AN INTEGRATED PINCH ANALYSIS FRAMEWORK FOR LOW CARBON INDUSTRIAL SITE PLANNING

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To my beloved mother and father

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ABSTRACT

Reduction of CO_2 emissions from energy generation and utilization has received growing attention in recent years due to the potential negative environmental impacts arising from CO_2 emissions, and the need to address the global sustainability challenges. Many of the previous published papers have only focussed on application of the various Pinch Analysis methods in isolation. Furthermore, with the rapid advancement in Pinch Technology, industries and practitioners face the challenge of keeping up-to-date with the Pinch Technology advancement, let alone implement them in industries. There is the need to develop a guide for industrial site planners to use and benefit from the suite of Pinch Analysis tools in an integrated manner towards systematically planning a low carbon emission site. The main objective of this study is to establish a systematic framework for low carbon industrial site planning, by using an integrated set of Pinch Analysis techniques. The framework consists of five main stages. The first stage is the data collection of resources. Second stage is the analysis of Total Site Heat Integration, followed by Stage 3 analysis of cogeneration potential. Stage 4 is the Power Pinch Analysis and finally Stage 5 is the Carbon Pinch Analysis. The new framework is demonstrated by using an illustrative case study, and has contributed significantly in addressing low carbon emission for industrial site, resulting an overall reduction about 64.7% of steam, 74.28% of power, and 99.8% of carbon emission. In summary, this new framework for low carbon industrial site planning is available for designers, planners or industrial site owner to optimise integrated energy and carbon emission for an industrial site.

ABSTRAK

Pengurangan pelepasan CO_2 daripada penjanaan dan penggunaan tenaga telah mendapat perhatian yang semakin meningkat sejak tahun kebelakangan ini oleh kerana kesan negatif persekitaran yang terjadi hasil daripada pelepasan CO_2, dan ianya suatu keperluan untuk mengajukan cabaran kestabilan global. Kebanyakan kertas kerja yang diterbitkan sebelum ini hanya tertumpu kepada penggunaan pelbagai kaedah Analisa Jepit secara berasingan. Tambahan pula, kemajuan pesat dalam Teknologi Jepit membuatkan industri dan pengamalnya menghadapi cabaran untuk mengikuti kemajuan Teknologi Jepit, apatah lagi melaksanakannya dalam industri. Ianya suatu keperluan untuk menyediakan panduan kepada perancang tapak perindustrian untuk menggunakan dan memanfaatkan kaedah Analisa Jepit secara integrasi ke arah merancang tapak perindustrian rendah karbon secara sistematik. Objektif utama kajian ini ialah untuk mewujudkan rangka kerja sistematik untuk perancangan tapak industri rendah karbon dengan menggunakan set integrasi teknik Analisa Jepit. Rangka kerja ini terdiri daripada lima langkah utama. Langkah pertama ialah pengumpulan sumber data. Langkah kedua ialah analisa Integrasi Haba Keseluruhan Tapak, diikuti Langkah 3 analisa potensi penjanaan Gabungan Kuasa dan Haba. Langkah 4 ialah Analisa Jepit Kuasa dan akhirnya Langkah 5 ialah Analisa Jepit Karbon. Rangka kerja baru ini dikaji dengan menggunakan kajian kes, dan menghasilkan pengurangan keseluruhan kira-kira 64.7% pengurangan haba, 74.28% pengurangan kuasa, dan 99.8% pengurangan pelepasan karbon. Secara ringkasnya, rangka kerja baru ini disediakan untuk kegunaan para pereka, perancang, atau pemilik tapak perindustrian untuk mengoptimumkan integrasi tenaga dan pengeluaran karbon.

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LIST OF SYMBOLS

F_{CO_2}	-	Flow rate of CO_2 in flue gas
F_C	-	Carbon flow rate
$F_{FC,cum}{}'$	-	Pure carbon cascade
F_{OG}	-	Flow rate of other gases aside from CO_2 in flue gas
F_T	-	Flue gas flow rate
η_{boiler}	-	Boiler efficiency
CH_4	-	Methane
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
F_{CE}	-	Carbon emission flow rate
F_{FC}	-	Fresh carbon flow rate
h	-	Enthalpy of saturated water
H	-	Specific enthalpy of steam
h_{header}	-	Specific enthalpy of a header
$h_{header, w}$	-	Specific enthalpy of saturated water at pressure header
m_{out}	-	Mass flow rate
N_2	-	Nitrogen
N_D	-	A set of steam demands
NO_x	-	Nitrogen Oxide
N_S	-	A set of steam sources
O_2	-	Oxygen
P	-	Pressure

P_{rs}	-	Pressure of external resource
q	-	Specific heat load
Q_{in}	-	Boiler thermal input
Q_{out}	-	Boiler thermal output
$Q_{out,VHP}$	-	Thermal output of VHP steam produced
SO_x	-	Sulfur Oxide
w	-	Specific power output of turbine
ρ	-	Density
ΣF_D	-	Total flowrates for carbon demands
ΣF_S	-	Total flowrates for carbon sources

LIST OF ABBREVIATIONS

AEEND	-	Available Excess Electricity for Next Day
ANN	-	Artificial Neural Network
BFW	-	Boiler Feedwater
CC	-	Composite Curves
CCS	-	Carbon Capture Storage
CEPA	-	Carbon Emission Pinch Analysis
CERT	-	Carbon Emission Reduction Target
CET	-	Carbon Emission Trading
CHP	-	Combined Heat and Power
CMH	-	Carbon Management Hierarchy
CPA	-	Carbon Pinch Analysis
CPCC	-	Continuous Power Composite Curves
CSCA	-	Carbon Storage Cascade Analysis
CSCC	-	Carbon Storage Composite Curves
CW	-	Cooling Water
E-GIS	-	Energy Geographical Information System
EPS	-	Electric Power System
GCC	-	Grand Composite Curve
GCCA	-	Generic Carbon Cascade Analysis
GDT	-	Grid Diagram Table
GHGs	-	Greenhouse Gases
GSAS	-	Global Sustainability Assessment System
HEN	-	Heat Exchanger Network
HI	-	Heat Integration
HPIMO	-	Hybrid Physical Input and Monetary Output

HPS	-	High Pressure Steam
HPS	-	Hybrid Power System
IEA	-	International Energy Agency
ISMs	-	Integrated Steel Mills
LHV	-	Lower Heating Value
LIES	-	Locally Integrated Energy Sector
LPS	-	Low Pressure Steam
MHA	-	Maximum Heat Allocation
MILP	-	Mixed-Integer Linear Programming
MINLP	-	Mixed Integer Non-Linear Programming
MOES	-	Minimum Outsourced Electricity Supply
MPS	-	Medium Pressure Steam
MSW	-	Municipal Solid Waste
OSEC	-	Outsourced and Storage Electricity
PA	-	Pinch Analysis
PCC	-	Power Composite Curves
PCT	-	Power Cascade Table
PDM	-	Pinch Design Method
PI	-	Process Integration
PoCA	-	Power Cascade Analysis
PoPA	-	Power Pinch Analysis
PSE	-	Process System Engineering
PTA	-	Problem Table Algorithm
RE	-	Renewable Energy
RMFP	-	Risk-Explicit Mixed-Integer Full-Infinite Programming
SCC	-	Site Composite Curves
SCT	-	Storage Cascade Table
SDC	-	Source and Demand Curves
SePTA	-	Segregated Problem Table Algorithm
SGCC	-	Site Level Grand Composite Curve
SHA	-	SePTA Heat Allocation

SPTA	-	Simple Problem Table Algorithm
SSSP	-	Site Source-Sink Profiles
STEP	-	Streams Temperature versus Enthalpy Plot
SUGCC	-	Site Utility Grand Composite Curves
TPES	-	Total Primary Energy Supply
TS-PTA	-	Total Site Problem Table Algorithm
TSHI	-	Total Site Heat Integration
TSP	-	Total Site Profiles
TSST	-	Total Site Sensitivity Table
TSUD	-	Total Site Utility Distribution
UGCC	-	Utility Grand Composite Curve
UTA	-	Unified Targeting Algorithm
VHPS	-	Very High Pressure Steam
WtE	-	Waste-to-Energy

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In recent years, the global climate change has been one of the most crucial issues which resulted from the emissions of greenhouse gases (GHGs). Global warming due to the rising emissions of greenhouse gases (GHGs) from various sources play an important role in climate change. Greenhouse gases are gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_x), sulphur oxide (SO_x) and fluorinated gases which trap heat in the atmosphere. Carbon dioxide, CO_2 is one of the main greenhouse gases and contributes the largest share of global GHG emissions. Many extensive works and efforts have been reported to reduce carbon emission especially in energy planning sector. Reduction of carbon emission is often associated with reduction of energy (Lawal *et al.*, 2012). According to IEA Statistics (2014), human activities are responsible for the increment of greenhouse gases and energy use is the largest source of emissions since the use of fossil fuel (Figure 1.1).

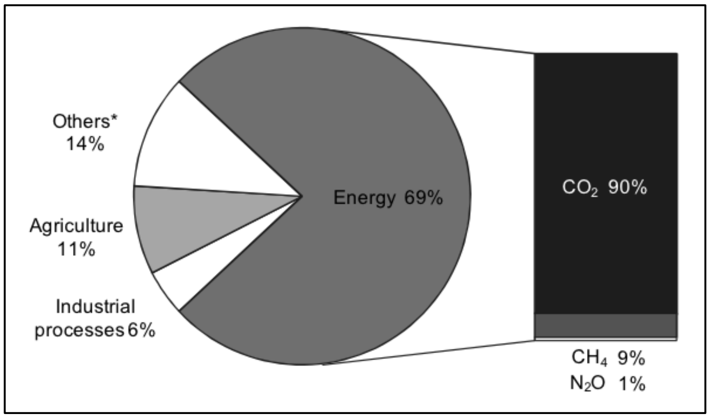

Figure 1.1 Shares of global anthropogenic GHG, 2010 (IEA Statistics, 2014)

The increment of energy demand is driven by the economic growth and development which according to the IEA Statistics (2014), the global total primary energy supply (TPES) has more than doubled between 1971 to 2012 and fossil fuels which is over 80%, remain at the heart of global energy use (Figure 1.2). Despite heightened initiatives established to achieve low carbon emission, the CO_2 emissions from fuel combustion have kept rising very rapidly. Figure 1.3 illustrates world CO_2 emissions by sector in 2012 and it can be shown that industries contribute 38% of CO_2 emissions (18% due to electricity and heat generation).

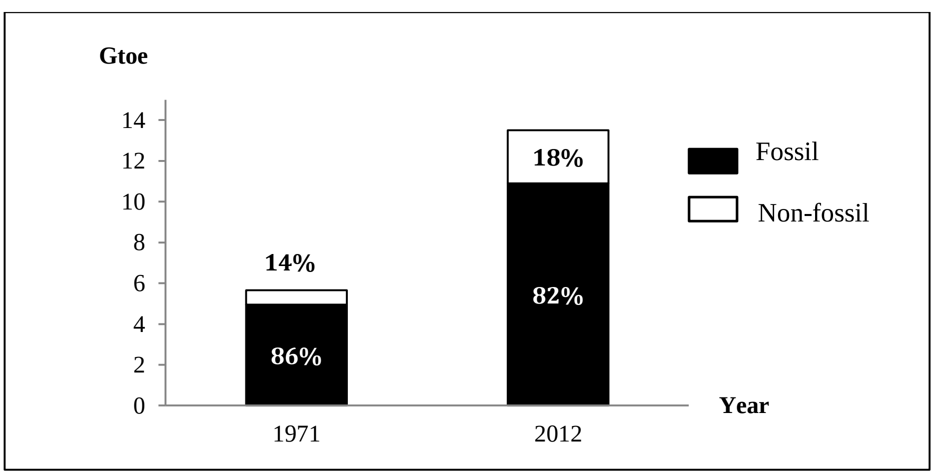

Figure 1.2 World primary energy supply (IEA Statistics, 2014)

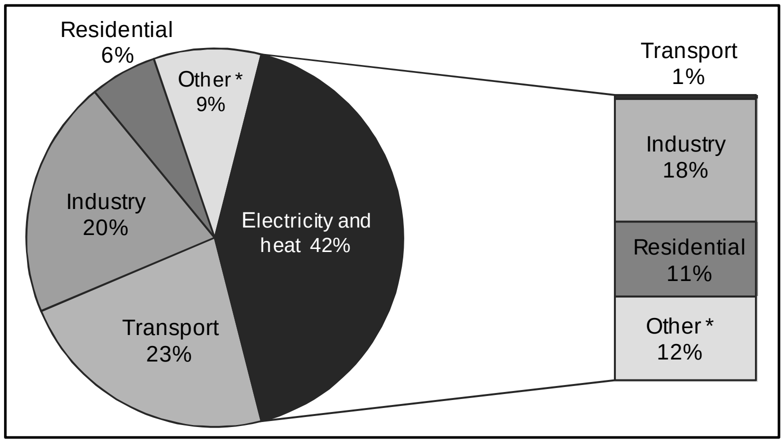

Figure 1.3 World CO_2 emissions by sector in 2012 (IEA Statistics, 2014)

Based on these trends, it can be concluded that large amount of CO_2 has been emitted from industrial sites which consumed large amount of fossil fuels in order to supply energy in the form of electricity and heat. Most of previous and recent works aimed to reduce carbon emissions and has led to the implementation of energy technologies such as zero carbon resources (e.g., renewable energy such as solar, wind, hydropower or biomass) as well as carbon capture and storage.

At the same time, Pinch Analysis techniques has been extensively developed in energy planning sector to reduce carbon emission while simultaneously considering economic and technical constraints. Pinch Analysis techniques has notably and exceptional ability since it was first developed based on thermodynamic priciples to determine the optimal design of heat recovery networks for process plants (Hohmann, 1971; Linnhoff and Twnsend, 1982). Later, the Pinch Analysis tools have been extensively developed and implemented for design of resource conservation networks including mass, combined heat and power, water and hydrogen network, gas and properties, carbon, and power. The use of Pinch Analysis as a tool in emission targeting is very promising and has contributed significantly in addressing carbon emission reduction simultaneously targeting for renewable energy resources.

1.2 Problem Statement

There is a need to reduce the growing emission of CO_2 emission by industrial sector. Industrial site planner can play a big role to develop a low carbon emission industrial site by utilising the concept of symbiosis among industries. For example an industry with excess heat or electricity can transfer the surplus heat to a nearby plant which has deficit. A plant which generates carbon emission can treat and then supply CO_2 for industry which consumes carbon as its raw material. Furthermore, an industrial site planner can enact rule, select the best industries which can contribute to symbiosis mechanism, develop centralized utility system, and develop mechanism for symbiosis when planning for a low carbon emission industrial site.

In addition, there are various graphical tools based on Pinch Analysis which were developed to guide industries and site planners in minimizing their energy and carbon emissions. Pinch Analysis is a systematic tool for maximizing resource integration limited by a bottleneck which is called ‘pinch’. Pinch Analysis tools can be either graphical or numerical approaches. The graphical Pinch Analysis tools provide various useful insights for planners while the numerical Pinch Analysis tools give fast and accurate calculations. The main strength of Pinch Analysis tools as compared to a more comprehensive and complicated mathematical model is it is simple to construct, obey the thermodynamic rules, easy to visualize and planners can take part in the development of the system.

Some of the well-known Pinch Analysis tools related to energy and carbon emission are Heat Pinch Analysis, Total Site Heat Integration, Combined Heat and Power, Power Pinch Analysis and Carbon Pinch Analysis. Although all these tools are available, no work which guide industrial site planner in using these tools in an integrated manner for a systematic low carbon emission site planning has been done. Following is the problem statement for this research:

Given an industrial site owner who would like to plan a low carbon industrial site, the owner needs to select the most suitable industries to be located in its industrial site to enable the optimal integrated energy and carbon emission among the industries. Given also the various types of Pinch Analysis tools such as Heat Pinch Analysis, Total Site Heat Integration with cogeneration, Power Pinch Analysis, and Carbon Emission Pinch Analysis which have been developed for the minimisation of carbon emission in industries but however have not been used in an integrated manner. It is desired to study all the available Pinch Analysis tools which can contribute to low carbon emission in the industries in order to develop a systematic framework for the industrial site owner to be able to fully utilize these tools. This framework is expected to be available as a guidance for an industrial planner in planning a low carbon emission industrial site.

1.3 Objectives

The main objective of this study is to develop a systematic framework for low carbon emission industrial site planning by using an integrated set of Pinch Analysis techniques. Sub objectives of this study are as follows;

1. To study and identify suitable Pinch Analysis tools for industrial site energy and carbon reduction planning.
2. To develop a framework that integrates the identified Pinch Analysis tools for the selection of suitable industries to be built on the industrial site for low carbon emission industrial site planning.
3. To demonstrate the applicability of the new framework on a case study.

1.4 Scope of Study

This study presents a systematic framework for planning an industrial site addressing low carbon emission which is based on an integrated set of Pinch Analysis (PA) techniques.

1. State-of-the art review of low carbon emission site planning and Pinch Analysis. Reviewing the state-of-theory low carbon emission site planning and Pinch Analysis techniques which have been used for energy and carbon reduction.
2. Studying and identifying the relevant PA tools for industrial site in terms of energy supply and demand planning, as well as carbon emission reduction. Among the potential tools are Total Site Heat Integration (TSHI), Combined Heat and Power (CHP), Power Pinch Analysis (PoPA), and Carbon Pinch Analysis (CPA).
3. Studying the data resources needed to be collected in terms of steam, power and carbon for the low carbon emission industrial site planning based on the integrated Pinch Analysis approach. Data needed to be obtained from industries which submit their application to be constructed on the industrial site will be identified and tabulated in table form with proper guideline to the industrial site planner.
4. Developing a framework that integrates the identified Pinch Analysis for low carbon emission industrial site planning. The new framework will guide the industrial site planner on which Pinch Analysis tool to use, when to use it and how it can be utilized in the low carbon industrial site planning context.
5. Demonstrating the applicability of the new framework on a case study. The new framework will be tested on a case study to demonstrate its applicability for industrial site planner.

1.5 Significance of Study

1. The systematic low carbon emission site planning framework can guide industrial site owner to select the most suitable industries to be located in its site which can contribute to energy and carbon symbiosis mechanism, enact relevant rules, plan on the appropriate size of its centralized utility system, and develop mechanism for the energy and carbon symbiosis among industries.
2. The creation of the energy and carbon symbiosis mechanism in the industrial site can lead towards reduction of fossil fuel and outsourced electricity consumption and reduction of carbon emission from industrial site.
3. The development of proper infrastructure and mechanism for industries symbiosis will lead towards improved efficiency as well as other income generation and job creation within the industrial site.

1.6 Dissertation Outline

This dissertation consists of 5 chapters. Chapter 1 describes the introduction parts including background of study, problem statement, objectives, scopes and significance of study. Chapter 2 briefly reviews the development and reported works of Pinch Analysis and low carbon planning for industrial site. Detailed methodology of the new developed framework are proposed in Chapter 3. The findings of this study are discussed in Chapter 4. Finally, Chapter 5 concludes the overall study and proposed a few recommendations for future works.

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