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An Improved Approach for Sustainable Outsourcing Strategy

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Abstract

In the modern business world, the trend that calls for a harmonious coexistence between economic development and the natural environment is growing ever stronger. Under such global context, the sustainability of a company has become more and more emphasized. As a crucial part of the supply chain management, the outsourcing process should as well be able to deal with such concerns under the guidance of a sustainable outsourcing strategy. In this report, a weighted scoreboard model (WSB) is developed for the evaluation and selection of suppliers when doing outsourcing. An equivalent carbon dioxide emission index is introduced as the unified criterion for measuring the sustainability of an outsourcing process. A brief case study is then conducted to illustrate the application and validity of the proposed model. The numerical results have shown that carbon emission index works as an informative representation of the sustainability measurement and bringing this new criterion into the outsourcing evaluation process alters the final ranking of suppliers.

Key words: sustainable outsourcing strategy, unified criteria, weighted scoreboard (WSB), carbon dioxide emission

1 Introduction

1.1 Introduction

In the modern world, the competition in providing high quality products or services have

been upgraded from intercompany to inter-supply chain. There exists eager demand for improving the total performance of the supply chain as a whole. In general, improving the efficiency while reducing the overall cost of the whole supply chain as much as possible is the ultimate goal. In another word, we want to maximize the supply chain surplus. To realize this goal, we have to endeavour on all aspects of the supply chain, from its infrastructure to its operating strategy.

One of the possible approach is to professionalize each link of the supply chain by outsourcing, which means companies within a supply chain should only focus on their core competence and outsource their marginal functions at relatively higher performance and lower costs. In order to fulfil all those requirements, the outsourcing process should be determined carefully with the help of a reasonable and reliable decision-making procedure: outsourcing strategy.

In another context, along with the increasingly serious environmental problems, worries for human beings' future and people's demand for higher life quality both arise quickly. The whole modern society is now paying more and more attention to the sustainability of the supply chains and companies. Taking responsibility and promote the company's public reputation is also very important parts in a good competitive strategy of a supply chain or a company.

Thus, as a very important part of the supply chain strategy, the outsourcing strategy should also be able to adapt itself to this tendency. Criteria of sustainable development of the company and the supply chain should be taken into account when discussing the decision-making process. This will in turn help the whole supply chain achieving strategic fit.

In such global context, a sustainable outsourcing strategy is urgently demanded by all the supply chain managers. This is a quite new but hot topic. Plentiful research and study is needed to explore it and make it a golden key to a better future.

Figure 1 Sustainable outsourcing: Key to the future [1]

1.2 Project description

In this master thesis project, an extensive literature review is carried out so as to fully understand the whole picture of this field. Based on those existing solutions, the candidate tried to bring about some innovation into this field. By selecting a reasonable criterion for measuring the sustainability of a company/a production or service process, the candidate tried to build up an extended mathematical model and set up an improved approach for the decision-making process of sustainable outsourcing strategy, which mainly deals with the evaluation and selection of suppliers. Further on, a case study should be conducted in order to illustrate the effectiveness of the model.

Detailed tasks in this project are described as follows.

1.2.1 Understanding the project assignment and set-up a project plan.

The first step of the project should be learning and understanding of the assignment. As a master thesis, the candidate step into a new but relevant field wielding acquired knowledge and learning skills. A preparation period should be settled for getting familiar with the topic. Then a rough project plan should be drafted with MS Project. Task summary, Gantt chart and milestones should be included within the file in order to clarify the planned progress of this project.

1.2.2 Performing an extensive literature review.

As long as the decision-making process for outsourcing strategy is a complete new concept for the candidate, an extensive literature review need to be carried out before anything practical could be done. This period is a studying process. The candidate is supposed to acquire enough knowledge to build up his own cognitive value on this subject. Then new ideas could spark upon this base.

1.2.3 Summarizing.

Alongside with the extensive literature review, a summarizing period is necessary to make the project more principled. The drivers and key criteria should be clarified and related possible methodologies should be summarized. Summarizing is a preparation for the further work. Only by doing this well, the project could be organized in a reasonable way and have a solid foundation.

1.2.4 Modelling and case study.

After all the preparation before, the core value of the project should be established by building up a graceful mathematical model. An elegant corresponding algorithm is also necessary. And practical problem would be proposed and solved with the established model and algorithm.

Software learning and programming would be quite intensive during this step. Rational thinking and careful coding and debugging is required.

1.2.5 Documentation of the work.

The documentation of the work should be done all the way as the project proceeds. A detailed and accurate thesis report should be provided after the project is finished. In this thesis report, what the candidate learned and summarized is included. A systematic exposition writing is performed to give a comprehensive demonstration about the improved approach for sustainable outsourcing strategy.

2 Background

Before start discussing the detailed contents of sustainable outsourcing strategy, we need to fully understand a few basic concepts: outsourcing, outsourcing strategy, sustainability. In this section, we will go through these step by step so as to acquire an overview of the theme.

2.1 What is outsourcing?

There are many versions of definition for the concept "outsourcing". The following one could be considered as a representative: "In business, outsourcing involves the completely contracting out of a business process (this process can either be production process or service process) or operational/ non-core functions, which is usually performed inside the organization itself, to an external party/organization" [2]. Simply speaking, instead of doing the process itself, the company introduces an external partner to perform it.

Figure 2 All kinds of outsourcing process [3]

The reason for introducing such outsourcing process could be complicated. There are many different kinds of reasons that will cause a company to do so. One of them could be stock-out of a particular product or service. In order to fulfil the demand and keep the customers' satisfaction on a high level, the company must outsource this product/service. Or sometimes the existing production/service capacity is too low to meet the incoming demands. In this situation, as the order should not be delayed, the company need to introduce a partial outsourcing process to replenish the gap of production/service capacity. In another situation, the cost of providing a specific product/service inside the company or organization could be higher than purchasing it from the external suppliers. To reduce the total cost, which in turn increases the overall profit margin, the company need to outsource this part.

In fact, all the existing solutions for a production/service process could be marked with a price. And we can see, in all the situations mentioned above, the internal solutions' prices are higher than the external solutions' prices. Then, logically, outsourcing occurs. Consequently, we can conclude that the outsourcing process is a natural result of pursuing higher rate of profit by a commercial organization, which is normally a company.

2.2 Why a company should do outsourcing?

By knowing what is outsourcing, we can set about exploring why a company should do outsourcing. Surely the ultimate objective of outsourcing is to strengthen the company's core competence and enhance the profit margin. The reason for doing it is still quite comprehensive and complicated. We would go over some of the most important ones below.

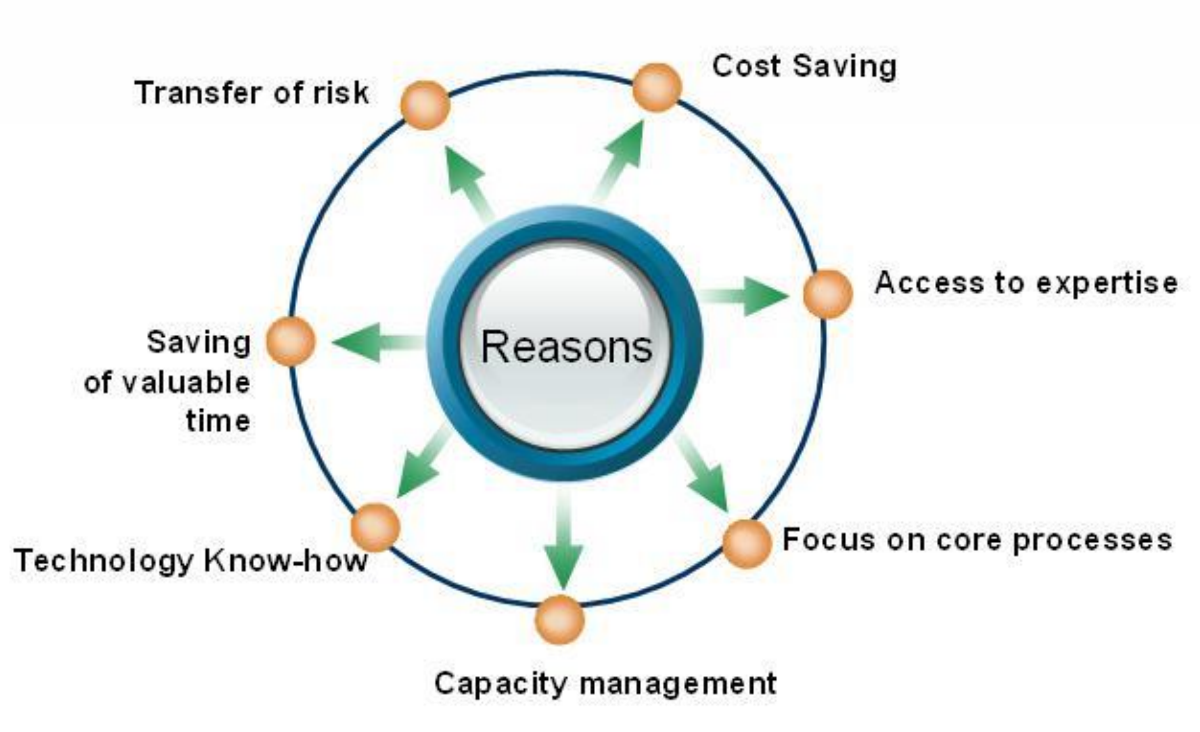

Figure 3 Top reasons/benefits for outsourcing [4]

1. To reduce cost from economics perspective. This one is quite simple for understanding. According to those mentioned above, the original driving force that makes outsourcing occur is the pursuit of higher economic profits. The suppliers that provide the product/service are experts and specialists in the particular fields. The outsourcing model is now being leveraged by over 40% of the world's top five hundred companies including Apple, GE, IBM, Microsoft, ABB and etc. [5] The offshore outsourcing, for instance, can bring about cost saving at 50% - 70% depending on the on-site and the resources that are outsourced. By the year 2015, over three million US job positions and a hundred billion dollars' worth of wages are outsourced to Asian and African countries due to cheaper labour forces.

2. The company could focus more on its core competence. In the modern world, strengthen the core business competence and build up barriers surrounding it could be one of the popular and successful

competitive strategy. Doing outsourcing gives a company the chance to concentrate on its core competence.

3. Demand uncertainty transferred to suppliers. The real business world is much more complicated than its mathematical models. Only reducing the cost is not enough for a company to be successful and survive in the cruel competition. The ability to resist the unpredictability of the market would be helpful. By doing outsourcing, a part of demand uncertainty will be transferred to the suppliers so relatively the company itself becomes stronger when facing up to the fluctuation of the market.

4. Capital investment transferred to suppliers. All the production/service process, to some extent, require capital investment. Outsourcing of some of these processes allows a company to transfer the corresponding capital investment to the suppliers. Thus, the company is freed from the capital burden and able to optimize its cash flow.

5. Taking advantage of access to suppliers' new technologies and innovation to reduce product development cycle time. As we have mentioned above in the second point, the outsourcing process enables a company to focus more on its core competence, which also applies for the suppliers. This means each company in a mature supply chain can focus on its core competence and try to develop new technology and innovation for better efficiency. As these companies are linked together within a supply chain by outsourcing process, the advantage of such improvement in efficiency will be shared through the whole supply chain. Thus, the total surplus of the supply chain will be enhanced.

Other than those that we have stated above, outsourcing also enables the company to improve the overall quality, to obtain cash infusion, to improve its flexibility and etc. Generally speaking, it is too difficult for a modern company to survive on the market by itself. Cooperation within the supply chain is crucial for business success. Outsourcing provides a reliable pattern that companies can work together to improve the overall performance.

2.3 What is outsourcing strategy?

Literally, the outsourcing strategy is the strategy of how to do outsourcing. It is the guideline on how to perform the outsourcing process. In fact, it includes two major parts: When outsourcing should be done? How to perform the outsourcing process properly? A complete outsourcing strategy should be able to answer these two questions above.

The first question involves a decision-making process: to outsource or insource? To solve this problem, a series of criteria should be put forward to estimate the situation properly and establish a firm theoretical foundation for the further decision making. In this stage, one of the most widely used criterion is the cost of the process, which means assessment is done by comparing the cost of doing the process inbound and outbound. Many other criteria are also adopted in practice, we may go through some of them in the later sections of literature review.

The second one, after the company determined to carry out the process through outsourcing, deals with details which help to perform the outsourcing process. It is not only about the evaluation and selection of suppliers, but also the proper allocation of the existing demand among the selected suppliers. We can call this critical job “supplier management”. These measures within the supplier management are often done progressively.

Normally, in the first place, a group of qualified suppliers would be listed and a set of criteria is formulated to evaluate these existing suppliers in the beginning. Then, according to the criteria set, each supplier will be evaluated. This evaluation process could have different manifestation modes such as mathematical programming (MP), data envelopment analysis (DEA), genetic algorithm (GA) and so on. The supplier evaluation approaches are also evolving, from the simply cost-oriented to cost-quality combination then multi-criteria evaluation. No matter what method the company use, a shrunken group of suppliers, which might include one or several “optimal” suppliers, will be sorted out. After that, the company’s existing demand will be allocated among these “optimal” suppliers. There are quite a few reasons to do this. One of them is the “optimal” suppliers may also have their own capacity and the demand cannot be met with only one supplier. Another one is the old saying “Do not put all your eggs in one basket”. The company cannot risk its business prospects. More backups are needed for possible crisis. Also, more parallel suppliers would bring in competition, which might be able to motivate the suppliers to raising its productivity and lower the price.

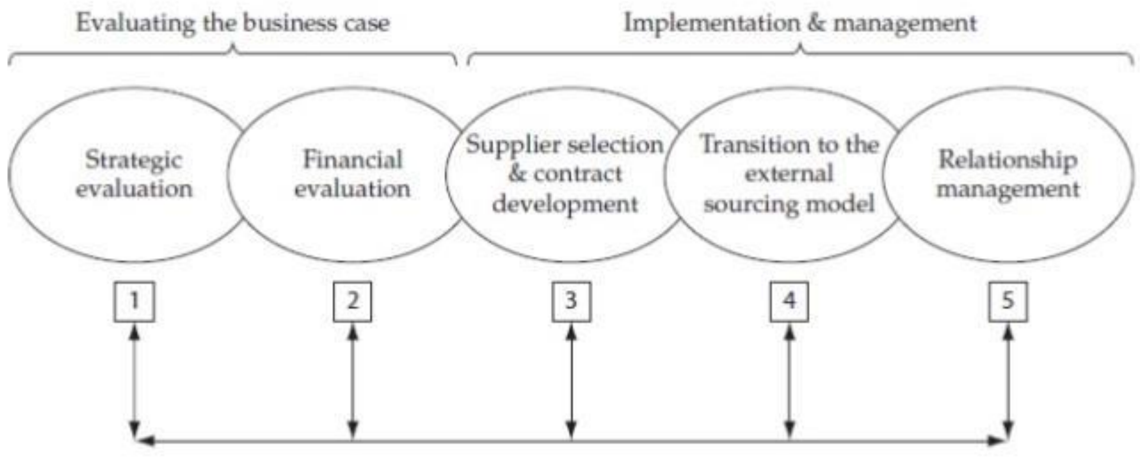

Figure 4 The concept of outsourcing strategy [6]

All those mentioned above are included in the term “outsourcing strategy”. Other than the evaluation and selection of the suppliers, the relationship management and some other management tasks should also be executed under the guidance of the outsourcing strategy. This is the core concept and the uppermost guiding ideology for the outsourcing process. The whole process will be carried out firmly following this strategy.

2.4 What is sustainability?

A typical explanation of the word “sustainability” in dictionary is “the ability to be maintained at a certain rate or level”. This, in fact, is a quite universal concept. According to the definition of the United Nation’s World Commission on Environment and Development in 1987, “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (quote from the Brundtland Report)

At present, when people talking about “sustainability”, they are mostly talking about its ecological connotation and its additional significance in economics: “In ecology, sustainability is the property of biological to remain diverse and productive indefinitely. Long-lived and healthy wetlands and forests are examples of sustainable biological systems. In more general terms, sustainability is the endurance of systems and processes. The organizing principle for sustainability is sustainable development, which includes the four interconnected domains: ecology, economics, politics and culture” [7]. In current business world, the environmental influence and the moral problems are two particular things that people care about the sustainability of a company.

The environmental aspect of sustainability is easy to understand. No matter what kind of industry a company deals with, the production or service process will consume a lot of natural and/or social resource, including energy, raw material, labour force and etc. Also, during or after the process, other than the product/service itself, waste will be produced, such as emission of greenhouse gas, waste water and leftover material. All these could have direct or indirect impact on the natural environment. To achieve environmental sustainability, we need to find ways to reduce the negative effects.

The moral aspect of sustainability involves with the human beings that participate in the process. Labour protection is one of the typical theme considering moral sustainability. Companies have the duty to protect their employees from being harmed during working period. For instance, providing protective garment for workers who work in a chemical plant that is producing toxic substance is necessary. And protecting workers from working overtime and death from overwork is also a common problem.

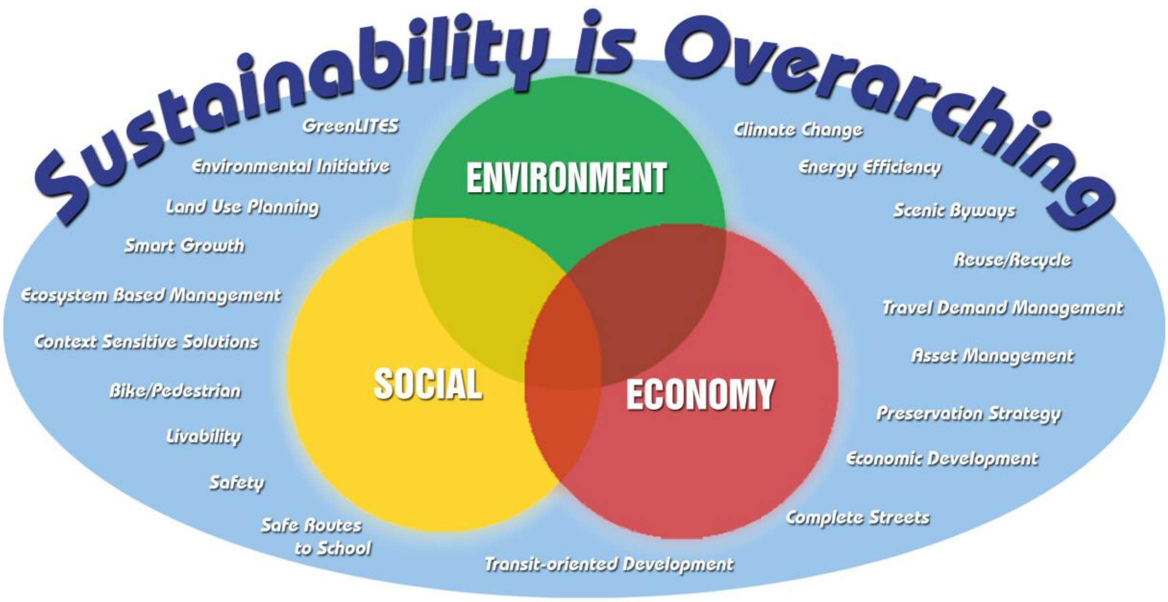

Figure 5 The connotation of sustainability [8]

Here in this report, we mainly want to discuss the environmental connotation of sustainability. The candidate tried to give out a unified standard that measures the sustainability of a company in a particular business process. Then, combined with the analysis of current research, an improved approach of sustainable outsourcing strategy will be proposed.

2.5 What is sustainable outsourcing strategy and why?

As mentioned before, the traditional outsourcing strategies consider only the financial or business-related indicators, such as the overall cost of the process, average delivery time or cycle time, the quality of the product/service and etc. As people become more and more aware of the importance of achieving the harmonious coexistence of human beings and the nature, the modern society calls eagerly for a sustainable development in all the industries, which compels us to seek the balance between business success and the price paid for sustainability: environmental, moral principles, labour protection and etc. By taking those indicators into account, we compromise a sustainable outsourcing strategy. In short, sustainable outsourcing strategy is a compromise between pursuing highest possible commercial profits and the sustainable development of the company.

Criteria for sustainable outsourcing strategy is complicated and comprehensive. There exist a lot of different criteria in different companies: the exposure level of daily noise for each labour is used for cell manufacturing; the carbon emission per unit is used for some mass production company; the coolant/energy consumption per unit is used for some CNC processing; the daily working hours of each labour is used for some IT outsourcing.

All those listed above are criteria that been used in practice. In this master thesis project, the candidate will try to narrow down the scope of the problem and essentially merge all these into a unified criterion.

3 Literature review

In order to establish a comprehensive and profound knowledge of the topic, an extensive literature review is required for this master thesis project.

3.1 From a historical perspective

As time goes on, the cognition and research to the outsourcing strategy is also evolving. This evolutionary process has gone through the change from cost-oriented principle to multi-criteria evaluation. In this section, we will briefly go through the phylogeny of the outsourcing strategy in a historical view.

As mentioned above, the outsourcing process is a natural result of pursuing commercial profit. No matter what kind of business a company is dealing with, produces products or provides services, seeking for profit is an eternal theme. To increase the total profit, cost should be reduced as much as possible. Considering cost saving, the transaction cost theory (TCT) is naturally dominating in practice for outsourcing strategy. The theory first brought up by Coase and developed by Williamson [9][10]. The theory describes the situation when a company needs to decide whether to do insourcing or outsourcing the company should compare the production cost C_p and the transaction cost C_t by checking the value of $C_p – C_t$. If $(C_p – C_t)>0$, which indicates cost could be reduced by outsourcing, outsourcing happens. Here, the transaction cost C_t should include both the operational cost and the contractual cost (which consists of the bargaining and communicational costs). This TCT method emphasize the importance of cost-reduction effect of the outsourcing process. Some of the successors, such as G. Walker and D. Weber [11] [12], carried out a series of exploration and thorough study on this method.

However, later in the ending decades of the twentieth century, along with the development of management science, the TCT started to be criticized for its singular focus on cost minimization. Researchers in this field tried many ways to complement with or substitute for the TCT, such as property rights theory (PRT), agency theory (AT) and power theory (PT) [13] [14] [15]. Later at the turn of the century, Douma and Schreuder [16] proposed that a resource-based view (RBV) should be adopted to help understanding the outsourcing strategies and the corresponding decisions. Based on this RBV, a knowledge-based theory (KBT) was developed. It regards the company as collections of resources or sets of knowledges [17]. No matter what those researchers proposed, their core ideologies are the same: the single criterion cost could no longer satisfy the demand of modern business management. Naturally, the multi-criteria strategies appear. Many different approaches are introduced to help realizing the multi-criteria strategies, such as the balanced scorecard, data envelopment analysis, mathematical programming and so on [18].

Recently, along with the increasingly severe environmental issue, there arises a trend to take the environmental sustainability into the daily management of an enterprise and make it become normal and necessary [19] [20]. As an important part of the business strategy, the outsourcing strategy should also be able to fit in this trend. A few of the pioneer have stepped into this field to form up combination of the traditional thinking and the sustainability of the companies [21] [22]. However, most of these studies are based on specific scenes and cases and their conclusion and theories are impossible to be generalized and applied extensively. Thus, there are works need to be done in this field. A more general and comprehensive view needs to be created. This is also the mission of this master thesis project.

3.2 From a methodological perspective

After the TCT is considered to be inappropriate, new multi-criteria strategies are widely used in this field. A lot of different approaches are introduced by researches to solve the problem of evaluation and selection of suppliers. In this section, we will make a brief review of the approaches that are applied in determining outsourcing strategy from a methodological perspective. These approaches could be roughly divided into two groups. The first group is individual approaches that use a single method in their solutions. The second group, in the contrary, is integrated approaches that combine two or more methods in their solutions.

3.2.1 Individual approaches

There are quite a lot of individual approaches that has been used in researches, such as the balanced scorecard (BSC), the data envelopment analysis (DEA), mathematical programming (MP), analytical hierarchy process (AHP), analytical network process (ANP), genetic algorithm (GA), fuzzy set theory (FST), case-based reasoning (CBR) and so on.

Genetic algorithm (GA) is a metaheuristic algorithm inspired by the natural selection process and is a sub-class of the evolutionary algorithms. GA is commonly used to pursue solution with high quality in operational research. In the algorithm, bio-inspired operators such as mutation, crossover and selection are used to search for optimal solutions. F. Niakan, A. Baboli, T. Moyaux and V. Botta-Genoulaz [23] performed a research on the sustainable dynamic cellular manufacturing system. In this research, the energy loss, which is represented in the research by the efficiency of each machine, is considered as a supplement to the cost criterion. Thus, a new bi-objective mathematical model is introduced. In order to solve this bi-objective model, a non-dominated sorting genetic algorithm (NSGA-II) is developed.

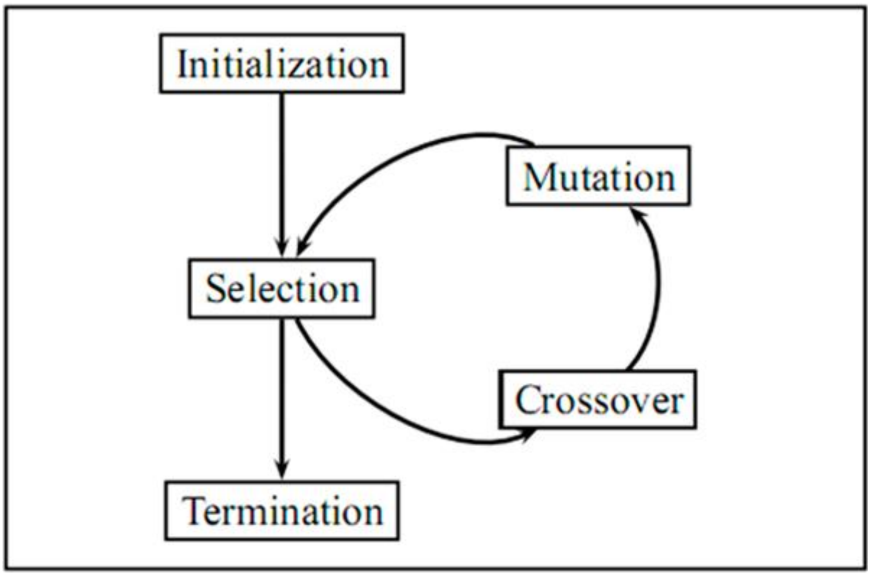

Figure 6 A simple flow chart of genetic algorithm [24]

Mathematical programming (MP) is in fact a general class. It includes quite a few sub-classes, such as linear programming, integer linear programming, integer non-linear programming, goal programming and etc. Talluri and Narasimhan [25] performed the linear programming approach in the evaluation of alternative suppliers. They introduced two linear models to maximize and minimize the performance of a candidate supplier according to the best target measures that are set by the purchaser. They claim that by measuring both the highest and lowest efficiency of every supplier would give a more comprehensive view of their capability. Karpak, Kumcu and Kasuganti [26] created a goal programming model for the evaluation and selection of suppliers. They applied three criteria in this model, which are cost, quality and delivery reliability. These three criteria serve as three goals in the model to determine the optimal order quantity. The demand of the purchaser and the capacity of the supplier are used as constraints.

The analytic hierarchy process (AHP) was developed by Tomas L. Saaty [27] [28]. This approach mainly deals with solving decision problems with multi-criteria and uncertainty. Expertise of decision-makers are collected and hierarchic structures are adopted to model sophisticated decision problems in a way that disassemble them into a few sub-problems which are easier to be solved. Chyan Yang and Jen-Bor Huang [29] performed a research on IS outsourcing with help of this AHP model. This paper addresses the current research stage of information outsourcing in the Information System management field and points out that merely conceptual discussions are not enough to aid the decision maker sufficiently. This work argues that five factors, including management, strategy, economics, technology and quality, should be considered for information outsourcing decisions. It uses the analytic hierarchy process (AHP) method to help companies in structuring the outsourcing problems. The proposed model offers systematic steps and quantitative results to increase the precision of outsource decisions. The core contribution of this paper is the practical operations of the methodology in the area of IS outsourcing. There is also a similar work from Yang, Kim, Nam and Min [30], which uses this model to deal with general business process outsourcing.

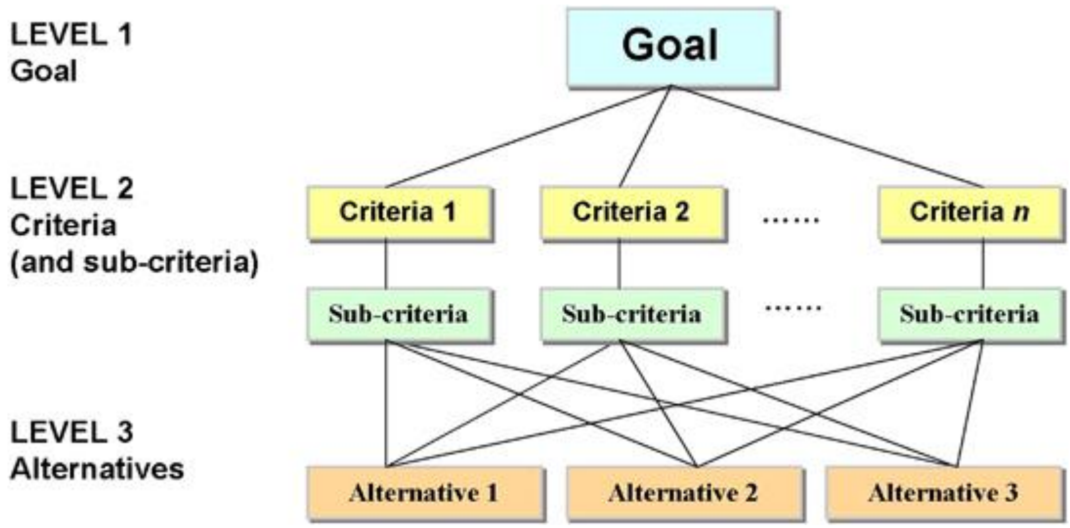

Figure 7 A typical AHP diagram [31]

The analytic network process (ANP) is an approach that developed based on the AHP approach. It could be taken as a more general model of AHP where a network structure is used to replace the hierarchy structure. Bayazit [32] applied this model to handle the evaluation and selection of suppliers. In his model, ten evaluating criteria, which could be mainly classified as performance attributes and capability attributes, are proposed. All of the criteria are considered as controlling factors for a pairwise comparison matrix, which formulates the interrelationships among all the criteria.

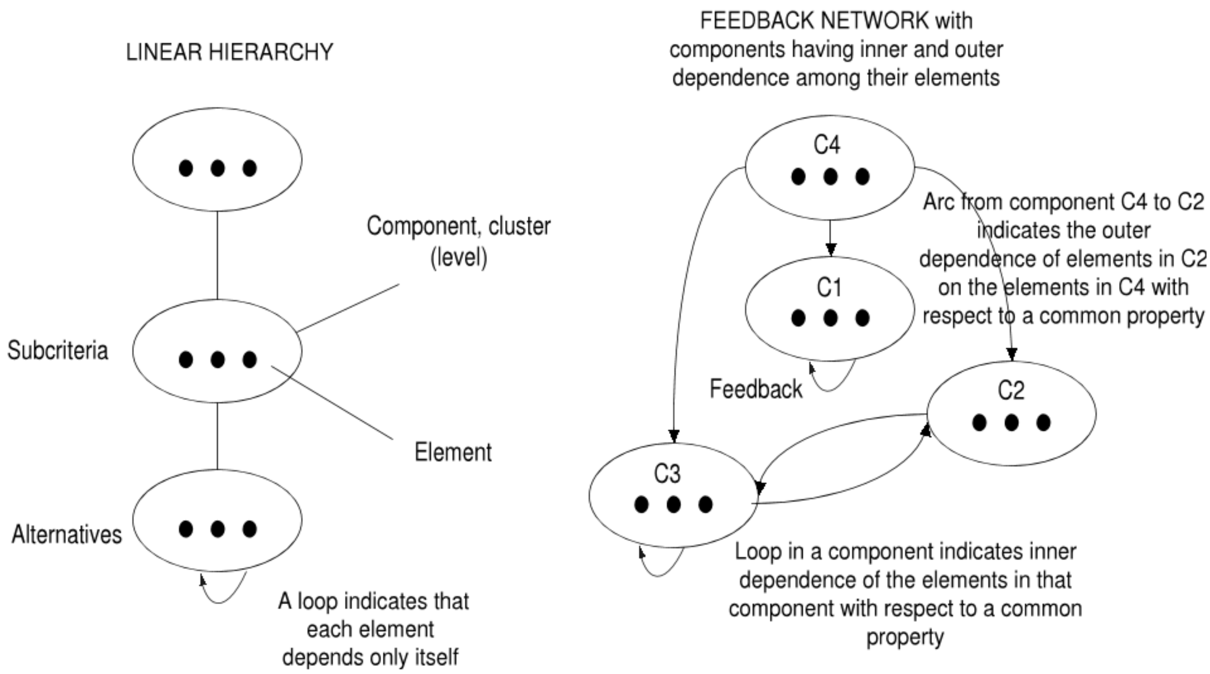

Figure 8 A simple comparison between AHP and ANP [33]

The balanced scorecard (BSC) approach is a method that measures the performance of the suppliers according to each individual criterion with a qualitative scale. Then a total weighted score will be calculated in respect to the balance between the different criteria. The final evaluation is performed in the form of a scorecard or a ranking list. Barla [34] carried out a case study with the help of such BSC method. Though he claimed it as Multi-attribute selection model (MSM), it is essentially a typical BSC model.

The data envelopment analysis (DEA) is normally considered to be a nonparametric approach for estimate the relative performance of organizational units with multiple inputs and outputs, which makes the direct comparison very difficult or even impossible. Liu, Ding and Lall [35] applied a simplified DEA model to help evaluating the overall performance of suppliers. The model is used to find suppliers that have higher capability in providing various products so that the total number of suppliers could be reduced. Two output criteria and three input criteria are referred to in the model. In fact, according to a literature review paper which presented by Ho, Xu and Dey [36], the DEA approach is the most prevalent individual approach.

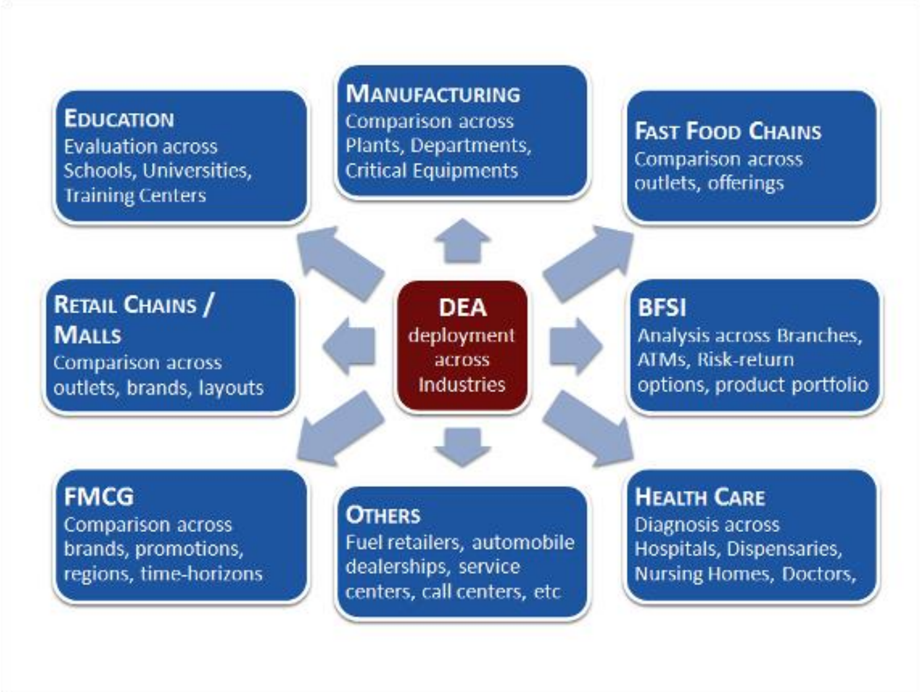

Figure 9 A illustration for DEA approach [37]

Other than those approaches that we discussed above, there are still many individual approaches, such as Tabu search (TS) [38] and etc., to deal with the outsourcing strategy problem. We do not bother to review all of them in this project.

3.2.2 Integrated approaches

As all those methods have their advantages and disadvantages, there also many researchers that would like to combine different methods in their solutions to achieve better result. These we call "integrated approaches". In the following, some of the prevalent ones will be reviewed.

In the research of Felice, Petrillo and Autorino [39], an integrated approach, which is a combination of AHP and BSC, is applied to develop a framework for sustainable outsourcing. They call it analytic balanced scorecard method (A-BSC) and claim that the method is effective for analysing the strategic performance within an outsourced supply chain. A case study is also included in the paper which illustrated the feasibility of the model.

Ravindran, Bilsel, Wadhwa and Yang [40] applied the combination of AHP and GP in their research. This paper mainly addresses the issue of disruption risk in the process of supplier selection that seeks to reach lower supply chain cost. The objective here is to develop multicriteria supplier selection models incorporating supplier risk and apply the approach to a real global IT company. The proposed model has two phases where the first one filters a large set of suppliers to a smaller and manageable pool of potential suppliers using multi-objective ranking methods with the help of AHP. In the second phase, order quantities are allocated among the selected suppliers from the first phase using a multi-objective optimization model. The essence of the study is that in the multi-objective formulation, price, lead-time, Value-at-Risk type risk and Miss-the-Target type risk are explicitly considered as four competing objectives that have to be minimized simultaneously. The Value-at-Risk represents those less frequent events such as labour strike and natural disaster while Miss-the-Target type of risk stands for more frequent and possible events such as late delivery and low-quality performance which cause less damage to the operations than the previous kind. The criteria used in the first phase includes information technology, long term improvement and risk where environmental sustainability is absent. The comparison of the optimal solutions shows that under different Goal Programming methods, price and lead time have robust results but both Value-at-Risk and Miss-the-Target criteria are very sensitive to the choice of GP method.

Wang and Yang [41] introduced a new integrated approach in their work of decision aid for information systems outsourcing. To address the outsourcing of the information system (IS) of a company, this paper chooses a hybrid method where both analytic hierarchy process (AHP) and preference ranking organization method for enrichment evaluations (PROMETHEE) are used to evaluate potential suppliers. Six factors, including economics, resource, strategy, risk, management and quality are emphasized in this framework as key criteria. A numerical example is illustrated together with sensitivity analysis and shows that management, economics and risk have the greatest impact on the complete ranking. The core message of this work is to illustrate how the hybrid method, in this case, AHP/PROMETHEE II, provides powerful tools to rank candidates in information systems and to analyse the relations between criteria. From a practical point of view, the proposed approach can easily deal with supplier selection that involves several conflicting performance criteria (qualitative as well quantitative).

Wu and Chien [42] addressed the similar problem with an integrated approach that consists of AHP and MP. Vendor selection strategy and vendor evaluation are semi-structured decision problems that require subjective judgments from decision makers to reach proper balance among various performance levels of different attributes, while order allocation and Material Requirements Planning problems are structured decision problems in which the decision elements and their connections can be totally structured. There exists a gap in the literature that can be filled with a more integrated framework. While most of the existing studies focus on either vendor selection or order allocation, this study proposes a decision analysis framework for semiconductor assembly outsourcing to integrate semi-structured decision problem for strategic vendor evaluation and structured decision problem for order allocation. This paper summarized the vendor selection criteria into hierarchy from strategic objectives, fundamental objectives, to the associated attributes. Strategic objectives include cost, quality and reliability, delivery, technology, support, management and context as well as partnership. Inside the category of management contest, there exists a fundamental objective which includes attribute of green environment issues. This can be understood as an exploratory touch upon the sustainability issue but it is not the main focus and contribution of this paper.

Araz, Ozfirat and Ozkarahan [43] applied a novel integrated approach, which is a combination of PROMETHEE, fuzzy set theory (FST) and goal programming (GP), in their research paper. The problem objective of this study is to evaluate and manage outsourcing suppliers analytically and then apply the proposed methodology to a textile company in reality. The proposed methodology is based on PROMETHEE, which is a well-known multi-criteria decision aid method, and fuzzy goal programming. The developed framework allows the incorporation of decision makers' imprecise and vague expectation levels for the goals by means of interactive fuzzy parameters. Existing outsourcers are evaluated in terms of the objectives then the most appropriate suppliers for the strategic partnership are selected and ordered quantities are allocated to them. The highlight of the study is that the numerical results show significant benefits of applying such a methodology for the company at hand. And it also identifies the differences in performances across suppliers assisting in monitoring the suppliers' performances.

Faez, Ghodsypour and O'Brien [44] conducted their research with the help of integrated approaches. This paper lends itself to the issue of vendor selection problem by incorporating an integrated fuzzy case-based reasoning, which could be taken as a combination of fuzzy set theory (FST), mathematical programming (MP) and case-based reasoning (CBR). A typical case-based reasoning approach is based on retrieval and adaptation of old solutions to new and similar problems, which has commonly been recommended as a decision support system for the logistic management in companies. This paper starts from the conventional approach and seeks to deal with the imprecise and vague nature of many values by using the fuzzy logic. In the proposed model attribute values are determined by trapezoidal fuzzy numbers. The proposed two step model includes both selection of the vendors and the quantity allocation among them using a mathematical optimization model. Selected vendors are evaluated based on three main criteria: cost, delivery and quality, where sustainability is absent. In the numerical example, when a certain weight combination is determined among the three criteria, the mathematical model will select the vendors and also assign proper order quantity respectively. By applying the conventional case-based reasoning method in a fuzzy environment, this paper improves vendor selection decision results and also determines the allocated order quantity using the result of the integrated fuzzy approach using mathematical programming.

Among all those integrated approaches, the AHP is the most adopted individual one, as it gives an intuitive illustration of how the framework of the research should be organized. Other approaches, based on the AHP structures, generate more accurate solutions for the final decision-making process.

3.3 From a sustainable perspective

There is not much research about the sustainability in the outsourcing process. But as a burgeoning trend, more and more researchers have started to pay attention to this topic.

However, unified standards have not been set up in this area. Some of the researchers did empirical studies and only give out vague descriptions of the sustainability instead of operable criteria, like what Hutchins and Sutherland [45] did in their study.

Some others tried to give out a specific criterion of the sustainability of a business process or a company. But none of them achieve the universality, which means the criteria they used could not be easily applied to other companies. Guillen-Gosalbez [46] and Grossman introduced the Eco-indicator 99 into the field. The environmental performance of the network is measured by recording all the energy and material input and the waste output in a process. This information will be further identified and calculated to generate a performance indicator. However, this indicator is only suitable for chemical supply chains. In the research of Niakan, Baboli, Moyaux and Botta-Genoulaz [23], the labour protection connotation of sustainability was addressed. In this paper, dynamic cellular manufacturing systems are studied. The work intensity in such systems are quite high and the pressure on individual workers is also considerable. A daily noise dose (DND) constraint is introduced in this research to serve as the criterion of the sustainability of the system. In another article presented by Delzeit and Holm-Müller [47], quality of bioethanol and handling, conservation of biodiversity (rain forest) and no child labour are used as criteria of sustainability. In help with those criteria, the research aimed to minimize the negative social-ecological impacts and increase the sustainable production of biomass. Still, these criteria might fit the target problem well but are impossible to be generalized.

Thus, we can see that there exists an urgent demand for a standard criterion to measure the sustainability of a general business process or a company as a whole. We will try to carry out such a research around this theme in this master thesis project. The details are presented in the later sections.

3.4 From other perspectives

Other than those mainstream perspectives we discussed above, there are still some researchers carried out their research from an unusual starting point.

Schniederjans and Zuckweiler [48] did their work for the outsourcing-insourcing decision-making in an international contex where an international risk factor is introduced to the mathematical model for the first time in the literature. It emphasizes the significant trend of outsourcing in general and international outsourcing in particular. The methodology is based on the common equation for outsourcing-insourcing problems and is then developed in a unique manner for the model at hand. The paper thoroughly analyses potential risk factors where international outsourcing activity is involved which include economic, political and cultural risks. One highlight of the conclusion is the sensitivity analysis that exhibits that a relatively small change in the context-specific parameter can lead to very different results regarding the decision of international outsourcing. This argues strongly about the necessity of including international risk factor into the decision model. The framework presented in the paper can also be extended to include and deal with variability by applying sensitivity analysis. The uniqueness of the model fully allows wider application possibilities. The paper includes a highly relevant case study of a Fortune 500 corporation outsourcing manufacturing activities from the US to Mexico. The results show that the decision made in real business life by the company goes in line with the theoretical result from the underlying methodology in the paper. It reassures the usefulness and validity of the method presented and the inclusion of the international risk factor.

Abdel-Malek, Kullpattaranirun and Nanthavanij [49] together performed a study on the outsourcing strategy for multi-layered supply chains. They built a framework to compare and study different outsourcing strategies under the assumption and focus of multi-layered supply chain in this paper. Similar to using carbon dioxide emission as the key indicator to represent sustainability in this thesis, this paper uses safety stock level as the main performance measurement of the problem. One of their motivation is the ever-growing application of the internet and various electronic devices, which makes the competitive bidding more and more attractive. After presenting the analytical model of the multi-layered supply chain, this paper conducts numerical illustration of the model and in the end compares the Markovian versus the non-Markovian results for the analytical solution. What they find is that the length and variance of the lead-time as well as the inventory carrying costs are the most decisive elements for the competitive bidding strategies. If the difference between the competitive bidding and the traditional long-term partnership is not big, the potential gains can be decreased by the rising inventory cost of the safety stock. Their framework and approach offer companies a first cut evaluation of the suppliers under a multi-layered supply chain.

3.5 Summarizing of the current situation

In the literature, there exists numerous methodology, theory, approaches as well as frameworks that serve the common purpose of evaluating potential suppliers and determine the outsourcing strategy. Most have chosen criteria such as cost, quality and service level. Some have put emphasize on specific newly involved criteria such as international risk and technology. Very few have touched upon the topic of sustainability in general. Some have brought up related concept and discussions but none have done explicit work on this subject. Thus, a reasonable and universal standard regarding taking sustainability as one of the criteria when evaluating and selecting suppliers is absent in the current literature.

From the perspectives of the field of supply chain research itself as well as the practical side of the business world, establishing a proper model with sustainability as one of its main criteria is certainly important and urgent. In this master thesis project, the sustainability of business processes of suppliers is represented by an equivalent carbon dioxide emissions value and this idea has its source and root. It has been applied and studied in a similar manner in various areas as well [50] [51]. Also, this work should be appealing for more research effort towards this direction and further improve the evaluation process for decision makers.

4 Modelling of the new approach

In this section, the candidate wants to present a complete process of modelling of an improved approach for the sustainable outsourcing strategy. Based on the previously established methods, the improve approach tries to combine the traditional criteria and the suggested standard criterion for measuring sustainability and integrate them to form a new way of the evaluation and selection of suppliers.

4.1 Determining the standard criterion for measuring sustainability

As stated above, there are many different criteria for measuring sustainability in different industries and companies. But when we outsource a business process instead of executing it within a single section, the process will mostly be transferred between two different sections or companies within a supply chain. It means that the inconsistency of evaluation and selection standard between these two parts might cause many problems. For instance, the cost of communication will be highly increased and the possibility of misunderstand arising between the purchaser and the supplier also increase. Thus, a general standard is eagerly needed for the measuring of the sustainability when we are going to evaluate the suppliers from this perspective.

Then comes the main problem: which factor should be selected as the general indicator of sustainability of a business process? To solve this problem, we need to dig into the deep stratum. Essentially, there are two main characters that a general indicator should conform to: universality and convertibility.

The general indicator should be able to represent all or at least most kinds of companies. Thus, the indicator should exist widely in all kinds of industries or could be easily transformed from other indicators for sustainability. The candidate would propose to call this property “universality”.

On the other hand, the general standard should also be able to fit well with the traditional criteria so as to form an integrated combination, which means the indicator should also be converted into or at least compatible with some of the traditional criteria that are used in the supplier evaluation. This one the candidate calls “convertibility”.

Taking these two properties into consideration, the candidate deliberated many indicators that are used in practice. Among all those currently used indicators, the carbon dioxide emission (CDE) suits best. The bigger the CDE indicator is, the lower the sustainability is.

In the following two sub-sections, the appropriateness of this new CDE indicator will be illustrated.

4.1.1 Universality of the CDE indicator

As carbon dioxide emission is quite a universal phenomenon in the nature and also in all the industries. For example, the generation of electricity, like in a thermal power station, will also accompanied by the generation and emission of carbon dioxide. Or even if the process itself will not produce much carbon dioxide, the manufacturing of the relevant equipment, the consumption of energy and labour force will still add carbon emission to the environment.

On the other hand, as carbon dioxide is one of the typical greenhouse gas (GHG), the direct consequence of increasing carbon dioxide concentration in the atmosphere is the global warming which influences the world's ecosystem seriously. This effect is now widely known by the public. Also, the circulation of carbon dioxide in the world's ecosystem has already been thoroughly studied. Thus, taking the carbon dioxide emission as the indicator for the environmental sustainability could be easily accepted by most people.

Furtherly, from the bio-chemical perspective, the carbon dioxide is quite a stable small molecule inorganic which is normally considered as a final waste and does not need further processing on it. The digestion of

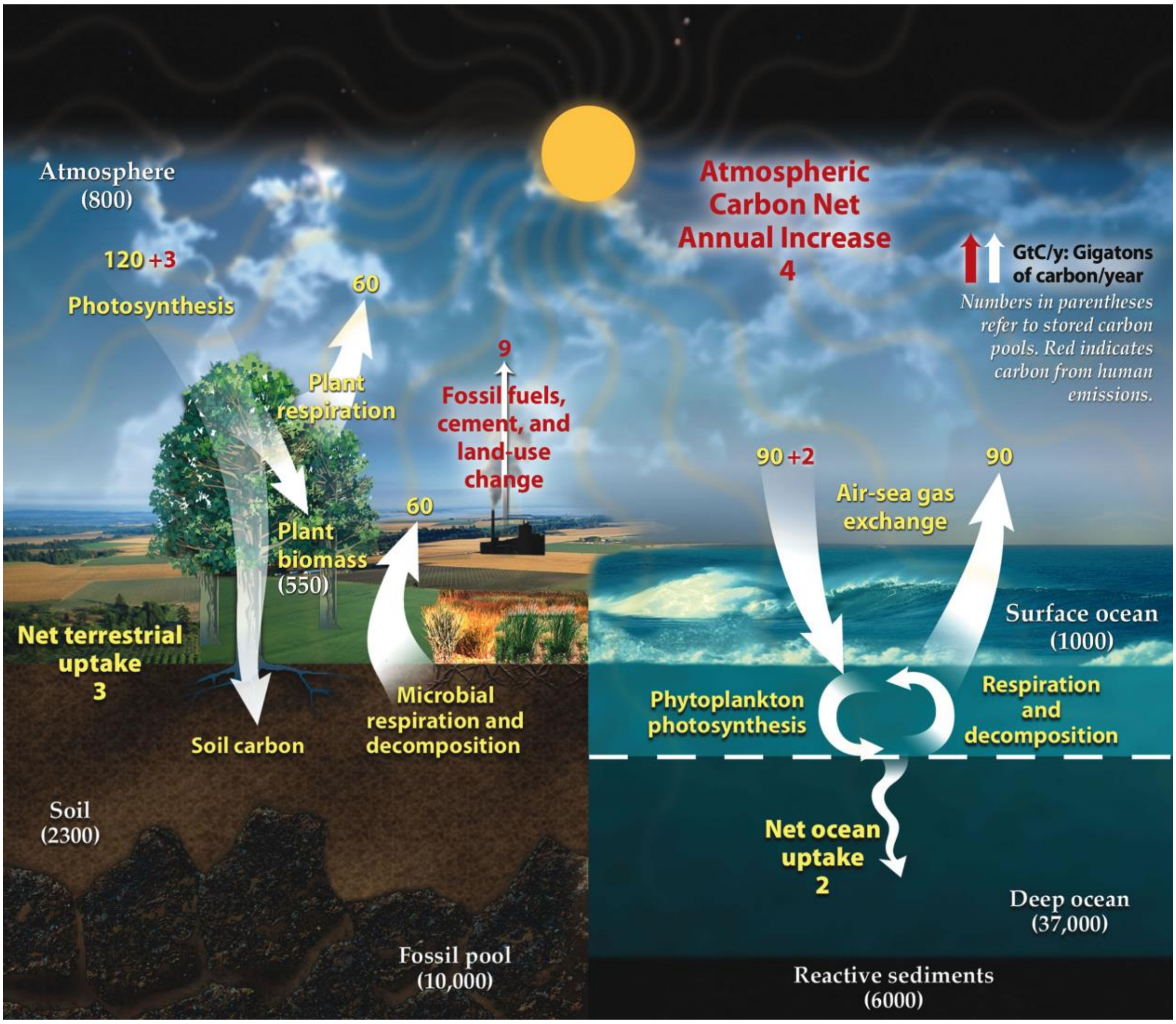

Figure 10 The carbon cycle in the global ecosystem [52]

In a business process, no matter it is a manufacturing process or a service process, energy consumption is inevitable. From this view, the energy consumption could be quite easily transformed into CDE indicator according to the local energy/carbon ratio [53] [54]. This energy/carbon ratio may differ among different regions. A region mainly relies on a thermal power station has an obviously lower energy/carbon ratio than one mainly counts on a hydropower station [55] [56].

Wastes and pollutants, no matter solid, gas or water, could also be transformed in to CDE indicator. Only a conversion coefficient is needed to do so. For example, we assume that a ton of waste water is generated during a manufacturing process. Furtherly, we assume that K_1 capital investment (which including the infrastructure and the materials cost and etc.), K_2 energy consumption is needed to completely purify this waste water so that it will do no harm to the nature and the society. Then K_1 is already a cost value. K_2 could be transformed into CDE in the way mentioned above. We can conclude that by set a carbon conversion coefficient k, most indicators for the sustainability of a business process can be converted into the CDE indicator.

If a company adopts advanced technology in disposing the waste water, the investment and the energy consumption may be reduced. Consequently, the CDE of this process for this company is reduced, which also means the sustainability of the company increases. In such company, the average cost of the products may increase and that is why we need to form an improved approach with consideration of sustainability. In this way, we can find out a feasible solution to balance the commercial profits and the sustainable development of the company and the society.

4.1.2 Convertibility of the CDE indicator

Nowadays, to impose restrictions on the global carbon dioxide emission is quite a popular topic in ecological economics. International business market is passionate about this trend. Carbon emissions quota and carbon tax is more and more crucial for modern industries [57]. The candidate does not want to discuss the essential economic theory behind the carbon emissions quota trading or the carbon tax. But thanks for the inspiration from these carbon pricing concepts, we could obtain one of the most important tool for this master thesis project: the conversion between the real carbon emission and the equivalent cost of that emission in currency.

Not exactly the same as carbon emission quota trading, which involves a lot of complicated elements such as climate policy ambition, auctions and so on. The only thing we need to know is how much a ton of carbon dioxide emission costs the human society to subside the consequent environmental influence. In brief, all we need is a psychological price that shows how much the company values its sustainability. For a concrete amount of carbon dioxide emission, we can easily calculate the total cost when we have such a price of carbon dioxide emission. And, obviously, the cost is one of the indispensable criterion that need to be considered in the evaluation and selection of suppliers.

Thus, from the above argument, we can conclude that the CDE indicator achieves perfect convertibility with the traditional outsourcing strategy criteria.

4.2 Mathematical modelling of the new approach

All those arguments before are only qualitative discussion about the CDE indicator and sustainability of business processes. To make it useable in the practice, we need an explicit mathematical model. As we have mentioned before in the literature review section, there are many different kinds of models for outsourcing strategy. We need to carefully pick an approach that is most suitable for our ideology. In order to simplify the modelling process and make it easier for determining the parameters, we assume that this model serves a supply chain of mass production in the manufacturing industry. For the other industries, the model may only need to be manipulated a bit to fit in the specific case.

4.2.1 Determining the set of criteria

For a multi-criteria model, only knowing the CDE indicator is definitely not enough. A complete set of criteria is needed to support the model. In order to evaluate the suppliers in all aspects and give out an appropriate estimation, the criteria should look into several different fields of the supplier. Normally, the cost, the quality, the transportation and the ability to deliver qualified products on schedule are considered to be important features for a company. In the following content of this section, we will nominate a series of suitable factors other than the CDE indicator for evaluating suppliers.

1. The main cost (denoted by M):

The main cost refers to the normal basic cost used in a business process. For example, in a factory that manufactures standard nuts, the main cost is the total cost of machining the raw material into the final product, including material cost, energy consumption and etc. This is one of the most important criteria in traditional approaches.

2. The logistic cost (denoted by L):

The logistic cost refers to the cost that spend on delivering the product.

3. The reliability index (denoted by R):

In this report, the reliability of a supplier is used to indicate the relationship between the purchaser and the supplier. In this project, we try to define this index from three different aspects. The first one is the time length that the supplier served in the business (years in service, denoted by R_s). The longer the supplier has been running the business, the more reliable it is. The second one is the number of customer the supplier serves at one time (customer referred, denoted by R_r). The more customer the supplier serves, the more reliable it is. The last one is the time length that the supplier has collaborated with the purchaser (year collaborated, denoted by R_c). The longer the supplier has collaborated, the more reliable it is. We accumulate the supplier's performance in all these three aspects according to pre-set weight to measure the total reliability of it.

4. The quality index (denoted by Q^*):

The quality index here is used to indicate the quality of the product. It can be quantitatively described as the percentage of unqualified product in the manufacturing process. Obviously, the less unqualified product is, the better the quality is.

5. The service index (denoted by S^*):

The service index here is used to measure the ability that the supplier has to fulfil the contract. Here in the report, we describe it as the percentage of delayed delivery. Similar with the quality index, the less delay the supplier has, the better service level it is.

Different factors could be chosen for different companies, but they should follow the main principles of this approach.

4.2.2 Inspirations from previous study and research

As we have reviewed before, there are many approaches that deal with the outsourcing strategy, such as the data envelopment analysis (DEA), the mathematical programming approaches (MP), the case based reasoning and etc. We need to decide which one is suitable for our project. Some discussion is introduced to explore this question, like following:

1. Qualitative or quantitative.

Many of these methods could be mainly divided into two groups: qualitative approaches and quantitative approaches. A typical qualitative approach is the case based reasoning, which only provides some rough principles for evaluation. All the details need to be discussed according to the company's actual situation. In contrary, mathematical programming (MP) are typical quantitative approaches that a set of standard parameters are needed to perform this method. Qualitative approaches are able to provide an intuitive sketch of the problem while the quantitative approaches can describe the problem in a mathematically more accurate way.

Still, there are some methods that could be regard as combination of both qualitative and quantitative approaches. The weighted scoreboard model is one of them. The weight of each parameter is determined by the company's demand and the performance grades in individual fields are determined by convention. These we can count as qualitative analysis. Then, the model will generate a total performance ranking for evaluation. This part is definitely a rough quantitative analysis. If we can make some adjustment to reduce the fuzzy part and enhance the accuracy, the weighted scoreboard model could be a good choice for out project.

2. Completeness and convenience.

From the aspect of an engineering student, the most important two characters for a method are: 1. the method is able to provide enough evidence for the decision making; 2. the method is convenient enough for extensive use. Some of the approaches are very easy to use. But they cannot provide a whole picture of the problem, such as the transaction cost theory. In contrary, some of the approaches might be able to provide more precise description of the real problem. But they are not suitable for practical applications due to the low maneuverability. Here in our project, for a finite given list of suppliers, the weighted scoreboard model can clearly demonstrate the merits and demerits of them with a complete set of parameters. It meets both the completeness and convenience requirement.

3. Inspiration and learning

In a broad sense, the outsourcing strategy should be counted as a segment of the supply chain management. The strategies that used for general supply chain management could also be used as reference for the outsourcing process. One that the candidate thinks helpful is the allocation of plants and warehouses in a supply chain network design [58]. The whole problem is transferred into a simple optimization question: to minimize the total cost. And an equation is formed as:

$$Z = \sum_{i=1}^{n} F_i y_i + \sum_{e=1}^{t} f_e y_e + \sum_{h=1}^{l}\sum_{i=1}^{n} c_{hi} x_{hi} + \sum_{i=1}^{n}\sum_{e=1}^{t} c_{ie} x_{ie} + \sum_{e=1}^{t}\sum_{j=1}^{m} c_{ej} x_{ej}$$

This objective function subjects to the following constraints:

$$\sum_{i=1}^{n} x_{hi} \leq S_h \quad \text{for} \quad \text{h} = 1, \dots, \text{l} \qquad (1)$$

The constraint in equation (1) states that the total amount of product shipped from a supplier should not exceed its capacity.

$$\sum_{h=1}^{l} x_{hi} - \sum_{e=1}^{t} x_{ie} \geq 0 \quad for \quad i = 1, \dots, n \qquad (2)$$

The constraint in equation (2) specifies that the total amount of product shipped out of a factory should not exceed the amount of raw material it received.

$$\sum_{e=1}^{t} x_{ie} \leq K_i y_i \quad for \quad i = 1, \dots, n \qquad (3)$$

The constraint in equation (3) notes that the total amount of product shipped out of a factory should also not exceed its capacity.

$$\sum_{i=1}^{n} x_{ie} - \sum_{j=1}^{m} x_{ej} \geq 0 \quad for \quad e = 1, \dots, t \qquad (4)$$

The constraint in equation (4) states that the total amount of product shipped out of a warehouse should not exceed the amount it received.

$$\sum_{j=1}^{m} x_{ej} \leq W_e y_e \quad for \quad e = 1, \dots, t \qquad (5)$$

The constraint in equation (5) states that the total amount of product shipped out of a warehouse should also not exceed its capacity.

$$\sum_{e=1}^{t} x_{ej} = D_j \quad for \quad j = 1, \dots, m \qquad (6)$$

The constraint in equation (6) states that the amount of product shipped to a customer must be aligned with its demand.

$$y_i, y_e \in \{0, 1\}, x_{ej}, x_{ie}, x_{hi} \geq 0 \qquad (7)$$

The constraint in equation (7) specifies that the warehouses and factories are either decided to open or not, 1 indicates open and 0 indicates not open.

Where,

m, n, l, t represents respectively the number of markets, potential factory location, suppliers and potential warehouse locations;

D_j is the annual demand from the customer j;

K_i is the potential capacity of factory at the site i;

S_h is the supply capacity of the supplier h;

W_e is the potential warehouse capacity at the site e;

F_i is the fixed cost of allocating a plant at the site i;

f_e is the fixed cost of allocating a warehouse at the site e;

c_{hi} is the per unit cost of shipping from the supplier h to the factory i;

c_{ie} is the per unit cost of producing and shipping from the factory i to the warehouse e;

c_{ej} is the per unit cost shipping from the warehouse e to the customer j;

y_i, y_e is respectively the existence of factory and warehouse at site i and site e, when exists the value equals to 1, otherwise 0;

x_{ej} is the quantity shipped from the warehouse e to market j;

x_{ie} is the quantity shipped from the factory at the site i to the ware house e;

x_{hi} is the quantity shipped from the supplier h to the factory at the site i.

We can see from the equation above that all the parameters will be transformed into cost. To make the final decision only need to minimize the objective Z and the correspondingly fixed parameters are the optimal solutions. This is only one of the available representative examples, and its result might seem limited to its case. But for our utility in this master thesis, this model gives out a nice and neat illustration of how we can manipulate the given information to formulate an objective function that suits the actual situation. If we can apply similar principles on our model, it would be convenient for the decision-making process. In the following section, we will try to do so.

4.2.3 Final modelling

In the normal weighted scoreboard model, the performance is more likely qualitative instead of quantitative. The performances are described with vague words and inaccurate numbers, such as very good (0.9), acceptable (0.5) and so on [34]. In order to enhance the precision of the weighted scoreboard model, we want to estimate the performance in individual field in standard process instead of a rough estimation depends on experience. What the candidate proposed to do is trying to transform all the parameters into a cost, inspired by the allocation of plants and warehouses in a supply chain network design.

As we have discussed in section5.1.1 and 5.1.2, different kinds of sustainability indicators could be transformed into a general CDE indicator and then the CDE indicator of a business process could be transformed into a parameter which is similar to the cost. According to the same principle, all the parameters could be converted into a cost.

The logistic cost: as a direct cost, this parameter does not need to be converted. Normally, the main cost value should be able to be obtained through the production management system (PMS) or similar documentations of the business process.;

The main cost of the process: as a direct cost, this parameter does not need to be converted. Similar like the main cost, the logistic cost should also be obtained from the documentations of the transportation process. An average value for each unit is then calculated.;

The reliability: as the reliability is represented by three sub-variables, we need to convert each of them into a cost and then sum up for the total reliability. For R_s, R_r, R_c, all three variables are in direct proportion with reliability level. In contrary, the cost has an inverse correlation with the total performance. In order to make them consistent, we need to modify them like following:

$$\mathrm{R} = \frac{C_{Rs}}{R_s} + \frac{C_{Rr}}{R_r} + \frac{C_{Rc}}{R_c} \qquad (8)$$

Where,

R is the supplier's equivalent cost of reliability, in capital/unit;

C_{Rs} is the transform coefficient for R_s, in capital/unit*year;

C_{Rr} is the transform coefficient for R_r, in capital/unit;

C_{Rc} is the transform coefficient for R_c, in capital/unit*year;

R_s is the supplier's time length in service, in year;

R_r is the supplier's customer quantity, dimensionless value;

R_c is the collaborated time length of the purchaser and the supplier, in year;

Generally speaking, as the total value R will be further modified by the corresponding weight, the transform coefficients could just be artificially picked at some simple values that could reflect the interrelationship between those three attributes. For instance, if the purchaser considers that all the three attributes will affect the reliability at the same level, their value could be simply picked as $C_{Rs} = C_{Rr} = C_{Rs} = 1$. Or if the purchaser thinks that the customer number referred is more important, the values could be set as $C_{Rc} = 1, C_{Rr} = 3, C_{Rs} = 1$.

The quality index: according to the settings before, Q^* is also in an inverse correlation with the total performance. We only need to transform its dimension to align with the cost. Like following:

$$\mathrm{Q} = C_q * Q^* \qquad (9)$$

Where,

Q is the supplier's equivalent cost of quality, in capital/unit;

C_q is the transform coefficient for Q^*, in capital/unit;

Q^* is the ratio of unqualified products, dimensionless percentage value;

As the Q value will be furtherly modified by the corresponding weight, the transform coefficient could be determined at a simple value that can help reflect the real loss caused by unqualified products or services. For instance, the cost a piece of unqualified product normally could be divided into the manufacturing cost and the subsequent cost which spend to deal with it. The first part is normally equal to the main cost, and the second part could be obtained from the waste management system or similar documentations of the process. The second part could also be eventually expressed in a percentage of the main cost. Thus, the coefficient C_q could be determined.

The service index: according to the settings before, S^* is also in an inverse correlation with the total performance. We just need to align its dimension with the cost. As the following:

$$\mathrm{S} = C_s * S^* \tag{10}$$

Here,

S is the supplier's equivalent cost of service level, in capital/unit;

C_s is the transform coefficient for S^*, in capital/unit;

S^* is the ratio of delayed delivery, dimensionless percentage value;

As the S value will be furtherly modified by its corresponding weight, the transform coefficient could be determined to be a simple value that helps reflecting the real loss caused by delayed delivery of products or services.

The sustainability index: as discussed before, all kinds of sustainability indexes should be transformed into equivalent CDE indicator. The transformation goes like following:

$$\mathrm{CDE} = \sum_{j=1}^{j} k_j * SS_j \tag{11}$$

Where,

CDE is the total equivalent carbon dioxide emission of the process of the supplier, in kg/unit;

k_j is the transform coefficient of SS_j, the dimension needs to be decided according the actual situation;

SS_j is the sustainability index j, the dimension needs to be decided according the actual situation;

Same as the other factors, the equivalent CDE value will be furtherly modified by the corresponding weight, the rule for choose the k_j and SS_j values is to reflect the actual equivalent carbon dioxide emission amount of each attributes.

Specially, the number of j is not limited but varies according the actual situation. Every possible factor that has impact on the environment should be considered, such as the fuel cost in transportation, the waste processing and the energy consumption. The concrete values in this equivalent CDE indicator is difficult to be found. We will discuss this problem later.

Furtherly, the CDE indicator should be transformed into equivalent cost with the help of a carbon price:

$$\mathrm{E} = P_e * CDE \qquad (12)$$

Where,

E is the equivalent cost of carbon dioxide emission, in capital/unit;

P_e is the transform coefficient (carbon price) for CDE, in capital/kg;

CDE is the total equivalent carbon dioxide emission of the process of the supplier, in kg/unit;

As the same as the other parameters, E will also be furtherly modified by its weight. Thus, the value of P_e should be determined as a simple value which can reflect the economic cost we will pay for the impact of the emission. The carbon price on the global carbon emission quota trading market could be a valuable reference.

To form up a complete weighted scoreboard model, only having criteria is not enough. The weight of each parameter and coefficients are also very important parts. They need to be determined carefully according to the actual situation of the company.

Thus, all the key parameters have been aligned as equivalent cost. Then we can model the ultimate problem as following:

$$Z_i = w_m * M_i + w_l * L_i + w_r * R_i + w_q * Q_i + w_s * S_i + w_e * E_i \qquad (13)$$

Where:

Z_i is the total equivalent cost of the supplier i in capital/unit;

M_i is the manufacturing cost of the supplier i in capital/unit;

L_i is the logistic cost of the supplier i in capital/unit;

R_i is the equivalent cost of reliability of supplier i, in capital/unit;

Q_i is the equivalent cost of quality level of supplier i, in capital/unit;

S_i is the equivalent cost of service level of supplier i, in capital/unit;

E_i is the equivalent cost of CDE of supplier i, in capital/unit.

w_m, w_l, w_r, w_q, w_s, w_e respectively are pre-determined weight of M, L, R, Q, S and E, they satisfy the following condition:

$$w_m + w_l + w_r + w_q + w_s + w_e = 1$$

Furtherly, the determination of the value of these weights should be carefully examined. For the first, the order of magnitude of all those parameters should be checked for individual cases. Then, the weights could be set in a way that the final values have close order of magnitude and are in proportion to the degree that the managers want to emphasize the criteria. Normally, the main cost will be regulated to occupy around 80%-90% of the final total value, the other parameters share the remaining part.

For each individual supplier, we can calculate its Z value according to the above equations. Simply, for a list of suppliers, we can easily evaluate them and find out the best choice by applying this improved approach and giving out a ranking of total performance (the total equivalent cost). A brief case study will be presented in the next section to illustrate the feasibility of this approach.

5 A brief case study

In this section, a brief case study will be carried out based on data from practice. We will try to apply the improved weighted scoreboard model to this data set and check out the result it gives out.

5.1 Basic facts in the case

The purchasing company is a manufacturer of vehicles in Guang Zhou, southern China. The company want to outsource the manufacturing process of a valve part that is used in its products. There is a group of suppliers that they have contact with could provide this product. This group includes four suppliers, each could be denoted by A, B, C and D respectively, due to the confidentially agreement with the purchasing company that granted the candidate the chance to access to this real case. All these four suppliers are located within China. In the table 1 blow, shows the parameters that are needed to apply the weighted scoreboard model. The monetary unit has been transferred from CNY to NOK for better understanding. All the data are obtained through real production process. Some of them are estimated by the purchasing company.

Table 1 The data sheet of the four suppliers

Parameters	Supplier A	Supplier B	Supplier C	Supplier D
Main cost (M), NOK/unit	37	35	38	39
Logistic cost (L), NOK/unit	1.3	0.4	0.7	1.1
Quality level (Q^*), percentage	0.23%	0.61%	0.21%	0.17%
Service level (S^*), percentage	6.30%	8.70%	3.70%	4.40%
Years in service, years	7	3	8	5
Customer referred, number	21	9	26	23
Years collaborated, years	3	1	3	2
Energy consumption, kWh/unit	2.1	2.9	2.1	2
Equivalent CDE, kg/unit	1.3	4.7	0.8	0.4

Most of the data in the table above could be obtained from the supplier's production management system (PMS). Among all these date, the equivalent CDE values are estimated values according to the realistic manufacturing process and the degree of damage to the natural environment. How to get this equivalent CDE a precise value is one of the most important job need to be done in the future. We will discuss it in the last section of this report.

5.2 Application of the weighted scoreboard model

In order to apply the weighted scoreboard model, we need to determine the coefficients and the weights first.

5.2.1 Determining the coefficients

For the quality level, as we need to transform the original quality level into a cost, the real cost of a defected product is important. Here in the case, based on the information from the suppliers' production management systems (PMS), the average cost of a defected product is approximately two times the main cost of the product. As the value will be adjusted by the weight again later, we would like to set the coefficient equal to cost of the defected product so as to make it easier for the calculation.

$$C_{qi} = Cost_{defect\ i} \approx 2 * M_i \tag{14}$$

As it should be a standard value, we should take an average value in calculation. Then equation (14) becomes:

$$C_q = \overline{Cost}_{defect} \approx 2 * \overline{M}_i \tag{15}$$

Where,

$\overline{M}_i$ is the average value of all main cost of the suppliers, in NOK/unit;

Here for this case, we pick the value as C_q = 75 NOK/unit.

For the service level, we have a similar consideration. In this case, the cost of delayed delivery is reported to be about 22% of the main cost of the delayed products. Thus, we have:

$$C_s = \overline{Cost}_{delayed} \approx 22\% * \overline{M}_i \tag{16}$$

And we can calculate the value as C_s = 8 NOK/unit.

For the reliability, as the value will be modified again by the weight, we can just pick some simple values to make the calculation easier. As the purchaser would view the three sub-attributes at the same influence level, we set the coefficient as:

$$\begin{cases} C_{Rs} = 1 \text{ NOK/(unit} * \text{year)} \\ C_{Rr} = 1 \text{ NOK/unit} \\ C_{Rc} = 1 \text{ NOK/(unit} * \text{year)} \end{cases} \tag{17}$$

The last coefficient is the "carbon price" P_e. This value could be determined in the help of carbon dioxide emission quota price in the carbon trading market. A market price is fluctuating. According to the information from California Carbon Dashboard, the price is ranging from \$11 to \$19, with an average at around \$13.50. Take exchange rate at 8.40, we can calculate the average carbon trading price is 113.4 NOK/ton or 0.1134 NOK/kg. As the value will also be modified again by the weight, we would directly use this average market price here as the coefficient. Which means:

$$P_e = 0.1134\ NOK/kg \qquad (18)$$

As the suppliers are located in China, where the energy is supplied mostly by thermal power plant, another coefficient needs to be determined is the coal consumption per kWh energy. According to the pertinent literature, this value is around 0.32kg/kWh. And furtherly, this could be transformed into the carbon dioxide emission value. We have the value at 0.994kg/kWh [59]. This means 1 kWh energy consumption will result in 0.994kg emission of carbon dioxide.

5.2.2 Determining the weights

The weight of a parameter functions as a regulator that adjusts the proportion of the corresponding parameter in the final value. Considering the order of magnitudes and the purchaser's balance in these criteria, the weights are determined like following:

$w_m = 0.1$, $w_l = 0.05$, $w_q = 0.3$, $w_s = 0.25$, $w_r = 0.05$, $w_c = 0.25$.

Where, $w_m + w_l + w_q + w_s + w_r + w_c = 1$.

Under this setting, the main cost will be regulated to occupy the largest portion (about 90%) in the final equivalent cost value. But it still remains at a level that the main cost will not decide the final ranking alone in general case. The other parameters share the remaining portion and make the final value varying so as to constitute different ranking.

5.2.3 Application of the model

As we have determined all the coefficients and the weights of parameters, the model could be applied to the case.

As the model is:

$$Z_i = w_m * M_i + w_l * L_i + w_r * R_i + w_q * Q_i + w_s * S_i + w_e * E_i$$

$$\mathrm{Q}_i = C_q * {Q^*}_i$$

$$\mathrm{S}_i = C_s * {S^*}_i$$

$$\mathrm{R}_i = \frac{C_{Rs}}{R_{s_i}} + \frac{C_{Rr}}{R_{r_i}} + \frac{C_{Rc}}{R_{c_i}}$$

$$\mathrm{E}_i = P_e * CDE_i$$

And $w_m = 0.1$, $w_l = 0.05$, $w_q = 0.3$, $w_s = 0.25$, $w_r = 0.05$, $w_c = 0.25$.

In the first step, we can calculate the total equivalent cost value for each supplier as following.

For supplier A:

$$Z_A = 0.1 * 37 + 0.05 * 1.3 + 0.3 * 75 * 0.23\% + 0.25 * 8 * 6.3\% + 0.05 * \left(\frac{1}{7} + \frac{1}{23} + \frac{1}{3}\right) + 0.25 * 0.1134 * (1.3 + 2.1 * 0.994)$$

$$= 3.7 + 0.065 + 0.0518 + 0.126 + 0.0262 + 0.0960$$

$$= 4.065 \text{ NOK/unit}$$

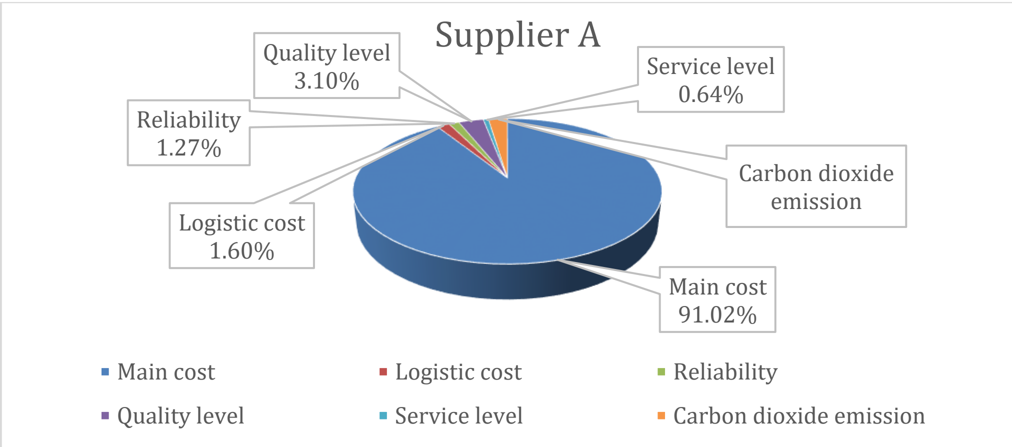

Figure 11 The proportion of each parameter in the total equivalent cost of supplier A

For supplier B:

$$Z_B = 0.1 * 35 + 0.05 * 0.4 + 0.3 * 75 * 0.61\% + 0.25 * 8 * 8.7\% + 0.05 * \left(\frac{1}{3} + \frac{1}{9} + \frac{1}{1}\right) + 0.25 * 0.1134 * (4.7 + 2.9 * 0.994)$$

$$= 3.5 + 0.02 + 0.1373 + 0.174 + 0.0722 + 0.215$$

$$= 4.1185 \text{ NOK/unit}$$

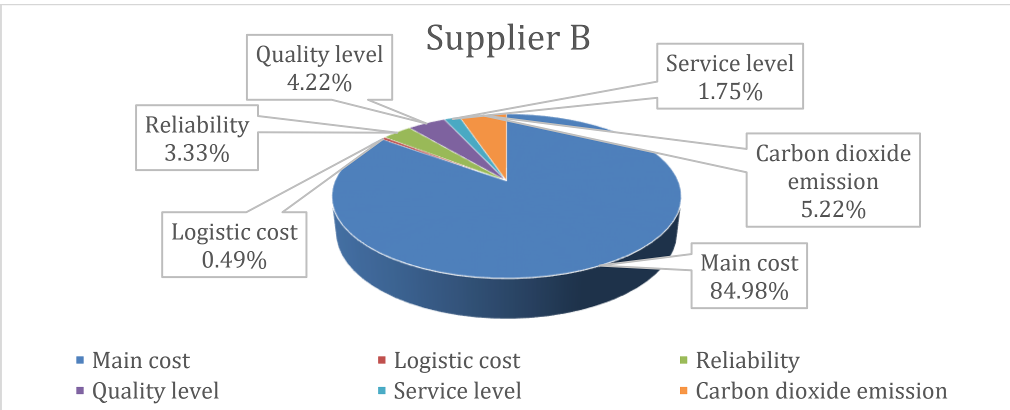

Figure 12 The proportion of each parameter in the total equivalent cost of supplier B

For supplier C:

$$Z_C = 0.1 * 38 + 0.05 * 0.7 + 0.3 * 75 * 0.21\% + 0.25 * 8 * 3.7\% + 0.05 * \left(\frac{1}{8} + \frac{1}{26} + \frac{1}{3}\right) + 0.25 * 0.1134 * (0.8 + 2.1 * 0.994)$$

$$= 3.8 + 0.035 + 0.0473 + 0.074 + 0.0248 + 0.0819$$

$$= 4.063 \text{ NOK/unit}$$

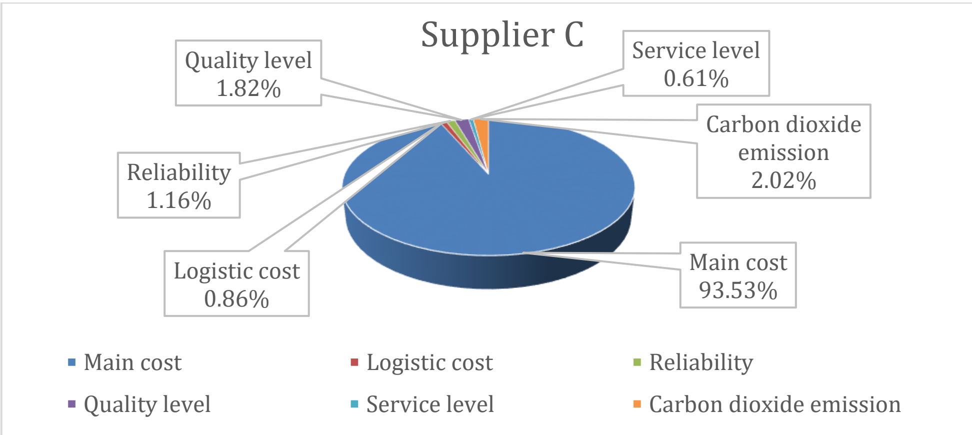

Figure 13 The proportion of each parameter in the total equivalent cost of supplier C

For supplier D:

$$Z_D = 0.1 * 39 + 0.05 * 1.1 + 0.3 * 75 * 0.17\% + 0.25 * 8 * 4.4\% + 0.05 * \left(\frac{1}{5} + \frac{1}{23} + \frac{1}{2}\right) + 0.25 * 0.1134 * (0.4 + 2.0 * 0.994)$$

$$= 3.9 + 0.055 + 0.0473 + 0.088 + 0.0372 + 0.0677$$

$$= 4.1862 \text{ NOK/unit}$$

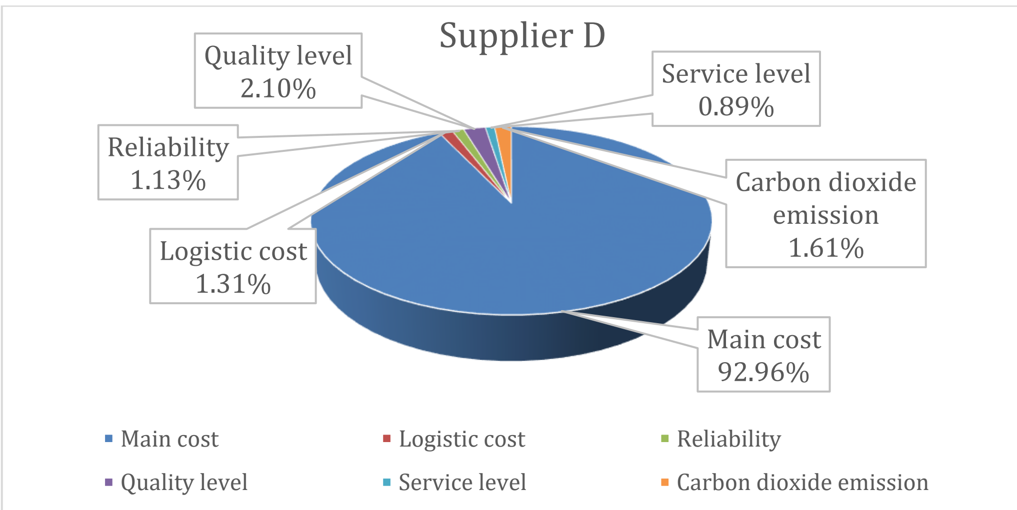

Figure 14 The proportion of each parameter in the total equivalent cost of supplier D

Then, as all the equivalent cost values are calculated, a ranking list could be set up as follows:

Table 2 The ranking list of the four suppliers

Rank	Supplier	Equivalent cost
1	C	4.0630
2	A	4.0650
3	B	4.1185
4	D	4.1862

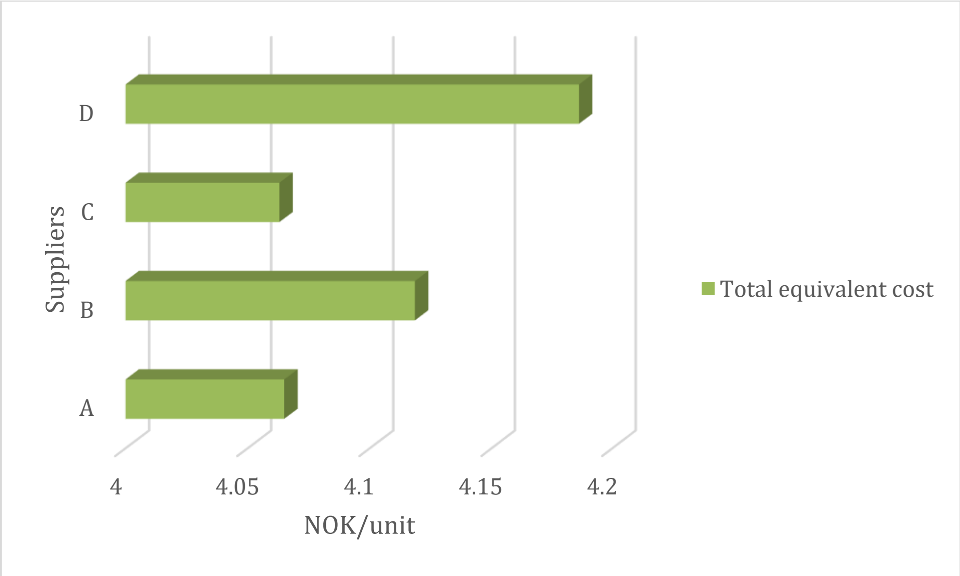

Figure 15 The ranking histogram of the suppliers based on equivalent total cost

According to the rankings listed in the table 2, we can conclude that the best sequence of selection is C →A→B→D. The supplier C has the highest priority.

5.3 Analysis of the result

The ranking list is only the result that the weighted scoreboard model gives out. We need to look into the details and try to find out if the model really works. Thus, a analysis is carried out to check the influence of the newly introduced CDE indicator.

The most important thing we need to investigate is the total equivalent cost values of the suppliers. The values could be divided into two parts: one that comes from traditional criteria and the other one comes from the CDE indicator. From this perspective, we can decompose those values like in the following table:

Table 3 Decomposed equivalent cost value

Supplier	Traditional cost	CDE cost	Total equivalent cost
A	3.9690	0.0960	4.0650
B	3.9035	0.2150	4.1185
C	3.9811	0.0819	4.0630
D	4.1185	0.0677	4.1862

Clearly, we can see that if the CDE indicator has not been taken into consideration, the ranking will be changed. The best sequence of selection will be B→A→C→D if the CDE indicator is excluded. The supplier B earns the highest priority. From the date sheet, we can see that the supplier B has the lowest main cost and the highest energy consumption and equivalent CDE value. We speculate that it might sacrificed all its sustainability, such as directly discharge its production wastes into the environment without necessary cleansing process, to lower the main cost. This change proves that the introduction of the CDE indicator has influence on the evaluation and selection of suppliers. By adopting this approach, a portion of suppliers which badly ignores the sustainability will be picked off from the top alternatives.

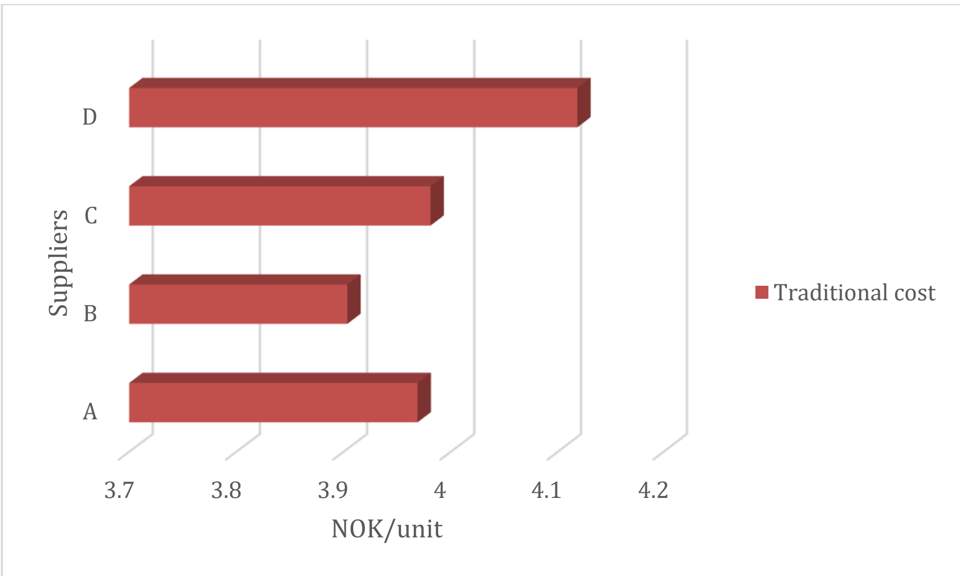

Figure 16 The ranking histogram of the suppliers based on traditional cost

Furtherly, we want to explore the balance between the traditional commercial criteria and the newly introduced indicator of sustainability. The supplier C has relatively low energy consumption (equal with supplier A and low than supplier B) and the equivalent CDE value. We can speculate that the supplier C invests some capital to the environmental protection facilities and has a better technique in production, which results in the relatively low CDE value and energy consumption. Its traditional equivalent cost is higher than supplier A and B. But combined with the equivalent cost in sustainability, the supplier C achieves the lowest total cost, which means that the purchaser endorses its effort in balancing the commercial profits and the environmental sustainability.

On the other hand, by referring to the original data sheet and comparing the CDE value and the energy consumption, we find that the supplier D has the lowest total value, which means it achieves the best sustainability among all four suppliers. However, on the contrary, the supplier D is evaluated to have the lowest priority. Combined with the data, we can speculate that the supplier D has invested huge amount of capital into the energy conservation and environmental protection facilities. That is why supplier D could achieve extremely low energy cost and equivalent carbon dioxide emission. But this investment also increases the main cost of the product significantly. According to the weight settings, the raise in the main cost cannot be balance with the CDE reduction. Its total equivalent cost is always the highest no matter if we take the sustainability into account. In the case, the purchaser does not want to sacrifice too much commercial profit to the sustainability requirement. Thus, the supplier D is defeated in the evaluation.

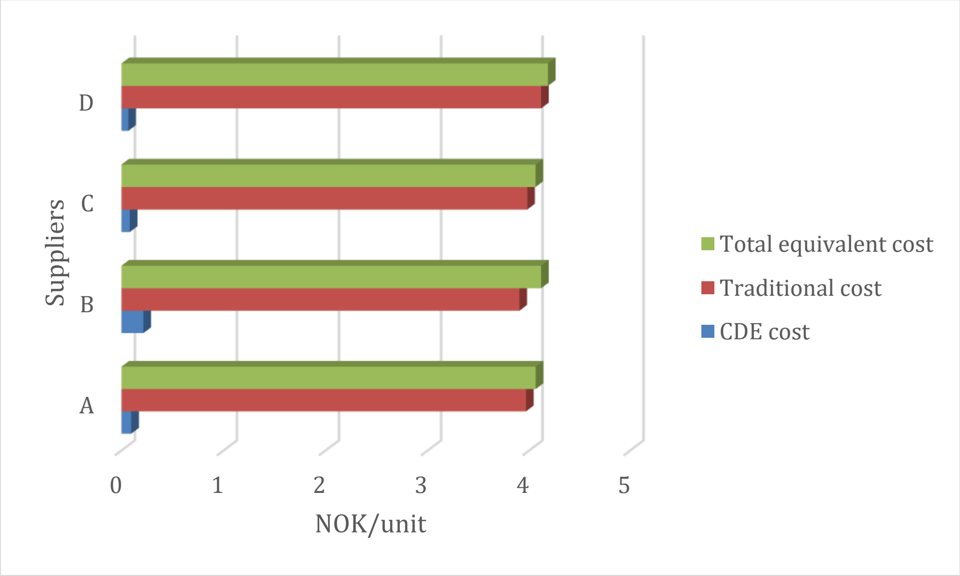

Figure 17 The comparison histogram of three costs

Further exploration is need to know more about the CDE indicator. A rough sensitivity analysis is needed to find out how this parameter will affect the final ranking sequence. As the carbon price in the global trading market is ever changing, we want to check if the performance of the suppliers (the priority ranking) will be influenced under different carbon prices. As the international market fluctuates a lot, we set the value that we used in the case as P_0 and the fluctuation range from 30% to 170% of P_0. Then the corresponding CDE values and total equivalent cost values are calculated and listed in the following tables.

Table 4 The values of supplier A under different carbon prices

Carbon Price	30%P_0	50%P_0	70%P_0	130%P_0	150%P_0	170%P_0
CDE value	0.0288	0.0480	0.0672	0.1248	0.1440	0.1632
Total equivalent cost value	3.9978	4.0170	4.0362	4.0938	4.1130	4.1322

Table 5 The values of supplier B under different carbon prices

Carbon Price	30%P_0	50%P_0	70%P_0	130%P_0	150%P_0	170%P_0
CDE value	0.0645	0.1075	0.1505	0.2795	0.3225	0.3655
Total equivalent cost value	3.9680	4.0110	4.0540	4.1830	4.2260	4.2690

Table 6 The values of supplier C under different carbon prices

Carbon Price	30%P_0	50%P_0	70%P_0	130%P_0	150%P_0	170%P_0
CDE value	0.0246	0.0410	0.0573	0.1065	0.1229	0.1392
Total equivalent cost value	4.0057	4.0221	4.0384	4.0876	4.1040	4.1203

Table 7 The values of supplier D under different carbon prices

Carbon Price	30%P_0	50%P_0	70%P_0	130%P_0	150%P_0	170%P_0
CDE value	0.0203	0.0339	0.0474	0.0880	0.1016	0.1151
Total equivalent cost value	4.1388	4.1524	4.1659	4.2065	4.2201	4.2336

Based on the values listed in the tables, we can rearrange them and set up a ranking priority table for all the prices (including the price P_0) as below. See table 8.

Table 8 The priority ranking under different carbon prices

Carbon Price	The Ranking: Selection Priority
30%P_0	B → A → C → D
50%P_0	B → A → C → D
70%P_0	A → C → B → D
100%P_0	C → A → B → D
130%P_0	C → A → B → D
150%P_0	C → A → D → B
170%P_0	C → A → D → B

From this table, we can clearly find that when the carbon price drops to 70% of P_0, the priority ranking is changed. When the price furtherly drops to 50% of P_0, more changes happen. On the other hand, when the price rises to 150% of P_0, the ranking is changed. As the price increases, the ranking of supplier B keeps dropping. The ranking of A, C and D are all rising. But the supplier C surpasses supplier A when the price changes from 70% of P_0 to 100% of P_0. The ranking of supplier D only changes after the price reaches 150% of P_0, due to its large main cost proportion. The line chart of the rankings under different prices of the suppliers is plotted as below. According to this sensitivity analysis, we can confidently conclude that in this case, the performance of the suppliers will be influenced by the changes in carbon price which is essentially affecting the equivalent CDE value. Thus, in this case, the CDE indicator is able to effectively help the supply chain managers to evaluate the suppliers considering their sustainability.

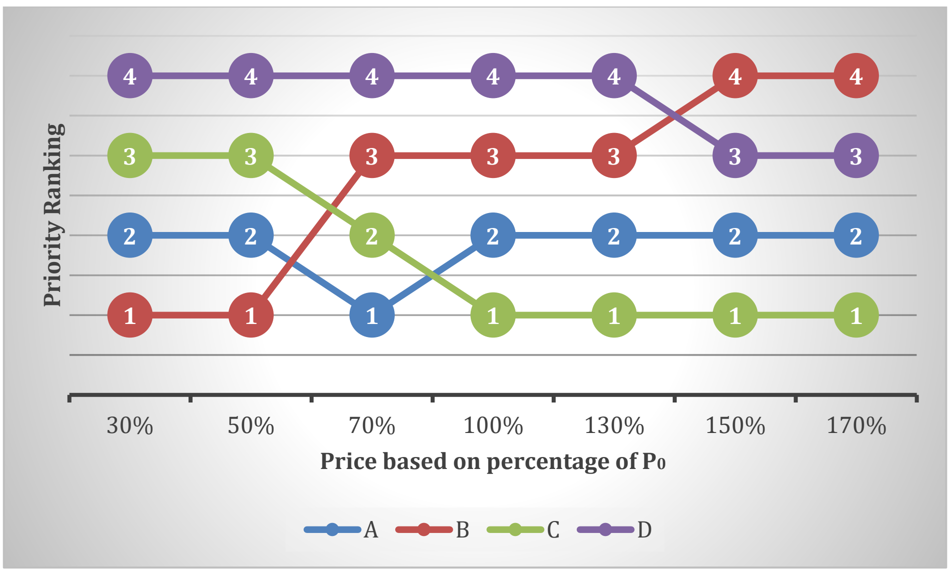

Figure 18 Ranking line chart of the suppliers under different prices

Based on the analysis in the above, we can summarize that the weighted scoreboard model with equivalent CDE indicator is able to provide a reasonable and reliable way for the evaluation and selection of suppliers regarding their sustainability. It could be used to help balancing the contradictions between a company's commercial profits and environmental sustainability.

6 Conclusion and future work

6.1 Conclusion

This thesis aims to further enrich the current literature of outsourcing strategy studies and bring in sustainability as one of the main criteria when it comes to evaluating and selecting potential suppliers. The sustainability of a company is not a new idea and it has obtained more and more attention from people in various business areas, especially from the perspective of supply chain management. However, there exists no uniform standard when it comes to describing the sustainability of a general business process.

This work proposes a framework for evaluating the sustainability using the equivalent carbon dioxide emission as an indicator. Based on the analysis in section 4 and the brief case study in section 5, we can conclude that this improved approach with weighted scoreboard model and the normalized measurement of the sustainability provides a new way of thinking when it comes to determining the sustainable outsourcing strategy. From the results, we believe that it has been a successful attempt to introduce a general criterion into the measurement of the suppliers' sustainability and further decision-making of outsourcing strategies. It is a manageable, doable, practical and informative criterion. It enables the managers of the supply chain to measure the sustainability of their companies with higher accuracy and to include the approach into their existing strategic assessment system. If the proposed approach can function as a unified standard, it will definitely be easier for decision makers to find the balance between the company's economic profits and environmental sustainability.

For this master thesis project, the report gives out a satisfactory answer. Each stage of the project has been performed and accomplished well. A self-consistent model has been constructed and its application is also proved to be convincing. The candidate would like to evaluate this project as a successful practice of the supply chain management combined with logical thinking and rigorous research methodology.

6.2 Future work

The improved weighted scoreboard model achieves preliminary success on integrating the indicator of sustainability with other commercial criteria. But there are still some shortcomings in this model. There are works that need to be done to consummate and strengthen the model. In the following sub-sections, we would discuss some of the possible works that should be done in the future.

6.2.1 Find a convenient and precise way to determine the equivalent CDE value

In section 4 we discussed the feasibility of transforming different kinds of sustainability index into a unified CDE indicator. In section 5, a practical case is examined. But the process of how those equivalent CDE value was obtain has been omitted. Because the process is tedious and complicated, we do not want to take a year's worth of columns to describe it. A simplified one will be illustrated here as following.

In the case mentioned in section 5, the suppliers' equivalent CDE value mainly including the carbon dioxide emission in the transportation, the equivalent carbon dioxide emission in the cleansing process of the wastes and etc. We take the carbon dioxide emission in the transportation as an example to illustrate how the equivalent CDE values is estimated.

The valve part in the case is normally transported in standard containers. Each container could accommodate 20,000 pieces, which has a total weight around 20 ton. The transportation is normally accomplished by cargo trucks. Such truck normally has a fuel consumption at around 0.40 L/km. By consulting the truck manufacturer, we obtained the carbon dioxide emission of a truck of this type is normally around 1140 g/km or 1.14kg/km. For supplier A, the distance of transportation is about 2500 km. Then we can calculate the equivalent CDE value for the transportation as following:

$$\mathrm{CDE}_{transport} = \frac{1.14kg/km * 2500km}{20000unit} = 0.1425kg/unit$$

This is only a part of the equivalent CDE value. The others could be more sophisticated, not like the energy consumption and the corresponding CDE value. In fact, some of the equivalent CDE values used in the case study is roughly estimated values based on experience. The exact value could not be obtained easily like the equivalent CDE value in transportation.

Thus, in the future, we should work on finding a convenient and precise method to determine the equivalent CDE value in a business process.

6.2.2 Introducing threshold value

The setting of the weights is closely related with the validity of the entire evaluation system. But the weight of the model is pre-set by the purchaser and cannot be changed randomly according to every supplier's situation. The evaluation is fair-and-square only when all the suppliers are investigated under the same standard. However, in some extreme circumstances, we might need to artificially set some threshold values, which function as filters, in order to make the model suits the actual situation better.

For example, the pre-requisites are the same as the case that we discussed in section 5. Now we calibrate the date and assume that there is a supplier who can produce the product in an extremely low cost at 20 NOK/unit in the price of causing extremely high damage to the natural environment, where the equivalent CDE value reaches 60 kg/unit, which is 150 times the equivalent CDE value of supplier D and around 46 times the CDE value of supplier A in the case. As the other parameters are exactly the same with supplier B, we can substitute the two new values into equation (13) and calculate the total equivalent cost. We get the value at $\mathrm{Z}_B{}' = 3.9756\ NOK/unit$. For this value, the supplier will still be ranked at the top. This is not a common incident. But it does exist in the world.

What should the decision makers do? Considering the harm to the nature is unbearable, a wise decision maker should find a way to eliminate such supplier from the list. Here, a threshold value would be helpful. For the example, if we set 15kg/unit as a threshold value, the problem could be solved.

From a broader perspective, the setting of threshold value could be applied to all the other parameters so as to help optimizing the solutions. For instance, some suppliers are quite efficiency and friendly to the natural environment. However, their available capacity is unstable or their yield is fluctuating sharply. Similar to the sustainability problems, the suppliers may still be listed as the top selections in this model. With the help of a corresponding threshold value, the suppliers will be excluded.

6.2.3 Extended model for multi-plant suppliers and allocation of demand

Normally, for big companies, several different suppliers will be selected to provide the same product/service. The total demand is needed to be divided and allocated among the selected suppliers. A complete outsourcing strategy model should be able to answer such problem. The model we established in section 4 could be extended to serve multi-plant suppliers and the allocation of demand.

This might be achieved by extending the model with an assistant parameter which represents the capacity of each individual supplying source. This proposal is a vague idea about the feasible solution. Much work needs to be done to bring it into reality.

6.2.4 Moral responsibility and labor protection

As we have mentioned in the section 2.4, in addition to environmental protection, sustainability also has connotation in moral responsibility and labour protection field. For those companies that basically will not cause high damage to the nature, such as the IT industries and the other high-tech companies, we should also set up a method to measure their sustainability in these aspects and include them into the proposed approach and establish a more general model.

The fact is, if we want to count in the moral responsibility and the labour protection, similar transformation is also feasible. For example, we assume that eight hours working time is standard and overtime is considered to be unsustainable. We may introduce a time-related coefficient τ:

$$\tau = \begin{cases} e^{\mathrm{T}-8}\mathrm{k}, & 8 \leq \mathrm{T} \leq 24 \\ \mathrm{k} * \mathrm{T}, & \mathrm{T} \leq 8 \end{cases} \tag{11}$$

$$\mathrm{CDE} = \tau * \mathrm{T} \tag{12}$$

Where,

T is the daily working length of a worker in hour;

k is the standard daily CDE coefficient of a worker, a constant in kg/hour;

From equation (11) and (12) we can see that along with the working time increases after reaching the standard working length, the coefficient τ increases rapidly. Thus, CDE increases too. The value of k could be set artificially according to the practical situation. For instance, when dealing with heavy physical labour the value could be set big and for light physical labour it could be set small.

In fact, this kind of modification of the transformation equation might also be helpful to solve the extreme problems we solved before using threshold values. A similar exponential function could be multiplied with each parameter that we need to examine. Under an extreme circumstance, the exponential multiplier might result in a very big number and stop the supplier from being ranked at the top of the list.

6.2.5 Fit the model with multi-layer outsourcing

In some industries, it is quite normal that the suppliers do not provide the products or services itself. They just purchase them from another supplier. Several layers of subcontractors will be involved in such outsourcing processes. In this case, it is very difficult or even impossible for the purchaser at the top layer to acquire complete information about the suppliers which eventually provide the products or services. Without the needed information, it is then hard to apply the proposed model. How to modify the model so that it could still be used to help decision-makers in the evaluation and selection of suppliers is also an important work that needs to be done in the future.

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