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ENERGY EFFICIENCY AND MANAGEMENT

Sustainable energy efficiency in aluminium parts industries utilizing waste heat and equivalent volume with energy management control system

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Abstract. The global aluminium industry faces a serious challenge in reducing greenhouse gas emissions as the demand for aluminium continues to increase. The aluminium industry has a responsibility to streamline its energy consumption, especially in the production process. There have been many studies discussing energy consumption performance in the industry. However, most of them only discuss energy saving partially, without involving energy consumption with various items produced. This paper proposes an energy savings measurement in the manufacturing industry. An energy baseline consumed per unit volume has been developed using the equivalent volume method with an energy management control system (EMCS). The study takes a case example from the automotive–aluminium component industry. The steps taken in the study are: examining the production process, converting the production volume to equivalent, calculating the energy consumption ratio, developing an energy baseline, simulating the savings performance, and then proposing an EMCS with key performance indicators (KPI) for sustainability. The results show that the development of a baseline using the ratio of energy and an equivalent volume of production gives a better data correlation with an R^2 value close to one. From the baseline, the best-demonstrated performance (BDP) can be used as a reference to set energy goals. Furthermore, the data and the deviant deleted have the same baseline value. They differ in energy reduction goal percentages. The practical application of this study is not only in the manufacturing industry but in other industries as well, such as building management. This study contributes to energy savings achieved with EMCS.

Keywords: energy conservation, energy management, energy report, virtual energy audit, lean manufacturing, continuous improvement, cost reduction.

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1. INTRODUCTION

Currently, the world is facing the issue of global warming and its dependence on fossil fuels [1]. The burning of fossil fuels causes the accumulation of greenhouse gases in the atmosphere. Meanwhile, exploitation and excessive consumption cause the availability of fossil energy to dwindle. Globally, the total fossil energy availability (total proved reserves for production), such as oil, natural gas, and coal, is only 49.9, 49.8, and 132.1 years, respectively [2]. Unless the world takes anticipatory action together, global warming and energy scarcity will immediately threaten the sustainability of life on Earth. There are only two ways to reduce dependence on fossil energy: increased energy efficiency (EE) and utilization of renewable energy (RE) [3]. EE helps to reduce carbon emissions, while RE provides clean and environmentally friendly energy. For that, all sectors, such as residential, commercial, and industrial, must involve renewable energy and energy efficiency. The growth of RE and EE development in all countries and sectors increases yearly [4,5]. EE and RE, particularly in developing countries, help to reduce carbon emissions, so they should be developed and suitable economic and energy policies put into practice [6]. RE specifically includes solar, wind, hydro, biomass, geothermal, and marine energy.

The industrial sector utilizes more energy than any other end-use sector. Currently, this sector accounts for around 37% of all energy delivered globally [7]. This energy is consumed by a wide range of industries, including manufacturing, mining, and construction, as well as for a variety of activities, such as processing and assembly, space heating and cooling, and lighting. With the development of human civilization and the growth of the world economy, the need for global energy will certainly increase. The world's dependence on fossil energy is still enormous, and renewable energy has not been able to replace 100% of fossil energy. In addition, dependence on fossil oil will continue to burden the environment due to exploitation. Therefore, efforts to save energy or conserve energy are necessary.

Firth et al. [8] investigated the environmental effects of potential worldwide waste heat emissions from the power generation, industry, transportation, and building sectors in the year 2030. They discovered that total waste heat emissions account for 23% to 53% of the global input energy based on the year and scenario, with potentials of 6% to 12% and 6% to 9%. Due to their economic significance, Garofalo et al. [9] concentrated on the waste heat potential of industrial processes for the vast energy and capital availability, the automotive sector for its permeation, and wearable devices for market size. In general, the potential for energy savings in industry is mostly found in production-related processes and utilities, followed by offices and warehousing [10]. Egilegor et al. [11] looked at ways to reuse more than 40% of the waste heat present in exhaust streams inside an industrial facility instead of releasing it into the environment. Su et al. [12] examined how the recovery and utilization of waste heat in different sectors can improve economic benefits, conserve energy, and reduce emissions. Wang et al. [13] developed the concept of mass-thermal network optimization in the iron and steel industry to consider current energy conservation technologies and low-grade heat recovery technologies in an overall situation. Loni et al. [14] summarized the studies about waste heat recovery technologies with the organic Rankine cycle (ORC) for high flexibility and compatibility with two waste heat sources. Araiz et al. [15] suggested using thermoelectric generators at a stone wool manufacturing plant to convert waste heat from a hot gas flow into usable electricity by combining two computational models to optimize the power output and economic cost. Zhao et al. [56] studied the use of various waste heat recovery (WHR) systems within industrial reheating furnaces to assess possible recovery efficiencies and suitability.

The metal processing industry, including the aluminium industry, is one of the industrial sectors that consumes quite a lot of energy. With the industry getting bigger or the process getting longer, the possibility of wasting energy will also increase. It is a real challenge to carry out process engineering and energy engineering so that it is efficient in energy consumption. Particularly in the global aluminium industry, energy efficiency is facing serious challenges in achieving the goal of halving greenhouse gas emissions by 2050 [16], while the demand for aluminium is expected to increase two to three times in the same year [17]. To realize energy savings, various industrial sectors have implemented EE programmes through energy audits [18]. An important factor in a successful EE programme in industry is the management's ability to engage staff and train them to become experienced in energy saving [19]. Therefore, EE programmes should include energy management, such as an energy management control system (EMCS) [20]. EMCS describes how energy management works in an organization from target to execution, with clear roles and responsibilities at each level. The adoption of an EMCS could be a useful tool for businesses to improve their production processes and day-to-day operations in the direction of energy efficiency [21]. Unfortunately, many EE programmes through EMCS have not been implemented yet by proper energy-saving measurement systems [22]. This certainly affects the determination of realistic and challenging savings targets for the next period.

Several studies have proposed strategic approaches, modelling analyses, and evaluation methodologies to realize energy savings in the manufacturing industry by implementing energy efficiency programmes. The feasibility of the suggested strategy to provide an efficient measure for promoting the sustainability of the manufacturing industry was proven by Cai et al. [23]. Andrei et al. [24] examined a knowledge-based framework to clarify the model for knowledge derived from industrial EE to current levels and the current context of industry transition. Mawson et al. [25] looked over methodologies and frameworks for analyzing energy usage at the machine process level. A multi-level holistic analysis was also given, allowing for consideration of individual machines, the manufacturing process chain, and the built environment with both discrete-event simulation and continuous-based simulation. Edgar and Keeton [26] investigated smart manufacturing (SM) systems that combine manufacturing intelligence in real time across an entire operation. They can handle systems at a much lower cost, increasing process knowledge and improving energy productivity. Zang et al. [27] proposed a data-driven analytical framework to reduce energy consumption and emissions for energy-intensive manufacturing industries. The energy and cost reductions could be achieved by 3% and 4%, respectively. Based on an integrated assessment and an energy consumption forecast, Mardani et al. [28] reviewed the various models of data envelopment analysis (DEA) for EE development. The results indicated that DEA showed great promise as a good assessment tool. Zsebik and Novák [29] gave examples and introduced tools for both short- and long-term energy planning based on historical energy use, baselines, and production schedules, as well as for prompt and short-term evaluation of monitored systems. Additionally, they displayed the outcomes and monetary gains of applying the tools at the investigated industrial plants. Lawrence et al. [30] conducted a critical analysis of specific energy consumption (SEC) using the pulp and paper sector as an illustration and in connection to industrial energy efficiency. They recommended using SEC as an ideal key performance indicator (KPI) by calculating it the same way with the same underlying assumptions in the same industry. To incorporate EE into production management, Andersson and Tollander [31] investigated the current level of energy-related KPI implementation and operationalization in the Swedish pulp and paper industry. The findings allowed for the identification of current best practices concerning energy KPIs as a potential for continuous improvement. Wen et al. [32] promoted the energy value mapping (EVM) approach. As an example, they suggested three phases: lean energy analysis using production-oriented key energy performance indicators, energy loss modelling to relate energy losses and productivity variables, and improvement strategies for managing production and energy efficiency.

Based on the reviews, many studies have discussed energy consumption performance in the manufacturing industry. The discussion focuses more on the knowledge, strategy, and framework to provide an efficient measure for promoting the sustainability of the manufacturing industry [23–25], SM systems that combine manufacturing data intelligence [26–28], methodological models of EE evaluation and measurement in high energy-consuming industries, and the analysis of energy management in manufacturing [25,29–32]. However, no study in the aluminium industry discusses in detail how to measure energy savings, especially using the method of energy consumed per unit equivalent volume produced and an EMCS. Although Zsebik and Novák [29] and Lawrence et al. [30] have discussed the baseline and energy-per-unit-volume of production, the discussion was unfortunately more about the individual process. Especially in the manufacturing industry, EE programmes must involve volume production. With the various items produced, such as aluminium parts in the automotive industry, the energy savings measurement is conducted fairly. This paper discusses the sustainable energy savings measurement in the aluminium parts industries, utilizing waste heat by developing a baseline of energy consumed per unit volume using the equivalent volume method within the framework of EMCS.

2. METHODOLOGY

2.1. Process flow analysis

Figure 1 shows the process flow of the area to be analysed for the study. This is to understand the production process to obtain improvement opportunities in energy savings from the utilization of WHR [12,33]. The flow from the sections of input, process, and output should be understood comprehensively before conducting an energy audit. The analysis further involves supporting areas such as utility, maintenance, engineering, etc. The main energy source is electricity, supplied by utility companies, and a small portion of photovoltaic (PV) modules are installed on top of factory buildings. Certain processes require energy from liquefied natural gas (LNG) and diesel oil.

This activity should identify energy-saving opportunities and provide strong recommendations after the audit. In this study, WHR is used directly from one process to another [34], not for power generation such as ORC [35]. In Fig.1, the blasting method used sand as a heat delivery medium at a constant temperature of 117 °C. The entire procedure took 60 min. It took 10 min to fill and unload. Those processes proceeded with no change in temperature. The blasting door swung wide, the hook was yanked, the goods were then lifted using a hoist, and the hanger was inserted into the cavity. The procedure was repeated 17 times per day. The total amount of work was

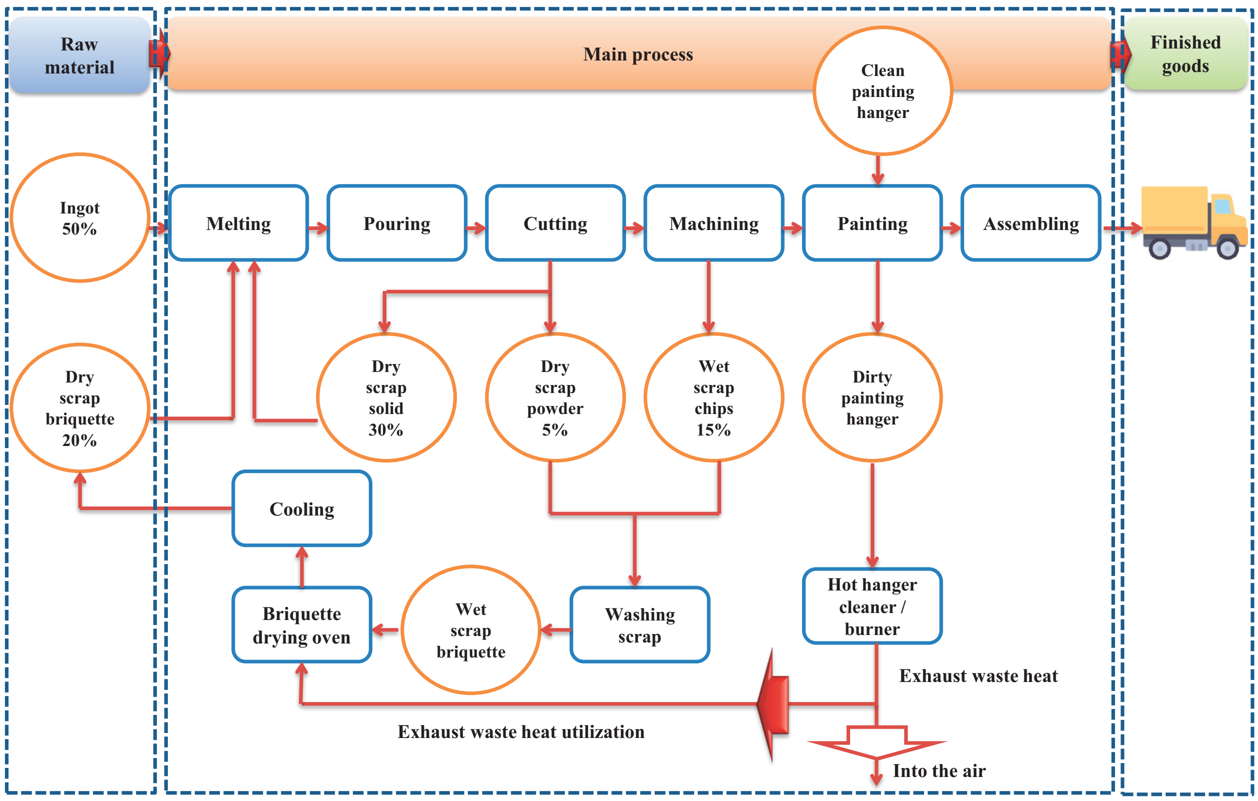

Fig. 1. Process flow of production and exhaust air utilization for scrap aluminium drying [34].

20.5 h. The average wind speed was 0.3 m/s. The discharge pipe was 1 m long. The velocity at the surface was 1017.4 m^3/h. The airflow rate determined was 1220.8 kg/h. The maximum air temperature recorded was 194 °C. As a comparison, the ambient air temperature was 30 °C.

As shown, the raw materials of 50% ingot and 50% dry scrap briquettes (DSB) go through the processes of melting, pouring, cutting, machining, painting, assembling, and becoming finished goods. The dry scrap powder (DSP) occurs in the cutting process. Wet scrap chips (WSC) occur in the machining process. The two scraps, DSP and WSC, are compressed into wet briquette scrap, dried in the briquette drying oven, and then cooled in the cooling process to be DSB. In general, the aluminium processing industry has the potential for waste heat recovery for energy savings [36,37]. The exhaust waste heat from the hot hanger cleaner is processed directly as the heat energy for the briquette drying oven. The aluminium refining process is not necessary because the scrap is not contaminated with other materials [38].

The potential energy using the hot air from the oven can be used for other processes, Q_{ex} [34] in Eq. (1):

$$Q_{ex} = \dot{m}_a c_{p,a} \Delta T, \tag{1}$$

where ṁ [kg/s] is the mass flow rate of air, $c_{p,a}$ [J/kg °C] is the specific heat of air, ΔT is the temperature difference between the high temperature of hot air T_{ex} [°C] and the ambient air temperature T_a [°C].

2.2. Baseline development

Baseline is the boundary line used as a measurement reference. In this case, baseline development is the process of developing a boundary line as a reference for measuring energy savings. The steps are:

First, transforming the volume of products to an equivalent volume by analysing the types of products correlated with the other factors, such as the total electrical capacity of production machines and utilities, cycle time, etc. [20,39], as in Eq. (2):

$$V_e = \frac{S_1}{S_{ref}} V_1 + \frac{S_2}{S_{ref}} V_2 + \frac{S_3}{S_{ref}} V_3 + \frac{S_n}{S_{ref}}, \tag{2}$$

where V_1, V_2, V_3, V_4 and S_1, S_2, S_4, S_{ref}, S_n are the types of product 1, 2, 3, referring to n and the standard process of production 1, 2, 3, referring to n, respectively. In this case, S_{ref} refers to a type of product volume as a reference to the equivalent volume of production.

Second, taking the energy consumption from the electrical meter reading and validating it with the energy bill received from the electricity company. For various types of energy consumed, each energy type is converted into a single energy type, such as electricity unit (kWh), as in Eq. (3):

$$E_n = V_n \times F_{n-el}\,, \tag{3}$$

where V_n and F_{n-el} are the volume and conversion factor of n-energy type consumed as electricity, respectively. The types and sources of the calculated energy consist of electricity (kWh), LNG (MMBTU), diesel oil (L), and PV (kWh).

Third, developing a baseline for measuring energy savings. There are several things to be considered, such as seasonal effects, volume, etc. Energy savings can be counted using methods of baseline measurement of energy savings (BMES), as in Eq. (4) [20],

$$E_{S,tot} = (C_{retv,b} - C_{retv,c}) * V_{e,c} * P_F, \tag{4}$$

where $E_{s,tot}$ is the total energy cost saved (IDR, Indonesian Rupiah). The $C_{retv,b}$ is the previous ratio of energy to volume consumed (kWh/production volume, or kg of gas/production volume). The $C_{retv,c}$ is the current ratio of energy to production volume consumed (kWh/production volume, or kg of gas/production volume). The $V_{e,c}$ is the current equivalent volume. P_F is the cost factor (IDR/kWh, or IDR/kg of gas). Then, $C_{retv,b}$ and $C_{retv,c}$ are formulated as in Eq. (5):

$$C_{retv,b} = C_{ue,b} / V_{e,b}$$

or (5)

$$C_{retv,c} = C_{ue,c} / V_{e,c}\,,$$

where $V_{e,b}$ is the previously baseline equivalent volume (unit or pcs). Both $V_{e,b}$ and $V_{e,c}$ are derived using Eq. (2). Thus, $C_{retv,b}$, $C_{retv,c}$ and $V_{e,b}$ or $V_{e,c}$ are the initial elements to identify for energy savings. The keys are the $V_{e,b}$ or $V_{e,c}$. The energy cost factor P_F must be included in electricity or gas billing separately. The cost factor P_F is given by Eq. (6):

$$P_{F,tot} = \sum_{1}^{n} \frac{P_1}{E_1} + \frac{P_2}{E_2} + \frac{P_3}{E_3} + \frac{P_n}{E_n}\,. \tag{2}$$

Fourth, simulating the energy savings performance with a baseline evaluation, as shown in Eq. (4). The simulation aims to provide an overview of the achievement of energy-saving performance over a certain period. The simulations can be performed daily but evaluations and corrections can be adjusted weekly. The simulation of energy savings periodically and routinely is easy to do if all the parameters requested by Eq. (4) are available. For this reason, tracking data to obtain the requested parameters must also be carried out in the same way and routinely. This step focuses on what actions the management should take to maintain energy-saving performance in the future.

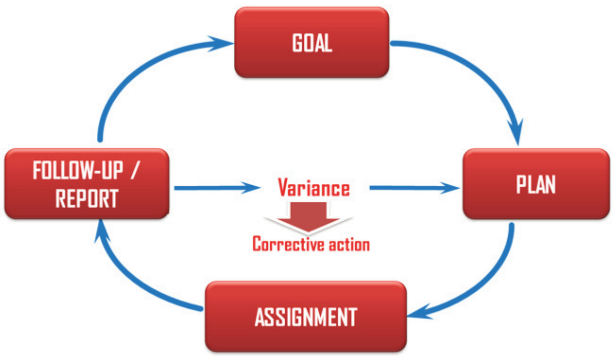

Fig. 2. System concept for energy management control system (EMCS) [20].

Fifth, proposing an EMCS with KPIs for sustainability. This should be initiated by top management at a high-level meeting to discuss the performance of the company. The goal is to gain commitment, support, and ownership from subordinates in the organization. The savings performances through EMCS can be displayed in the dashboard system, which allows the management to monitor performance in real time, anytime, anywhere. Management levels are classified as executive, middle management, and supervisory. Figure 2 depicts the EMCS system idea, which consists of a goal, plan, assignment, and follow-up/report. Plans should include goals at each level as well as tasks and follow-up on accomplishments. If there is a deviation or the achievement is lower than expected, corrective action must be taken right away. The performance information, such as meter readings, utility equipment checklists, production hourly control, regular energy audits, etc., provided by EMCS is generally sourced from a follow-up tool on the floor, called shop floor control (SFC). EMCS will assist the management in carrying out their tasks accurately at any time.

3. RESULTS

Table 1 displays the data processing of baseline development for energy consumption as an equivalent volume of production in the manufacturing industry. As shown in Table 1, the baseline period extended from January 2018 to February 2020. The production and energy data were simplified to a single unit for analysis. The production volume was converted to equivalent units using Eq. (2). The energy consumed from LNG and Diesel was converted to electricity units using Eq. (3). Meanwhile, the

Table 1. Baseline development for energy consumption to equivalent volume of production

Period	Energy (kWh)							Equivalent volume of production (pcs)					Baseline
	Electricity	LNG		Diesel		PV	Total	4 Wheels		2 Wheels		Total	kWh/pcs
	kWh	MMBTU	kWh	L	kWh	kWh	kWh	A	B	C	D		
Jan-18	2 507 638	6638	1 945 487	3228	33 500	1768	4 488 392	44 113	242 352	94 096	296 807	677 369	6.6
Feb-18	2 358 832	6277	1 839 683	10 002	103 800	1768	4 304 083	41 786	229 569	89 133	281 151	641 639	6.7
Apr-18	2 727 381	7081	2 075 322	5472	56 788	2074	4 861 565	49 210	270 353	104 968	331 099	755 629	6.4
May-18	2 701 144	7606	2 229 191	3202	33 230	2074	4 965 639	49 085	269 670	104 703	330 264	753 722	6.6
Jan-19	2 617 743	7161	2 098 769	3920	40 681	2074	4 759 267	45 924	252 302	97 960	308 993	705 180	6.7
Feb-19	2 452 135	6445	1 888 921	21 285	220 894	2074	4 564 024	42 718	234 687	91 120	287 420	655 945	7.0
Mar-19	2 757 089	7161	2 098 769	4340	45 040	2074	4 902 972	48 729	267 709	103 942	327 862	748 241	6.6
Apr-19	2 501 037	7111	2 084 115	4936	51 225	2074	4 638 451	46 399	254 911	98 972	312 188	712 469	6.5
May-19	2 412 174	7161	2 098 769	3200	33 209	2074	4 546 226	46 006	252 749	98 133	309 541	706 429	6.4
Aug-19	2 711 509	7274	2 131 887	–	–	2074	4 845 470	51 270	281 671	109 362	344 961	787 264	6.2
Sep-19	2 593 486	7024	2 058 617	–	–	2074	4 654 177	49 295	270 822	105 150	331 674	756 942	6.1
Oct-19	2 682 861	7326	2 147 128	–	–	2074	4 832 063	48 734	267 741	103 954	327 900	748 329	6.5
Nov-19	2 536 128	5967	1 748 828	–	–	2074	4 287 030	42 904	235 710	91 517	288 673	658 804	6.5
Dec-19	2 380 650	6295	1 844 959	–	–	2074	4 227 683	38 997	214 246	83 184	262 386	598 813	7.1
Jan-20	2 515 276	6544	1 917 937	–	–	2074	4 435 287	41 149	226 070	87 774	276 866	631 859	7.0
Feb-20	2 374 843	6683	1 958 675	–	–	2074	4 335 592	41 177	226 222	87 834	87 834	632 285	6.9

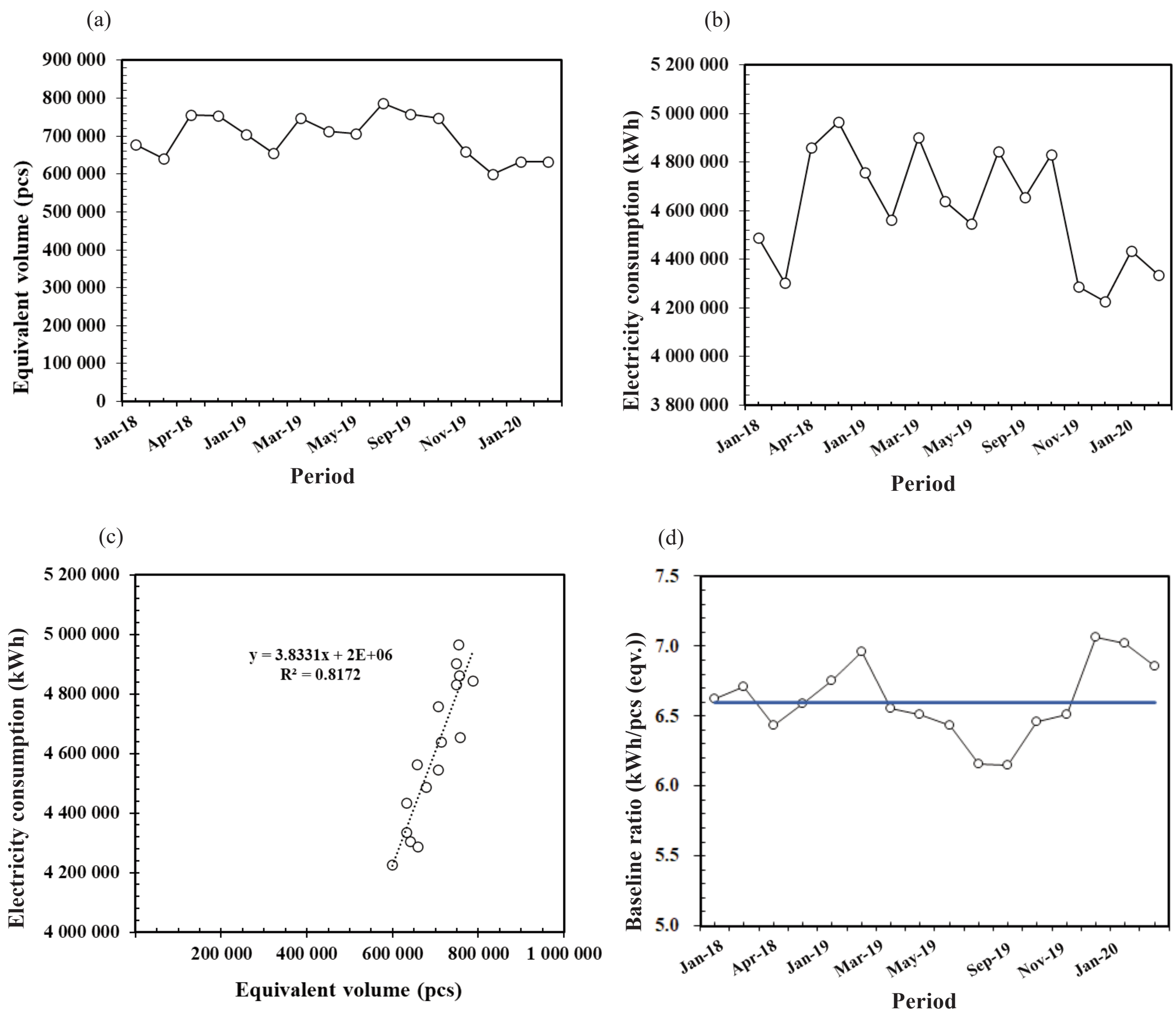

Fig. 3. Baseline development in four graphs: (a) equivalent volume of production, (b) electricity consumption, (c) correlation of energy vs production, (d) baseline ratio energy consumption/equivalent volume of production.

electrical energy (kWh) generated by the PV module was not converted but simply added up. The baseline ratio of energy consumption to production equivalent volume was determined using Eq. (5).

Figure 3 displays the baseline development process in four graphs based on data in Table 1. As shown in Fig. 3a and 3b, both equivalent products (pcs) and electricity consumption (kWh) fluctuate monthly during the baseline period. However, equivalent production is relatively stable compared to the more fluctuating electricity consumption. Besides, electricity consumption appears to decline further from the end of the year until the beginning of the following year. The correlation of the two data, equivalent products vs electricity consumption, is quite good at $R^2 = 0.81$, as shown in Fig. 3c. Figure 3d displays the baseline ratio of electricity consumption to equivalent products (kWh/pcs). As shown, both the equivalent volume and electricity consumption in the more stable months give a lower baseline ratio. In other words, during these months, electricity consumption is more efficient to produce an equivalent volume of production.

Figure 4 displays the goal setting for the energy-saving target for the following year derived from Fig. 3d. In this case, the savings target refers to the best-demonstrated performance (BDP) achieved in the previous year during the baseline period. Figure 4a shows that goal setting refers to BDP and the average as a baseline using the original data. As shown, with a BDP of 6.2 kWh/pcs and a baseline of 6.6 kWh, this equates to a 7% reduction target of energy consumption in the following year. Figure 4b shows that goal setting refers to BDP and the average as a baseline using the original data. The original data created

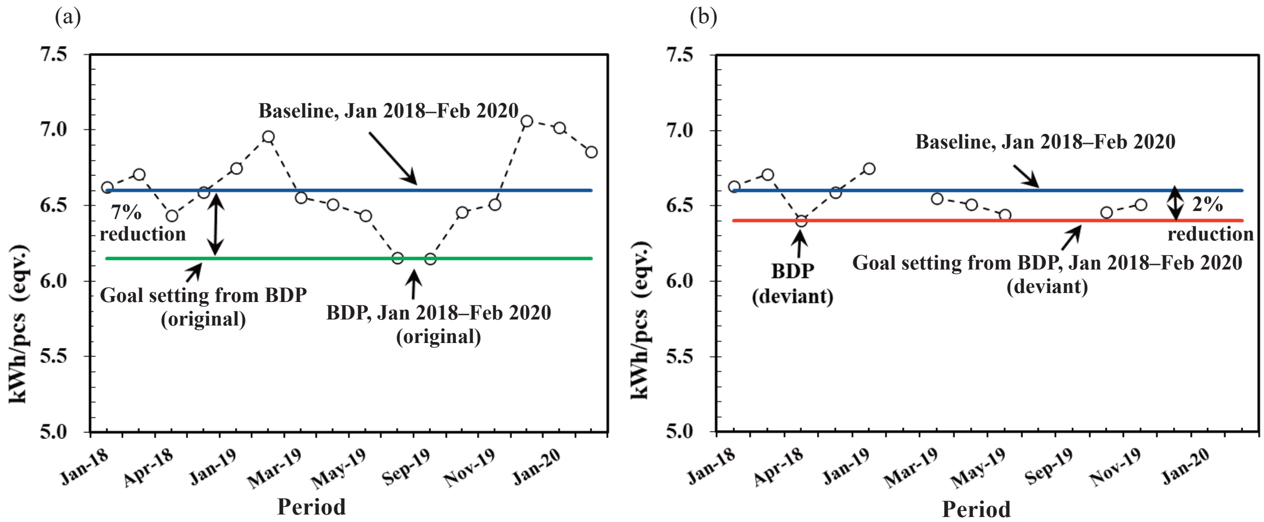

Fig. 4. Goal setting to best-demonstrated performance (BDP) for energy savings: (a) original data, (b) deviant eliminated.

norms data by eliminating the deviant data, as shown in Fig. 4b. As shown, with a BDP of 6.4 kWh/pcs and a baseline of 6.6 kWh, this equates to a 2% reduction target of energy consumption in the following year. Both Fig. 4a and 4b have the same baseline of 6.6 kWh/pcs. The summary is given in Table 2.

Table 3 displays a simulation of the energy-saving evaluation based on the baseline obtained in Fig. 3 using Eq. (1) to Eq. (6). The cost factor of electrical energy P_F is assumed as 1200 IDR/kWh [40]. The cost factor of electrical energy P_F is not always constant. Prices may increase depending on changes determined by the state

Table 2. Summary baseline development (from Fig. 4)

Data	Baseline (kWh/pcs)	BDP (kWh/pcs)	Goal setting (for next period)
Original	6.6	6.1	Reduce 7% from baseline
Deviant	6.6	6.4	Reduce 2% from baseline

Table 3. Simulation of the monthly energy-saving evaluation for March 2020–June 2021

Period	Baseline ratio (kWh/pcs)		Current ratio			Cost factor	Savings (IDR)	
	Original	Deviant	kWh	Pcs (eqv.)	kWh/pcs	IDR/kWh	Original	Deviant
Mar-20	6.6	6.4	4 500 000	710 000	6.3	1200	223 200 000	52 800 000
Apr-20	6.6	6.4	4 400 000	720 000	6.1	1200	422 400 000	249 600 000
May-20	6.6	6.4	4 300 000	730 000	6.4	1200	201 600 000	26 400 000
Jun-20	6.6	6.4	4 550 000	718 000	6.3	1200	226 560 000	54 240 000
Jul-20	6.6	6.4	4 600 000	730 000	6.3	1200	261 600 000	86 400 000
Aug-20	6.6	6.4	4 450 000	718 000	6.2	1200	346 560 000	174 240 000
Sep-20	6.6	6.4	4 650 000	725 000	6.4	1200	162 000 000	–12 000 000
Oct-20	6.6	6.4	4 530 000	738 000	6.1	1200	408 960 000	231 840 000
Nov-20	6.6	6.4	4 590 000	710 000	6.3	1200	272 400 000	102 000 000
Dec-20	6.6	6.4	4 625 000	745 000	6.2	1200	350 000 000	171 600 000
Jan-21	6.6	6.4	4 520 000	718 000	6.3	1200	262 560 000	90 240 000
Feb-21	6.6	6.4	4 580 000	720 000	6.4	1200	206 400 000	33 600 000
Mar-21	6.6	6.4	4 479 000	725 000	6.2	1200	367 200 000	193 200 000
Apr-21	6.6	6.4	4 670 000	735 000	6.4	1200	217 200 000	40 800 000
May-21	6.6	6.4	4 710 000	729 000	6.5	1200	121 680 000	–53 280 000
Jun-21	6.6	6.4	4 680 000	739 000	6.3	1200	236 880 000	59 520 000

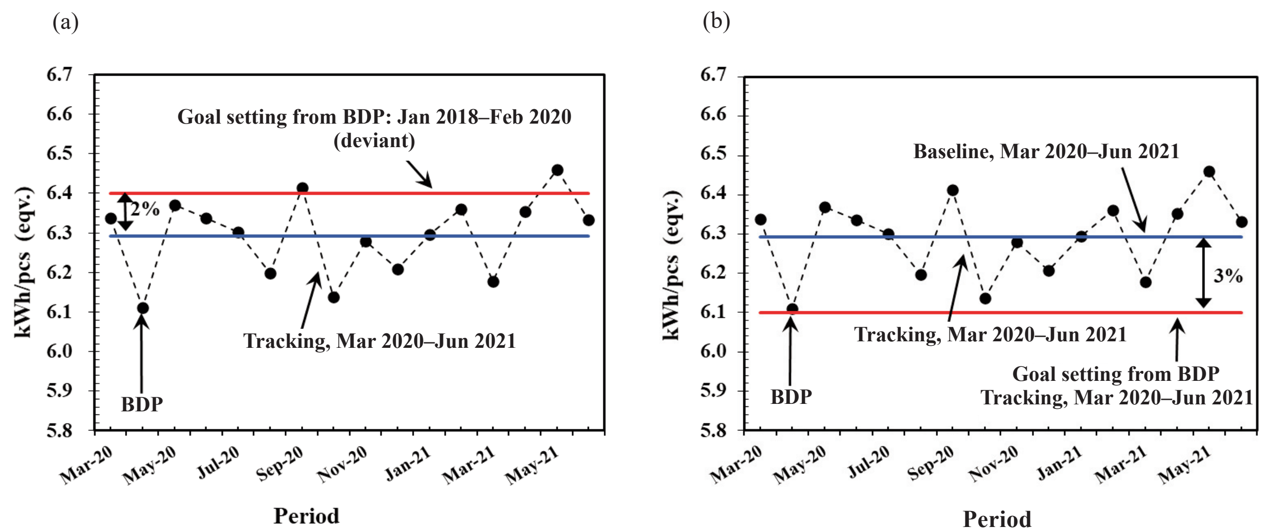

Fig. 5. Energy-saving performance March 2020–June 2021: (a) monthly tracking, (b) baseline and goal setting.

electricity company. As shown, the current energy ratio (kWh/pcs) changed according to changes in energy consumption (kWh) and production equivalent (pcs) monthly. Here, the calculation of savings (IDR) refers to the original or deviant baseline. From the simulation, energy saving will improve if energy consumption (kWh) decreases with output (pcs) increasing (the current ratio becomes smaller). That is, a greater difference between the baseline ratio and the current ratio will provide greater savings. The occurrence of minus energy savings with the deviant eliminated has been caused by a fairly high energy consumption without a proper increase in output.

Figure 5 displays energy savings performance for the tracking period of March 2020 to June 2021. Figure 5a displays the results of tracking from March 2020 to June 2021, which are based on the goal setting of the baseline deviant from January 2018 to February 2020. As shown, the achievement of tracking ratio (kWh/pcs) for May 2021 was still below the original baseline, but there were negative savings when using the baseline deviant. Figure 5b displays how the goal-setting process for the following period refers to the results of tracking from March 2020 to June 2021. As a result, there is a baseline ratio of 6.3 kWh/pcs which refers to the average, while 6.1 kWh/pcs refers to BDP. The same baseline ratio can be used for annual, monthly, weekly, and even daily tracking ratios by adjusting energy consumption (kWh) and equivalent volume (pcs). If BDP is used as the baseline reference, it means a 3% reduction as a set goal for the next period. The energy goal can be directly rolled down from top management to the ground level as a commitment to be realized together.

Figure 6 displays the detailed flow of internal information systems in an EMCS, based on the concept system in Fig. 2. The top management, middle management, supervisors, and finally the operator level all have the same goals to use less energy and be more productive. Additionally, the planning is modified in light of the objectives at every level of management. SFC is used as a field follow-up tool to make sure the goals are being met as intended. According to the circumstances on the ground level (the operator-level), follow-up frequency can be modified more often, for instance, every hour or as needed to obtain a specific amount. The crucial goal of the follow-up is to make sure there are no variances. If there is a variance, though, corrective action must be performed right away. To be considered a valid KPI in the management report, the shift, daily, or weekly performance is extracted from the SFC (green box). That is, the ground level provides real performance to the top management level via SFC. Weekly or monthly performance meeting (yellow cloud) is held where a management report is presented for the prior week or month. The key to the success of this system is: regular time, completing KPIs in management reports, attending meetings with data according to KPIs to support action plans, and ensuring all previous actions have been completed (no backlog). Table 1 provides more information on KPIs associated with this subject.

4. DISCUSSION

Based on the above results, three points need to be discussed:

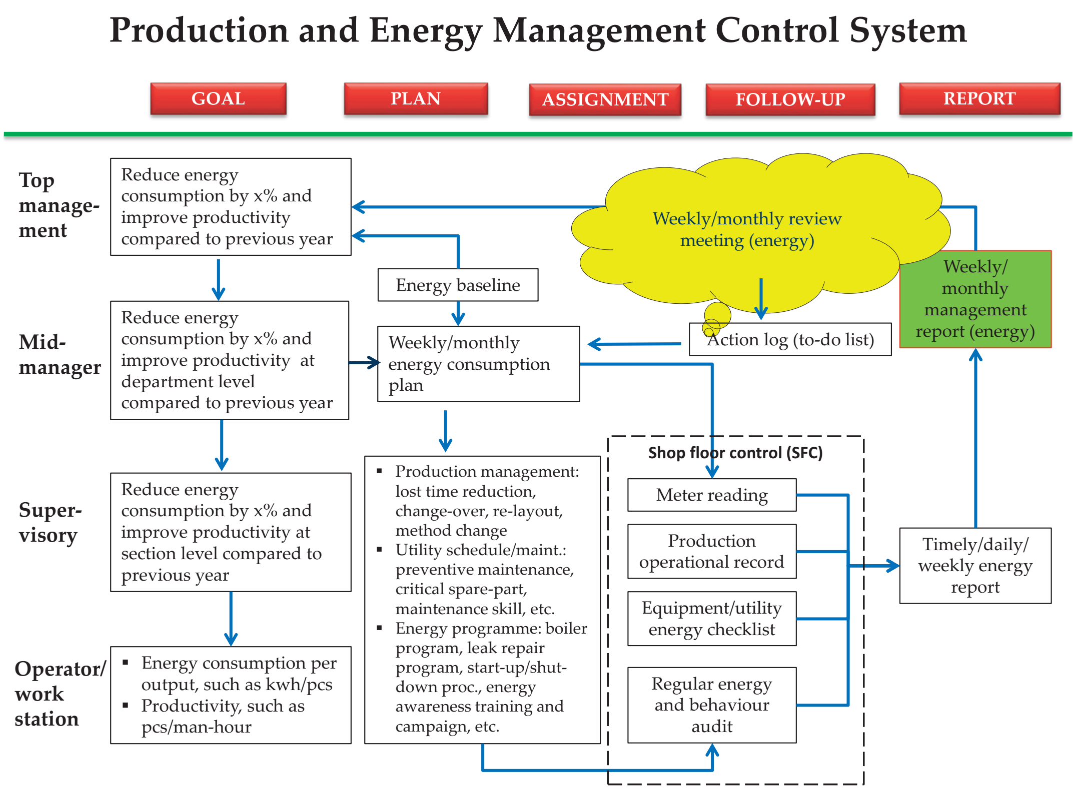

Fig. 6. Production and EMCS.

First, issues relating to further technical improvement for more energy savings. This can be done by conducting a method change with process re-engineering [36] and innovation [16], such as shortening the production process or, if possible, unifying several related processes. In addition, re-utilizing energy waste such as heat energy for the pre-treatment process needs to be taken seriously. To do this, several steps must be taken, such as re-analysing in more detail the process flow as has been done in Fig. 1 [34], making direct observations on the floor to ensure the expected improvement opportunities can be implemented properly, processing the data collected to ensure potential with engineering and economic calculations, re-engineering the system according to the calculated potential, working on system changes according to a mutually agreed plan. Changes for improvement must be planned with a good project management system. The purpose is to keep the production process as well as the ongoing energy efficiency programme running normally. Implementation of method changes during low season can also be considered so that changes can be carried out in a relaxed manner without panic and pressure.

Second, securing production lines under optimum production load conditions. To ensure that the energy in each machine as well as from the utility is consumed efficiently, the production plan must be secured for a longer time. This should be supported by good collaboration starting within the company and involving marketing, production planning, inventory control, production, utilities, etc. [41]. A stable workload for the production department will ensure optimal and efficient performance of the production process, utility, and energy. In addition, good maintenance is also carried out to ensure proper functioning of the production machines. The following points need to be considered so that energy consumption in each process becomes more efficient: reducing energy loss due to frequent start-stops, overcoming energy leaks, too long or too early pre-heating, excessive process settings, under-capacity processes, etc. For this reason, a checklist before, during, and after the production process needs to be carried out by the person in charge of the related process to ensure that everything functions efficiently.

Third, maintaining the achievement of goals against the baseline from week to week can be used as a reference in carrying out this process with the KPI [20,37]. As shown in Figs 3 and 4, the process of improving energy savings with clear goals and KPIs from previous achievements must be continued for the following year. This is a real continuous improvement process [22]. This process is still within the EMCS framework [20], related to the regular follow-up in weekly review meetings (WRM) through EMCS. For optimal results, top management should follow up on the EMCS in the weekly management report [20]. This meeting must be attended by the executive board and middle-level managers. The role of the executive here is to discuss the company's performance by the goals (including energy KPIs), which have been mutually agreed upon in advance. The WRM produces an action plan into a 'to-do list' to be followed up in the following week. The operational level should make the list and the SFC for the EMCS daily. The achievements are reported and discussed at the next WRM.

The practical application of this research is not only in the manufacturing industry but can also be applied to other industries and building management with adjustments, as necessary. This research contributes to achieving energy savings with a proper energy management control system and energy goal setting. EMCS is the basis for further continuous improvement, such as reusing the exhaust heat [42]. For further research, the energy savings in the EMCS dashboard need to integrate into a real-time tracking system by IoT technology for the management and the stakeholders [43–45], interconnected to big data intelligent systems [46–48], and cloud-based energy management systems [49,50]. Furthermore, EMCS can integrate with renewable energy systems, such as harvesting solar energy with rooftop PV [51,52] and residential biogas [53–55].

5. CONCLUSIONS

The development of an energy-saving baseline for measurements in the aluminium manufacturing industry has been discussed comprehensively. The development of a baseline should extensively analyse the process flow and the data for better understanding. The baseline used the ratio of energy consumed per unit equivalent volume of production. Some key findings can be summarized as follows:

- Baseline development with an equivalent volume of production can use original data or deviant data so that the average baseline becomes different.
- The baseline ratio of the average and BDP provides different savings targets, where the average provides a savings target of 2%, while the BDP is 7%. The target of the average baseline ratio is more moderate, while the target of the BDP baseline ratio is more challenging.
- Energy saving will improve if energy consumption decreases with output volume increasing. During the tracking period, both energy consumption and the equivalent volume of production must be properly controlled so that the savings target can be followed up to realize energy savings according to the target.
- The use of an EMCS ensures the sustainability of the targeted energy saving programme by involving all levels in an industrial organization.

This study can be used as a basis for continuous improvement to be further integrated into IoT technology for the management and the stakeholders, interconnected to big data intelligent systems, and cloud-based energy management system analysis for smart manufacturing systems.

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Säästev energiatõhusus alumiiniumosade tööstuses, kasutades heitsoojust ja samaväärset väljundmeetodit koos energiajuhtimissüsteemiga

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Alumiiniumitööstus seisab silmitsi tõsise proovikiviga kasvuhoonegaaside heitkoguste vähendamisel, kuna nõudlus alumiiniumi kui tooraine järele kasvab jätkuvalt. Alumiiniumitööstus vastutab oma energiatarbimise tõhustamise eest, eriti tootmisprotsessis. Tööstuse energiatarbimist on vaadeldud paljudes varasemates uurimustes, kuid enamik neist on käsitlenud energiasäästu vaid osaliselt, ilma et oleks arvestanud energiatarbimist erinevate toodete puhul. Selles uurimuses antakse soovitus energiasäästu mõõtmiseks töötlevas tööstuses. Välja on töötatud ruumalaühiku kohta tarbitud energia baastase, kasutades samaväärset väljundmeetodit koos energiajuhtimissüsteemiga. Uurimistöös tuuakse välja viis sammu energiatarbimise vähendamiseks autotööstuse alumiiniumkomponentide tootmise näitel: tootmisprotsessi uurimine ja tootmismahu teisendamine ekvivalendiks, energiatarbimise osakaalu arvutamine, energia baasmäära väljatöötamine, energiasäästu tõhususe simuleerimine ning seejärel energiajuhtimissüsteemi ja jätkusuutlikkuse peamiste tulemusnäitajate väljatöötamine. Tulemused näitavad, et baasmäära väljatöötamine energia ja samaväärse toodangu suhtarvu abil annab parema andmete korrelatsiooni ja ühele lähedase regressioonikordaja väärtuse. Baasmäära põhjal saab energiaeesmärkide püstitamisel kasutada võrdlusalusena parimat demonstreeritud jõudlust. Kasutatud andmetel ja saadud standardhälvetel on sama algväärtus, kuid need erinevad energia vähendamise eesmärkide seisukohast protsentuaalselt. Uurimuse praktiline rakendus on nii kasutus töötlevas tööstuses kui ka teistes tööstusharudes, näiteks hoonehalduses.