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Towards the development of carbon dioxide emission landscape in Singapore

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Abstract

Carbon dioxide emission is an important parameter for indication of environmental impact of an industrial process. For a process that has known product capacity or revenue information, an Economic Input-Output Life Cycle Assessment (EIO-LCA) model can be applied to estimate the carbon dioxide emission. Due to the difficulty in obtaining such information for many industries, a simple linear correlation was developed using data obtained from applying EIO-LCA model on certain known processes in conjunction with the land area information obtained by ArcGIS, a geographic information software program. Jurong Island, an industrial park housing more than 100 companies in Singapore is chosen as the case study site. Carbon dioxide emission from different industrial sectors in Jurong Island were also compared.

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Keywords: Carbon dioxide emission; industrial sector; Economic Input-Output Life Cycle Assessment (EIO-LCA); revenue; map.

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1. Introduction

Carbon dioxide, being the key greenhouse gas, contributes to climate change. Continuous efforts have been made to separate, capture and sequester the carbon dioxide emitted in various industrial processes. However, it is desirable to control the carbon dioxide emission from the process perspective over the addition of extra carbon dioxide treatment units. In order to achieve the reduction of carbon dioxide emission from the process perspective, it is crucial to investigate the carbon dioxide emission landscape in an industrial park setting. Unfortunately, carbon dioxide emission from specific processes and companies are rarely available in the public domain. Therefore, there is a need to develop methodologies to estimate the carbon dioxide emission solely based on certain publicly available information.

At present, the emission of carbon dioxide typically is estimated by an indirect indication of the amount of carbon dioxide equivalent based on the energy consumption. In certain processes, such as a power plant operation, the actual measurement device can be utilized to measure the carbon dioxide content in the flue gas stream. Nonetheless, tremendous efforts need to be invested to collect such information and the completeness of information and the error involved is highly dependent on the organization that carried out the information collection. Moreover, such information may not be released outside of the organization and therefore is of little benefit. Alternatively, an Economic Input-Output Life Cycle Assessment (EIO-LCA) model has been developed by Green Design Institute at Carnegie Mellon University to combine the economic activities of industries with the process-based LCA such that a robust and simple mathematical model can be used to determine the economic and environmental relationship for particular industries [1,2]. However, the nature of the industry, revenue or products and capacities will need to be known in order to apply the EIO-LCA model.

In this study, Jurong Island, an industrial park housing more than 100 companies in Singapore is chosen as the case study site. Different degrees of detailed information is known for various resident companies. The objective of this study is to develop a methodology to estimate the carbon dioxide emission based on the different known information of a company. Comparisons are made in terms of accuracy and robustness of the different methodologies developed. Carbon dioxide emission landscape of different industrial sectors in Jurong Island is also revealed.

2. Methodology

ArcGIS, a geographic information software, was used to create and maintain the company information database for Jurong Island based on a map obtained from Singapore Land Authority (SLA). Figure 1 shows the map of Jurong Island divided by land parcels, each identified by a unique lot number assigned by SLA. The land parcels can represent roads, docks, land occupied by companies or remain unused. It is also possible that multiple land parcels are occupied by a single company or a single lot may be shared by multiple companies.

Figure 1. Map of Jurong Island divided into land parcels (Blue indicates an identified tenant, white is unknown or empty).

The map database created by ArcGIS contains entries such land parcel identification number, area, tenant (company), industrial sector, products, capacities, product price, revenue, and carbon dioxide emission. Efforts have been put in collecting company information based on the lot identification number through SLA website, search engines as well as company's respective websites. Industrial sector is categorized in accordance with EIO-LCA defined sectors, such as Mining and Utilities; Paint; Petrochemical; Plastics; Resin; Specialty Chemicals and; Trade. The application of EIO-LCA requires information on the revenue. Therefore, an attempt has been made to estimate the revenue based on the current capacities and prices of products produced by the company of interest. The revenue values were further adjusted to USD using an online currency exchange rate calculator [3]. As the model data is based on 2002 numbers, the estimated current revenue values were scaled back to year 2002 using US Inflation Calculator [4]. Nonetheless, the information collected is far from complete. This also reflects the actual scenario in most regions/countries due to limited public access to information of this type.

While the industrial sector a company belongs to can usually be determined without difficulty, the products produced and product capacity information may not be readily available. Figure 2 shows the sector breakdown among the identified industries on Jurong Island. It can be seen that the petrochemical sector occupied more than half of the identified tenants followed by the trade sector.

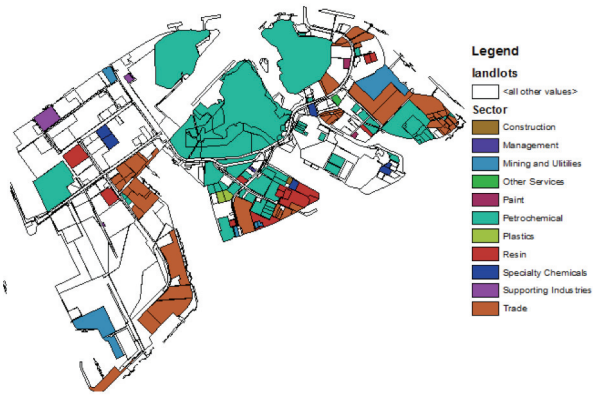

Figure 2. Map of Jurong Island with sector coloration scheme.

The use of land parcels allows the identification of land areas for each parcels. Thus, an attempt is used to correlate the carbon dioxide emissions based on the land areas occupied by each company in a particular sector, to which EIO-LCA model is applicable. As Jurong Island is mainly accommodates petrochemical industries, the petrochemical sector is selected for further analysis.

3. Results and Discussions

3.1. Basic model – Land area correlation with carbon dioxide emission

Among all the information regarding a company, such as products produced, product capacity, revenue, corporate income tax, and number of employees, the land area occupied by a company is the most readily available information due to the use of ArcGIS. While a company's market capital can also be determined easily, the volatility of the stock and the nature of multi-national business structure made the isolation of the specific business in Jurong Island a great challenge. Moreover, it is logical that a company occupying a large area tends to have higher carbon dioxide emission compared to a company within the same industrial sector occupying a small area. As a result, land area is initially chosen as the primary parameter to correlate with carbon dioxide emission in the absence of other information. It is reasonable to assume that if a company does not occupy any land area, no carbon dioxide will be emitted. Therefore, a correlation is obtained by linear regression of data points passing through the origin using the least-square method. The relationship between a petrochemical company's land area and the carbon dioxide emission estimated by EIO-LCA model is shown in Figure 3(a). Since the scale of operation for ExxonMobil is significantly larger than that of other companies, the same data is re-plotted by excluding ExxonMobil Singapore in Figure 3(b). It can be noted that the linear correlation over-predicts some of the carbon dioxide emissions of a number of companies such as Invista Singapore, Asahi Kasei Synthetic Rubber Singapore and DuPont Singapore. It can be possible that the products and capacities obtained from search engines were not complete for these companies. In fact, only a limited product line was found for these companies. It is expected that additional information on the company products and capacities can help to improve and validate the linearity of the correlation. On the other hand, the list of products obtained from ExxonMobil was obtained from the company brochure and the reliability of the data is more credible. A list of the individual product, estimated revenue and carbon dioxide emission for Exxonmobil Singapore is shown in A.2 and the information is compared against the linear correlation in Figure 2(c). There is reasonably good agreement between the data and the linear correlation. This correlation can serve to estimate the carbon dioxide emission for companies in the petrochemical sectors that have no information available other than the area occupied.

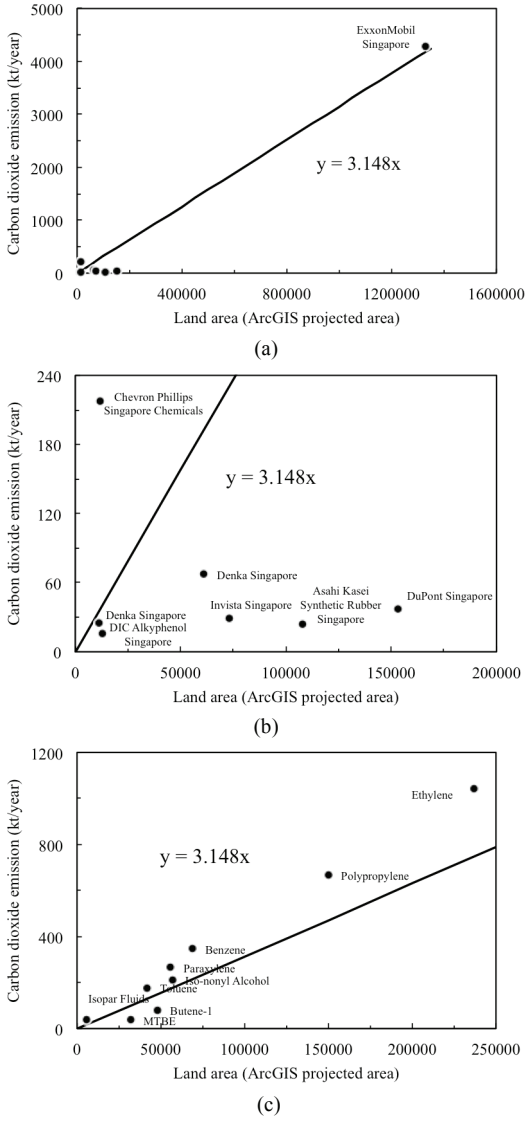

Figure 3. A plot of petrochemical land area with the carbon dioxide emission estimated by EIO-LCA model (a) All petrochemical companies with known information, (b) All petrochemical companies with known information, excluding ExxonMobil Singapore, (c) Individual products produced at ExxonMobil Singapore

3.2. Comparison of carbon dioxide emission among industrial sectors

There are 7 industrial sectors classified in the EIO-LCA model, namely petrochemical, plastics, resin, specialty chemicals, mining and utilities, paint, and trade. Among the companies whose carbon dioxide emissions have been identified by EIO-LCA model, the industrial sectors were mainly in petrochemical, plastics, resin, and specialty chemicals sectors. Table 1 shows the estimated revenue in the year 2002 and the estimated carbon dioxide emission. It can be seen that the petrochemical sector far exceeds the other three sectors in terms of revenue as well as carbon dioxide emission. Therefore, efforts in controlling and reducing the carbon dioxide emission should be emphasized on processes involved in the petrochemical sector.

Table 1. Comparison of carbon dioxide estimates among industrial sectors

Industrial sector	Revenue scaled to year 2002 (Million USD)	Estimated carbon dioxide emission (kt/yr)
Petrochemical	47,709	19,870
Plastics	420	14
Resin	781	150
Specialty Chemicals	3,097	2,396

At the present stage of research, there is insufficient data available for plastics, resin, and specialty chemicals companies to build a linear correlation similar to the petrochemical sector. On the other hand, the chemical processes involved in the production of petrochemical sector are fairly similar to plastics, resin, and specialty chemicals. It is often difficult to distinguish between the operations individually, since materials and processes are often shared among the different sectors. Therefore, the same linear correlation developed for petrochemical sector can also be utilized for plastics, resin, and specialty chemicals sectors.

4. Conclusions

Carbon dioxide emissions from different industrial sectors were estimated. For companies that have sufficient information such as products produced, product capacity, and revenue, an Economic Input-Output Life Cycle Assessment (EIO-LCA) model can be used to estimate the carbon dioxide emission. A simple linear correlation has been developed based on the application of EIO-LCA model on certain companies in Jurong Island, Singapore and identification of the company land area using ArcGIS, a geographic information software. When there is no product information available for a company, the land area obtained from ArcGIS can be used in conjunction with the linear correlation to obtain a basic estimation of the carbon dioxide emission. A comparison of the companies where EIO-LCA model is applicable, companies in the petrochemical sector have carbon dioxide emission far exceeding those in the other industrial sectors. Therefore, efforts in controlling and reducing the carbon dioxide emission in Jurong Island should be focused on the petrochemical processes.

Acknowledgements

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Appendix A. Tables of carbon dioxide emission

A.1. List of petrochemical companies that have estimated revenue and carbon dioxide emission

Company	Land area (ArcGIS projected area)	Revenue in the year 2002 (Millions of USD)	Estimated carbon dioxide emission (kt/year)
Chevron Phillips Singapore Chemicals	12,000	409	217
Denka Singapore	61,000	126	67
Denka Singapore	11,000	10	25
DIC Alkyphenol Singapore	13,000	30	16
DuPont Singapore	153,000	196	37
Invista Singapore	73,000	153	29
Asahi Kasei Synthetic Rubber Singapore	108,000	76	23
ExxonMobil Singapore	1,329,000	7,426	4,276

A.2. List of products, estimated revenue and carbon dioxide emission for Exxonmobil Singapore

Product	Land area (ArcGIS projected area)	Revenue in the year 2002 (Millions of USD)	Estimated carbon dioxide emission (kt/year)
Ethylene	237,000	1,800	1,041
Butene-1	48,000	140	81
MTBE	32,000	66	38
Polyethylene	632,000	2,440	1,405
Polypropylene	150,000	1,162	669
Iso-nonyl Alcohol	57,000	370	213
Isopar Fluids	6,000	67	38
Paraxylene	56,000	464	267
Benzene	69,000	600	346
Toluene	42,000	309	178