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Malte Herold Jeberg[1], Simon Hummelshøj Sloth[1], Janus Haslund Løgtved[1], Hans-Henrik Hvolby [1] [0000-0002-5574-5216] and Kenn Steger-Jensen ✉ [1,2] [0000−0002−2332−1443]

[1] Department of Materials and Production, Aalborg University, Denmark
[2] Department of Maritime Operations, University of South-Eastern Norway

✉ kenn@mp.aau.dk

Abstract. A decision model is presented to support selecting the best distribution to optimise earnings and minimise environmental impact. The model has been tested on a Danish wholesaler that wants to sell its goods on the Norwegian market. In this connection, they must therefore choose how the goods are to be distributed. Via the decision model, it is possible to choose the distribution and mode of transport they need for the individual markets, as it is not always the same modes of transport that are optimal for all markets. Thus, the model supports and shows that it is possible to optimise the company's earning capacity and minimise environmental impact by choosing the proper distribution. Furthermore, national requirements for reducing carbon can be expected to affect taxes and duties, which is why a sensitivity analysis has been prepared, which shows the effect of increasing carbon taxes on the contribution margin in the optimal modes of transport.

Keywords: Eco-efficiency, Distribution model, Sustainable distribution

1 Background

An eco-efficiency approach is needed to address environmental challenges such as climate change, acidification, eutrophication, etc. The concept of eco-efficiency was first introduced in the 1970s as the concept of environmental efficiency by Freeman et al. [1] and eco-efficiency as a business link to sustainable development in the 1990s by Schaltegger and Sturm [2].

According to Verfaillie and Bidwell [3], eco-efficiency brings together economic and environmental aspects to foster economic prosperity with more efficient use of resources and lower emissions.

However, it is well known that carbon dioxide emissions are directly proportional to the car fuel consumption rate affected by factors such as speed, load, acceleration, road gradient and traffic congestion [4]. Chang and Morlok [5] studied the Green Vehicle Routing Problem (GVRP) and proposed the impact of vehicle speed on fuel consumption. The characteristic of GVRP is to harmonise environmental and economic costs by planning effective routes to maximise benefits and meet environmental concerns. Raeesi and Zografos [6] used the Chicago road network as an example to introduce a realistic urban freight distribution model. They included flexible time windows and departure times, crowded city road network, random vehicle number, and instantaneous acceleration and deceleration of trucks in fuel consumption estimation.

Besides the transportation behaviour, the utilisation of payload and scale of business is essential to minimise carbon footprint per ton-mils. Tsoulfas and Pappis [7] suggested incorporating environmental factors and product recovery in transportation network decisions. Data envelopment analysis (DEA) can be used as a support tool to establish a relative eco-efficiency measure for the different bioethanol transportation modes and prioritising different modes according to these figures [8].

From an eco-efficiency perspective, intermodal transport has a lower environmental impact than competing modes [9]. For example, intermodal transport has, on average, 20-50% less CO2 emissions than all-road transport on 19 tested European routes [10].

Studies in modelling eco-efficiency in intermodal or multimodal transportation system are not fully exploited. The benefit of integrating ships advantage of low emissions per ton-km with truck advantage as last mils delivery to customers has not between presented, which is the focus in this paper.

2 Model

To reduce the carbon footprint, models must be developed that support choosing the right distribution method that optimises both earnings and minimises environmental impact simultaneously. It can be expected that the national requirements for reducing carbon will mean that taxes and duties on carbon will increase to realise the goals and thus affect earnings negatively proportionally if the choice of distribution is not chosen wisely.

When estimating the potential revenue of a new market and the transport cost of distribution, numerous variables and influencing factors must be considered. A model is thus developed, which can dynamically measure the profitability and eco-efficiency of distributing to a given market with goods. One objective of the model is to estimate the transport cost and environmental impact, as this will directly affect the profitability and eco-efficiency. The advantage of a model is the ability to test different scenarios and measure the different variables' sensitivity. The developed model has three main functionalities: 1) measuring the potential revenue in a given market, 2) calculating the cost of transporting the goods, and 3) measuring the environmental impact. The model structure and its steps are displayed in Figure 1

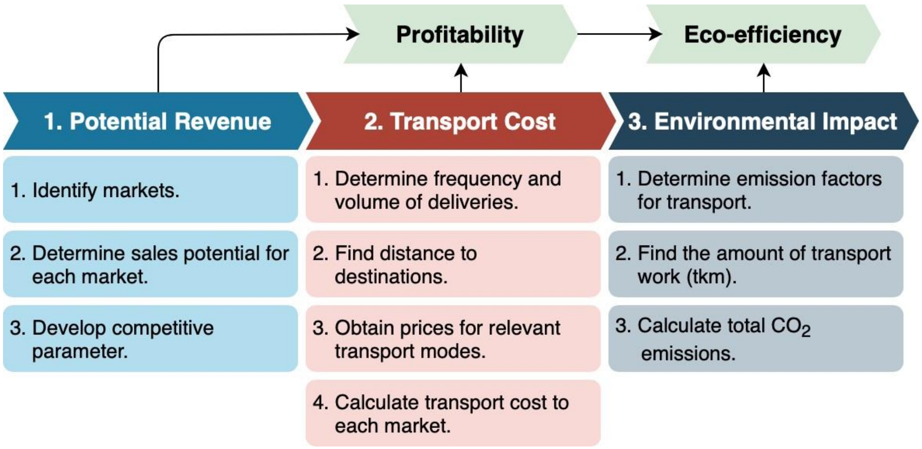

Fig. 1. Model structure

The **first** step addresses the potential revenue by identifying the relevant markets, followed by determining the sales potential for each market. Next, competitive factors must be evaluated. Finally, if necessary, the sales potential should be scaled according to these factors by introducing a competitive parameter into the model, e.g. scaling the revenue based on the number of competitors.

In the **second** step, the frequency and volume of deliveries are estimated and included as a variable in the model, making it possible to test the impact on total transport cost. Furthermore, the distance from the company base to each of the identified markets is fetched, which can be used to calculate the total transport cost to each market once prices from shipping companies have been obtained. Hereafter, the profitability is estimated by subtracting the transport cost from the potential revenue in each of the potential markets.

In the final step, an emission factor is determined for each mode used in the second step. The choice of transport mode will significantly influence the environmental impact of supplying goods to each market due to different emission factors. The total distance and volume of each delivery can be transformed into a total amount of transport work, measured in tonnes-kilometres (tonnes-km), multiplied with the emission factor resulting in the total amount of CO2 emitted. The profitability from step 2 of the model is used to calculate the eco-efficiency denoted as profit per ton CO2 emitted.

3 Case Study: A Danish Wholesaler

The model's applicability will be showcased through a case study using a Danish wholesaler as an example. The company seeks to enter the Norwegian market, which might be beneficial to supply with goods by sea along the west coast rather than with truck from the Oslo region due to a logistical imbalance. Which modes of transport, and if alternative routes should be considered, will vary depending on the preferences of the case company and the location of the target market. The case study will follow the structure in Figure 1.

3.1 Potential Revenue (Step 1)

In step 1.1, an analysis of the case company's overall strategy is performed to set requirements for the target market. The analysis led to the identification of 397 towns with strategical relevance for the case company. The revenue consists of the cost of goods sold and gross profit. For step 1.2, a simple linear regression of the cost of goods sold in a current market with strategical similarities to the target market was used as a basis for estimating the revenue. To estimate the gross profit margin range, a sales analysis was made of the current market.

Although the cost of goods sold is constant and independent of the location within the target market, the gross profit margin is not. Therefore, in Step 1.3, a competitive parameter was introduced to address the discrepancies between a currently serviced market and the target market. It is strategically important for the case company that the target market has a significant degree of isolation; hence the distance to larger cities was reflected in the competitive parameter. The gross profit margin is scaled with the competitive parameter, alternating the potential revenue depending on the strategic fit of each town, which yields the gross profit, enabling an estimation of the expected yearly revenue of a target market (town) as seen in equation 1.

$$\text{(1)} \quad \text{Revenue} = \text{P} \times \frac{\text{CP} \times \text{COGS}}{1 - (\text{CP} \times \text{GPM})}$$

where P is the target market population, COGS is the cost of goods sold, CP is the competitive parameter, and GPM is the gross profit margin.

The potential revenue was calculated for all of the 397 towns. An example of an identified town is Vaksdal, with a population of 1335 people. Using Equation 1, a yearly estimated cost of goods sold of €51 per person, scaled by a competitive parameter of 0.91 and a scaled gross profit margin of 18.59 %, yielding an estimated potential annual revenue for Vaksdal of around € 76K.

3.2 Transport Cost (Step 2)

In **step 2.1**, the annual volume per area in the target market was approximated from the potential sales, assuming that the value-density (value in € per m^3) is the same within the two markets. As the estimated volume is based on annual demand, a yearly delivery frequency (shipments per year) is needed to determine the volume per shipment. However, the price per unit of volume is highly dependent on the space utilisation of the shipping trailer. The volume demand of a single town is only a fraction of a full trailer, driving up the price and reducing the contribution margin. Therefore, it is beneficial to aggregate several towns to bring down transport costs. For this case, clustering analysis was used in conjunction with a short iterative manual process to refine the clusters and ensure no volume demand of a cluster violates the maximum capacity of a trailer. This yielded a total of 29 clusters in Norway, and a fragment of these can be seen in Figure 2.

In **step 2.2**, the distance to the market must be identified before estimating the total transportation cost. If several towns are to be visited, determining the shortest route can be categorised as a travelling salesman problem. To solve a travelling salesman problem, a distance matrix is needed. In a country with many remote areas, such as Norway, it is recommended to use the driving distance between towns instead of the Euclidian distance. A distance matrix of driving distances can be obtained from e.g. the Google API, which extracts the distance between any two destinations from Google Maps.

In **step 2.3**, the prices for the relevant transport modes must be found. The Norwegian market calls for a comparison between road and ship transport to be made, and therefore two alternative routes will be calculated. The first will use road transport (through the port of Kristiansand) directly to the customers, whereas the other will employ ship transport to the nearest port of the cluster. After consulting shipping companies that currently supply the target market, price sheets for transporting goods the relevant distance were obtained.

Finally, in **step 2.4** the transportation prices to supply each cluster can be found by extrapolating or interpolating the prices to the final destination. The mode of transportation will influence the applicability of linear extrapolation, and road transport prices are more likely to be accurately estimated using this method. Therefore, specific prices for as many of the target destinations as possible should be obtained.

When estimations of transportation costs have been obtained, they are subtracted from the revenue to obtain the profitability of a given cluster, as shown in equation 2.

$$(2)\quad \text{Profitability} = R - (C \times F)$$

where R is the annual revenue of a cluster, C is the stated cost of transportation, and F is the yearly frequency of deliveries.

Prices of transportation for the two alternative routes to each of the 29 clusters were obtained. The profitability of a cluster (highlighted in Figure 2, including previously mentioned Vaksdal) is calculated using equation 2 and yielded a profit of € 142K and € 143K for road transport and sea transport, respectively.

3.3 Environmental Impact (Step 3)

Step 3.1 requires determining the emission factors for the chosen modes of transport. Several studies have been made regarding which emission factor is most suitable, and for this case, a factor of 62g CO_2 per tonnes-km of road transport is used. For ship transport, a factor of 16g CO_2 per tonnes-km is used [11].

Step 3.2 requires a calculation of the amount of transport work (tonnes-km) to be carried out, which can be calculated by combining the weight of the supplied goods by the travelled distances. The amount of yearly pallets distributed is known from the calculation of the transport costs. Moreover, the average weight of a pallet of goods can be found from the strategically similar market. Therefore, it is possible to calculate a total weight for the supplied goods, which in combination with the distances returns the total tonnes-km.

In **step 3.3**, the total tonnes-km is multiplied by the emission factors to estimate the total CO_2 emission for each of the chosen transportation routes. Note that inventory logic can be used for the last (mile) distribution by dividing this distance by two if making several stops for delivering goods. This assumes equal distances between the target towns and equal distribution of supply between the towns.

Finally, the eco-efficiency of the market can be calculated as shown in Equation 3:

$$\text{(3)}\quad \text{Profit per ton } CO_2 = \frac{\text{Profitability}}{(TK \times SEF \times SP) + TK \times REF \times (1 - SP))}$$

where TK is the total tonnes-km, SEF is the emission factor for ship, REF is the emission factor for road transport, and SP is the proportion of ship transport.

For the case company, the eco-efficiency was calculated for all clusters. For the example cluster, using Equation 3, it was calculated to be € 13.5K and € 22K profit per ton CO_2 emitted for road transportation and sea transportation, respectively.

Figure 2 (next page) depicts an extract of Norway and some of the clusters contained within. In picture 1, an overall higher contribution margin is achieved by road transport rather than by sea transport, as seen in picture 2. There are, however, some clusters that are as good or even slightly better when using sea transport. These are often clusters located close to a port, for example, the three clusters in the red circle close to the port of Bergen. On the contrary, these clusters have a significantly higher eco-efficiency, averaging 75% higher using sea transport.

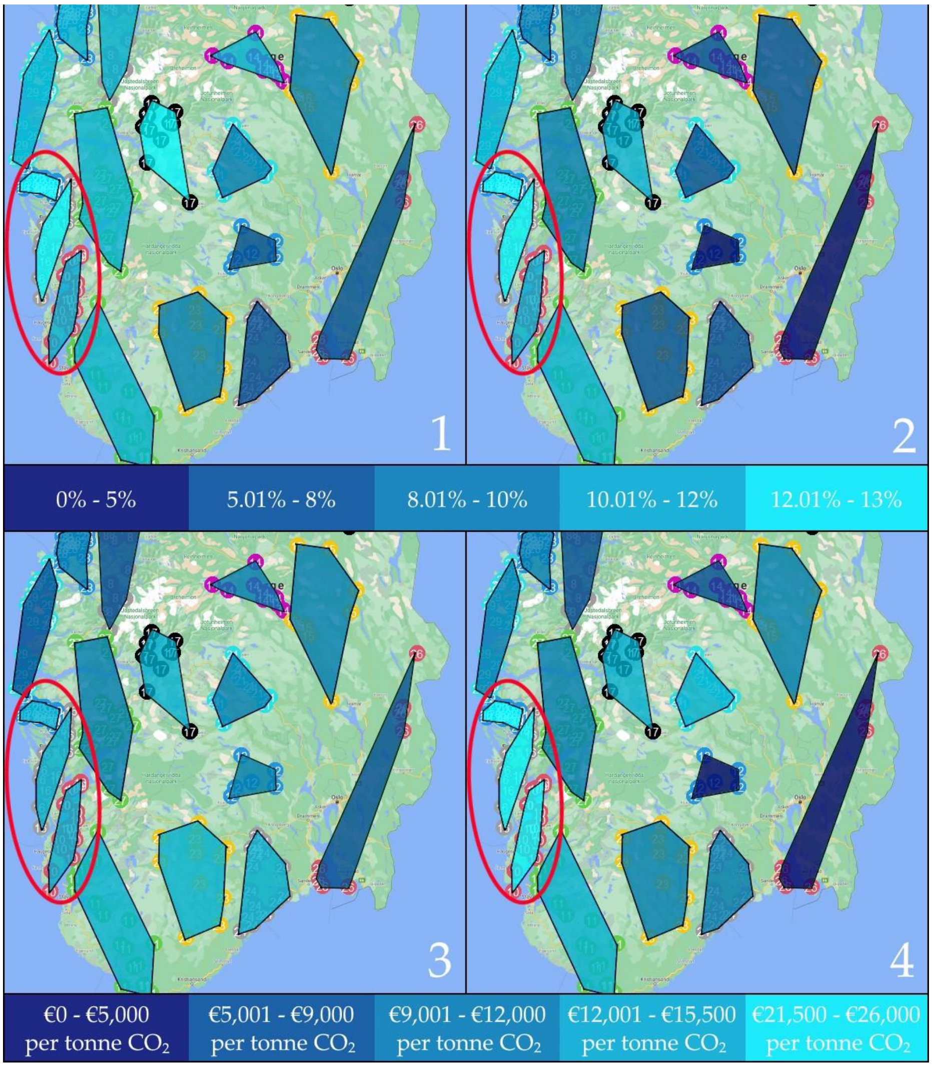

Fig. 2. The juxtaposition of the contribution margin and eco-efficiency of different areas in Norway. Picture 1 and 2 illustrates the contribution margin for road and sea transport, whereas picture 3 and 4 illustrate the eco-efficiency for road and sea transport.

4 Concluding Remarks

This model provides the case company with the possibility to test different scenarios before moving into a new market. It can help to make decisions not only based on profitability but also taking eco-efficiency into account. For the calculated example cluster, it becomes clear that even though the profitability is very similar regarding which mode of transportation to choose, the eco-efficiency of a solution using sea transportation can be employed with significantly less emission of CO_2. Furthermore, as shown in Figure 3, a future expected increase of CO_2 tax will further impact the profitability of different modes of transport. This framework should be applicable to similar cases when important exporting decisions are to be made.

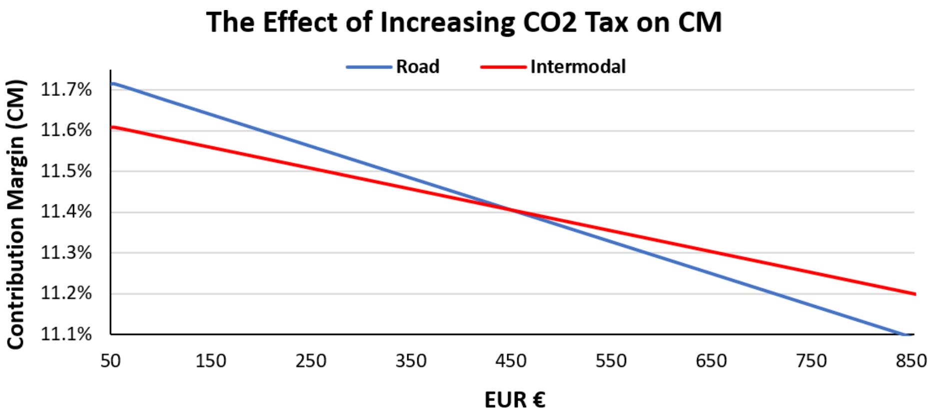

Fig. 3. The effect of increasing CO2 tax on the contribution margin (CM) for both road and sea scenario. The CO_2 tax in Norway is currently € 53.5 per ton.

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