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MINIMIZING TRAVEL DISTANCE AND CO_2 EMISSIONS WHEN RECONFIGURING RETAIL STORE NETWORKS

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Kenneth Carling*, Vijay Paidi*, Niklas Rudholm‡

Abstract: Retail chains continually expand, reconfigure, and contract their store networks to serve their customers and maximize profits. One notable consequence of these actions is changes in the distances between consumers' residences and nearest stores, altering their transportation-related CO_2 emissions. Therefore, this study aims to examine the environmental impact of the reconfiguration of the IKEA store network in Sweden during the twenty-first century and compare the actual reconfiguration to one that minimizes consumers' travel distances and, thus, CO_2 emissions. The expansion of the IKEA network in Sweden between 2004 and 2016, adding four (2004–2007) and then three (2013–2016) additional stores, reduced consumers' average travel distance to their nearest store from 87 to 65.2 km. However, had IKEA managers used our web-available decision support tool, eCOmpass, this reduction could have been achieved after the first round of store additions since the distance-minimizing locations for the four new stores established in 2004–2007 would have reduced average travel distance to 64.9 km.

Keywords: Facility location, emission reduction, *p*-median modeling, firm entry, firm exit.

JEL-codes: C44, C88, Q54, R30, R40

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1. Introduction

Swedish consumers travel on average 30 km to brick-and-mortar stores for durable goods shopping; almost all these trips are made by car, and they comprise about a sixth of the total travel by private cars in Sweden (Trafikanalys, 2013). In addition, last-mile retail transport (i.e., transport from retail stores to the consumer's residence) is still dominated by consumers' private cars, making last-mile delivery the most expensive, least efficient, and most environmentally problematic part of the overall delivery process (Vanelslander et al., 2013). As such, the impact of retailing on the environment has frequently been debated in Sweden, where the distances between consumers' residences and retail stores are often considerable, especially in northern Sweden.[1] Nonetheless, Turhan et al. (2013), who reviewed the key factors for retailers' location decisions, reported that the environmental aspect of transportation was not deemed a critical factor in retailer location decisions.

This oversight might not be that important if the potential gains from using optimal retail locations were limited. However, Carling et al. (2013b) used the *p*-median model to investigate how much CO_2 emissions could be reduced if the stores for three types of retailers (consumer electronics, locksmiths, and pet shops) where located at the point minimizing CO_2 emissions rather than at their actual locations in the Dalecarlia region of Sweden. Their results showed that CO_2 emissions could be reduced by 22% on average for all types of retailers and by as much as 35% for consumer electronics stores.

The analysis by Carling et al. (2013b) was a one-time investigation of the optimality of existing retail locations for three types of stores. A more profound impact on travel distances to retailing is likely found when big-box retailers establish a store, or even a whole new retail trade area, in a region. The Swedish retail giant IKEA continually expands and reconfigures its store networks to serve its customers and maximize profits. The entry of IKEA into a region was shown to increase total durable goods sales in the

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[1] Our analysis uses road distance as a proxy for CO_2 emissions. In a study of how to measure retail-related CO_2 emissions in Sweden, Carling et al. (2013a) found that CO_2 emissions were strongly correlated with travel distance once outside inner-city areas. Consequently, we have not attempted to refine the measure of CO_2 emissions further.

entry municipality by about 20% on average (Daunfeldt et al., 2017). Additionally, incumbent retailers in the entry regions benefit from IKEA entry, at least when entry occurs in more rural areas (Håkansson et al., 2019).

As Huff (1963) demonstrated, consumers tend to choose a particular shopping area based on its attractiveness and travel distance. Since new IKEA stores tend to attract consumers from far away (Daunfeldt et al., 2017), it is vital to investigate how reconfigurations of the IKEA store network will affect consumers' travel distances and emissions, and to what extent using mathematical tools for location analysis might reduce such emissions.

However, retailers rarely know the locations that minimize the need for last-mile transport, and the mathematical tools needed to solve the optimization problem are not readily applicable to most retail chain managers. They could use consultants or researchers to address this problem, but at considerable cost and inconvenience since the analysis would have to be repeated for each new store network reconfiguration cycle the retailer is contemplating. Consequently, for the potential reductions in CO_2 emissions from optimal retail locations to be realized, the mathematical methods for location analysis must be made readily available to the retail community in a manner they can utilize.

Therefore, the dual purpose of this study is to present a newly developed and publicly available web tool for location analysis (eCOmpass) and use it to analyze the environmental consequences of the reconfiguration of the IKEA store network in Sweden during the twenty-first century.[2] This analysis compares the actual reconfiguration of stores after the turn of the twenty-first century to the one that minimizes consumers' travel distances and, thus, last-mile CO_2 emissions. The eCOmpass tool is open source and may be used for location decisions beyond retailing. Moreover, it can be transferred to other geographical markets, provided access to the market's spatial distribution of its population and road network.

[2] The decision support tool eCOmpass, including an instruction manual based on the IKEA analysis made in this article, can be accessed on https://ecompass.se/. For replication purposes, we have also made the datasets on IKEA store locations in Sweden at different points in time available there.

We examine how two Swedish IKEA store network reconfigurations affected consumers' travel distances. Our analysis uses the Swedish IKEA store network at the turn of the twenty-first century as the baseline. The first reconfiguration of this network in more than 10 years occurred between 2004 and 2007, adding four new stores, and a second reconfiguration occurred between 2013 and 2016, adding three new stores. Before the first reconfiguration, consumers' average travel distance to their nearest IKEA store was 87 km. After the first reconfiguration, consumers' average travel distance was instead 71.2 km, a reduction of 15.8 km or 18.2%. After the second reconfiguration, consumers' average travel distance was instead 65.2 km, a further reduction of 6.0 km or 8.4%. Therefore, over the two reconfigurations between 2004 and 2016, consumers' average travel distance was reduced from 87 to 65.2 km, a reduction of 21.8 km or 25.1%.

However, if IKEA had focused on emission reductions and used eCOmpass, they could have done considerably better. If the four new stores added in the first reconfiguration between 2004 and 2007 had been optimally located, as given by our decision support tool, consumers' average travel distance to the stores in the network would have been 64.9 km. Hence, we could achieve the same average distance that IKEA achieved with 20 stores with only 17 stores. Moreover, after adding three more stores to the network (as IKEA did between 2013 and 2016) at their optimal locations, we could achieve an average travel distance of 61.7 km. Consequently, if eCOmpass had been available at that time, IKEA could have reduced consumers' average travel distance from 87 to 61.7 km (by 25.3 km or 29.0%). The additional travel reduction using the locations suggested by the eCOmpass tool compared to the actual locations (25.3 km instead of 21.8) equals 3.5 percentage points, or 16% (= 25.3 – 21.8 / 21.8).

The remainder of the paper is organized as follows. Section 2 describes the reconfiguration of the IKEA store network in Sweden during the twenty-first century. Next, Section 3 presents the eCOmpass localization decision support tool. Then, Section 4 examines the environmental impact of the IKEA store network reconfiguration, some possible extensions of our analysis, and potential caveats when using the eCOmpass tool. Finally, Section 5 summarizes and discusses our results.

2. The Swedish IKEA store network 1958 to 2023

IKEA is one of the world's largest retailers, with 468 stores in 63 countries, of which 21 are in Sweden. New IKEA stores tend to attract consumers from far away and are therefore widely believed to be more important for regional development than the average large retail establishment (Daunfeldt et al., 2017). In 2023, IKEA Sweden had 35 million store visits[3] and a total turnover of 19.2 billion SEK.[4,5]

The first IKEA store was established in 1958 in Älmhult, Sweden. However, IKEA's real success came between 1965 and 1972 when it established new stores in Stockholm (1965), Sundsvall (1966), Malmö (1967), and Gothenburg (1972). This store network expansion coincided with a large increase in housing in Sweden called *Miljonprogrammet*, where the Swedish government annually granted loans to build 100,000 new residences between 1965 and 1975 to reach one million after 10 years. The locations of these new residences largely coincided with the locations of the new IKEA stores and created the means for further expansion in the coming years. Eight additional IKEA stores were established in Sweden between 1977 and 1993 (see Table 1 for details), resulting in 13 stores.

Then, four IKEA stores were established in Sweden between 2004 and 2007: Gothenburg (2004), Kalmar (2006), Haparanda (2006), and Karlstad (2007). Among these, Kalmar, Haparanda, and Karlstad are all smaller cities with fewer than 80,000 inhabitants and 80 inhabitants per sq km. The fourth new IKEA store during this period was established in the urban area of Gothenburg and was the second IKEA store in the region. Gothenburg is Sweden's second-largest city; its metropolitan area comprises 13 municipalities with approximately one million inhabitants. The first IKEA store in the region was located on the southern edge of the metropolitan core and had been open since 1972, while the new store was instead located north of the river, on the northern edge of the metropolitan core.

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[3] According to Statistics Sweden, the Swedish population was 10.5 million in 2023.
[4] 1.9 billion USD, exchange rate on January 2, 2024.
[5] Source: https://www.ikea.com/se/sv/newsroom/corporate-news/ikea-fortsaetter-att-vaexa-i-sverige-investerar-nu-i-saenkta-priser-pub61b92480, accessed on January 2, 2024.

There was another round of IKEA store openings in Sweden between 2013 and 2016 in the cities of Borlänge (2013), Uddevalla (2013), and Umeå (2016). These additions are in many ways similar to the previous ones in Kalmar (2006), Haparanda (2006), and Karlstad (2007). For example, Karlstad and Umeå have local universities, and Borlänge and Kalmar have university college campuses. In contrast, the municipalities of Haparanda and Uddevalla had no higher education institutions at the time of IKEA entry. In addition, they are similar in population size and density to the previous round of rural store openings, again with fewer than 80,000 inhabitants and 80 inhabitants per sq km.

Finally, one additional IKEA store was opened in Sweden in 2022. It differs from previous IKEA stores in several important aspects. Firstly, it is a so-called city store located in the center of Stockholm. Therefore, customers rarely visit the store by car, and the goods bought are usually small enough to be transported to the consumer's residence without a private car or transported there by a professional carrier. In either case, the environmental impact due to last-mile delivery of this type of store will differ considerably from a new IKEA store located on the outskirts of major cities like Stockholm, Gothenburg, and Malmö, and even more so compared to the IKEA stores located in the more rural areas of Sweden. Consequently, we opted to exclude this store from our primary analysis but have included it in the analysis presented in the online supplemental material (Section A1, Fig. 4).

Table 1. IKEA store locations in 2023, their opening year, address, and coordinates.

Store	Entry year	Street address	Postal code	Latitude	Longitude
Entries 1958–1993					
IKEA Älmhult	1958	Handelsvägen 4	343 33 Älmhult	56.550128	14.162557
IKEA Stockholm Kungens kurva	1965	Modulvägen 1	141 08 Kungens kurva	59.271002	17.916666
IKEA Sundsvall	1966	Gesällvägen 3	857 53 Sundsvall	62.445176	17.334777
IKEA Malmö	1967	Kulthusgatan 1	215 86 Malmö	55.552489	12.989743
IKEA Gothenburg Kållered	1972	Ekenleden 2	428 36 Kållered	57.603742	12.048695
IKEA Linköping	1977	Västra Svedengatan 7	581 11 Linköping	58.432467	15.586468
IKEA Gävle	1981	Valbovägen 307	818 32 Valbo	60.633759	16.993094
IKEA Jönköping	1981	Kompanigatan 6	553 05 Jönköping	57.773762	14.203621
IKEA Västerås	1984	Domkraftsgatan 2	721 38 Västerås	59.608244	16.456656
IKEA Uppsala	1986	Rapsgatan 3	753 23 Uppsala	59.848242	17.694211
IKEA Helsingborg	1988	Marknadsvägen 7	260 36 Ödåkra	56.092249	12.762610
IKEA Örebro	1991	Kundvägen 2	702 31 Örebro	59.212934	15.134691
IKEA Stockholm Barkarby	1993	Folkungavägen 50	177 35 Järfälla	59.421108	17.859059
Entries 2004–2007					
IKEA Göteborg Bäckebol	2004	Transportgatan 23	422 46 Hisings backa	57.774386	12.001883
IKEA Haparanda	2006	Norrskensvägen 2	953 36 Haparanda	65.845223	24.126509
IKEA Kalmar	2006	Bilbyggarvägen 6	393 56 Kalmar	56.685677	16.320974
IKEA Karlstad	2007	Bergviksvägen 43	653 46 Karlstad	59.378745	13.419860
Entries 2013–2016					
IKEA Borlänge	2013	Norra Backagatan 1	781 70 Borlänge	60.481601	15.421267
IKEA Uddevalla	2013	Östra Torpvägen 30	451 76 Uddevalla	58.356521	11.818656
IKEA Umeå	2016	Marknadsgatan 1	904 22 Umeå	63.807555	20.254731

Note: A twenty-first IKEA store was established in Gallerian in Stockholm city, Stora Hamngatan 37, 111 53 Stockholm, in 2022. We have chosen to exclude that store from this analysis since it is the only IKEA City Store, and customers do not usually use cars to access the store or bring purchased products home to their residences. In the Online Supplemental Material, we have also analyzed the impact of this store on distances and emissions (see Section A1, Fig. 4).

Fig. 1. IKEA store locations in 2023.

3. Using the decision support tool eCOmpass

3.1 User input and eCOmpass output

The eCOmpass user must provide some information for the tool to work. First, they must decide on the geographic level of the analysis: national, regional, or municipality. In the case of IKEA, this will be at the highest level (i.e., national).

Second, there are two distinct types of location problems to be considered. In the first case, the retailer intends to locate N facilities at S predetermined potential locations, where $N \leq S$. In this case, the user will apply the "Exploit" alternative. Then, on the second page of the support tool, the user is asked to supply a .csv file with information on existing store coordinates[6] (longitude, latitude) and an indicator variable equal to one for the P existing locations (facilities) and zero for the S potential new locations. Finally, the user must input the number of new facilities (N) the retailer wants to establish (out of the S potential locations). Note that the "Exploit" mode can also be helpful if the retailer wants to reduce their number of stores and compare the impact on the driving distance of closing different (sets of) stores.

In the second case, the retailer still has P existing facilities and wants to open N new ones. However, in this case, the retailer would like to know the locations of the N new facilities that minimize CO_2 emissions. The procedure using the tool is like the one above: the user must first choose the geographical level, but then they will now use the "Explore" alternative instead of the "Exploit" alternative. As before, the user can supply a .csv file, but if doing so, it should now only include existing locations (i.e., the indicator variable for the store will always take the value one in the .csv file when using the "Explore" mode). This second type of analysis can then, for example, support the retailer in combining the environmental impact of the location decision with other deciding factors to narrow the potential locations for further investigations, such as land availability and cost.

[6] There is also the option to supply addresses. However, the example given here will use the coordinates alternative throughout the description of the system.

The eCOmpass tool will deliver an identical output for both cases.[7] It consists of estimates for consumers' total minimized weighted travel distances and CO_2 emissions, as well as their average travel distance to their nearest IKEA store and the associated CO_2 emissions. Moreover, the output contains information on the share of consumers served by each store. Finally, a map of Sweden with the locations (new and old) marked is provided, and the coordinates of the old and new locations can be obtained from the map. In addition to the precise coordinates of each location, the map will also mark a surrounding area that will achieve average distances and CO_2 emissions close to the ones given by the optimal or chosen point.[8]

After familiarizing themselves with the tool, the user can make counterfactual analysis on several possible location decisions by re-running the analysis. This re-analysis can be done using the "Explore" or "Exploit" alternative or both to compare average driving distances and resulting CO_2 emissions between outcomes.

3.2 The eCOmpass optimization process

Section 3.1 shows how and for what purposes the eCOmpass decision support system can be used. However, this still leaves the question of how the tool derives the optimal locations when a user applies either the "Exploit" or "Explore" alternative. For a detailed description of the technical aspects of the eCOmpass tool, including the building of the origin-destination (OD) matrix, data acquisition, quality matters, and a justification for the behavioral assumptions about consumers, see Carling et al. (2024). Here, we will instead provide a more intuitive description of the process.

There are four settings for exploitation and two settings for exploration to enable an analysis of all possible counterfactual cases. To focus on ideas, we begin with the simplest case where $P = 0$ and $N = S$ (i.e., the retailer has no existing store network and intends to locate N stores at N given sites). The tool has a built-in OD matrix that provides the distance and created CO_2 emissions between any pair of origins (where a consumer travels

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[7] The main output from the eCOmpass tool for the analysis made in Section 4 is provided in the Online Supplemental Material.

[8] The size of the area surrounding the optimal point depends on how the population points are created at each geographical level: the diameter is 20 km when the analysis is done at the national level, 5 km when done at the regional level, and 1 km when done at the municipal level.

from) and destinations (a potential store site to which a consumer may travel) in Sweden. In computing the traveling distance and created CO_2 emissions, it is postulated that the consumer travels to the nearest store along the shortest route in the road network.[9] Therefore, it is a straightforward look-up in the OD matrix to obtain the metrics for the consumer based on their origin. This procedure is repeated for all consumers in the concerned (geographically delimited) market to obtain the average distance and CO_2 emissions. This case allows for a counterfactual analysis where the *N* sites may be changed into another set of sites of size *N*, followed by a comparison of the metrics.

The case of $P > 0$ and $N = S$ is evaluated similarly. First, the distances and CO_2 emissions are looked up in the OD matrix when the consumers' destinations are limited to the *P* sites and then compared to any of the $P + N$ sites as the destination. In this case, some consumers will be sufficiently served by the existing *P* sites, whereas some will change to the new *N* sites, reducing the average distance and CO_2 emissions.

Consider now the case where $P = 0$ and $N < S = N + 1$, so there is one more predefined site than the retailer requires. This means that there are $N + 1$ combinations with *N* predefined sites to compute as described above, and the tool returns, out of the $N + 1$ combinations, the one combination of *N* predefined sites that yields the lowest average CO_2 emissions. In principle, this solution could be attained by replicating the look-up approach. However, this is infeasible whenever *N* is substantially smaller than *S* because the number of combinations becomes large. Instead, the tool uses a meta-heuristic optimizer, "Pulp_CBC," in the Python environment, which is a Branch and Bound algorithm. The optimizer is open-source and can be used for commercial and non-commercial applications. The optimizer identifies the *N* sites that minimize the average travel distance and CO_2 emissions. The approach to managing the case where $P > 0$ and $N < S$ is similar, but it should be noted that it is imposed that *N* sites must not overlap the existing *P* sites.

The two exploring cases, *N* and $P = 0$ or $P > 0$, are managed similarly to $P = 0$ and $N < S$ as well as $P > 0$ and $N < S$. The only difference is that the consumer may now be

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[9] Jia et al. (2013) studied how Swedish customers travel to retail stores using GPS-tracking data and found that they tend to use the shortest distance between their residence and the store.

destined for any site within the market area. Infinitely many potential sites exist on the plane and along the road network. However, the eCOmpass tool limits the destination sites to about 500, irrespective of geographical level, keeping only reasonable sites as options. This limit is imposed by only keeping as candidate sites those that are at a road network node and with a population of at least 100 inhabitants in its vicinity at the municipal (vicinity = 0.7 km) and regional (vicinity = 6 km) level and of at least 1,000 inhabitants at the national level (vicinity = 100 km) (c.f. Carling, 2024).

4. Environmental impact of the IKEA store network reconfiguration

The locations of the IKEA stores opened between 1958 and 1993 are used as the baseline in the calculations of the environmental impacts presented in Table 2. The new stores that opened in the 2004–2007 and 2013–2016 periods are assumed to have been opened groupwise and sequentially in two reconfigurations of the store network.[10] First, the impact of the actual reconfiguration made by IKEA is calculated and presented using the "Exploit" mode of the decision support tool. Then, it is compared to the optimal ones given by the "Explore" mode in the decision support tool.

Table 2. IKEA store reconfiguration between 2004 and 2016, existing locations, optimal locations, and resulting reductions in average travel distance.

		Average distance to nearest IKEA store			
Years of entry	Number of IKEA stores	Distance to existing IKEA locations	Reduction in distance in km (%)	Distance to optimal locations of new stores	Reduction in distance in km (%)
1958–1993	13	87.0 km			
2004–2007	17	71.2 km	15.8 km (18.2%)	64.9 km	22.1 km (25.4%)
2013–2016	20	65.2 km	6.0 km (8.4%)	61.7 km	9.5 km (13.3%)

Note: 1 kilometer = 0.62 miles.

At the beginning of the twenty-first century, Swedish consumers had an average travel distance to the nearest IKEA store of 87.0 km (for details, see the Online Supplemental Material, Section A1, Fig. 1). The establishment of four new stores (Gothenburg,

[10] The eCOmpass instruction manual (accessible on https://ecompass.se/) also includes an example of how to analyze a contracting network of stores. Since this is a rather unlikely situation for IKEA Sweden, we have not included this hypothetical example in the article or its Online Supplemental Material.

Haparanda, Kalmar, and Karlstad) between 2004 and 2007 reduced this average distance by 15.8 km or 18.2% (Online Supplemental Material, Section A1, Fig. 2). Then, the three new stores (Borlänge, Uddevalla, and Umeå) established between 2013 and 2016 reduced the distance by an additional 6 km or 8.4% (Online Supplemental Material, Section A1, Fig. 3). Consequently, the reconfigurations completed to date during this century have reduced the average travel distance for Swedish consumers to their nearest IKEA store by 21.8 km or 25.1%, reaching an average travel distance of 65.2 km.

How much better could IKEA have done by using the eCOmpass tool? Using the optimal locations instead of the actual ones, the first round of openings could have reduced the average travel distance by 22.1 km (25.4%) instead of 15.8 km (18.2%) (Online Supplemental Material, Section A2, Fig. 5). Note here that by using the eCOmpass tool, IKEA could have reached the same average travel distance for their consumers with 17 instead of 20 stores. The second round of openings could then have decreased the average travel distance by an additional 9.5 km (13.3%) instead of 6.0 km (8.4%), reaching an average travel distance of 61.7 km (Online Supplemental Material, Section A1, Fig. 6).

Environmentally conscious retailers that want to minimize travel distance should note that it is better to make a set of entries in one go rather than making them one by one, even when using the eCOmpass tool. Using the stores opened between 1958 and 1993 as the baseline, with two sets of optimally located entries (four stores first and three stores later), it was possible to reach 61.7 km in average distance. However, had all seven stores been located at once, the average travel distance for consumers would have instead been 58.2 km (Online Supplemental Material, Section A3, Fig. 7). In addition, in the extreme, had all 20 stores been optimally located at once using the eCOmpass tool, this distance would have instead been 52.4 km (Online Supplemental Material, Section A3, Fig. 8).

Above, we focus solely on consumers' average travel distance to the IKEA stores. However, reducing this distance will also likely increase the number of consumer visits requiring more transport work. Shriver and Bollinger (2022) showed that reducing consumers' distance from retailers increased demand at stores, with a 10% reduction in retail store distance increasing retail expenditure by 1.9%. It is likely that this increase did not arise entirely from new store visits, with some of the increase coming from existing consumers increasing their expenditure when travel distance and its associated costs decrease.

However, if we assume that this increase in demand is all caused by an increase in the number of visits and that each new visit requires a trip by car, based on the 35 million IKEA visits made in 2023 in Sweden, a 10% reduction in distance would increase the number of visits by 665,000. When using the eCOmpass tool, the reduction in travel distance with the optimal locations and going from 17 to 20 stores in Sweden was equal to 13.3%, implying that the number of store visits would increase by 665,000 × 1.33 = 884,450. Total travel distance to IKEA stores for Swedish consumers would then still decrease by 2.5% (= 35 million × 64.9 km / 35.9 million × 61.7 km) after reconfiguring the store network. However, as mentioned above, this is an extreme example, and the results here should be interpreted as a lower bound of the reduction in travel and emissions due to the IKEA expansion in 2013–2016.

Another potential problem is that the optimal locations suggested by the eCOmpass tool might already be occupied and unavailable to the retailer. Therefore, we have also investigated how sensitive our results are to deviations from the optimal solutions using the IKEA reconfiguration that occurred between 2013 and 2016. We already know the optimal locations from the analysis presented in Table 2 and that we could reach an average distance to the nearest IKEA store of 61.7 km if we use those locations. Then, we chose counterfactual locations that would likely be used if the optimal ones were unavailable or not chosen for some reason.

For one location, Umeå, this is easy since this is an optimal location and a real one. However, while the optimal location is to the northwest of Umeå, the actual location is in a retail trade area south of the city. The distance between the locations is approximately 40 km. The second optimal location is in the vicinity of Östersund but located to the southeast and well outside the city. Östersund is a city of approximately 50,000 inhabitants and has one existing external retail area called the Lillänge retail trade area. Here, we assume that a reasonable counterfactual would be to place the new IKEA store in the existing retail area, and the distance between the locations is approximately 35 km. Finally, the third optimal location suggested by the eCOmpass tool is to place a second IKEA store just outside Sweden's third largest city, Malmö. Two other cities in Sweden have more than one IKEA (Stockholm and Gothenburg), and in both these cases, the second IKEA store has been placed in retail areas on the opposite side of the city from the first store. Therefore, we assume that if the optimal location was impossible to use, IKEA would choose the location in a similar manner as in Gothenburg and Stockholm, which would place the new IKEA store in the Jägersro retail trade area. The distance between the optimal and counterfactual locations is approximately 15 km.

Then, we create a .csv file with the coordinates of the existing 17 locations, along with the coordinates of the three counterfactual locations we chose, and use the eCOmpass tool's "Exploit" alternative to calculate the average travel distance for the consumers from that alternative. These calculations show that the three misallocations of between 15 and 40 km caused a 2.7 km (or 4.3%) increase in average travel distance to the nearest IKEA store. So, not being able to use the optimal locations does reduce the potential emission savings of using the eCOmpass tool, but not to the extent that it renders it useless.

5. Summary and discussion

Swedish consumers travel considerable distances to brick-and-mortar stores to shop for durable goods, especially in rural areas where public transportation is not well-established (Trafikanalys, 2013). Previous studies have also shown that most trips from retail stores to the consumers' residences are made by car, making last-mile delivery the least efficient and most environmentally problematic part of the delivery process (Vanelslander et al., 2013). Nonetheless, the environmental aspect of transportation has not previously been deemed a critical factor in retailer location decisions (Turhan et al., 2013).

This oversight might not be that important if the potential gains from using optimal retail locations were limited. However, Carling et al. (2013b) showed that considerable gains in emissions could be made by using locations that minimize travel distance for consumers. One potential problem is that even if retailers want to locate at environmentally optimal locations, they are rarely know to them, and the mathematical tools needed to solve the optimization problem are not readily applicable to most retail managers.

Therefore, this study aimed to make the mathematical tools for identifying environmentally optimal locations readily available to retail managers via an online decision support system (eCOmpass) and to demonstrate its usefulness via an analysis of the expansion of the IKEA store network in Sweden during the twenty-first century.

Our analysis showed that the two sets of store openings made by IKEA in the twenty-first century, one between 2004 and 2007 and the other between 2013 and 2016, reduced consumers' average travel distance to their nearest store from 87 to 65.2 km, a reduction of 21.8 km or 25.1%. However, if IKEA had focused on emission reductions and used the eCOmpass tool, they could have done considerably better. The analysis showed that optimally locating the first set of stores opened between 2004 and 2007 would have been sufficient to reach an average travel distance of 64.9 km. Therefore, the same average travel distance IKEA achieved with 20 stores could have been achieved with only 17 if they were optimally located. In addition, optimally locating the additional three stores opened between 2013 and 2016 could have achieved an average travel distance of 61.7 km with the 20 stores.

Distance savings of 3.5 km (65.2 km – 61.7 km) might not sound that impressive, but remember that IKEA Sweden had 35 million consumer visits in 2023. Even if we (subjectively) assume that somewhat less than a third of those represent a trip by car, this would still mean that 10 million return trips are made to IKEA annually. Using the optimal locations suggested by the eCOmpass tool would save 70 million km being driven each year, representing a considerable reduction in CO_2 emissions.

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CRediT authorship contribution statement

Kenneth Carling: Conceptualization, methodology, validation, and funding acquisition. **Vijay P. Paidi:** Methodology, software, validation, and visualization. **Niklas Rudholm:** Data curation, formal analysis, investigation, writing–original draft, project administration, and funding acquisition.

Data availability

All data, an instruction manual, and the online decision support tool eCOmpass can be accessed via https://ecompass.se/.

Declarations

Declarations of interest: none

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