0.160	−0.738	0.498	0.250	−0.440
*X*23	0.170	0.758 [1]	−0.572	0.416	−0.166	−0.020	0.699
*Y*11	−0.044	−0.378	0.781 [1]	−0.170	0.202	0.289	0.027
*Y*12	0.085	0.011	0.833 [1]	0.227	−0.430	−0.178	−0.129
*Y*13	−0.058	0.457	0.626 [1]	−0.090	0.321	−0.125	0.138
*Y*21	0.076	−0.013	0.164	0.864 [1]	−0.310	0.024	0.097
*Y*22	−0.057	0.065	0.044	0.926 [1]	0.045	0.103	0.023
*Y*23	−0.016	−0.062	0.128	0.792 [1]	0.286	−0.147	−0.133
*Y*31	0.002	0.078	0.215	−0.155	0.729 [1]	0.092	−0.009
*Y*32	−0.223	−0.649	0.441	−0.017	0.471 [1]	0.173	0.228
*Y*33	0.118	0.098	−0.168	0.154	0.821 [1]	−0.227	−0.085
*Y*34	0.010	0.251	−0.338	−0.008	0.670 [1]	0.057	−0.046
*Y*41	−0.211	0.017	0.064	−0.190	0.298	0.890 [1]	−0.153
*Y*42	−0.051	−0.011	0.059	0.279	−0.008	0.911 [1]	−0.175
*Y*43	0.358	0.065	−0.151	0.076	−0.219	0.868 [1]	0.217
*Y*44	−0.132	−0.104	0.034	−0.259	−0.115	0.583 [1]	0.184
*Y*51	−0.221	0.418	0.060	−0.119	0.283	0.019	0.524 [1]
*Y*52	0.288	−0.080	−0.244	0.376	−0.579	−0.152	0.750 [1]
*Y*53	−0.126	−0.200	0.189	−0.275	0.358	0.131	0.798 [1]

[1] Value of standardized factor loadings.

5.2. The Structural Model Evaluation

The inner model identifies the relationship among all the constructs based on theory. In other words, this model is applied to test the hypothesized relationship. According to [26], the purpose of a structural model using a PLS approach is to maximize the variance explained by the variables in the model. This goal is achieved using a calculation of the *R*-squared coefficient as the goodness-of-fit measure. Whereas [86] recommended that the suggested *R*-squared values for endogenous constructs lie in the 2% (low) to 64% (high) range, if these values are greater than 67%, it indicates the occurrence of multicollinearity among independent or exogenous variables [87].

In our research, the overall model fit is assessed by the average path coefficient (APC), average *R*-squared (ARS), and average variance inflation factor (AVIF). In all cases, to confirm that a model is fit, the *p*-values of APC and ARS must be smaller than 0.05 and the AVIF indices are smaller than 3.3. Based on Table 8, the *R*-squared values extended outward from a level of 16% up to 44%, and the fit index values satisfy the maximum requirements, so the proposed model is considered a good fit.

Table 8. Measurement of structural model.

Constructs	*R*-Squared of Endogenous Variable	Relation Category [88]
Policy (*X*1)	Exogenous variable	-
Financial–economic (*X*2)	Exogenous variable	-
Managerial–organizational (*Y*1)	0.161	Weak
Technological (*Y*2)	0.434	Moderate
Workforce (*Y*3)	0.270	Weak
Used feedstock-fuel (*Y*4)	0.439	Moderate
Energy efficiency improvement (*Y*5)	0.436	Moderate

6. Discussion

Of the 12 hypotheses proposed in this study, threewere not supported. Table 9 and Figure 5 show the results of the hypothesis testing. H1 and H2 propose that government regulation would influence the managerial–organizational performance of the firms and the feedstock and fuel used by the company. These hypotheses are fully supported by significance values of less than 0.01 and 0.001, respectively. This condition is also reinforced by the correlation values (*r*) among constructs (see Table 6) between policy and managerial–organizational (0.327) and policy and used feedstock and fuel (0.474).

Table 9. Results of structural model.

Hypotheses		Path or Structural Coefficient	Remarks
H1	: Policy → managerial-organizational	0.401 [2]	Supported
H2	: Policy → used feedstock-fuel	0.663 [1]	Supported
H3	: Financial–economic → technological	0.273 [3]	Supported
H4	: Financial–economic → workforce	0.216 [4]	Supported
H5	: Managerial–organizational → workforce	0.377 [2]	Supported
H6	: Used feedstock-fuel → technology	0.546 [1]	Supported
H7a	: Policy → EEI	−0.222 [4]	Supported
H7b	: Financial–economic → EEI	0.292 [3]	Supported
H7c	: Managerial–organizational → EEI	0.421 [3]	Supported
H7d	: Technological → EEI	0.085	Not supported
H7e	: Workforce → EEI	0.153	Not supported
H7f	: Used feedstock-fuel → EEI	0.073	Not supported

[1] Significant at $p < 0.001$; [2] significant at $p < 0.01$; [3] significant at $p < 0.05$; [4] significant at $p < 0.10$.

There is a positive relationship between the financial–economic and technological factors (H3), as well as workforce (H4). Both paths are significant, having significance values of less than 0.1 and 0.05. Respectively, the correlation values between these constructs are 0.291 and 0.211 (see Table 6). H5 tests the relationships between the managerial–organizational factor and workforce. This hypothesis is supported (*p*-value of less than 0.01 and $r = 0.413$). H6 states that there is a positive relationship between the used feedstock–fuel and the technological factor. It is found to be significant and highly correlated (*p*-value of less than 0.001 and $r = 0.567$).

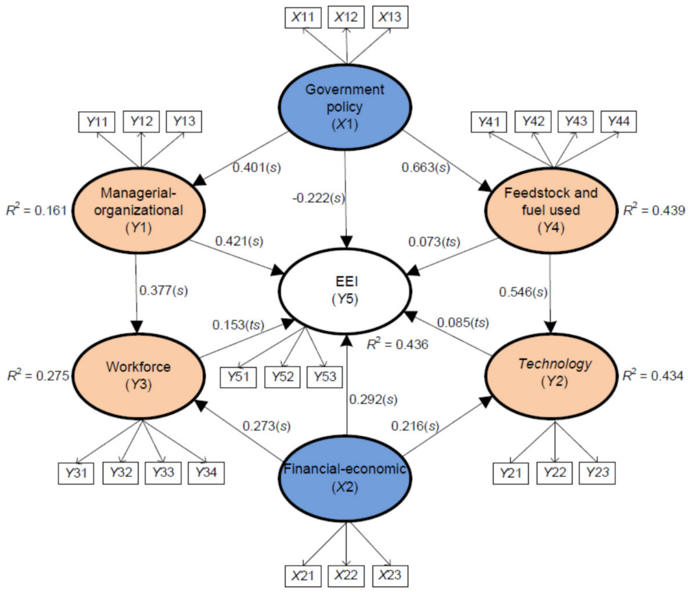

Figure 5. The proposed conceptual framework with result.

H7 concerns all constructs related to the EEI factor. It is interesting to note that there are significant (p-value of less than 0.1) and negative (−0.222) relationships between policy and the EEI factor. Thus, government policy is negatively associated with EEI programs, implying that governmental regulation regarding improved energy efficiency is not directly affected (weak correlation r = 0.194 and no significance). This finding is supported by [14], who stated that lack of policy does not directly affect the energy efficiency gap. If the government policy factor is observed through the correlation value of policy against other constructs—that is, the managerial–organizational system (r = 0.327), workforce (r = 0.517), the technological factor (r = 0.507), and feedstock–fuel used in production (r = 0.474)—this indicates that the government has to establish and issue a policy regarding EEI for each aspect. In other words, the government previously had to provide regulations related to the energy management of firms, availability guarantee and price of the feedstock and fuels consumed by steel industry, incentive and subsidy for energy-saving technology and process implementation, and support to upgrade the knowledge and skill of employees. In accordance with [72], assessing the impacts of energy efficiency policies on EEI is a complex task. Furthermore, they found that policies could not be executed in isolation, where the feedback effects of a policy could either strengthen or weaken the effectiveness of other policies. The energyefficiency regulations shouldbe designed by adjusting the barriers to the energy-efficient technology adoption to make the policy's execution more effective [89].

Our study also clarifies the conditions stated above with regard to involving indirect effects. Indirect effects are connectionsbetween one construct and another that is mediated through other constructs. As shown in Table 10, the total indirect effects of policy have the greatest value (0.271) and significant at a p-value of less than 0.1. It reveals that the mediating variables are found between the government policy and EEI factors. In this case, with the exception of the financial–economic factor, the other factors mediate the relationship between policy and the EEI variable.

The hypotheses related to the technological factor (H7d) do not have a significant influence on the EEI factor or are not supported. This result is surprising, and one possible reason for it could be that, of the 12 firms, 11 firms adopted the EAF steel-making method for the first time, and companies have, thus, never replaced that technology. Thus, the respondents do not have comparable data or evidence related to the energy-saving effects of the other steel production technologies. Additionally, the EAF in Indonesia's steel mills have an average age of 38 years (see Table 1), whereas a firm respondent that adopted the integrated BF production route had been using it for only six years.

Table 10. Analysis of direct and indirect effects.

Causal Relationship							Direct Effect	Indirect Effect	Total Effect [2]
Policy					→	EEI	−0.222	0.271 [1,5]	
Policy	→	Managerial			→	EEI	-	0.169	
Policy	→	Feedstock-fuel			→	EEI	-	0.048	0.049
Policy	→	Managerial	→	Workforce	→	EEI	-	0.023	
Policy	→	Feedstock-fuel	→	Technological	→	EEI	-	0.031	
Financial–economic					→	EEI	0.292	0.060 [1]	
Financial–economic	→	Technological			→	EEI	-	0.018	0.352 [4]
Financial–economic	→	Workforce			→	EEI	-	0.042	
Management-organizational					→	EEI	0.421	-	0.479 [3]
Management-organizational	→	Workforce			→	EEI	-	0.058	
Technological					→	EEI	0.085	-	0.085
Workforce					→	EEI	0.153	-	0.153
Used feedstock-fuel					→	EEI	0.073	-	0.119
Used feedstock-fuel	→	Technological			→	EEI	-	0.046	

[1] Sums of indirect effects for paths with two and three segments; [2] The sum of direct and indirect effect; [3] significant at $p < 0.001$; [4] significant at $p < 0.01$; [5] significant at $p < 0.1$.

The workforce was found to have no significant influence on the EEI factor. Based on the result, H7e is not supported. The explanation could be that an important feature of the steel-making process is its continuousity and the fact that it is highly automated. Consequently, workforce intervention on the shop floor is relatively limited. H7f is rejected, as the used feedstock–fuel is found to have no significant relationship with the EEI factor. Even the energy intensity relieson theraw material and its flows, varies among plants, and should not be used to compare individual plants [80].

Based on the resultsof the interviews, it was found thatwhen the Indonesian steel industry was developedduring the 1960s, the adopted process technology was based on the use of natural gasas the primary fuel. This policy was issued by the government due to the abundant availability of natural gas resources owned by Indonesia at the time. Currently, with the exception of natural gas, the energy requirement of Indonesia's steel industry is met primarily by the supply of electricity. Natural gas use is more inefficient. This is mainly due to a supply shortage for these industries (less than 80% of total natural gas demand) and an increase in its price. Facing this situation, the national steel industries reacted by switching to electricity use rather than decreasing energy intensity. The share of the electricity cost in this sector accounts for about 60% of the total energy use, while the share of natural gas and fuel oil use in this industry is 38% and 2%, respectively [18].

According to [2], energy prices also determine the price of the raw material, especially for some energy-intensive companies. Related to raw material, Indonesia's steel mills still rely on imports of iron ore, scrap, coke, and semi-finished products—that is, slab and billets. The domestic market can supply only about 30% of the total scrap requirements, whereas the scrap needs of the national steel industry have reached 5.2 million tons per year [90]. The study by [2] on the case of the Dutch industry reveals that a relationship between energy-saving behavior and energy cost seems not to exist, but it is possible for it to be valid in a highly energy-intensive industry. Hence, they also state that prices of energy is the driver of energy efficiency. This is in line with [91], who concludes that rising energy prices are among the most significant driving forces of EEI adoption.

7. Conclusions

Our study examined six categories that are related to barriers to energy efficiency:government policy, the financial–economic factor, the managerial–organizational factor, technology, workforce, and used feedstock–fuel. Further, we investigated the linkages among the categories and presented a more holistic analysis of the subject than an isolated study would have provided. This was further strengthened by the findings of [89].

The technological factor, workforce, and used feedstock and fuel were three of the variables that were expected to have a significant relationship with EEI programs. However, these hypotheses were not, in fact, supported. Keeping in mind that the path coefficient of the other hypotheses are significant, these factors have to be associated with the other factors—that is, policy, managerial–organizational factor, and financial–economic factor, so that technology, workforce, used feedstock and fuel could contribute to implementation of EEI measures.

The government regulation or policy must be mediated by factors in order to contribute to improved energy efficiency. In other words, this category had a negative path coefficient or could not directly influence energy end-use efficiency action. According to [92], government policy instruments related to setting standards for industrial energy efficiency were required to boost EEI. Whereas the individual category that had the highest direct effect on this energy-saving activity was managerial–organizational.

We expect these research results to provide preliminary insightsinto Indonesia's steel industry and inputs to be considered by decision makers with regard to establishingnew and revised policies, regulations, and interventions by the government related to EEI. The two major policy concepts for industry related to improved energy efficiency are energy audit programs and voluntary agreement programs (VAPs), also known as Long-Term Agreements (LTAs). In Indonesia, energy audit programs have primarily been used. Based on the findings of this paper, we suggest that future policy-makers may also consider more advancedpolicy programs also involving energy management, e.g., VAPs/LTAs. As noted by [93], "There is no universal approach to implement energy management practices and they can differ from company to company. These practices may involve visualization, group learning, knowledge, and exchange of experiences." Therefore, such new policy design is suggested to take into account the specific country's culture and industrial structure in order to be as cost-effective as possible.

As regards energy managers, the findings from this paper indicate a potential for further energy efficiency improvements in Indonesian steel mills. Such further improvement lies in enhanced energy management practices, but also awareness raising activities among employees, and capacity building.

The respondents ranged from technical personnel to energy managers. The researchers did not notice any differences in responses depending on the positions of the respondents in the company. However, as shown by [62,91], future research could be extended to also include other sources of information, e.g., trade associations, financial organizations, local government, and many more, to further strenghten the study's validity.

Despite the limited number of studies on mills, weconsiderthese findings to be ofinterest asan initial analysisofthebarriers to the implementation of energy use efficiency programs in Indonesia's steel mills. If referring to rules of thumb for robust SEM-PLS modeling related to the sample size that was suggested by [94], then the number of respondents in our research design was still not fully sufficient. As the study was aimed at evaluating the analytical or theoretical generalization rather than statistical generalization [27,95], thus the number of respondents were considered to be sufficient. Conducting solely a qualitative data evaluation leaves more room for fallacy and confusion, as stated by [96]. As regards potential risk of social desirability bias, the data collection did not percieve that to occur. However, the results of this paper, should be viewed in light of the fact that such may happen. In addition, previous research in other countries supports both the methodological approach used in our study, as well as the findings in the research being conducted [13,49,62,79,91]. This study is suggested to be continued, extending the approach, using both qualitative and quantitative research design, and also involving more respondents.

Moreover, although these research results could not be statistically generalized for the steel industry in another country norfor all energy-intensive manufacturing sectors, they still make an important contribution to the area of improved industrial energy efficiency and barriers to the deployment of EEI. Furthermore, this preliminary framework investigation provides an indication of a foundation for, and new insight into, future studies on Indonesia's steel industry, as well as other industrial sectors.

We suggest that further research should be conducted to deepen the study of each barrier category in order to promote a more comprehensive understanding of EEI deployment. In addition, further research could also be broadened to other energy-intensive manufacturing sectors. Finally, a study of the effective drivers or driving forces ofenergy efficiency is needed and could shed more light on decreasing and overcoming the obstacles that have been discussed.

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

Appendix A. Summary of Questionnaire

On a scale of 1–5, indicate whether you 1 (very unimportant/very irrelevant)–5 (very important/very relevant).

Appendix A.1. Government Policy

1. Absence of economic incentiveregulation for industry that implements the EEI.
2. Lack of incentive amount.
3. Distortion in energy efficiency policies.

Appendix A.2. Financial and Economic

4. Slow rate of return on the investment.
5. High initial capital cost.
6. Hidden cost of production disruption/inconvenience.

Appendix A.3. Managerial and Organizational

7. Low priority given to energy management.
8. Management resistance to change.
9. Long decision-making process.

Appendix A.4. Technological

10. Inadequate energy-efficient technologies.
11. Lack of the integrated technical skill.
12. Long period for adjustment of energy-efficient technologies.

Appendix A.5. Workforce

13. Lack of skilled technical personnel.
14. Lack of staff awareness.
15. Focus on the daily production problems.
16. Lack of employee training on energy conservation.

Appendix A.6. Quality and Type of Feedstock and Fuel Used

17. Quality of raw material or feedstock used.
18. Quantity of scrap used.
19. Type of energy or fuel used
20. Energy prices.

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