ENERGY ASSESSMENT OF STEEL WHEEL MANUFACTURING IN THAILAND

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A RESEARCH STUDY REPORT SUBMITTED AS A PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING IN ENVIRONMENTAL TECHNOLOGY AND MANAGEMENT

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ABSTRACT

This study focuses on a major steel wheel manufacturing company located in the Well Grow Industry Estate in Chachoengsao, Thailand. The objective of the research is to investigate the energy consumption associated to steel wheel manufacturing (gate-to-gate assessment), major contributing units and possible options for improvement. Data were collected from each unit process of the company and calculations made based on a number of basic rules and assumptions. It was found that a large amount of electricity is consumed to satisfy the high and constant production of steel wheel with about 291 kWh of consumed per tonne of product. The total energy consumed on an annual basis was found to amount to about 164 TJ, i.e. about 3,330 MJ per tonne of product. In comparison to another similar still wheel manufacturing process in EU, this requirement in energy appears to be large as about twice higher (about 1,730 MJ per tonne of product is consumed in the EU's case). This energy consumption is contributed at 87.4 % by electricity, 10.2 % by LPG, and 2.4 % by diesel. Most of the electricity consummed is from the compressor, i.e. about 31% of total electricity consumption. The production of steel wheel from steel sheet appears to be efficient as only 16 % of scraps are produced as compared to 29 % in the EU's case. In terms of energy cost, it was found that 85.4 % of the total cost is contributed by electricity followed by LPG with 10.9% and diesel with 3.7 %. If the steel wheel manufacturing company investigated in this study could improve the energy efficiency of its operation and reach that reported for the EU's steel wheel manufacturing company, cost saving could reach 830 THB per tonne of product, which is about 40 million THB per year.

Keywords: Steel wheel manufacturing, Energy consumption, Energy conservation, Energy efficiency, Energy cost, Thailand

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INTRODUCTION

1.1 Rationale and Problem Statement

1.1.1 Thailand's Energy Consumption History

In Thailand, over the past few decades, energy consumption has been sharply increasing as a result of economic development and is expected to continue rising to meet the demand. Fossil energy resources are limited and more than half of the national energy demand depends on energy imports. As the energy demand is increasing, the dependency on fossil energy and related imports are increasing, leading to energy security concerns at the national level for the future. This energy security challenge is also accompanied with environmental issues such as climate change, as result of increasing fossil based emissions of greenhouse gases. Therefore Energy Efficiency and Conservation policies and measures are required to address the above challenges.

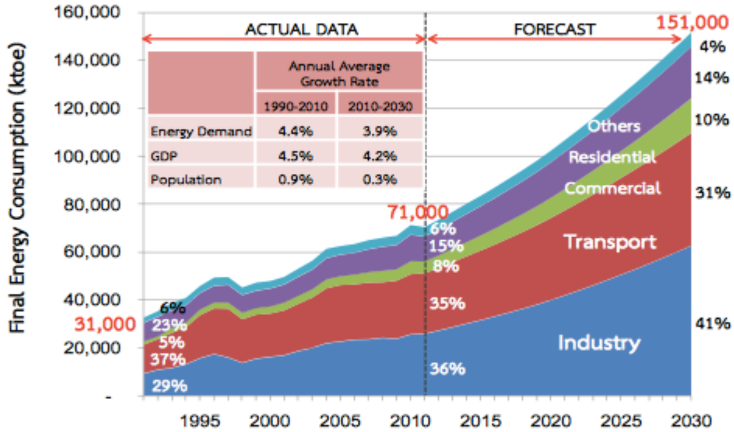

Fig. 1 Energy consumption in the past and future demand trends under the BAU case [1]

During 1990 to 2010, the Energy consumption in Thailand has been continuously increasing. It is now about 2.3 times higher than the 1990 level based on business as usual (BAU) case [1]. The growth rates of Energy consumption in the industrial and commercial building sectors are significantly increasing. In 2030, the Energy consumption of industry sector will contain 41% of overall Energy consumption so it is necessary to understand, study, and improve the Energy Efficiency in this sector. The one of high energy intensity industry is steel wheel manufacturing.

1.1.2 Thailand's Energy Efficiency Policies

In Thailand, in 1992, the National Energy Policy Office (NEPO) under the Office of the Prime Minister initiated the development of the Energy Efficiency policy by establishing the Energy Conservation Act (ENCON Act). The Energy Conservation Fund (ENCON Fund) was set up by the ENCON Act to support Energy Efficiency projects or programs in terms of finance.

In 1993, the Energy Conservation Program (ENCON Program) was established to operate the development of Energy Efficiency programs. The ENCON Act also announced Royal Decrees for "Designated Building" and "Designated Industry". To promote Energy Efficiency, the Thailand Energy Award was created so as to encourage entrepreneurs to implement Energy Conservation measures and push forward high-Energy Efficiency development.

In 2003, the Department of Alternative Energy Development and Efficiency (DEDE) was established under the Ministry of Energy and made responsible for the development of Energy Efficiency programs in Thailand. The Energy Efficiency Revolving Fund (EERF), Tax Incentive, and ESCO Fund were set up in 2003, 2006, and 2008 respectively to support the budget management. The latest Energy Efficiency policy programs set up in 2011 are the Energy Efficiency Revolving Standard (EERS) and the 20-year Energy Efficiency Development Plan (20-year EEDP) with the Building Energy Code (BEC), Energy Efficiency Resources Standard (EERS), and Demand Side Management (DSM) bidding program as related schemes.

The ongoing Energy Efficiency related programs are those shown in Fig.2 below. To improve and promote Energy Efficiency, external agencies such as the Electricity Generating Authority of Thailand (EGAT) and the Board of Investment (BOI) are also involved in this plan.

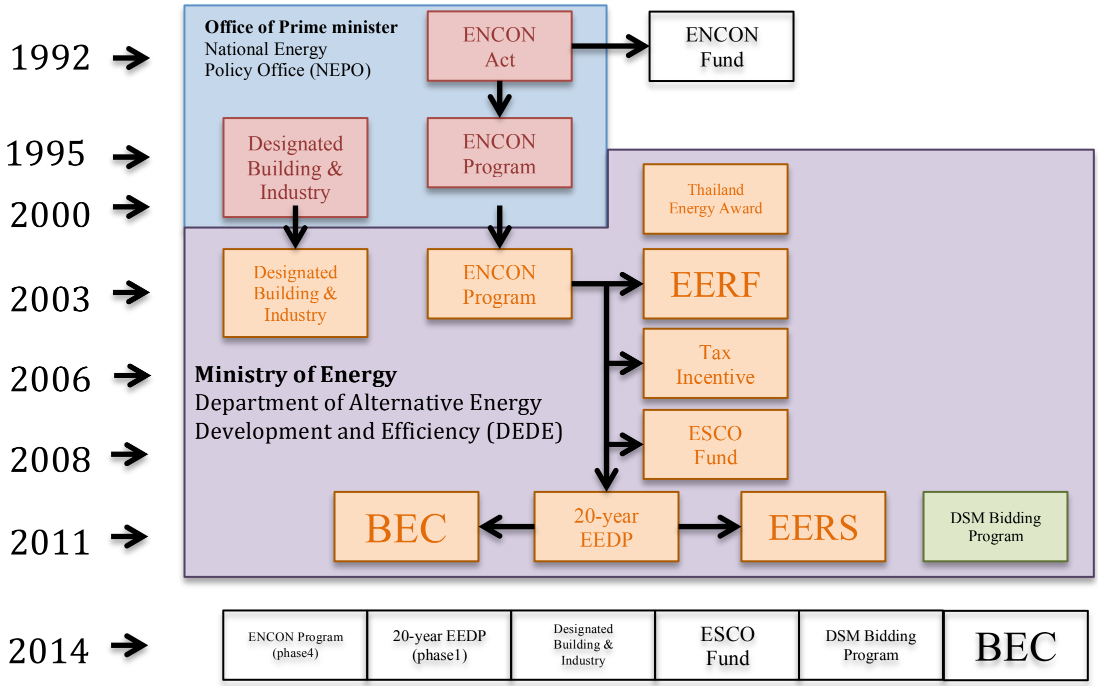

Fig. 2 Thailand's energy conservation policy's timeline

1.1.3 Background Information of Steel Industry

Steel production is a very energy intensive industry and contributes several processing steps including iron-making, primary and secondary steelmaking, casting and hot rolling. These depend on each designed process: cold rolling, annealing, tempering, coating and/or heat treatment [2]. Steel has a very high melting point (about 1,500 degree Celsius) so energy is the most important input in process and coal is used as fuel for melting and forming steel, electricity is used in process also.

Steel wheel production process has steel as the raw material and is also and energy intensive industry. To make a steel wheel for car, it is necessary to have specific, carefully, and various processes because they have to consider about safety of user first. So the energy assessment of steel wheel manufacturing is studied in this report

1.2 Scope and Objectives

This study focuses on steel wheel manufacturing (gate-to-gate approach), not including steel production and the use phase of steel wheel. The objective of the research was to investigate the energy requirement for steel wheel manufacturing, major contributing units, and associated costs. The investigations also aimed at discussing options for improvement, including already implemented ones, identifying challenges and providing some recommendations for improvement.

1.3 Literature Review

1.3.1 Life Cycle Assessment of Steel Production

Steel is one of the major materials used in the manufacturing of products. It is a basic material in diverse industries such as cars, furniture, etc. In Thailand, over the period 2004-2008, steel consumption increased by about 0.8 million tonnes (or about 6.3%) [3]. The increased demand of iron may have direct adverse impact on the environment [4,5]. Life Cycle Assessment (LCA) is a tool that can be used to evaluate the environmental impacts associated with the steel industry [6].

The steel industry can be classified into three levels: crude steel, semi-finished steel, and finished steel. The categorization of the steel industry is shown in Fig. 3.

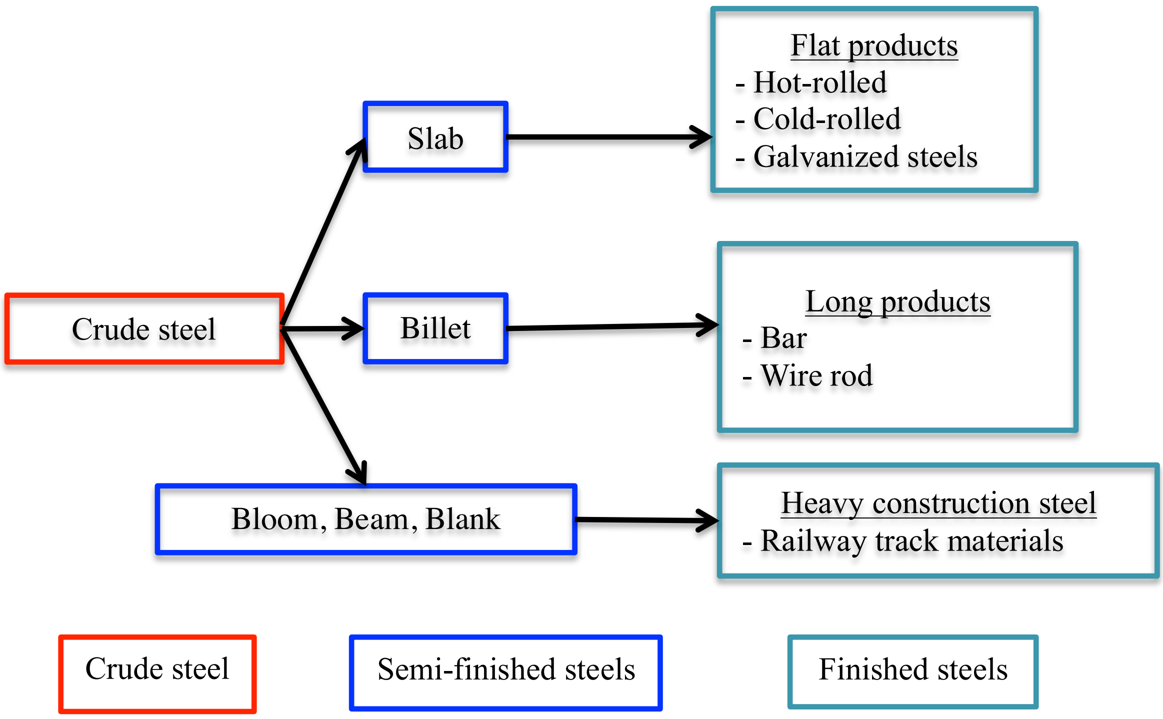

Fig.3 Steel industry categorization [6]

The first level of steel industry is crude steel. This industry provides the mineral (iron) and to produce crude steel for next step of steel production. After crude steel production, the crude steels are going to the different processes to forming in various shapes (slap, billet, bloom, beam, and blank) that is semi-finished steels. At last, the semi-finished steels are prepared to change into finished steels up to usability of work.

Tongpool et al. [6], performed an analysis of steel production in Thailand and assessed its associated life cycle environmental impact. The boundary of the production system considered is illustrated in Fig. 4.

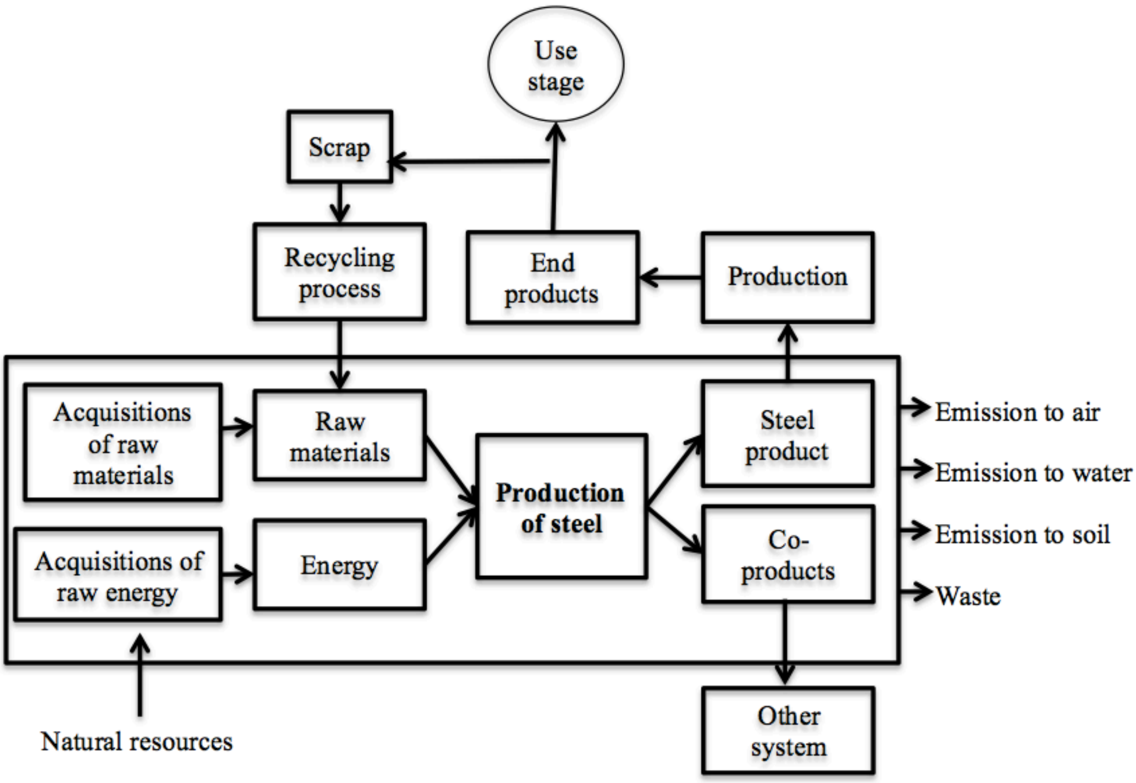

Fig. 4 Boundary of the steel product system under LCA study [6]

As part of the boundary of the steel production system illustrated in Fig. 4, the input data associated with raw materials acquisitions and energy consumption were considered as well as emissions of pollutant and wastes to air, water, and soil. The recycling of steels and scraps within the process were also included in the assessment. The impact assessment covered global warming potential, fossil fuels, ecotoxicity, minerals, carcinogens, and respiratory inorganics. The major causes of the impacts were contributed by steel, energy, and zinc (add-on material). The emissions from the steel production plant showed relatively low impacts. It was found that Small amount of zinc input can cause huge environmental impacts. The impacts related to fossil fuels, minerals, and ecotoxicity, of 1-kg zinc were found to be 2.9, 116.9, and 39.6 times of those caused by 1-kg cold-rolled steel, respectively. It was found that the reduction of zinc consumption and the improvement of zinc production process, in terms of reduction of heavy metal emissions, could largely contribute improving the environmental performance of the galvanized steels [6].

1.3.2 Life Cycle Assessment of Steel and Aluminum Wheel

Investigations associated with steel wheel manufacturing and utilizations were performed by "PE INTERNATIONAL & Five Winds Strategic Consulting" [7]. The investigations focused on a cradle-to-grave virtual LCA of aluminum and steel truck wheels. The objective of the study was to compare the environmental performance of steel wheel and aluminum wheel.

The investigations indicated that based for a typical EU steel wheel manufacturing process, steel coil and steel wires are used as raw materials, natural gas, and electricity as energy sources, air for some machines, and clear coat as coating substance. Steel wheel manufacturing consists of three main steps that are: disc fabrication, rim fabrication, and wheel assembly.

In the analysis by this study, it was found that on a per functional unit basis, aluminum wheel production impacts Global Warming Potential (GWP) more than steel wheel production by about 3.8 tonnes of CO_2 equivalents. In contrast, it was found that aluminum wheels contribute savings of 4.1 tonnes of CO_2 equivalents during the use phase over their lifetime when compared to steel wheels with a break-even point around 810,000 miles, that is, the 3.8 tons of CO_2 equivalents in production will be paid during the use phase over lifetime. With regards to other impact categories, including, smog potential, acidification potential, eutrophication potential, and primary energy demand, it was found that aluminum wheels have less impact during the use phase when compared to steel wheels (because of lesser amount of NO_x released to air during the use phase). In conclusion, the study revealed that the use of aluminum wheels appear to be more environmentally friendly than the use of steel wheels.

CHAPTER 2
THEORIES

2.1 Steel Wheel Manufacturing

A review and description of the processes involved in steel wheel manufacturing are provided in this section based on the steel wheel manufacturing company investigated in this work. A number of machines are used for steel wheel manufacturing in this factory such as hydraulic air press with diamond cutter, air pump (compressor), boiler, and so on. Steel wheel production is comprised of three key steps: wheel disc fabrication, wheel rim fabrication, and wheel assembly. Each of these steps is described in details in the next sections.

2.1.1 Disc Fabrication

The disc is the first part of a steel wheel to be produced. Steel sheet (see Fig. 5) is put in to the hydraulic machine for cutting into square and shape as a pattern, which customer ordered. In process, material (steel sheet) is prepared to be stocked before they are transferred to the blanking process. In blanking process, steel sheets are cut by a machine into desired shape. After that, blanked steel sheet will be passed through No.1 and No.2 forming, respectively, for creating a desired pattern such as bulge of the wheel. It is then pierced and trimmed for making hub hole and later re-struck for making bolt hole. Wind hole will be made by piercing and coining as same as bolt hole (see Fig. 6). The steel sheet designed will be inspected, and then unloaded. The last process is disc stock prior to assembly process.

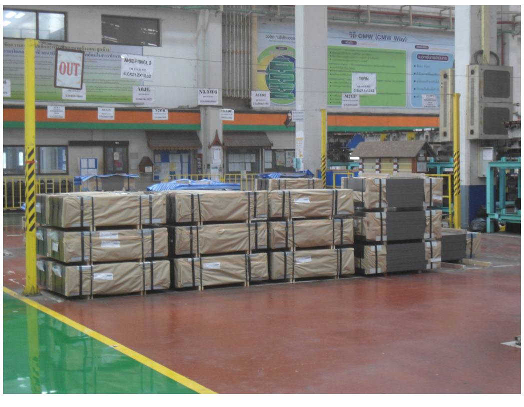

Fig. 5 Steel sheet (main material input)

Fig. 6 Pressing line operation

2.1.2 Rim Fabrication

The steel sheet is prepared to be stocked as the starting material. The steel sheet passes through the bending and marking processes to build the structure of rim and determine the weld spots. After that, the steel sheet will be welded to achieve the specified shape before trimming. The appropriate width is straightened from the edge conditioning method. Prior to pass through the multi-step of rim forming, the flaring process must be required at determined temperature for tire installation. Next, the rim is shaped by expanding stage (see Fig. 7). The flange is later fabricated by conditioning. After the rim is designed, the leak test and rim inspection must be required to check the quality of the rim before unloading and stocking.

Fig. 7 Rim line operation

2.1.3 Assembly

In the assembly line operation, the steel sheets from the trimming and pressing processes are gathered for wheel assembly (see Fig. 8). The disc and rim are firstly loaded in the line operation. The disc is then pressed fit into the rim. Hole piercing stage will be done at the rim valve. Sub-assembly process is required before the final wheel assembly for checking any distortion. A secure arc welding connects the rim and disc into the final unit. The rim will be thoroughly inspected and ran out for checking the efficiency. Finally, the assembly wheel is unloaded and prepared for the coating process in the next stage.

Fig. 8 Assembly line operation

2.1.4 Rust Protection

For keeping it rust-free, Electro-Deposit Primer (EDP) coating operation plays this important role for enhancing the high performance and protecting the wheel from rusting. To simplify the process, after the completed steel wheel is loaded, the surface pre-treatment must be achieved for cleaning the contaminants by the determined amount of hot water. Cation electro deposition is then done to chemically coat the body of the wheel. The coated wheel will be taken to the oven for baking. Next, the baked wheel is then unloaded and stocked. The final check must be emphasized by appearance inspection, arc welding inspection and flash butt checking (see Fig. 9).

Fig. 9 EDP coating operation

2.1.5 Top Coating

In this last process, if customers desire colored steel wheels, the product from EDP line goes to painting room to paint the wheel (see Fig. 10). The top coating process is physically achieved by cross-cutting operation for the testing the quality of the wheel and then transferred to the warehouse for final unloading.

Fig. 10 Top coating (painting) operation

2.2 Overall Steel Wheel Manufacturing Process Flow

As shown in Fig. 11, the disc is firstly fabricated by pressing operation. The blanking which includes 2 stages of forming process are required in a flow forming machine in order to design the production details before piercing and trimming. The disc will pass through the machine for restrike. The bolt hole and wind hold are then pieced and coined. In the same time, the rim is fabricated by trimming operation. The specified shape and appropriate width are done by welding and trimming stage. There are 3 stages of forming process required for rim fabrication. Also, leaking test and appearance inspection are lastly done in the operation line. The disc and rim from fabrication process, trimming and pressing are later assembled and transferred to the coating process.

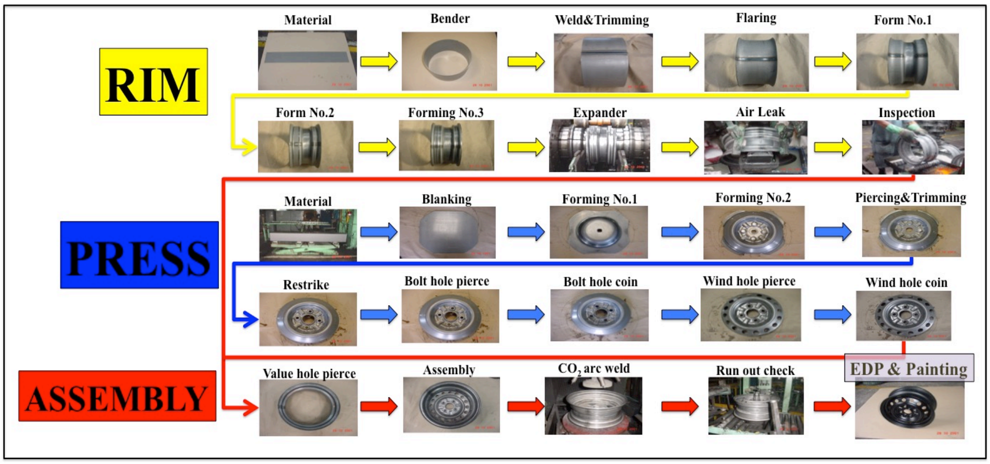

Fig. 11 Material process flow

CHAPTER 3
METHODOLOGY

3.1 Introduction of the Steel Wheel Manufacturing Company

As part of the internship study that preceded this research work, the development of energy efficiency policy, plans and tools in Thailand were reviewed to investigate how industries react to energy conservation and energy improvement measures. As part of these investigations, a number of case studies were looked at, including a steel wheel manufacturing company of which process was found to be energy intensive. This particular steel wheel manufacturing company was selected for a more in depth assessment of its energy consumption in this study. The steel wheel Manufacturing company investigated in this work is located in the Well Grow Industry Estate in Chachoengsao, Thailand. It has 240 of manpower in production line with 5 million steel wheels of productivity per year. The process consists of 2 press lines, 3 rim lines, 2 EDP lines, and 1 painting line. These products will be a part of Japanese car such as Toyota, Suzuki, Honda, and etc.

3.2 Steel Wheel Manufacturing Process

The steel wheel manufacturing company investigated imports the steel raw material they require for wheel manufacturing from Japan. The steel is then processed through a series of operations as detailed in Fig. 12. These consist of Pressing (Rim), Trimming (Disc), Assembling, and Coating.

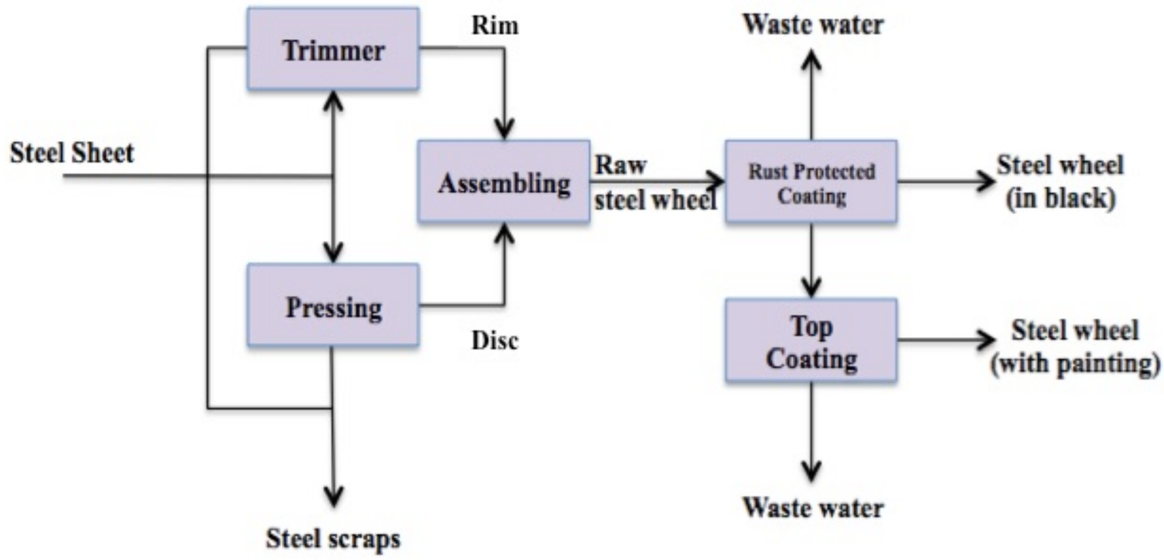

Fig. 12 Steel wheel production process flow

As can be seen from Fig. 12, the process consists in several steps as briefly described next. Firstly, steel sheets are prepared to be stocked by imported from Japan, then send them to the 2 production lines, which are Pressing line (Disc fabrication) and Trimming line (Rim fabrication) and they are stocked for assembly line. In assembly line, Disc and Rim are joined together by assembly process and the raw steel wheel are finished and stocked. As the general property of steel, it can be oxidized by air and water to cause rust. So, to complete the steel wheel production, the rust protection coating plays the important role and needs to be in a process of this production. After this process, the steel wheels are stocked in a warehouse and ready to be sold. In addition, if customers require the extra options in terms of color, the top coating (painting) is reserved in this company.

3.3 Energy Consumption and Cost Assessment

In order to evaluate the energy consumption and related costs associated with steel wheel manufacturing, the production process as described above was investigated. The investigations focused only on the steel wheel manufacturing process as depicted in Fig. 12, i.e. from steel sheet input and processing to steel wheel production. Every unit of production was surveyed and energy consumption identified for each of the machine/process involved also using records from the company. Following this initial assessment, major energy intensive processes and equipment were listed and data compiled over a year of production (2014) on a monthly basis. The energy data collected for each of the processing unit was then processed and analyzed to identify main types of energy consumed, most energy intensive units, and related energy cost. Based on these investigations, analyses were made to provide potential options/recommendations for improvement, if any, and also address important challenges/limitations that should be dealt with to optimize the production process of steel wheel energy wise. The inventory data and processing of that information for each unit of production are reported in the next chapter along with an analysis of its implications.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Inventory Data

4.1.1 Materials

Steel sheet is a key material to produce steel wheel. It is imported from Japan and has very specific characteristics. The inventory data of all material inputs and outputs that were collected for the year 2014 is reported in Table 1.

Table 1 Material input and output

Month	Steel sheet (tonnes)	Product (tonnes)	Scrap (tonnes)
Jan	4,907.608	4,138.288	769.320
Feb	5,092.283	4,296.923	795.340
Mar	5,575.482	4,724.692	850.790
Apr	4,215.765	3,565.565	650.200
May	4,595.303	3,882.603	712.700
Jun	5,265.634	4,428.274	837.360
Jul	4,841.479	4,071.049	770.430
Aug	4,552.951	3,854.791	698.160
Sep	4,919.371	4,179.011	740.360
Oct	4,898.611	4,138.401	760.210
Nov	4,824.297	4,078.447	745.850
Dec	4,504.262	3,812.952	691.310
Average	4,870.045	4,108.367	753.030

As observed from the above table, in 2014, a monthly average of 4,870 tonnes of steel sheet was processed and 4,108 tonnes of steel wheels were produced. The monthly average production of steel scrap was about 753 tonnes. The scrap produced by the factory is not reused or recycled within the process but sold to a scrap bidding company. As mentioned in Table 1, the highest steel wheel production occurred in March. This is because it is the last month of the first quarter of the year, which causes the company to complete their circulation. This can also be observed in the last month in other quarter periods of the year (June and September), the production is highest when compared to another month in the quarter. Nevertheless, the amount of wheel production is also influenced based on customers' demand.

4.1.2 Electricity

Electricity is used in every sector of the steel wheel manufacturing company. In Table 2, the monthly electricity consumption is shown for each press production line. These 2 lines of disc fabrication operate throughout the year. On an average monthly basis, they contributed about 229,659 kWh of electricity consumption in the year 2014.

Table 2 Electricity consumption in press lines

Month	Electricity consumption (kWh)		
	Press#1	Press#2	Total
Jan	121,321.00	93,728.00	215,049.00
Feb	127,983.00	98,320.00	226,303.00
Mar	152,290.00	131,172.00	283,462.00
Apr	109,710.00	95,634.00	205,344.00
May	129,705.00	96,090.00	225,795.00
Jun	158,831.00	99,010.00	257,841.00
Jul	139,698.00	99,110.00	238,808.00
Aug	133,436.00	86,224.00	219,660.00
Sep	146,190.00	86,826.00	223,016.00
Oct	143,190.00	94,608.00	237,798.00
Nov	153,585.00	90,784.00	244,369.00
Dec	131,465.00	86,690.00	218,155.00
Average	136,567.00	95,121.00	229,659.50

There are 3 lines for rim fabrication that are in operation throughout the year and consumed on average about 266,054 kWh per month as reported in Table 3 for the year 2014.

Table 3 Electricity consumption in rim lines

Month	Electricity consumption (kWh)			
	Rim#1	Rim#2	Rim#3	Total
Jan	52,135.00	97,532.00	102,989.00	252,656.00
Feb	55,421.00	99,943.00	106,325.00	261,689.00
Mar	76,057.00	125,776.00	122,390.00	324,223.00
Apr	56,013.00	85,031.00	101,535.00	242,579.00
May	59,722.00	91,833.00	108,864.00	260,419.00
Jun	64,972.00	104,583.00	123,913.00	293,468.00
Jul	51,311.00	106,126.00	110,373.00	267,810.00
Aug	49,977.00	101,821.00	109,559.00	261,357.00
Sep	54,076.00	106,732.00	113,113.00	273,291.00
Oct	48,621.00	108,233.00	112,829.00	269,683.00
Nov	50,438.00	107,257.00	104,994.00	262,689.00
Dec	50,634.00	107,646.00	88,829.00	247,109.00
Average	53,105.50	105,354.50	107,594.50	266,054.50

For the assembly processing unit, there are 6 lines but the last line is the reserved one. For the year 2014, the average monthly electricity consumption in this process was about 34,813.50 kWh. There is no separate information for the assembly lines 1 to 4 because there is only one meter to measure the electricity consumption of those lines together.

Table 4 Electricity consumption in assembly lines

Month	Electricity consumption (kWh)			
	Assy#1,2,3,4	Assy#5	Assy#6	Total
Jan	26,985.00	5,930.00	336.00	33,251.00
Feb	28,207.00	6,126.00	245.00	34,578.00
Mar	42,291.00	5,564.00	520.00	48,375.00
Apr	28,825.00	4,839.00	430.00	34,094.00
May	29,250.00	5,562.00	490.00	35,302.00
Jun	28,097.00	5,897.00	1,720.00	35,714.00

Table 4 Electricity consumption in assembly lines (Cont')

Month	Electricity consumption (kWh)			
	Assy#1,2,3,4	Assy#5	Assy#6	Total
Jul	26,159.00	6,180.00	2,710.00	35,049.00
Aug	24,165.00	5,515.00	2,870.00	32,550.00
Sep	27,009.00	5,561.00	2,700.00	35,270.00
Oct	25,557.00	6,265.00	2,030.00	33,852.00
Nov	27,324.00	6,064.00	2,770.00	36,158.00
Dec	26,011.00	4,910.00	2,540.00	33,461.00
Average	27,166.50	5,730.50	1,875.00	34,813.50

As shown in Table 5, there are other processing units that consume electricity. These include: EDP, top coating, compressor, and the cooling tower. In 2014, their contribution to electricity consumption on an average monthly basis amounted to 180,843 kWh, 43,852 kWh, 354,251 kWh, and 62,324 kWh, respectively.

Table 5 Electricity consumption in other sectors

Month	Electricity consumption (kWh)			
	Rust protecting (EDP)	Top coat	Compressor	Cooling tower
Jan	181,494.00	45,343.00	354,642.00	55,633.00
Feb	185,511.00	47,483.00	389,628.00	60,364.00
Mar	192,489.00	48,495.00	411,033.00	80,417.00
Apr	171,501.00	42,495.00	373,989.00	62,388.00
May	179,920.00	41,615.00	403,693.00	62,879.00
Jun	193,589.00	45,555.00	389,376.00	70,002.00
Jul	181,723.00	43,955.00	353,860.00	66,518.00
Aug	180,192.00	44,200.00	338,417.00	62,261.00
Sep	176,664.00	42,580.00	353,151.00	62,714.00
Oct	172,514.00	43,750.00	350,464.00	50,111.00
Nov	182,070.00	43,630.00	345,893.00	56,959.00
Dec	165,664.00	41,070.00	340,666.00	57,074.00
Average	180,843.00	43,852.00	354,251.00	62,324.50

4.1.3 Liquefied Petroleum Gas and Diesel

Aside from electricity, Liquefied petroleum gas (LPG) and diesel are also used. The monthly consumption of these fuels is detailed in Table 6.

Table 6 LPG and diesel consumption

Month	LPG (kg)	Diesel (L)
Jan	35,671	9,222
Feb	23,783	9,150
Mar	37,777	10,408
Apr	30,941	7,605
May	34,535	8,257
Jun	29,281	9,030
Jul	27,682	8,858
Aug	28,702	8,015
Sep	33,621	8,874
Oct	32,106	8,288
Nov	23,376	8,071
Dec	28,228	7,970
Average	30,475	8,646

In this sector, diesel is consumed by fork lift cars for transporting steel wheels from the production line to the warehouses. LPG is used in the boiler to produce steam for the ovens and rust protecting line. In February and November 2014, the LPG consumption dropped as the boiler was shut down for maintenance.

4.2 Steel Wheel Overall Production Data

Based on the inventory data collected from the steel wheel manufacturing company for the year 2014, the major input and output data of the manufacturing process were identified and are reported in Table 7.

Table 7 Overall materials and energy input and output in 2014

	Flow	Amount per year	Unit
Input	Steel sheet	58,193	tonnes
	Lubricant	9,600	litre
	Electricity	14,338,855	kWh
	LPG	365,703	kg
	Diesel	103,748	litre
	Water*	33,672	m^3
Output	Steel wheel	49,171	tonnes
	Scraps	9,022	tonnes
	Waste water**	32,782	m^3

Note: *Water includes Deionized water (DI) and Reverse Osmosis water (RO) which is produced from estate's tap water by factory's process; **Wastewater is the output of wastewater treatment process

As observed from the above table, in 2014, this company produced about 49,171 tonnes of steel wheels and 8,253 tonnes of scrap. About 365,703 kg of LPG, 103,748 liters of diesel, and 14,338,855 kWh of electricity were consumed in the production lines. It is noticed that a small amount of lubricant is used for coating steel wheels. Two tanks of 400 L each are used per month to glaze the steel wheels. Water is used in 2 processes: (1) cooling the machines and (2) boiling for cleaning. The resulting wastewater is subject to primary treatment on-site before being released to the estate sewage system for further treatment. Due to confidentiality issues over a number of data, lubricant and wastewater were excluded from the investigations of this work.

4.3 Materials Input and Output

The amount of production depends on customer orders in each month. The monthly average amounts of materials, products and scraps generated over a year were found to be 58,193 tonnes, 49,171 tonnes, and 9,022 tonnes respectively. Scraps are sold to scrap bidding companies and therefore out of the system since these not reused or recycled by the company.

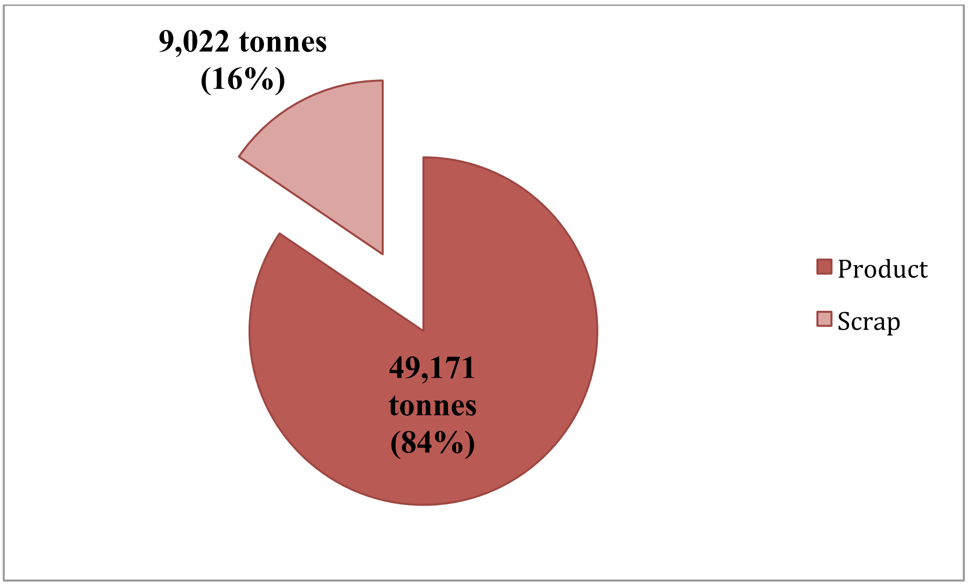

Fig. 13 Annual material input and output in 2014

About 84% of product and 16% of scraps were produced in 2014. This steel wheel company is therefore characterized by good production efficiency if compared to a typical steel wheel manufacturing in EU, where it was found that about 29% of scraps is produced [7].

4.4 Energy Use

Energy is a very important resource for industries to operate. For steel wheel production, the total energy consumption was found to be 164 TJ, electricity being the main type of energy consumed with over 85% followed by LPG and diesel (see Fig. 14):

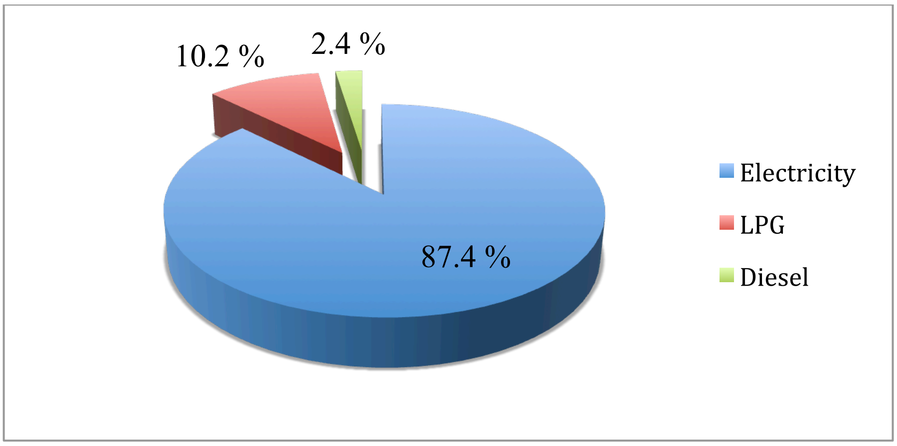

Fig. 14 Annual Energy consumption in 2014

Considering the annual energy consumption for steel wheel manufacturing, 143 TJ of electricity, 16.8 TJ of LPG, and 3.9 TJ of diesel were found to be consumed in 2014. This is about 3,330 MJ per tonne of product. This is much higher than the value reported for steel wheel manufacturing in EU, i.e. 1,730 MJ per tonne of product [7]. This may be due to the fact that Thailand has a hot climate (high temperature) which results in the air having a lower density as compared to cooler air (in Europe) and requiring therefore the compressor to work harder (use more energy) to compress air. It may also be due to some differences in the processes and machines used for steel wheel manufacturing but details for the EU's company referred to in this study were not shown in their report due to confidentiality issues.

The share of energy consumption of the main processing units is detailed in Table 8.

Table 8 Energy consumption in each unit

Units	MJ	%
Rim	32,176,030.00	19.65
Press	28,056,000.00	17.14
Assembly	4,276,540.00	2.61
EDP	21,633,310.00	13.21
Top Coat	5,301,710.00	3.24
Compressor	44,048,120.00	26.90
Cooling tower	7,473,200.00	4.56
LPG	16,822,325.30	10.27
Diesel	3,942,424.00	2.41
Total	163,729,659.30	100

In the production line, energy is consumed in each unit as detailed in Chapter 2. The remaining units include some equipment and machines that consume both electricity and fuels, including LPG and diesel. Compressors, which are new high efficiency equipment, are used for air supply in various processing units. LPG is consumed as fuel in the boiler and a recycling line has been established to conserve as much as possible of the heat produced. Diesel is also consumed by forklift cars to transport materials in different parts of the factory. The energy consumption per product is shown in Table 9.

Table 9 Total energy and electricity consumption per product

Unit	Thailand	EU
MJ/tonne	3,329.80	1,730.06
MJ/wheel	26.64	13.84
kWh/tonne	291	159
kWh/wheel	2.33	1.27

In table 9, it is observed that steel wheel manufacturing in Thailand for the company investigated is about twice more energy intensive than the one in the EU. Electricity is the main type of energy consumed. Looking more into the details of electricity, its consumption in each processing unit was investigated. The results are illustrated in Fig.15.

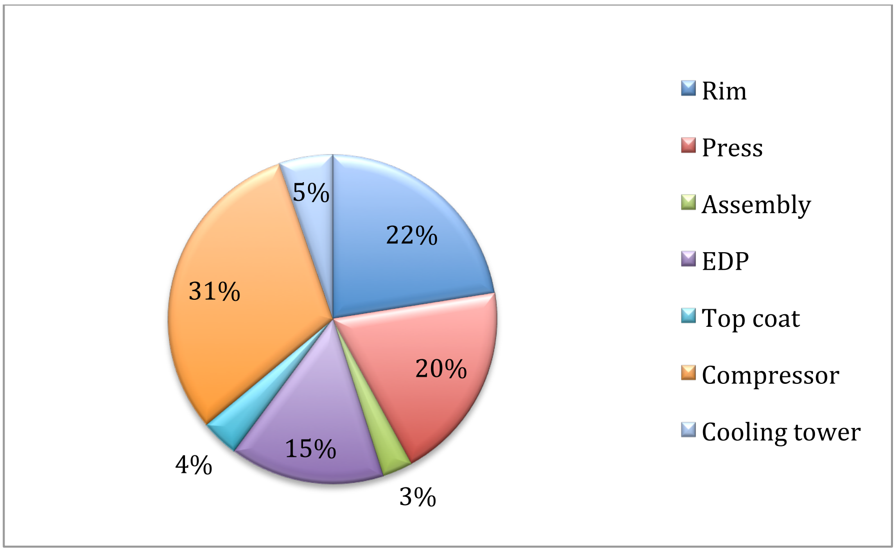

Fig. 15 Share of electricity consumption for each production process

Electricity consumption occurs in every production unit of the steel wheel manufacturing production line. Of the total amount of electricity consumed in the production line, 22% is used in the rim line, 20% in the press line, 3% for the compressor, and 5% in the cooling tower. The largest source of electricity consumption is the compressor with 354,251 kWh per month or 89.85 kWh per tonne of product. Hence improving the efficiency of the compressor is an obvious option to reduce electricity consumption. However, the company already purchased a few years back 5 new high efficiency compressors as mentioned earlier.

Based on the electricity inventory data collected from the steel wheel manufacturing company for each processing unit, Fig.16 shows how the consumption of electricity varies over time and for various units of production.

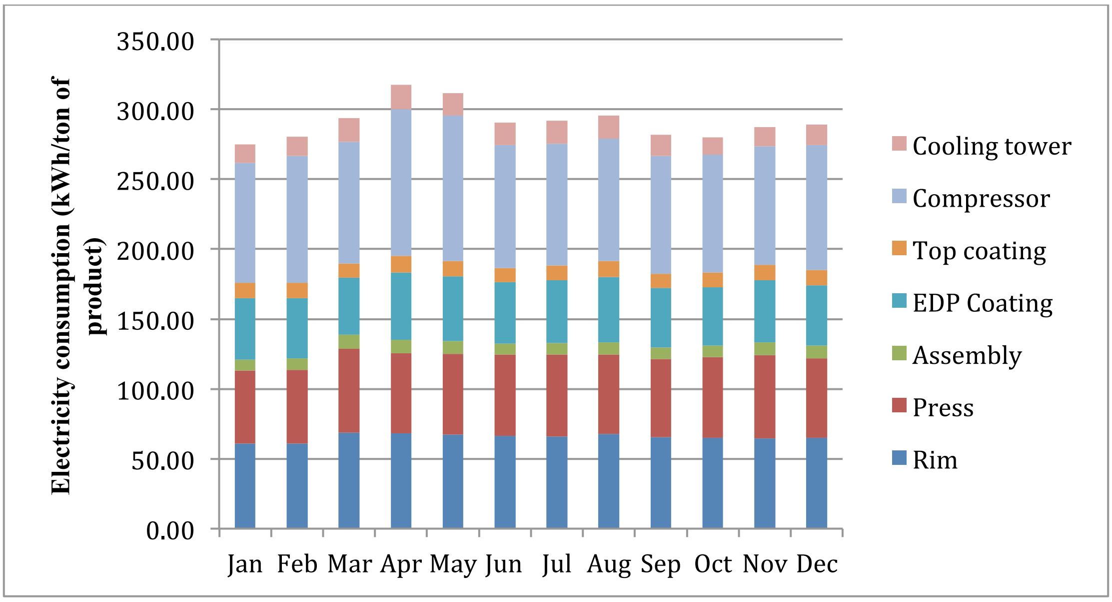

Fig. 16 Electricity consumption per tonne of product in each month

In the above figure, it is observed that the average of total electricity consumption is 291.18 kWh per tonne of product. It can be classified into 3 main groups, which are:

1. High energy intensity: this concerns the compressor. It consumes about 90 kWh per tonne of product.

2. Medium energy intensity: this concerns the rim lines, press lines, and EDP coating. They consume around 50 kWh per tonne of product.

3. Low energy intensity: this concern the assembly lines, top coating, and cooling tower. They consume no more than 15 kWh per tonne of product.

Looking at the total electricity consumed, it is observed that it peaks in April. This may be related to the high level of temperatures experienced during that time (summer in Thailand). On a monthly basis, it is observed that the amount of electricity consumed per tonne of product is quite constant throughout the year, with a standard deviation not exceeding 12.61 of total electricity consumption; this is not significant. However, a much larger amount of electricity is consumed (291 kWh per tonne of product) as compared to the steel wheel manufacturing case of Europe (it is about 57 kWh per tonne of product) [7].

4.5 Energy Cost

Another energy-related aspect of most concern for companies, industries, or businesses is the cost of operation. In this report, material cost was not included as cost information related to materials was not accessible from the company. Energy cost was therefore the focus of the investigations. The energy cost was estimated based on the following information: (1) electricity cost is 1.4 THB per MJ, (2) LPG cost is 0.5 THB per MJ, and (3) diesel cost is 0.8 THB per MJ. The share of energy cost is shown in Fig. 17.

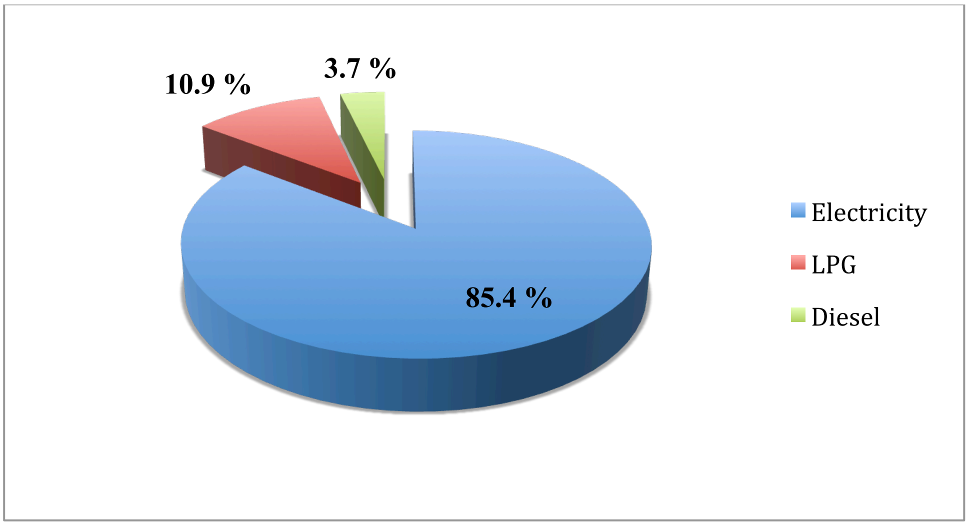

Fig. 17 Cost contribution to produce a steel wheel

In 2014, this company spent almost a hundred million THB for energy. Electricity was found to contribute 85.4% of the total cost followed by LPG with 10.9% and diesel with 3.7%. As for energy consumption, electricity is obviously a major contributor to the overall energy cost. An option to decrease the cost could be to improve the efficiency of processes or machines by replacing old ones by new more efficient machines and possibly stop some units through careful planning of the overall wheel production process (optimizing the production process). Details of cost contribution from each of the various processing units are shown in Table 10.

Table 10 Breakdown of energy cost per processing unit

Units	Energy cost (THB)	%
Rim	16,088,015.00	19.21
Press	14,028,000.00	16.75
Assembly	2,138,270.00	2.55
EDP	10,816,655.00	12.92
Top Coat	2,650,855.00	3.17
Comp	22,024,060.00	26.30
Cooling tower	3,736,600.00	4.46
LPG	9,142,568.10	10.92
Diesel	3,112,440.00	3.72
Total	83,737,463.10	100

In 2014, the energy cost to produce about 49,171 tonnes of steel wheel was found to amount to 83,737,463 THB. The major cost contributors to this cost are: the rim lines, the press lines, and the compressor. They were found to contribute 19.21%, 16.75%, and 26.30%, respectively of the overall energy cost. They constitute the main lines of steel wheel production. The energy cost for the case of the company in Thailand versus what it would be if the energy consumption of its steel wheel manufacturing process could be optimized to that of the EU's case is shown in Table 11.

Table 11 Energy cost comparison between base and optimized scenarios

	Thailand's base case scenario	Thailand's optimized scenario (based on EU's case)
Product	49,171 tonnes	0.555 tonne
	Energy cost (THB) per tonne of product	
Electricity	1,453.75	796.26
LPG	185.93	74.75
Diesel	63.30	-
	Energy cost (THB) per wheel	
Total	13.62	6.97

As shown in Table 11, the energy cost associated with steel wheel manufacturing in Thailand amounted to 13.62 THB per wheel or about 1,703 THB per tonne of product in 2014. Based on the EU's energy consumption scenario, the energy cost associated to steel wheel manufacturing would be reduced to 6.97 THB per wheel or about l,871 THB per tonne of product. If the energy consumption of steel wheel manufacturing in Thailand could be reduced to reach that of the EU's case, about 830 THB per tonne of product could be saved. This would represent an outstanding 40 million THB of energy cost saving over a year (for 2014 in this case).

4.6 Measures for Energy Conservation and Efficiency Improvement

As this company consumes a large amount of energy, a number of options were investigated and in some instances implemented to improve the energy efficiency of steel wheel production. The major energy related improvement measures that have been pursued for the company are as detailed below:

1. Installation of inverters

Inverters are installed in motorised machines. This equipment works in adjusting the input electric current so as to decrease electricity loss in a motor. This measure has been implemented in the factory for 2 years and has enabled the company to save about 0.1% of its total energy cost.

2. Installation of economizer

The economizer is a heat exchange device. It is used to recycle most of the heat back into the boiler. The installation of this device has contributed energy savings representing 0.1% of the total energy cost.

3. Shutting of one EDP line

One of the two EDP (rust protecting) lines was stopped while the process in the other one was sped up. This change in the mode of operation of this particular unit enabled energy savings representing about 0.9% of the total energy cost.

4. Checking of air leak

A major maintenance program implemented in the factory concerned air leaks. This is a major cause of energy loss in compressors. This particular measure enabled to generate energy savings representing about 0.3% of the total energy cost.

5. Production schedule management

The company implemented a number of changes in the scheduling of its operation to decrease energy consumption. This included operating the compressor at times outside peak load hours. Also the overall processing operations for steel wheel prudction were reduced from 24 hours to 20 hours per day shifting a number of processing operations to night time to take advantage of lower temperature and therefore less requirement in energy by some machines to operate. From such rescheduling of operations, about 1.3% of the total energy cost could be saved.

The implementation of the overall energy conservation and efficiency measures reported above enabled the company to save about 2.7% of its total annual energy cost or about 2.2 million THB.

CHAPTER 5
CONCLUSIONS

5.1 Main Findings

Energy consumption is currently higher than 20 years ago about 2.3 times when compare to 1990. The one sector, which is a major contributor, is the industry (about 41% sharing of Energy consumption (see fig.1)). As generally observed, steel is one of the major materials used in the manufacturing of products. Steel wheels are one of the products consuming steel for their production. Steel wheel manufacturing is a very energy intensive industry and the focus of this study.

The steel wheel manufacturing company investigated in this work is located in the Well Grow Industry Estate in Chachoengsao, Thailand. It has 5 million steel wheels of average productivity per year. The process consists of 2 press lines, 3 rim lines, 2 EDP lines, and 1 painting line. This study focused on steel wheel manufacturing (gate-to-gate approach); not including steel production and the use phase of steel wheel. The objective of the research was to investigate energy consumption and related costs for steel wheel manufacturing, major contributing units and possible options for improvement.

After the data collection for the year 2014 and its analysis, it was found that this steel wheel manufacturing company produces 49,171 tonnes of steel wheel (about 5 million pieces) and 9,022 tonnes of scraps or about 16% of the input steel sheet. During the process, scraps are produced. They are are not reused or recycled within the process but sold to a scrap bidding company. Only a primary wastewater treatment system is in place in the factory which consisting in a coagulation and flocculation process to remove heavy metals. Sludge from the wastewater treatment plant is sent to landfills. About 163 TJ of energy was consumed to satisfy the annual production of steel wheel in 2014. This was mainly contributed by electricity, about 87.4 %, followed by LPG (10.2%) and diesel (2.4%). Most of the electricity was found to be consumed by the compressor (about 31% of the overall electricity consumption). In term of energy cost, 85.4 % of the total cost was found to be contributed by electricity followed by LPG with 10.9% and diesel with 3.7 %.

The steel wheel manufacturing investigated in this work was found to have a high requirement in electricity, about 291 kWh per tonne of product on average, as compared to an EU steel wheel manufacturer which was found to consume about 159 kWh per tonne of product. For Energy consumption, if this company could improve the energy efficiency of its operation to reach that of the steel wheel manufacturing company in the EU, it could save at least 830 THB per tonne of product or a staggering 40 million THB over a year. At present, a number of energy conservation and efficiency measures have been identified and implemented by the company enabling a saving of about 2.7% of its total energy cost.

5.2 Challenges and Recommendations

Based on published information, it appears that steel wheel production is more environmentally friendly than aluminum wheel. However, including the use phase in the analysis, a study by PE International & Five Winds Strategic Consulting [7] showed that aluminum wheel would perform better after a driven certain number of kilometers. Therefore options to improve the energy performance of steel wheel production along with innovations enabling to reduce the weight and enhance the durability of steel wheel as compared to aluminum wheel should be considered.

The processes followed in the EU to produce steel wheels should be investigated to identify possible options (know how), including technologies (technology transfer) that could be applied in the context of Thailand to improve the energy efficiency of steel wheel manufacturing in Thailand.

With regards to energy efficiency, the company reported that the support that can be obtained for improvement as provided under some energy efficiency programs and tools in Thailand is not attractive enough unlike the case for larger industries like PTT or SCG. With regards to electricity, the main organization dealing with this issue is EGAT, a state enterprise managed by the Ministry of Energy. Although, the ministry has many experts to work in improving the energy efficiency of Thailand's industry fewer human resources are available to provide support for companies such as the one of this study. Hence, at present, there is no strategy to encourage energy conservation operations in the company. Only an energy report is to be submitted to DEDE with no further requirements to fulfill (no follow up).

To improve the energy related efficiency of its operations, the steel wheel manufacturing company should have an energy expert in charge of the management of its energy consumption. Such an expert is lacking at the moment, since the lack of such a resource and also because it is not required by law, the company does not have an ISO

50001 to deal with energy management. Despite this, the company has been pro-active in taking the initiative of implementing a number of options to reduce energy consumption and cost as detailed in Section 4.6. Such actions need to be encouraged and promoted with adequate support from relevant energy organizations to ensure the permanence of such actions and sustainable improvement of energy conservation and efficiency.

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APPENDIXES

APPENDIX A: ACTUAL DATA, ENERGY CONTENTS, AND ASSUMPTIONS

Table A1 The actual energy use of this steel wheel Manufacturing

Type	Thailand's case	EU's case
Electricity	14,296,491 kWh	318.3 MJ
LPG	365,703 kg	1.7 kg
Diesel	103,748 L	-
Product	49,170.996 tonne	555.2 kg

Table A2 Energy content of each type of energy

Type	Energy content
Electricity	3.6* MJ/kWh
LPG	46 MJ/kg
Diesel	38 MJ/L

**For Energy consumption consideration, the factor of electricity will be 10 MJ/kWh because it must be considered by primary energy.*

Assumption 1: Giving the weight of steel wheel as 8 kg/wheel

Assumption 2: Giving the cost of energy as shown in Table A3 (by Thailand's case approximately)

Table A3 Cost assumption

Type	Energy content
Electricity	5 THB/kWh
LPG	25 THB/kg
Diesel	30 THB/L

APPENDIX B: CALCULATIONS

B-1 Energy consumption calculations

Thailand's case

Energy consumption

Electricity: $14{,}296{,}491\ kWh \times 10\ \frac{MJ}{kWh} = 142{,}964{,}910\ MJ$

LPG: $365{,}703\ kg \times 46\ \frac{MJ}{kg} = 16{,}822{,}325\ MJ$

Diesel: $14{,}296{,}491\ L \times 38\ \frac{MJ}{L} = 3{,}942{,}424\ MJ$

Total: $142{,}964{,}910 + 16{,}822{,}325 + 3{,}942{,}424 = 163{,}729{,}659\ MJ$

Electricity consumption per tonne of product

$$14{,}296{,}491\ kWh \div 49{,}170.996\ tonne = 290.75\ \frac{kWh}{tonne}$$

Electricity consumption per wheel

$$290.75\ \frac{kWh}{tonne} \times \frac{1\ tonne}{1000\ kg} \times 8\ \frac{kg}{wheel} = 2.33\ \frac{kWh}{wheel}$$

Energy consumption per tonne of product

$$\frac{163{,}729{,}659\ MJ}{49{,}170.996\ tonnes} = 3{,}329.80\ \frac{MJ}{wheel}$$

Energy consumption per wheel

$$3{,}329.80\ \frac{MJ}{wheel} \times \frac{1\ tonne}{1000\ kg} \times 8\ \frac{kg}{wheel} = 26.64\ \frac{MJ}{wheel}$$

EU's case

Energy consumption

Electricity: $318.3\ \text{MJ} \times \frac{1\ kWh}{3.6\ MJ} \times 10\ \frac{MJ}{kWh} = 888.42\ MJ$

LPG: $1.7\ kg \times 46\ \frac{MJ}{kg} = 76.36\ MJ$

Diesel: $-$

Total: $884.2 + 76.36 = 960.56$

Electricity consumption per tonne of product

$$884.2\ \text{MJ} \times \frac{1\ kWh}{10\ MJ} \times \frac{1}{0.5552\ tonne} = 159.25\ \frac{kWh}{tonne}$$

Electricity consumption per wheel

$$159.26\ \frac{kWh}{tonne} \times \frac{1\ tonne}{1000\ kg} \times 8\ \frac{kg}{wheel} = 1.27\ \frac{kWh}{wheel}$$

Energy consumption per tonne of product

$$\frac{960.56\ MJ}{0.5552\ tonnes} = 1730.06\ \frac{MJ}{wheel}$$

Energy consumption per wheel

$$1730.06\frac{MJ}{wheel} \times \frac{1\ tonne}{1000\ kg} \times 8\ \frac{kg}{wheel} = 13.84\ \frac{MJ}{wheel}$$

B-2 Cost Calculations

Thailand's case

Electricity cost: $290.75\ \frac{kWh}{tonne} \times 5\ \frac{THB}{kWh} = 1453.75\ \frac{THB}{tonne}$

LPG cost: $\frac{365{,}703kg}{49170.996\ tonne} \times 25\ \frac{THB}{kg} = 185.93\ \frac{THB}{tonne}$

Diesel cost: $\frac{103{,}748\ L}{49170.996\ tonne} \times 30\ \frac{THB}{L} = 63.30\ \frac{THB}{tonne}$

Total:

$$1453.75\ \frac{THB}{tonne} + 185.93\ \frac{THB}{tonne} + 63.30\ \frac{THB}{tonne} = 1702.98\frac{THB}{tonne}$$

EU's case

Electricity cost: $159.25\ \frac{kWh}{tonne} \times 5\ \frac{THB}{kWh} = 796.25\ \frac{THB}{tonne}$

LPG cost: $\frac{1.7\ kg}{0.5552\ tonne} \times 25\ \frac{THB}{kg} = 74.75\ \frac{THB}{tonne}$

Total: $796.25\frac{THB}{tonne} + 74.75\ \frac{THB}{tonne} = 871.00\frac{THB}{tonne}$