ENERGY MANAGEMENT STUDY IN INDOOR FARMING PLANT FACTORY

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ABSTRACT

This thesis reports the energy efficiency study conducted in two distinct indoor farming facilities namely the AgroCube (the container type of indoor farming facility) and the plant factory (commercial scale indoor farming facility). Both of these facilities were owned by Malaysian Agricultural Research and Development Institute (MARDI) which are located in Serdang, Malaysia. This pioneering study is important to establish the unique energy profile of indoor farming facilities as well as analysing the specific energy consumption of crops produced. Both of these findings are vital in further improving the present energy use as well as reducing overall operational costs. Therefore, this was carried out in these facilities involving walk-through audit, electrical power logging for a duration of one week to establish their load profiles and identifying the significant energy users (SEUs), energy analysis and finally the specific energy consumption of the crops produced. The load profiles for LED lighting system, water pump, air conditioning system and other smaller electrical equipment were distinguished during this study. The load profile, total power demand, average demand and peak demand were obtained and used to calculate the specific energy consumption of the crop. From the energy apportioning, it was found that the total energy consumption during 1 week for AgroCube is 414.153kWh while for the MARDI's plant factory is 3788.423kWh. The specific energy consumption for the AgroCube was 17.15kWh/kg and 19.2kWh/kg for the MARDI's plant factory. Several possible strategies for saving energy for all term were proposed to further improve these values based on operational requirements by MARDI including payback period. For both of the plant factory, the significant strategies for short term is to turn off air-conditioner during low consumption, medium term is to switch to inverter air-conditioner and for long term is integration with solar energy.

ABSTRAK

Tesis ini melaporkan kajian kecekapan tenaga yang dilakukan di dua fasiliti pertanian dalaman yang berbeza iaitu AgroCube (fasiliti pertanian dalaman jenis kontena dan kilang tanaman (kemudahan pertanian dalaman skala komersial). Kedua-dua kemudahan ini dimiliki oleh Institut Penyelidikan dan Kemajuan Pertanian Malaysia (MARDI) yang terletak di Serdang, Malaysia. Kajian perintis ini penting untuk menubuhkan profil tenaga unik fasiliti pertanian dalaman serta menganalisis penggunaan tenaga tanaman yang dihasilkan. Kedua-dua penemuan ini penting dalam menambah baik lagi penggunaan tenaga semasa dan juga mengurangkan keseluruhan kos operasi. Oleh itu, ini telah dilakukan di fasiliti ini yang melibatkan 'walk-through' audit, 'data logging' tenaga eletrik selama satu minggu untuk menentukan profil beban masing-masing dan mengenal pasti pengguna tenaga yang signifikan (SEU), analisis tenaga dan akhirnya penggunaan tenaga spesifik tanaman yang dihasilkan. Profil beban untuk sistem pencahayaan LED, pam air, sistem penyaman udara dan peralatan elektrik lain yang lebih kecil dibezakan semasa kajian ini. Profil beban, penggunaan tenaga total, purata penggunaan dan penggunaan tertinggi diperoleh dan digunakan untuk mengira penggunaan tenaga spesifik tanaman. Dari pengagihan tenaga, didapati bahawa penggunaan tenaga keseluruhan selama 1 minggu untuk AgroCube adalah 41.4153kWh sementara untuk kilang tanaman MARDI adalah 378.8423kWh. Penggunaan tenaga khusus untuk AgroCube ialah 17.15kWh / kg dan 19.2kWh / kg untuk kilang tanaman MARDI. Beberapa strategi yang mungkin untuk menjimatkan tenaga dicadangkan untuk menambah baik lagi nilai-nilai ini berdasarkan keperluan operasi oleh MARDI disertakan bersama tempoh bayaran balik. Bagi kedua-dua kilang tanaman, strategi penting untuk jangka pendek ialah mematikan penghawa dingin semasa penggunaan rendah, jangka sederhana adalah menukar kepada penyaman udara 'inverter' dan untuk jangka panjang adalah integrasi dengan tenaga solar.

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LIST OF SYMBOLS AND ABBREVIATIONS

AH	-	Absolute Humidity
AHU	-	Air Handling Unit
CHWP	-	Chilled Water Pump
CO_2	-	Carbon Dioxide
CWP	-	Cooling Water Pump
ECMs	-	Energy Conservation Measures
GAI	-	Green Area Index
GIS	-	Geographic Information System
GPS	-	Global Positioning System
GWh	-	Giga Watt-hours
HID	-	High-Intensity Emission
Ktoe	-	Kilo tonne of oil equivalent
kW	-	Kilo Watt
LED	-	Light Emitting Diode
LNG	-	Liquid Natural Gas
MARDI	-	Malaysian Agricultural Research and Development Institute
PF	-	Plant Factory
PV	-	Photovoltaics
RH	-	Relative Humidity
RPM	-	Revolutions Per Minute

SPAD	-	Soil Plant Analysis Development
TNB	-	Tenaga Nasional Berhad
TOU	-	Time of Use
VPD	-	Vapour Pressure Deficit
VRI	-	Variable Rate

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CHAPTER 1

INTRODUCTION

1.1 Background study

Energy comes in various forms, such as heat (thermal) energy, light (radiant) energy, motion (kinetic) energy, electrical energy, mechanical energy etc. Energy conservation is the principle which dictates that energy is neither created nor destroyed; it only changes from one place to from (Cengel, 2013). Energy conservation is the effort to reduce energy consumption by using less energy and will eventually save the investment in energy generation. As a result, it will eventually reduce energy consumption and distribution costs and improve the economy of nation (Al-Mofleh et al., 2009).

Energy management is the process of monitoring and tracking energy to conserve, control and reducing a building's energy consumption. It is conducted by an energy manager to minimize energy cost, waste and environmental effects. Management and control of energy usage not only save money but helps to reduce climate change and improve corporate reputation. Energy management aims to achieve and sustain optimal energy procurement and utilisation around the organization, which can help mitigate energy cost and reduce environmental effects. Nonetheless, energy management is widely accepted as the best method for reducing the direct and indirect usage (Spiegel, 2019).

Among the aims of energy management is to reduce energy cost, the more energy usage in an organization the higher electricity bill that needs to be paid and therefore energy management can substantially reduce expenditure on energy through proper energy management (Golušin et al., 2013). Many organizations were reported to save up to 20% on their energy bills only through better energy management (Department of Energy (DOE), 2015). Apart from that, the risks related to hiking of energy prices and shortage of supply also increase as the world population steadily grows. Energy management can reduce these risks by reducing the demand on energy.

1.2 Problem statement

The population growth and climate change are two major issues to mankind today. Among the area affected by these two issues were the agricultural sector. The increasing demand of agriculture products while difficulties for growing them due to climate change has resulted innovative demand technique of farming being developed. One such techniques is indoor farming. In indoor farming, the crops were grown in a building with controlled environment. Among crops that can be grown indoor is lettuce, kale, mustard greens, basil and others. Since indoor farming requires precise environment control involving temperature, humidity, and light, they consume a significant amount of energy. It is estimated that about 30% of production costs were the energy cost. As similar studies were rather scanty in the literature, this study was proposed to evaluate the energy consumption and establish a load profile in two types of plant factory, indoor farming facilities namely the MARDI's plant factory (commercial scale) and the AgroCube (container type indoor farming). The study will enable the effort to reduce energy consumption in indoor farming as well as allowing indoor farming becoming more affordable to the community. Hence, a comprehensive energy audit and case was conducted in MARDI (Malaysian Agricultural Research and Development Institute). From the case study, the unique load profile in plant factory was established and relevant energy conservation and energy efficiency measures were proposed.

1.3 Objective

The main objectives of this study are:

i. To establish the energy profile of large-scale plant factory (MARDI's plant factory) and container type plant factory (AgroCube) in MARDI, one of the indoor farming facilities developed in Malaysia.

ii. To propose energy saving measures and perform specific energy consumption with plant produced in both types of the plant factories.

1.4 Scope of study

The scope of this study is:

i. Preliminary energy audit involving walk-through audit and generate analysis on electricity bills
ii. Detailed energy audit involving electrical energy analysis using power logger
iii. Both (i) and (ii) conducted at plant factory and AgroCube at MARDI, Serdang
iv. Energy profiling is done when both of the plant factory only planting 1 type of vegetable (lettuce) throughout the month
v. Energy profiling is done 2 weeks from harvest time
vi. Energy data analysis and equipment load apportioning
vii. Proposal for energy-efficient measures
viii. Establishing the specific energy consumption per kg of product produced in the indoor farming facility

1.5 Significance of study

This significance of study are as follows:

i. This study provides useful information regarding the electrical energy consumption pattern in both of the plant factory, which is a pioneering effort in Malaysia.
ii. Establishment of the status quo for electrical energy consumption per kilogram of crop produced at both of the plant factories.
iii. This study will also serve as guideline for future expansion and improved in indoor farming and other similar facilities.

1.6 Thesis organization

This thesis consists of 5 chapters. Chapter 1 presents a short introduction of study including the background of study, problem statement, objective, the scope of study and significance of study.

Chapter 2 comprehensively reported the previous relevant research works on the various related topics in the current study. It contains the world energy scenario and energy consumption in Malaysia. It also covers about precision farming and its use in Malaysia. Next, in this chapter contain previous research about plant factory, also the controlled system in the plant factory such as light, temperature, humidity and others. Lastly, it also consists of detail about energy profiling and its types.

Chapter 3 presents the methodology for the energy audit of the plant factory. In consists of a work flow chart for Master's Research also the detail about energy audit that will be done with energy audit flow chat. The method of writing energy audit report also explained in this chapter. Energy audit main equipment that is Hioki PW3360 clamp on power logger with other equipment such as weather meter, thermometer and light meter specifications are listed in this chapter.

Chapter 4 is about the plant factory background that includes electricity distribution and background and also the electrical equipment inventory in the plant factory. Result of analysis about energy load profile, energy apportioning and tariff is shown in this chapter. Lastly, the potential saving that can be applied is suggested.

Chapter 5 contains the conclusion of the study of thesis and several recommendations for improvement that can be used in further research about this topic.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review is an overview of the main articles and other sources on the chosen topic. Research tools in the study may include journal articles, books, government reports, websites, etc. This chapter offers an outline, overview and relevant findings on indoor farming and plant factory. Other aspects of energy efficiency and energy management are also covered in this review.

2.2 World energy scenario

The world of energy is marked by a number of deep gaps. The gap between the promising energy for all and the fact that nearly a billion people still have no access to electricity. The gap between the current scientific evidence showing that global greenhouse gas emission needs to be cut faster and data indicates that energy-related emissions reached another record high in 2018. The gap remains high between expectations of a rapid, renewables-driven energy transition and the reality of the current energy system where rely on fossil fuels. And the gap between the well-supplied stability in the oil markets and the constant uncertainty regarding geopolitical tensions and difficulties.

The Current Policies Scenario shows what would happen if the world continued pursued its path now, with no further policy changes. In this scenario, the demand for energy increased annually by 1.3% to 2040, with rising demand for energy services unregulated with further attempt to enhance efficiency. Although this is well below the unprecedented 2.3% growth, it will generate an exponential upward trend in energy-related emissions as well as increasing tension in virtually every aspect of energy security in 2018.

Energy demands are rising by 1% per annum to 2040 in the stated policy scenario. Low carbon sources, driven by solar photovoltaic (PV), supply more than half of this growth, and natural gas are driven by increased trade in liquid natural gas (LNG) account for another third. In the 2030s, the demand for oil is booming, and the use of coal is lowering. Some parts of the energy sector are undergoing rapid transformation, led by electricity. Some countries, especially those with “net zero” ambitions, are building up all aspects of their supply and consumption a long way. The momentum behind clean energy technology, however not sufficient to offset the effects of the growing global economy and population growth. The emission increasing slows, but without a peak before 2040, the world falls well short of the specific sustainability target (Anon, 1981).

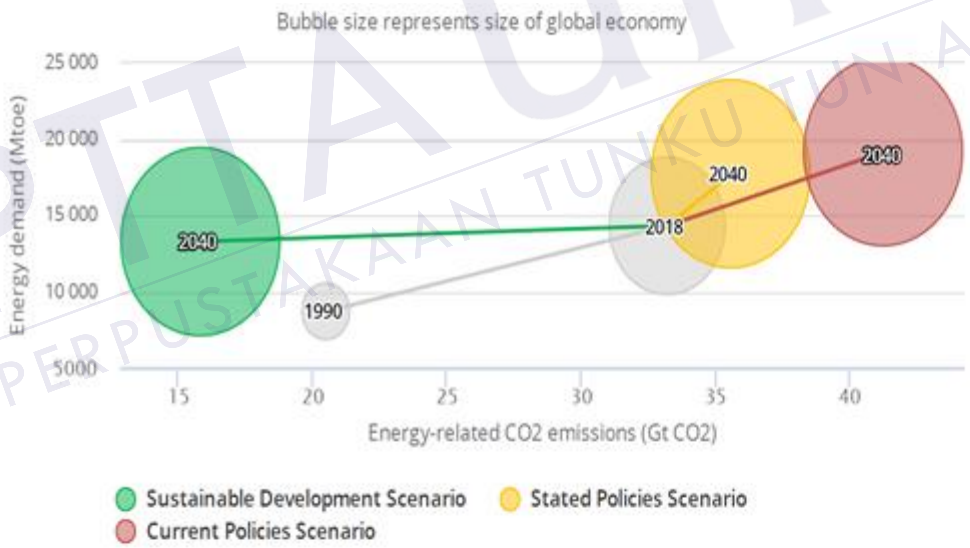


Figure 2.1: World demand for primary energy and CO_2 emissions energy-related by scenario (Anon, 1981)

2.3 Malaysia consumption of energy

Consumption of energy is a total amount of energy or power used by individuals, organizations, countries or others. In this study, the energy used is focused on electrical energy in Malaysia. In recent years, Malaysia has become one of the leading countries with higher per capita energy consumption, especially electricity. Malaysia experienced rapid growth of economic with the increasing electricity demand. This is due to the rapid development of industrialization, urbanization and population growth. Electricity consumption rises by 2,533 GWh on average each year. The consumption of electricity was 3,464 GWh in 1971 and increased to 94,278 GWh in 2008 (Mohamed Asmy Mohd Thas Thaker1 & Md. Fouad Amin3, n.d.).

In 2017, total electrical energy generated was 162,184 GWh compared to 1997 where only 37,065 GWh was generated. The source of energy generated is 42.5% (68,866 GWh) from coal were the largest contributor. The second is Gas 39.2% (63,585 GWh) and the third-largest is hydro 16.6% (26,846 GWh) followed by diesel 1.1% (1,708 GWh), others 0.7% (1,179 GWh) and 0% for oil. The data were obtained from the Energy Commission Handbook ("Malaysia Energy Statistics Handbook 2020," 2021).

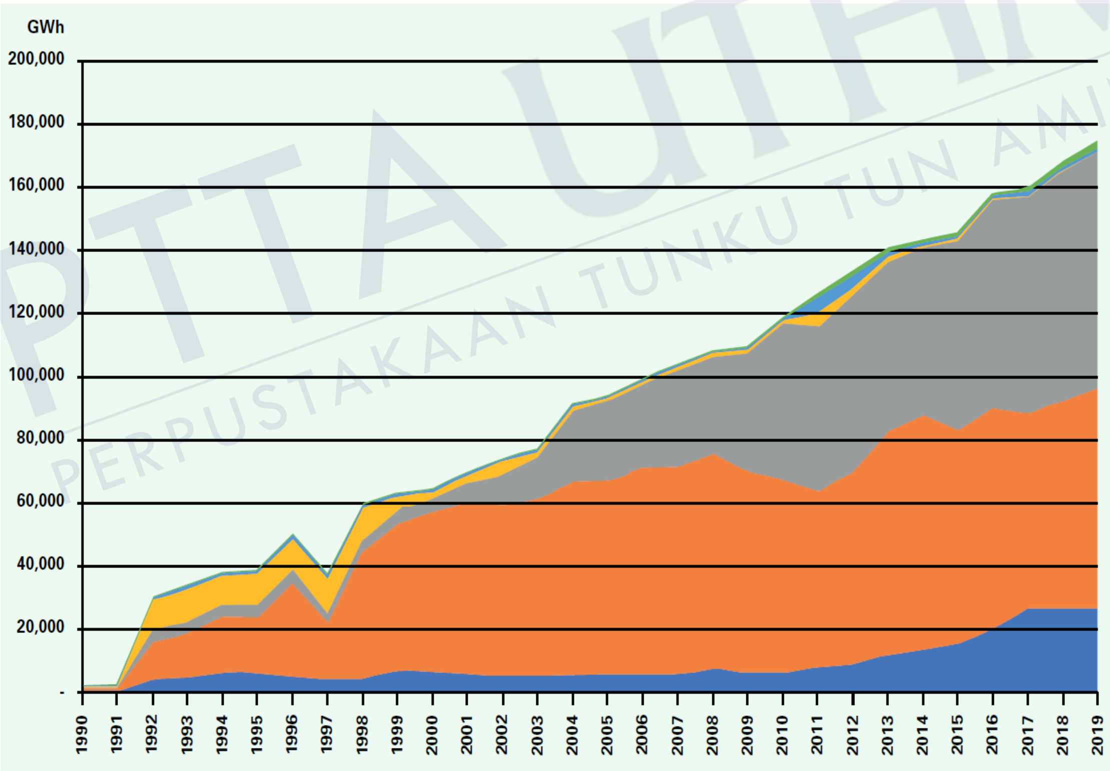
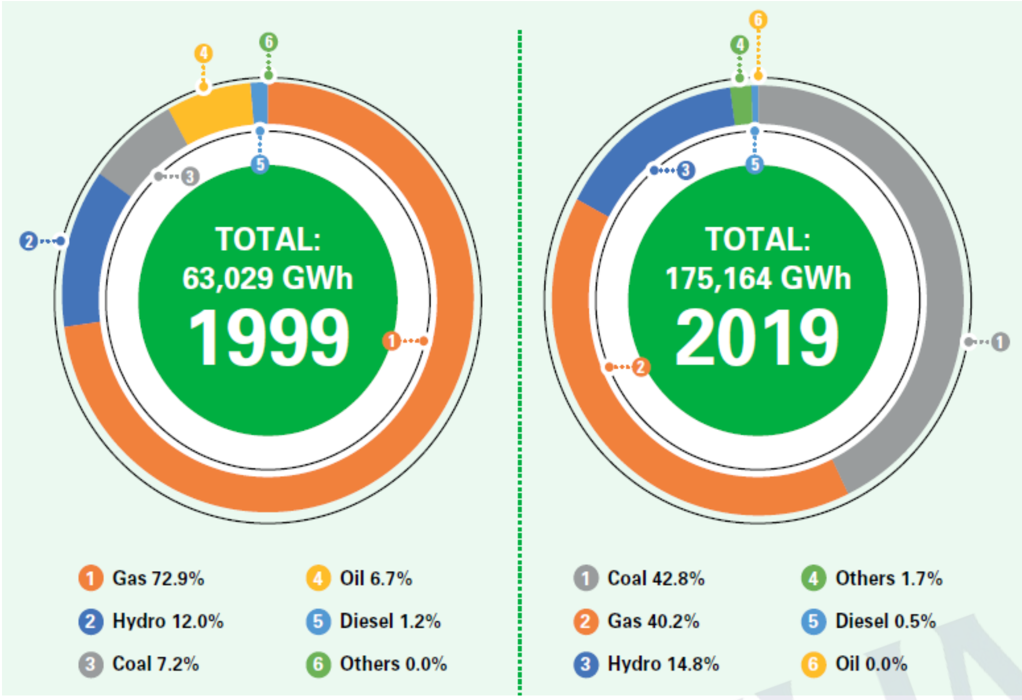


Figure 2.2: Graph of electrical energy generated from 1990 to 2019 ("Malaysia Energy Statistics Handbook 2020," 2021)



(a) (b)

Figure 2.3: Energy generated percentage (a) 1999 and (b) 2019 ("Malaysia Energy Statistics Handbook 2020," 2021)

By referring to the handbook, in 2016 the total energy consumption by sector is 57,218 ktoe (kilo tonne of oil equivalent) compared to 23,786 ktoe in 1996 where transportation is the largest consumer with 42.0% (24,004 ktoe) followed by industry 28.0% (16,019 ktoe) and 15.3% (8,829 ktoe) for non-energy use. While for residential and commercial is 14.1% (8,049 ktoe) and lastly agriculture sector 0.7% (415 ktoe). 1 ktoe is equal to 11.6 3GWh.

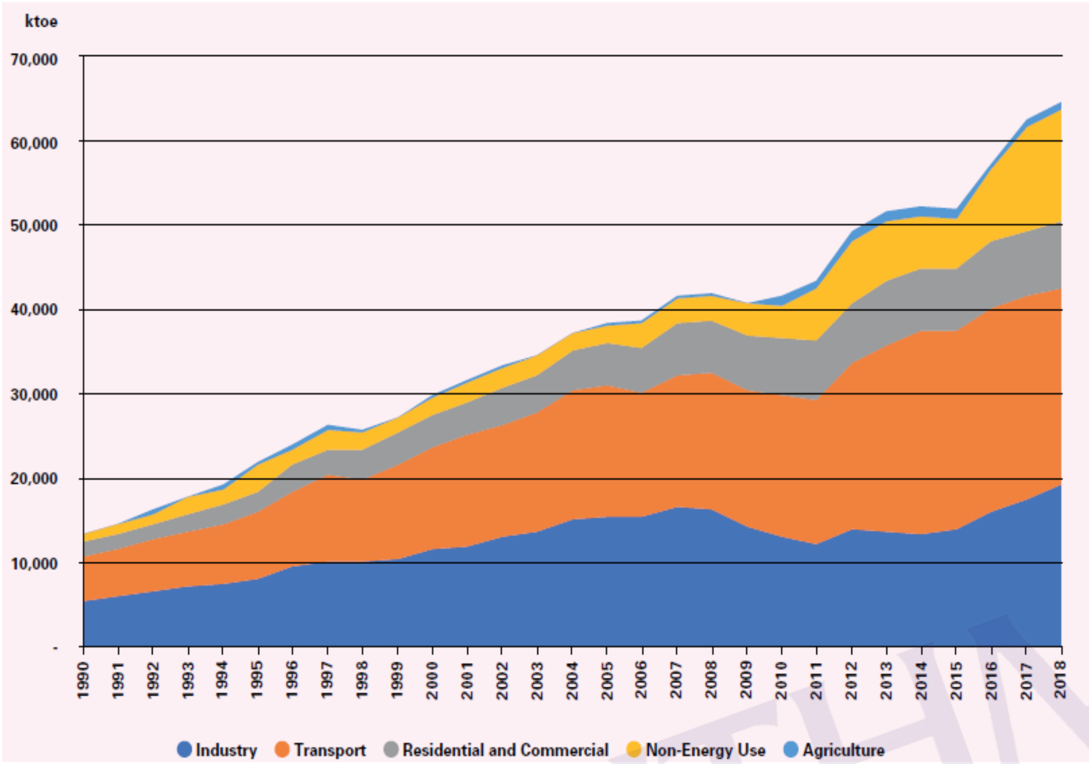


Figure 2.4: Graph of energy consumption by sector in Malaysia ("Malaysia Energy Statistics Handbook 2020," 2021)

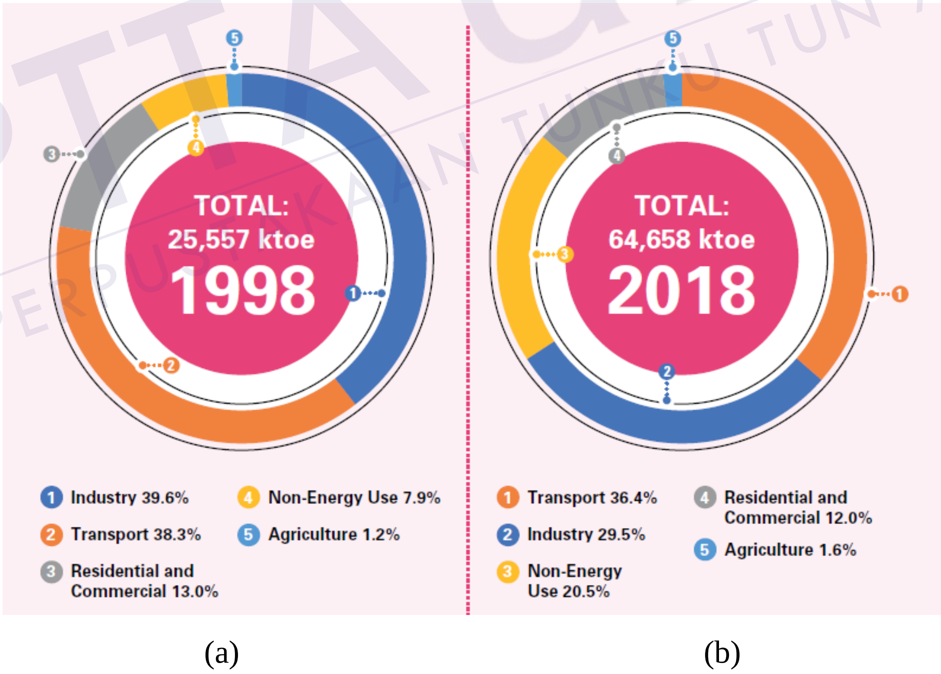


Figure 2.5: Energy consumption percentage by sector in Malaysia (a) 1998 and (b) 2018 ("Malaysia Energy Statistics Handbook 2020," 2021)

From the electrical energy generated graph above we can see that the energy generated in Malaysia is increased every year to provide enough energy for the consumer in all sectors that also increase from year to year.

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