Distribution Center Location Analysis For Nordic Countries By Using Network Optimization Tools

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THE UNIVERSITY OF VAASA REPORTS 12

Vaasan yliopisto
UNIVERSITY OF VAASA

Publisher
Vaasan yliopisto

Date of publication
December 2018

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Type of publication
Research paper

OrcID

Name and number of series
University of Vaasa Reports, 12

Contact information
University of Vaasa
School of Technology and Innovations,
Production
P.O. Box 700
FI-65101 Vaasa
Finland

ISBN
978-952-476-839-9 (online)

ISSN
2489-2580 (University of Vaasa Reports 12, online)

Number of pages
50

Language
English

Title of publication
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Abstract
Many supply chain and logistics related location decisions are driven by demand. This paper analyses population densities in Sweden, Finland, Norway and partly Denmark and analyses how a minimum impedance approach would set up the distribution center (DC) locations. For each scenario, travel time maps are generated.

Firstly, each country is analyzed separately and 1...5 DC cases are analyzed. Then a merged Nordic area is introduced and a similar approach is used to set up 1…6 DCs. Finally, a sensitivity analysis is conducted to study how the large population of Umeå or Vaasa should be increased in order to make the top five in the Nordic level.

The results show distribution centers could be formed in the case of population driven demand products. This also gives insight into how the results can vary when changing perspective from national analysis to Nordic level.

Keywords
Facility location, Geographical Information System (GIS), Logistics, Location – allocation, Service area creation, Transportation optimization

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support received for the Botnia Atlantica BA3NET project from the Interreg European Regional Development Fund, Österbottens förbund, Vasa stad, Kvarkenrådet, Trafikverket Sverige och Region Nord, Föreningen Blå vägen, Nordland Fylkeskommune, Statens vegvesen, Jernbanedirektoratet, and Midtskandia.

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1 INTRODUCTION

Companies make daily decisions concerning logistics operations which have effects on how supply chains form and through which routes components flow to manufacturers and how products flow to customers. Logistics is a type of service operations combination such as shipping, warehousing, forwarding and information processing. Supply chains form networks of logistic service providers and customers downstream of the chain.

Decisions on logistical facility location can make a significant impact on the success or failure of a firm. A company can achieve competitive advantage by increasing service value per cost ratio. Therefore, logistical challenges such as network and transportation decisions, facility location decisions, logistics planning, forecasting decisions and inventory decisions have been extensively studied to generate improved methodologies. Optimal operations, automated decision support and breakthrough technological inventions are three solutions which researchers have been developing for logistics problems. Mathematical modelling is used for optimized decision making in areas such as supply chain design, inventory and material management and transportation. Advanced technologies have been developed to facilitate real-time communication and operations such as radio frequency identification, global positioning systems and electronic data exchange; advanced planning can be introduced as an instance of automated decision support systems (Khaled & Kim, 2012).

The choice of facility location plays an important role in the success or failure of logistics operations. Utilizing the geographical information system can be considered a practical approach which integrates spatial information into facility location decision making. Furthermore, the increased power of computation and number of commercially available GIS software contribute to assessing logistical location decisions through geographical information.

In this paper, determining distribution center location is performed based on the population of Nordic countries. The purpose of the analysis is to study a hypothetical scenario where customer location presents an important input for final delivery. By using the optimization technique, potential locations for distribution centers are analyzed. The idea is to analyze how the optimized locations and increasing numbers of distribution centers affect the delivery time. Scenarios for Norway, Sweden and Finland are analyzed separately and as a combined Nordic scenario.

2 LITERATURE REVIEW – GEOGRAPHICAL INFORMATION SYSTEM AND LOGISTICS

The problem of logistics distribution center location comprises determining distribution centers in order to minimize the transportation cost. Various algorithms have been developed to resolve the problem, which can be categorized into qualitative and quantitative methods. Qualitative approaches consist of expert selection, comparative analysis, fuzzy evaluation and analytic hierarchy process. These methods can partially resolve the problem, but they are subjective in terms of some factors (Esnaf & Küçükdeniz, 2009; Tu, Chang, Chen & Lu, 2010).

Quantitative methods include gravity methods, and mixed integer and Bi-level programming. When the problem size increases, it is more challenging to solve the problem by quantitative methods due to the NP-hard structure (Manzini, Gamberi & Regatierri, 2006; Wang, Yao & Huang, 2007; Zhou, Peng & Wang, 2013).

Heuristic optimizations such as genetic and Tabu algorithms are extensively utilized to solve complex optimization problems. Hua, Hu & Yuan (2016) applied adaptive particle swarm optimization (PSO) algorithms for a logistics distribution center location problem.

Huang, Menezes & Kim (2012) conducted a research study on how to locate distribution centers based on the price variability of suppliers, and sourcing methods, Fixed Fraction and Free Switching, are used. Based on problem mathematical modelling, it was concluded that optimal locations are inclined toward suppliers offering lower average prices, and higher price variability shifts optimal locations toward gravity centers of demand.

In addition, geographical information system (GIS) based tools have been used in infrastructure planning for a long time, and increasingly by companies operating logistics operations. A geographical information system is a computer system which can capture, store, query, analyze and display geographically referenced information describing both location and attributes of spatial features on the earth's surface. GIS tools are robust and they have high capability in complicated phenomena visualization. There has been an increasing interest in using GIS for economic analyses and it has been applied initially for enhancing accuracy in trip cost and benefit transfers (Bateman, Jones, Lovett, Lake & Day, 2002; Chang, 2006).

In addition, the use of geographical information systems provides an opportunity for analyzing the heterogeneity of spatial elements which can be population densities, road networks and landscape features (Metters & Marucheck, 2007).

In social service organizations, applying GIS technology can contribute to comprehending their market scope, the location of their clients and how to allocate resources in a district to fulfill service demands (Davenhall & Kinabrew, 2011).

For decision making on shelters and emergency service locations in a metropolitan evacuation planning project studied by Esmaelian, Tavana, Santos Arteaga and Mohammadi (2015), a combination of geographical information systems (GIS) and the multi-criteria decision-making approach of Preference Ranking Organization Method for Enrichment Evaluation IV (PROMETHEE IV) was used. Three structural attributes such as population density, building age density, and durability density from open data sources are considered for determining areas vulnerable to earthquakes. In a research project, geographical information system tools and open data were applied to visualize and analyze the relationship between physical distance to hospitals and heart mortality degree (Yamashita & Kunkel, 2010).

Environmental human activities such as land use can influence the producing of goods and other services. In a study by Burkhard, Kroll, Nedkov and Müller (2012), land cover data such as remote sensing, land survey and GIS, with data from interviews, statistics, modelling, and observations are linked to evaluate ecosystem service supply and demand, and transferred to diverse spatial and temporal aspects. Furthermore, ecosystem service supply and demand and quantifying information behind maps are linked, and the research outcomes present patterns of human activities based on time and location.

Population data can play a significant role in service-oriented procedures. A research study was performed by Masters et al. (2013) on how to decrease neonatal and maternal mortality in Ghana, particularly in rural areas. Geospatial techniques were applied to evaluate travel times between populations and healthcare facilities, and population information was divided into 1 square kilometer cells, and then travel time to health facilities were calculated. A pilot study in social service planning utilizing GIS technologies was conducted by Leung, Pun-Cheng and Ho (2015), which demonstrates alternative approaches in locality service planning by analyzing population and location of service users of food assistance in Hong Kong.

3 METHOD

The purpose of this paper is to evaluate facility location by considering distances and travel time between facilities and demand points based on population location information. In detail, the research goals are:

1) Defining the most optimized location for 1 to 5 distribution centers in the following countries: Finland, Norway and Sweden.

2) Determining the most optimized location for 1 to 5 distribution centers in the Nordic level, including Norway, Finland, and Sweden.

3) Generating different travel time zones based on selected facility locations in both the Nordic level and each country layer.

The first step is to model the population information as demands points. In a research project, Rouzafzoon & Helo (2016) simulated the population density by uploading open data from an official Finland statistical website. The population information is available on different scales such as the number of people in each 1 square km, 5 square km and the municipality level. In this paper, population dataset on the scale of municipality level (LAU 2) is collected from each country's official statistical and population information website. Principally, data such as city name, area code, longitude, latitude and population number are used for uploading to GIS software.

The next step includes calculating distances between the uploaded points based on existing roads. The majority of facility location research projects have utilized open data sources, which are accessible public data for discovering patterns, resolving complicated problems and making data-driven decisions. For instance, logistics analyses can be performed by using OpenStreetMap (OSM) data source, which includes diverse information such as route types, speed limits, route directions and distance.

In addition, the degree of detailed information which can be obtained from solutions depends on the level of detailed data that exists in population and road datasets. Therefore, at the Nordic level analysis, sea routes between the countries are created and included in the optimization process.

Table 1. Population and road dataset information

Country	Year of Data	Population Dataset Source	Road Dataset Source
Finland	2016	Official Statistics of Finland	Digiroad, OSM
Sweden	2016	Official Statistics of Sweden	OSM
Norway	2017	Statistics Norway	Kartaverket, OSM
Denmark	2018	Statistics Denmark	OSM

For choosing the most optimized distribution locations, demand points and potential distribution location should be uploaded to the software. There are various solution finding settings for location-allocation problems such as Minimize impedance, Maximize coverage, Maximize capacitated coverage, Minimize facilities, Maximize attendance, Maximize market share, and Target market share.

In this study, minimize impedance setting is chosen, which minimizes the sum of all weighted costs between demand points and facility locations. The impedance type can be chosen for location-allocation problem-solving. If the impedance is determined as distance, the shortest route between demand points and facilities is considered for the analysis. If the chosen impedance is time, then the location-allocation problem is solved based on the quickest route. In this research, minimize impedance reduces the overall distance that people travel to reach the selected distribution center. In addition, the number of people living in each point is considered as the demand point weight, and the Impedance Cutoff parameter which excludes demands outside all facilities impedance cutoff, is not applied in the research study.

During the resolving procedure, an origin-destination matrix of shortest-path cost between facilities and demand points is generated based on the road network. The solver creates a modified version of the matrix by a process called Hillsman editing. Then the location-allocation solver creates a set of semi-randomized solutions and applies a vertex substitution heuristic (Teitz & Bart) to refine solutions by generating a set of good solutions. A metaheuristic then merges these groups of solutions to create improved solutions. The metaheuristic approach returns the best solution when no further improvement is possible. The combination of these approaches provides near-optimal results.

The location-allocation problem is a combinatorial optimization problem type and the number of possible solutions increases quickly. Therefore, exhaustive search techniques are unfeasible for reaching optimized solutions within rational search times. Hence, heuristic methods are applied for quicker searches.

In this study, travel time zones or service area creation are implemented. A service area is a region around any defined location where all streets are accessible within the specified impedance. For instance, a 1-hour service area for a distribution center includes all streets which can be reached within 1 hour from the distribution center. In addition, the service area impedance parameter can be set as distance or travel time from a facility.

When optimized facility locations are selected by solving the location-allocation problem, they can be used for creating travel time zones. Parameters such as impedance, direction (away, from or toward the facility), allowed or not allowed U-turn at junctions, and restrictions such as one-way roads can be defined in the setting. Furthermore, there are merging polygons options such as Overlapping, Not overlapping, and Merge by break value for service area creation with multiple distribution centers.

The service area solver employs Dijkstra's algorithm to traverse the network. The solver purpose is to retrieve a subgroup of linked edge features in a way that they are situated within the network distance or cost cutoff. The service area solver can create lines, polygons around lines, or both features.

The classic Dijkstra's algorithm returns the shortest path from a starting point **s** to a destination location **d**, by maintaining a set of junctions, **S,** whose final shortest path from **s** has already been computed. The algorithm continuously finds a junction in the group of junctions that has the minimum shortest-path estimate, adds it to set of junctions **S** , and updates the shortest path calculation of all those adjacent of this junction that are not in **S**. The algorithm repeatedly processes the junctions until the destination junction is added to **S**.

4 RESULTS

The solution can be obtained for a location-allocation problem through the software after generating the location-allocation analysis layer, determining the required network analysis objects and defining appropriate analysis properties.

Once the solving process is completed, if the output shape type property is determined as straight lines, the location-allocation solver creates lines which connect the solution distribution centers to their allocated demand points. In addition, it sets the facility type property of a Candidate facility to Chosen if it is part of the solution, but in the figures below, only chosen facilities are displayed.

After solving a location-allocation is accomplished, the result can be examined by checking at the properties of facilities, demand points and lines. In addition, studying all demand points assigned to a distribution center can be performed by setting facility ID equal to the interested facility ID. As can be observed in the tables below, facility location and allocated demand numbers are retrieved from facility properties.

The location-allocation problem solutions and generated service areas are presented in Figures 1 to 25. After defining the optimized solutions for the location-allocation problem by the software solver, the results are used for generating service areas. For service area creation, impedances are chosen based on the travel time with hourly units, the direction is set “Away from facility”, U-turn at junctions is allowed, and one-way road restrictions are applied.

4.1 Finland

Table 2. Finland 1 DC Information

Location	Allocated Demand
Häme	5,416,797

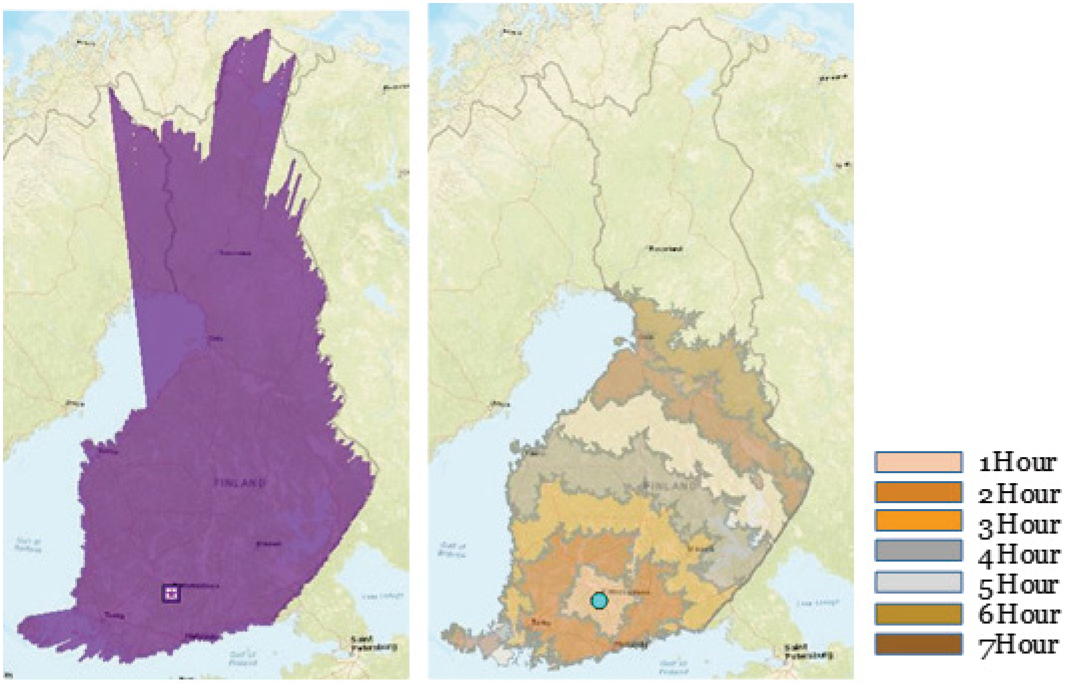

Figure 1. Finland 1 DC location and service areas

Table 3. Finland 2 DC Information

Location	**Allocated Demand**
Helsinki	3,993,520
Oulu	1,423,277

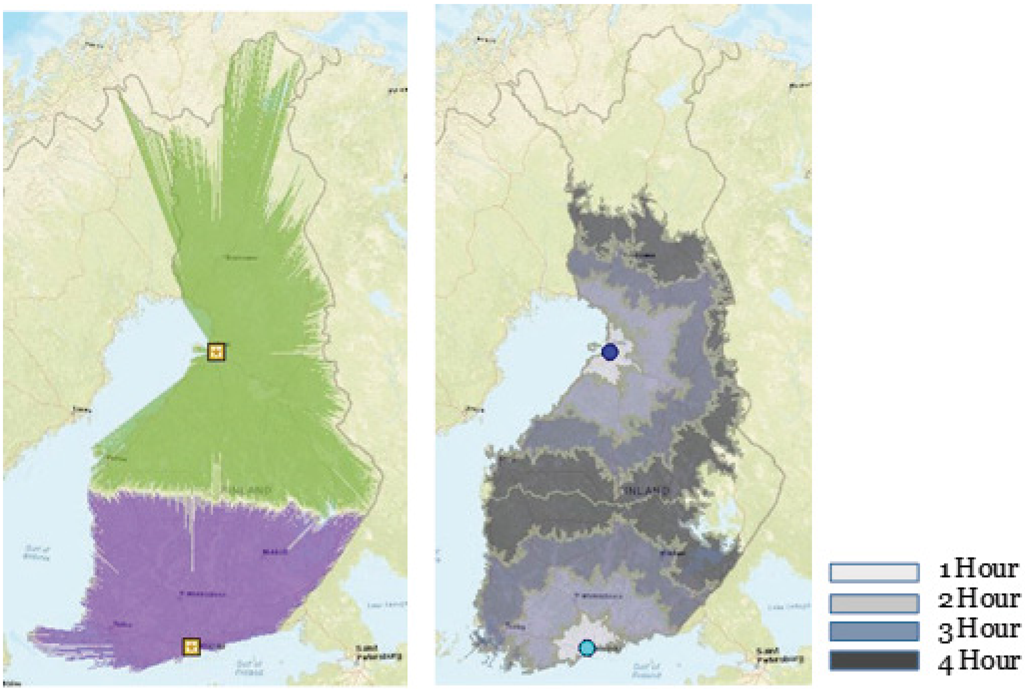

Figure 2. Finland 2 DC location and service areas

Table 4. Finland 3 DC Information

Location	Allocated Demand
Helsinki	2,401,678
Oulu	1,101,048
Tampere	1,914,071

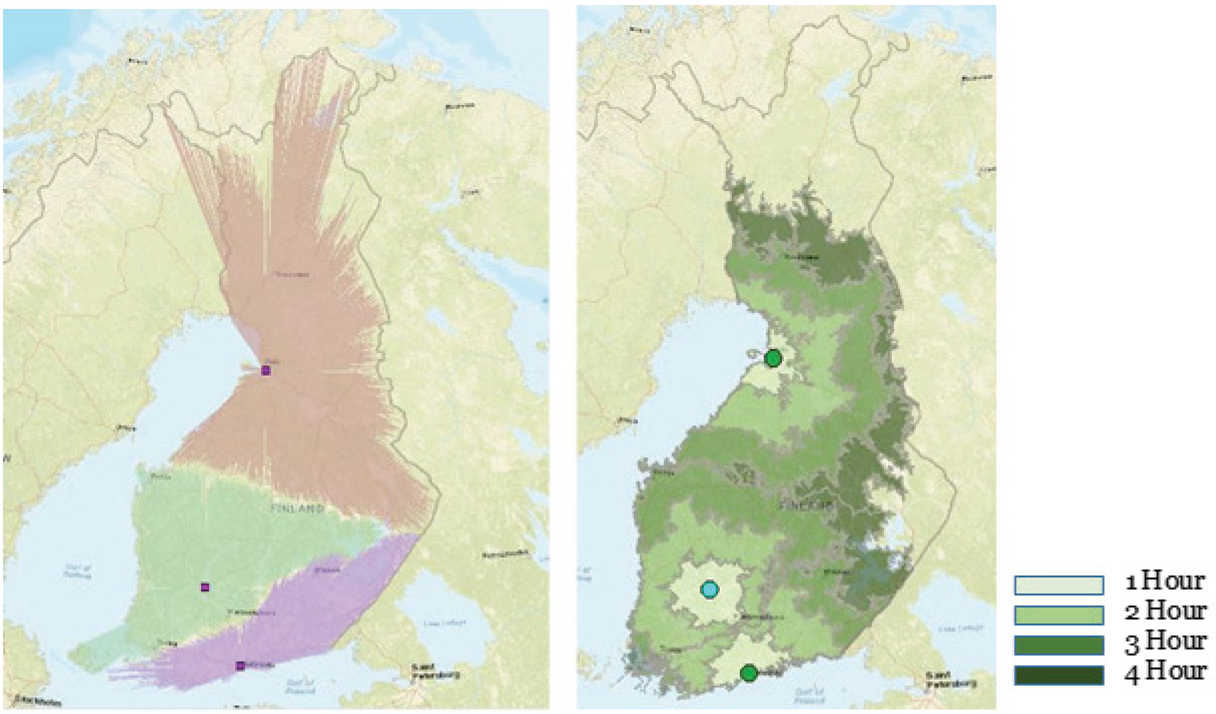

Figure 3. Finland 3 DC location and service areas

Table 5. Finland 4 DC Information

Location	Allocated Demand
Helsinki	2,239,028
Oulu	748,918
Tampere	1,620,633
Kuopio	808,218

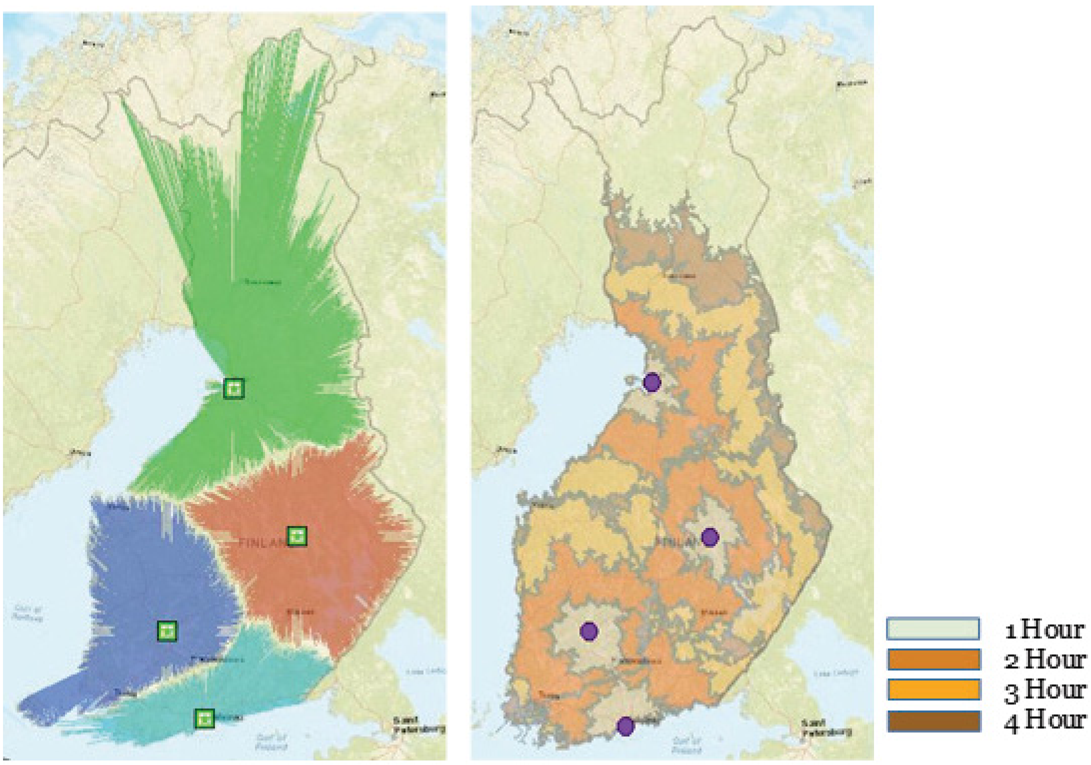

Figure 4. Finland 4 DC location and service areas

Table 6. Finland 5 DC Information

Location	Allocated Demand
Helsinki	2,119,991
Oulu	748,918
Tampere	1,155,869
Kuopio	808,218
Turku	583,801

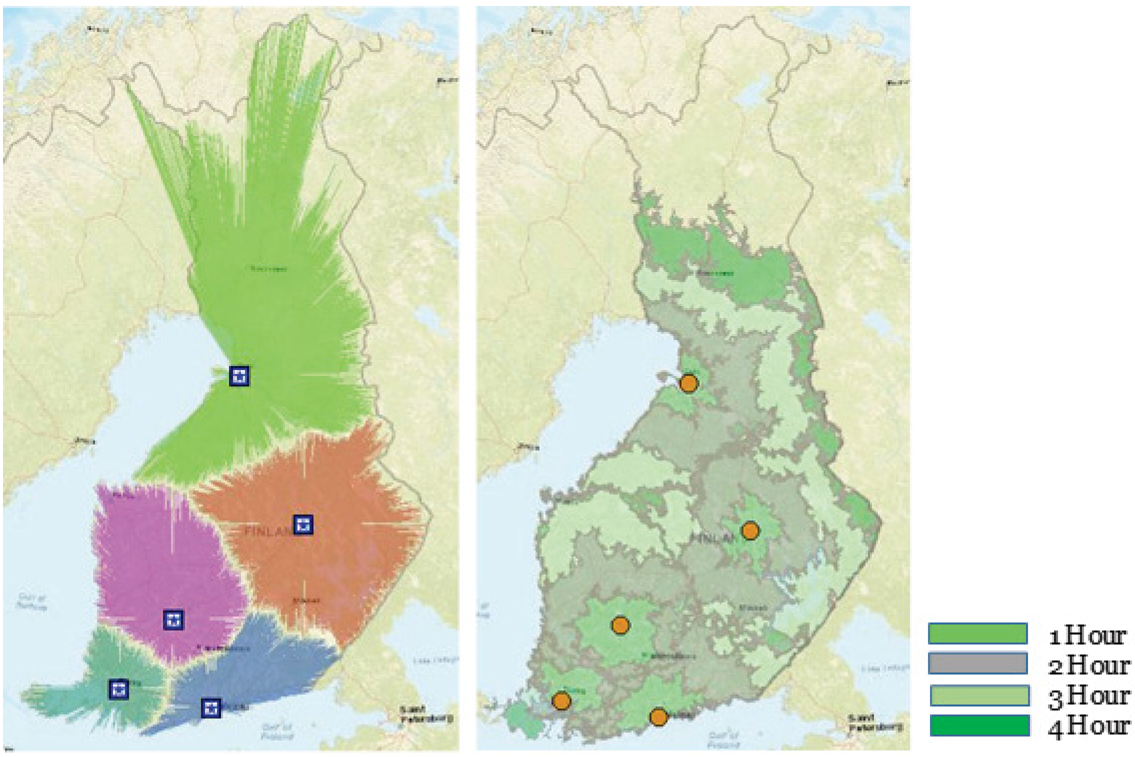

Figure 5. Finland 5 DC locations and service areas

4.2 Sweden

Table 7. Sweden 1 DC Information

Location	Allocated Demand
Kumla	9,995,153

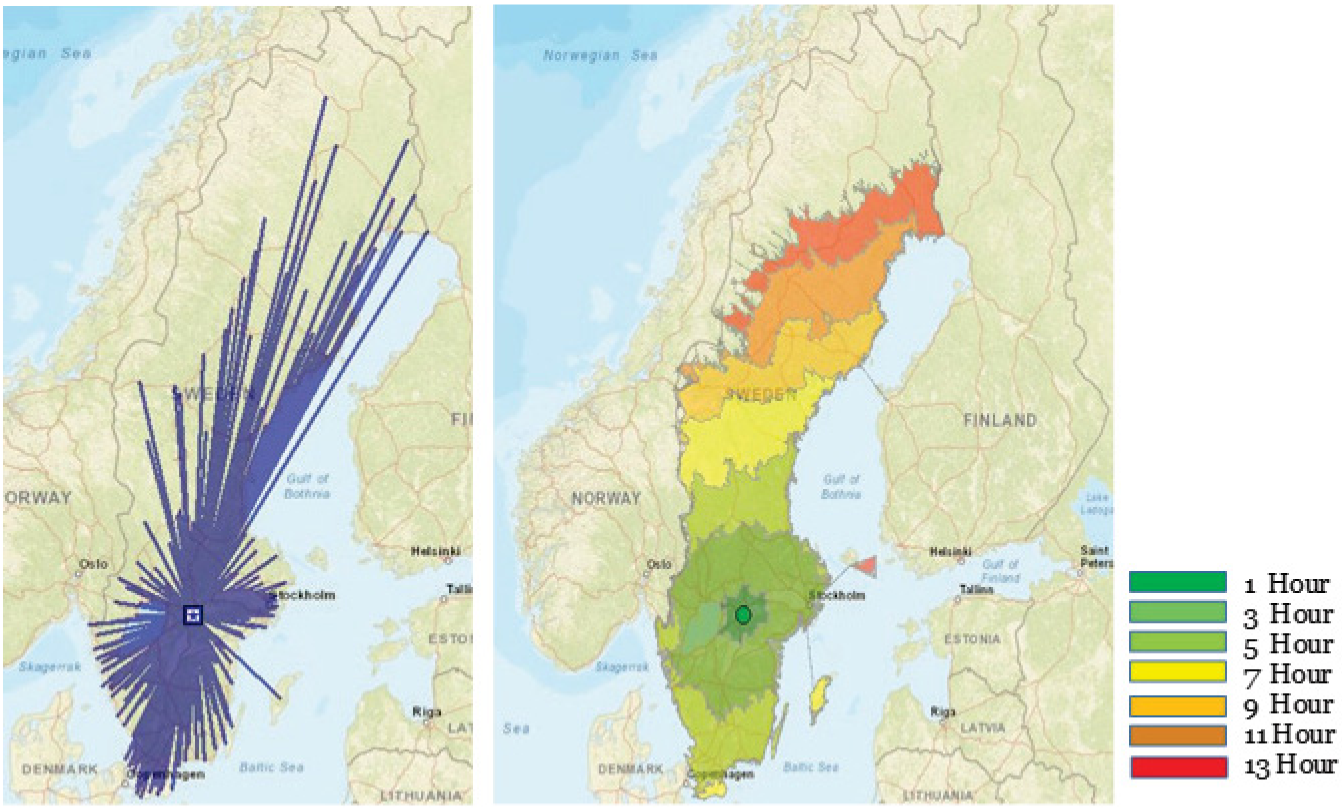

Figure 6. Sweden 1 DC location and service areas

Table 8. Sweden 2 DC Information

Location	Allocated Demand
Sollentuna	5,724,778
Halmstad	4,270,375

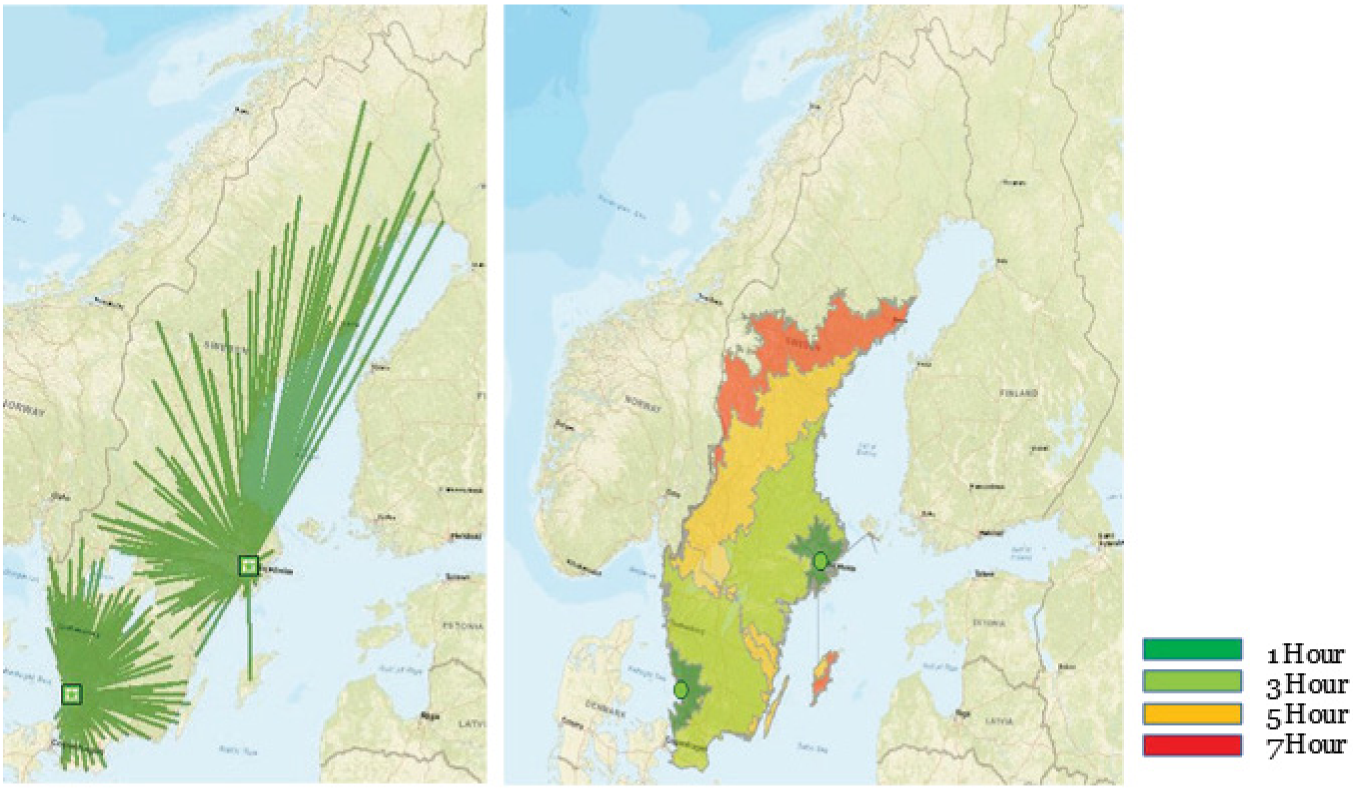

Figure 7. Sweden 2 DC locations and service areas

Table 9. Sweden 3 DC Information

Location	Allocated Demand
Umeå	893,126
Stockholm	4,844,373
Halmstad	4,257,654

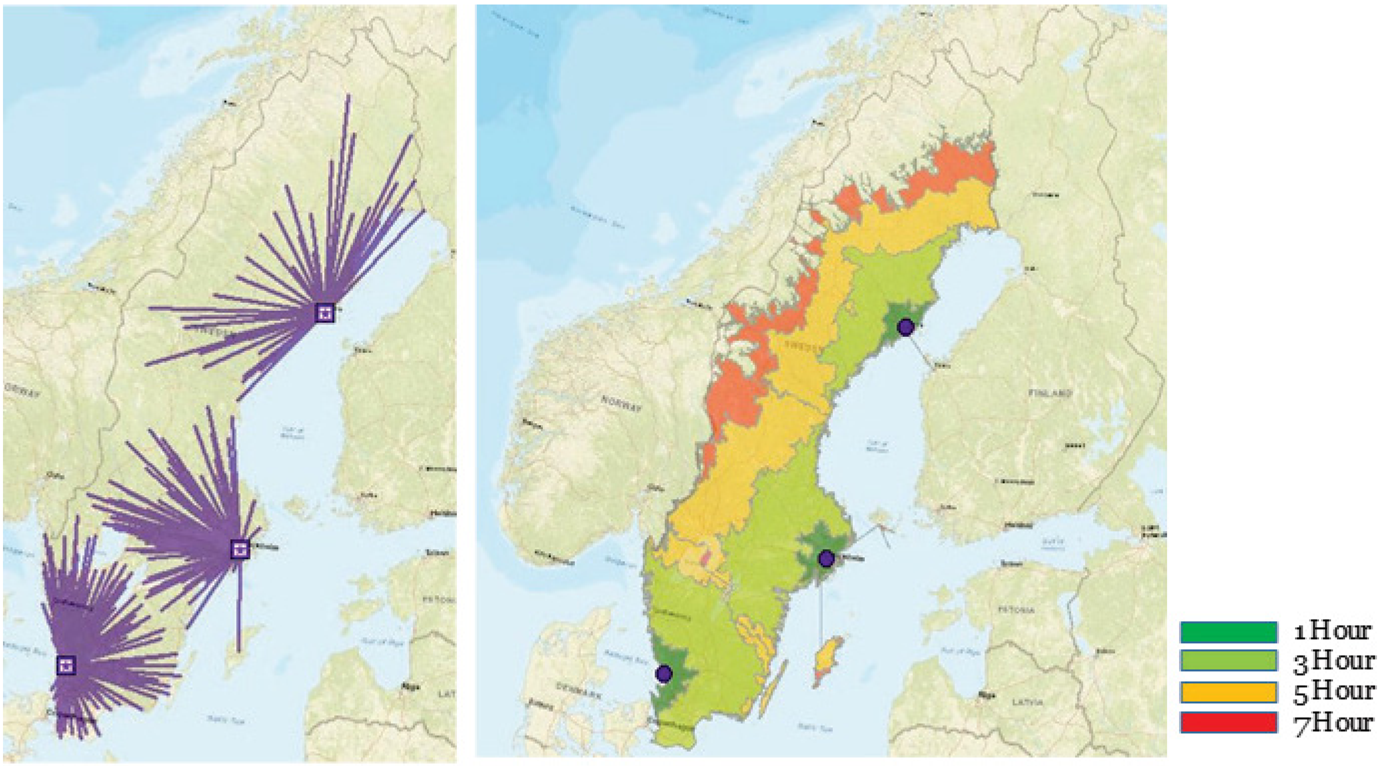

Figure 8. Sweden 3 DC locations and service areas

Table 10. Sweden 4 DC Information

Location	Allocated Demand
Umeå	893,126
Göteborg	2,541,352
Stockholm	4,584,207
Eslöv	1,976,468

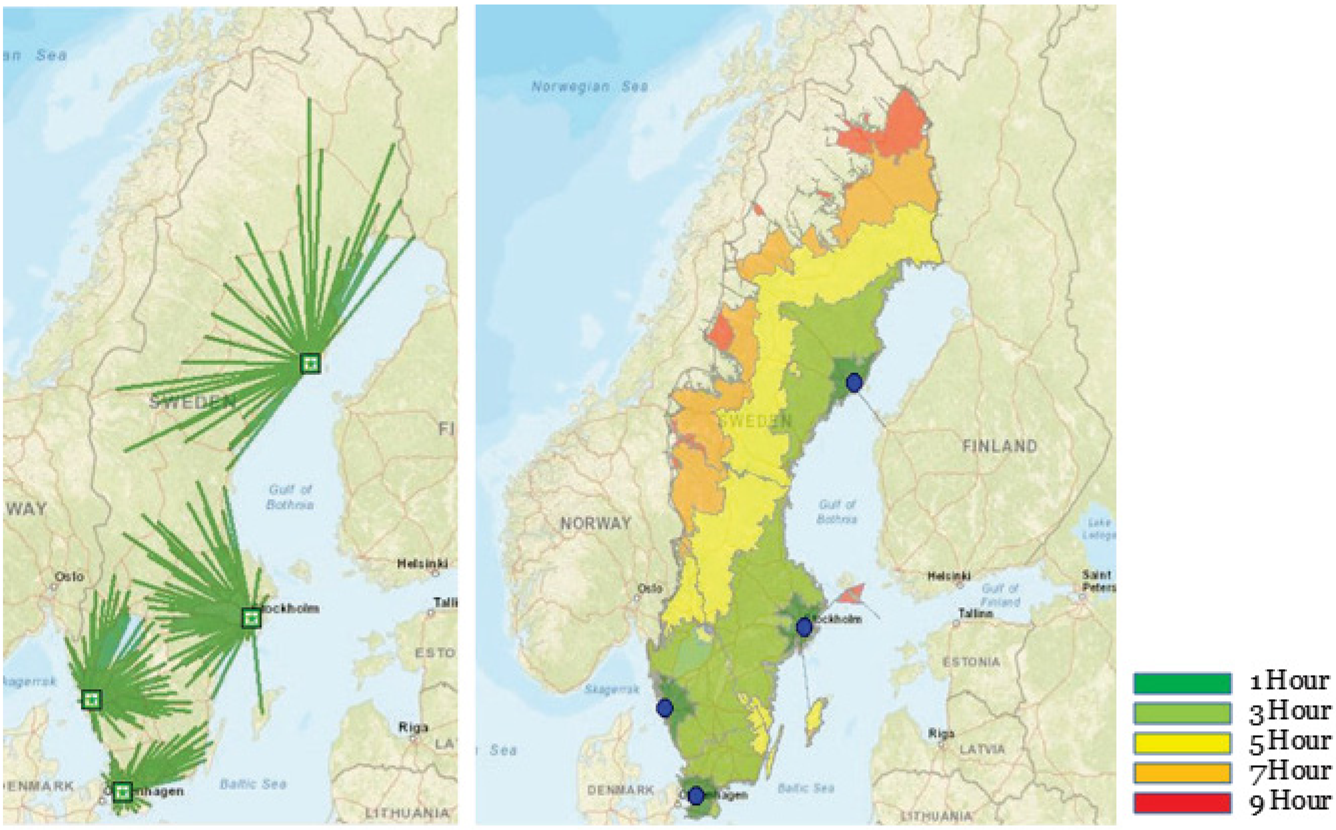

Figure 9. Sweden 4 DC locations and service areas

Table 11. Sweden 5 DC Information

Location	Allocated Demand
Umeå	882,926
Örebro	2,010,478
Göteborg	2,062,856
Stockholm	3,089,431
Eslöv	1,949,462

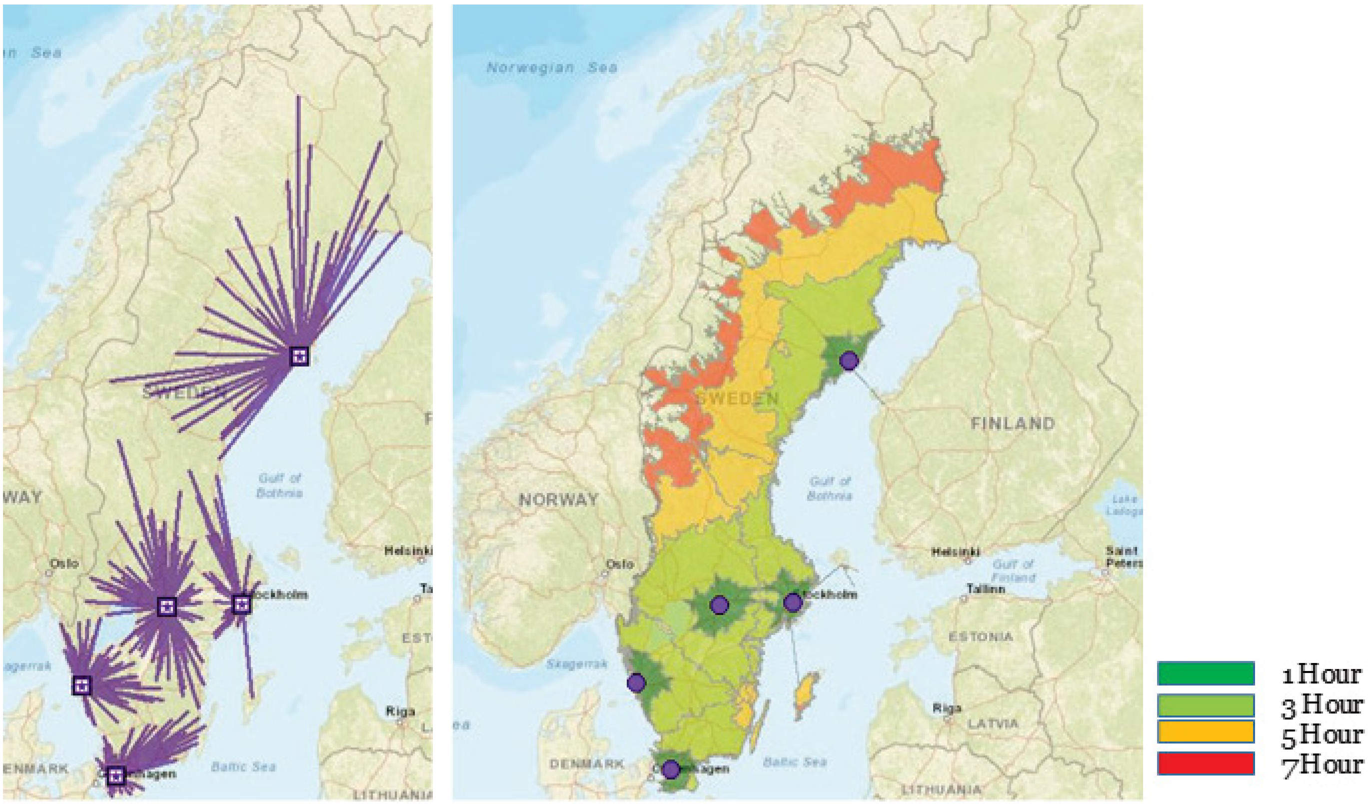

Figure 10. Sweden 5 DC locations and service areas

4.3 Norway

Table 12. Norway 1 DC Information

Location	Allocated Demand
Oslo municipality	5,250,747

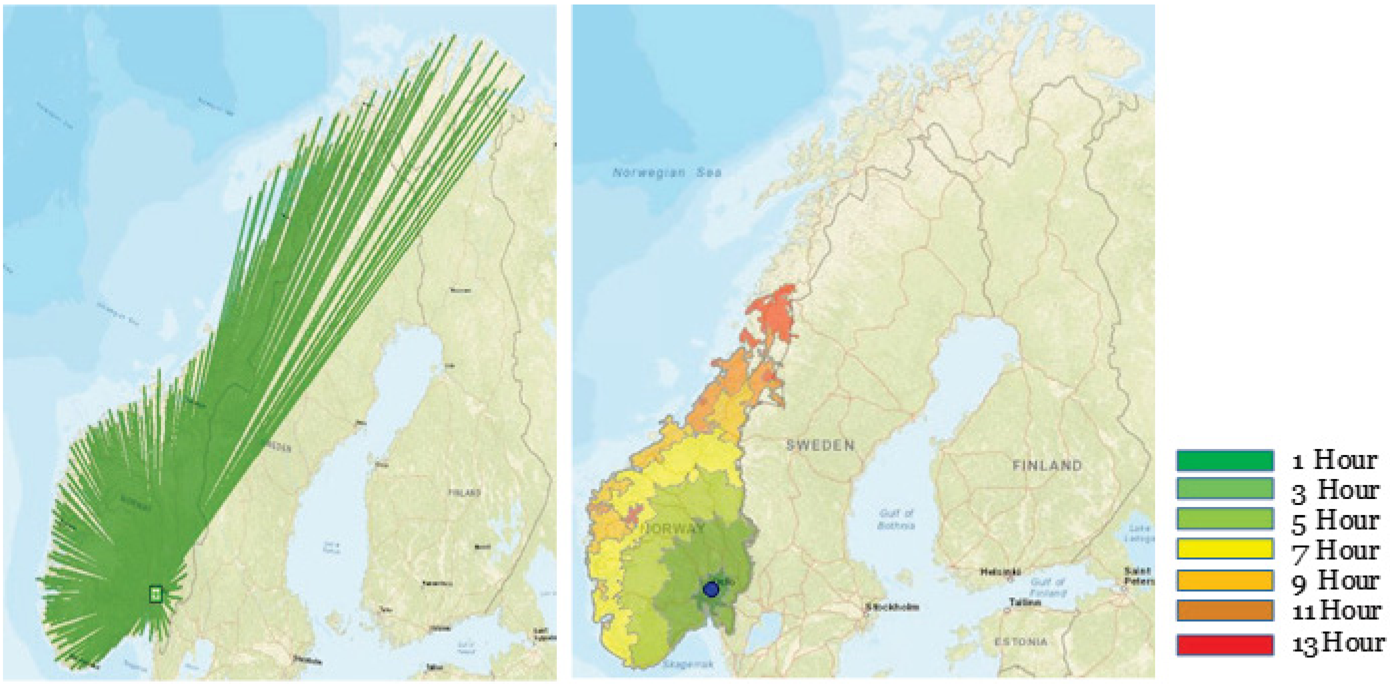

Figure 11. Norway 1 DC locations and service areas

Table 13. Norway 2 DC Information

Location	Allocated Demand
Lødingen	492,182
Oslo municipality	4,758,565

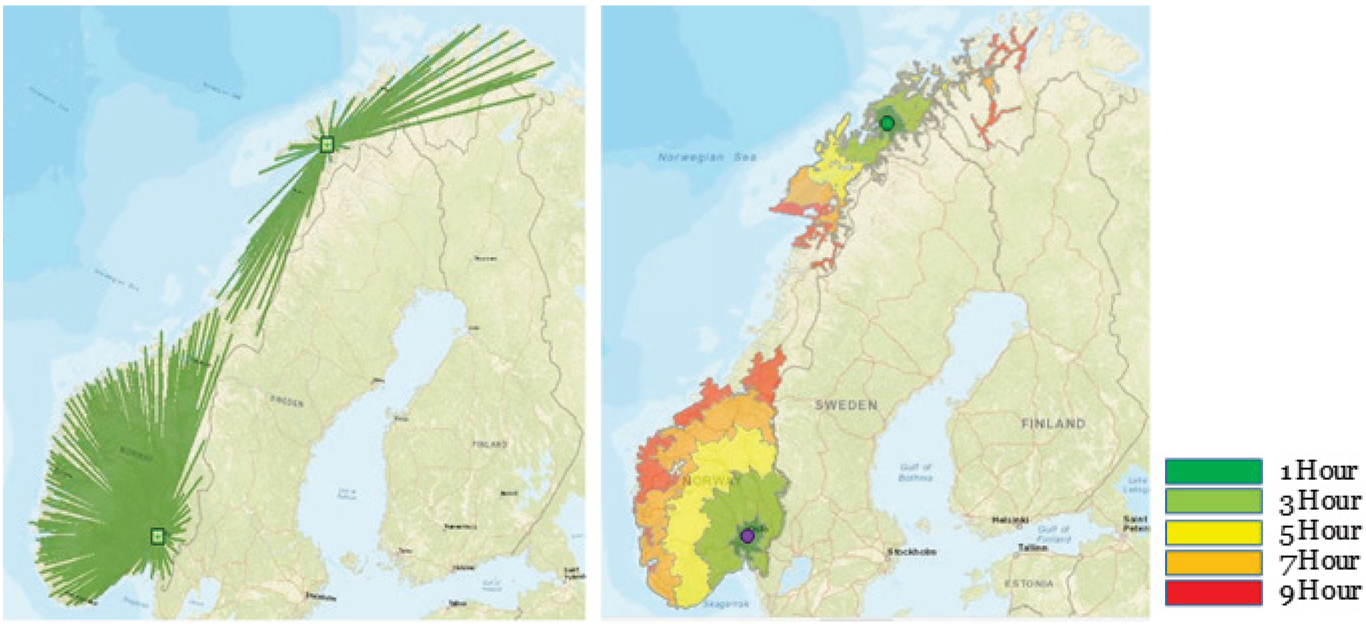

Figure 12. Norway 2 DC locations and service areas

Table 14. Norway 3 DC Information

Location	Allocated Demand
Lødingen	492,182
Bergen	1,354,516
Oslo municipality	3,404,049

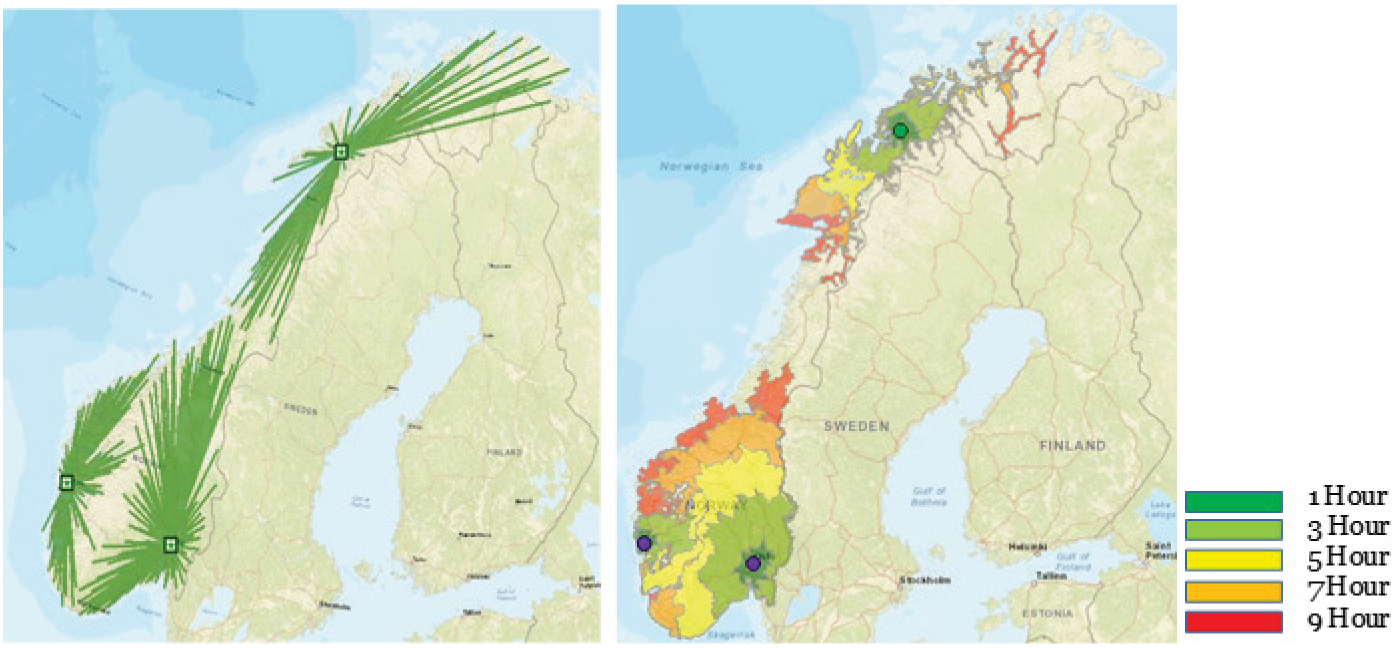

Figure 13. Norway 3 DC locations and service areas

Table 15. Norway 4 DC Information

Location	Allocated Demand
Sørreisa	397,035
Stord	1,133,336
Trondheim	839,978
Oslo municipality	2,880,398

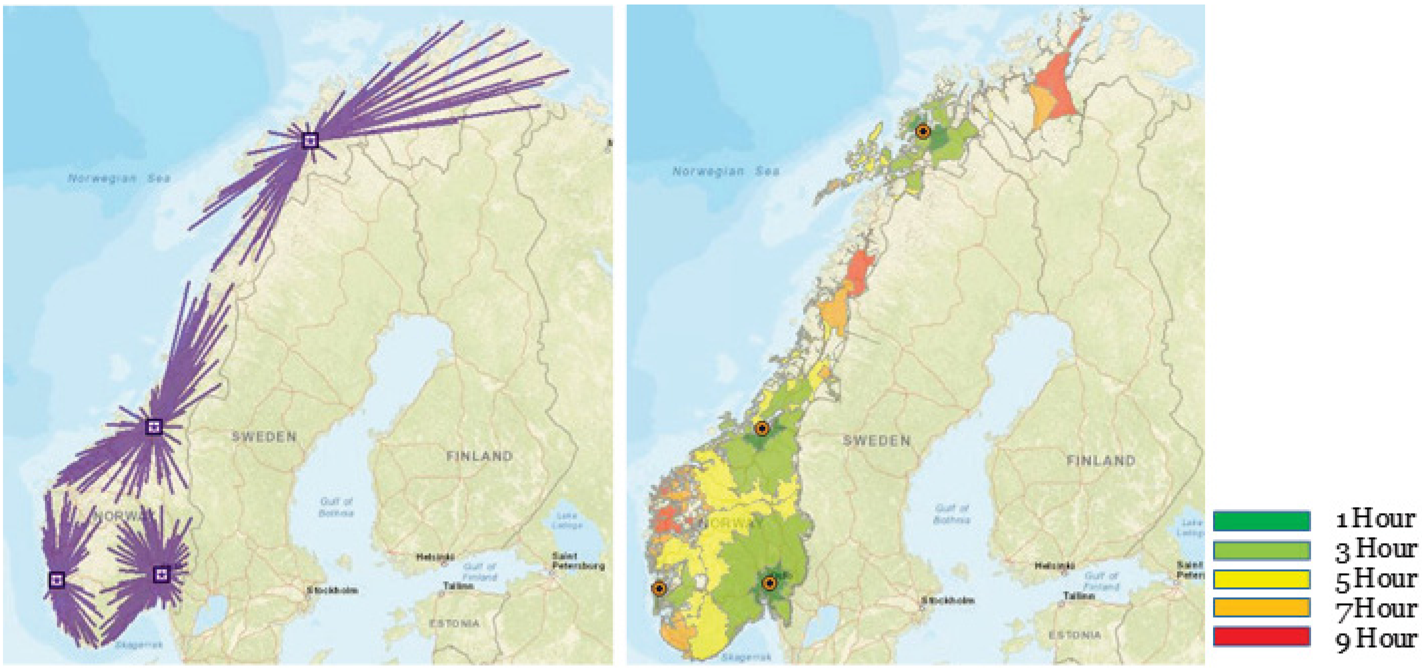

Figure 14. Norway 4 DC locations and service areas

Table 16. Norway 5 DC Information

Location	Allocated Demand
Sørreisa	397,035
Trondheim	805,722
Bergen	624,795
Sandnes	710,135
Oslo municipality	2,713,060

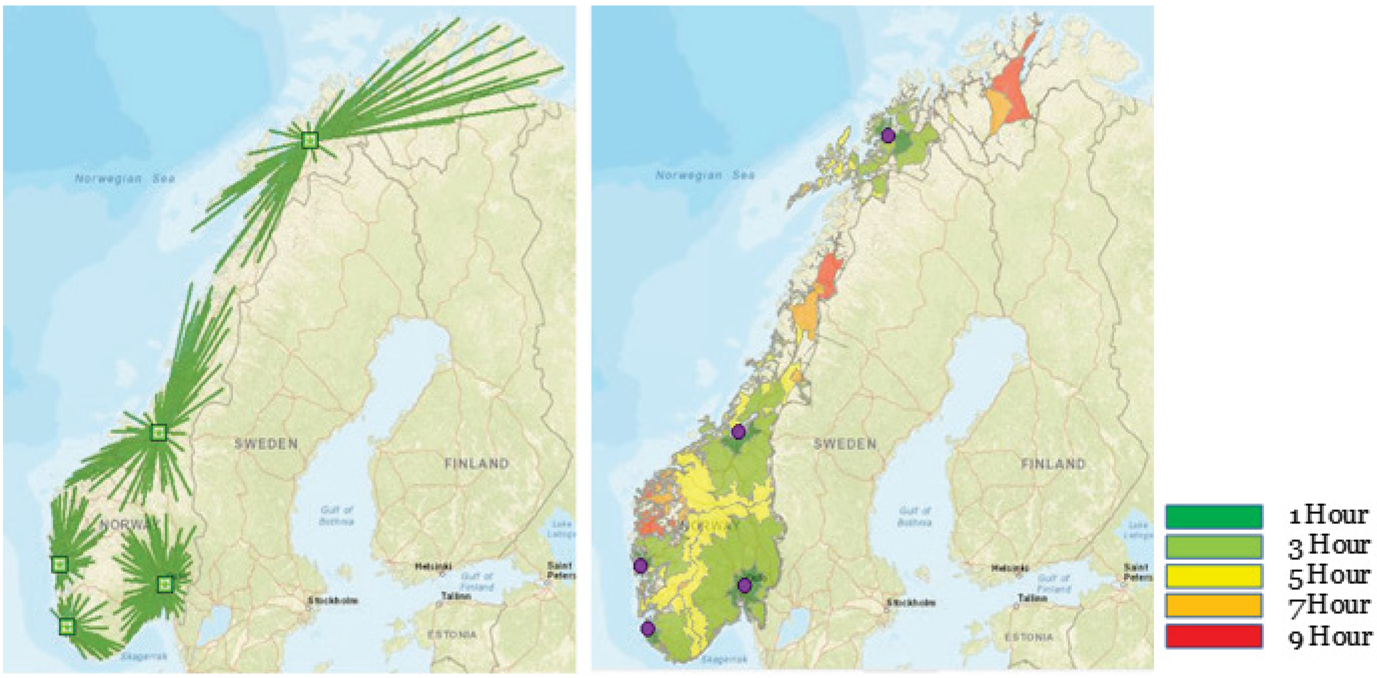

Figure 15. Norway 5 DC locations and service areas

4.4 Distributions centers in the Nordic level

Table 17. Nordic level 1 DC Information

Location	**Allocated Demand**
Kungsör, SE	20,748,698

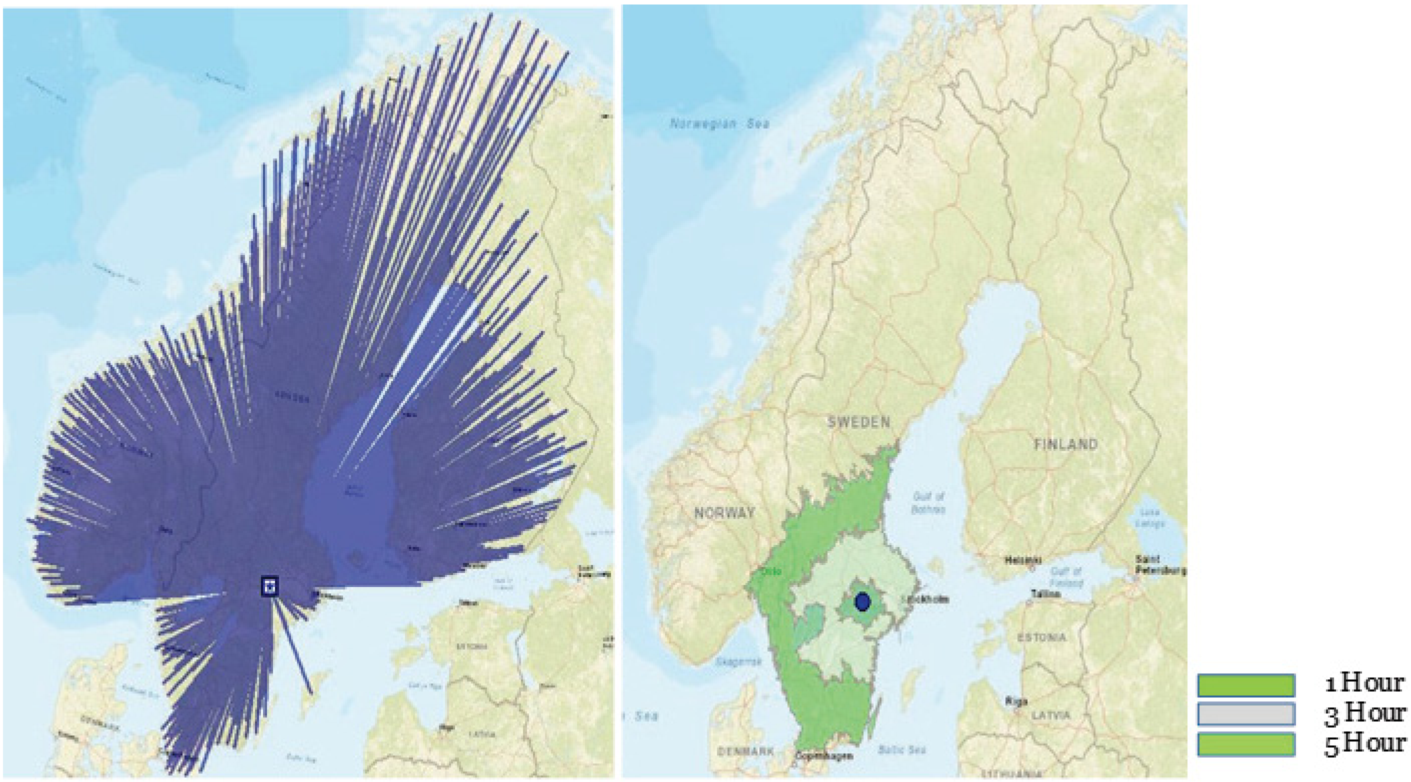

Figure 16. Nordic level 1 DC location and service areas

Table 18. Nordic level 2 DC Information

Location	Allocated Demand
Kangasala, FI	6,095,059
Kristinehamn, SE	14,653,639

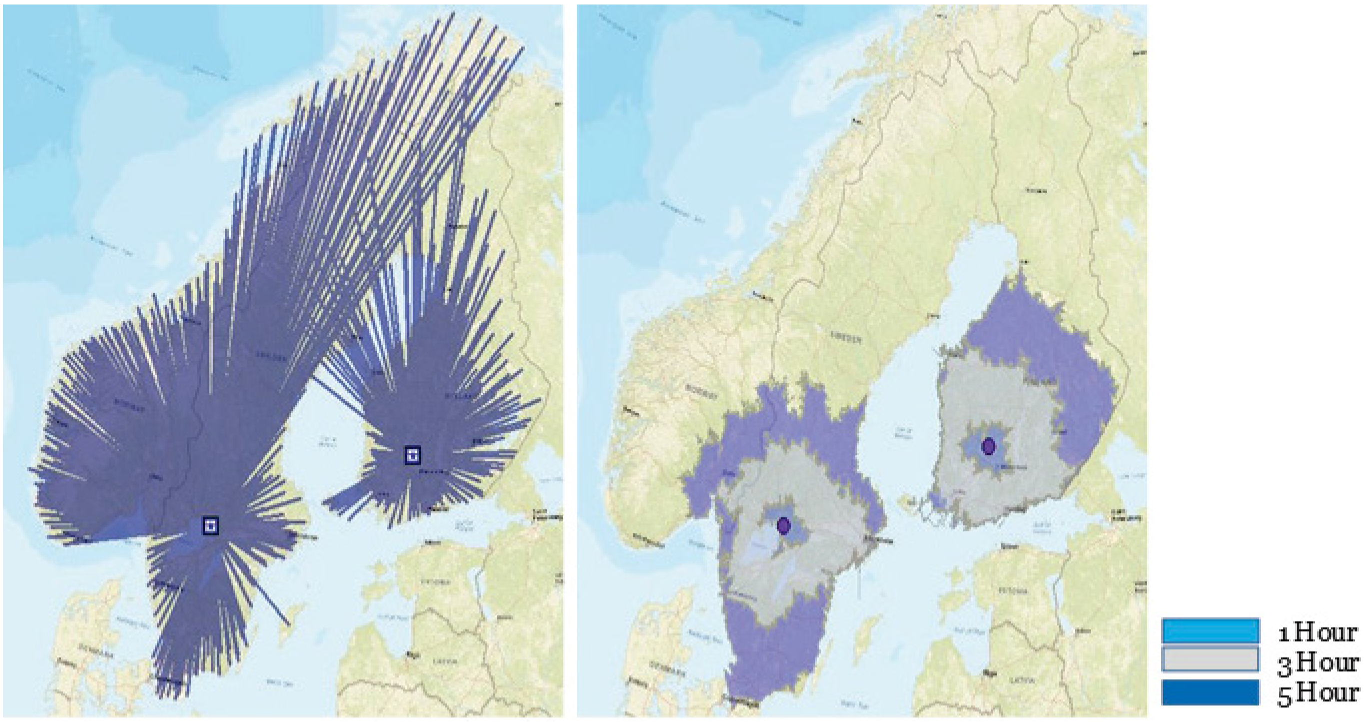

Figure 17. Nordic level 2 DC location and service areas

Table 19. Nordic level 3 DC Information

Location	Allocated Demand
Katrineholm, SE	8,009,153
Kangasala, FI	6,050,631
Oslo, NO	6,688,914

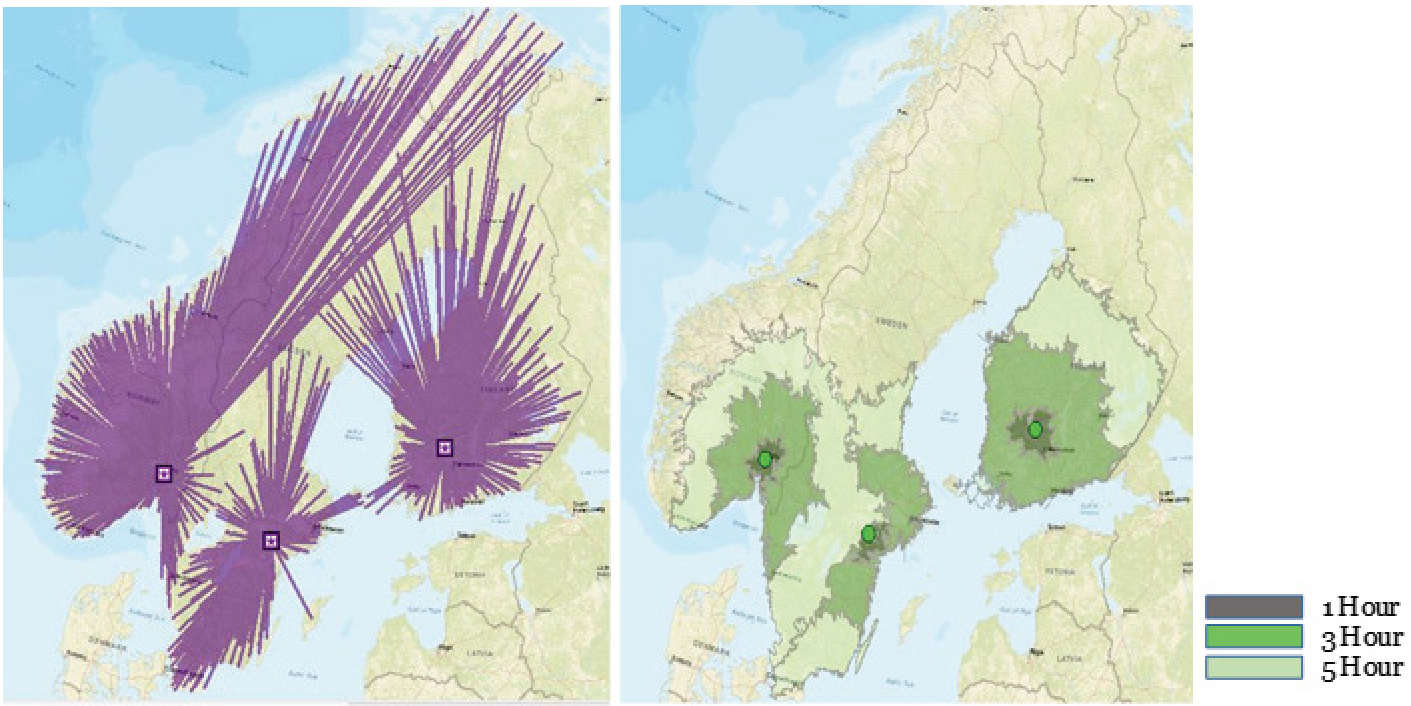

Figure 18. Nordic level 3 DC location and service areas

Table 20. Nordic level 4 DC Information

Location	Allocated Demand
Stockholm, SE	4,897,706
Kangasala, FI	6,048,981
Oslo, NO	5,673,097
Halmstad, SE	4,128,914

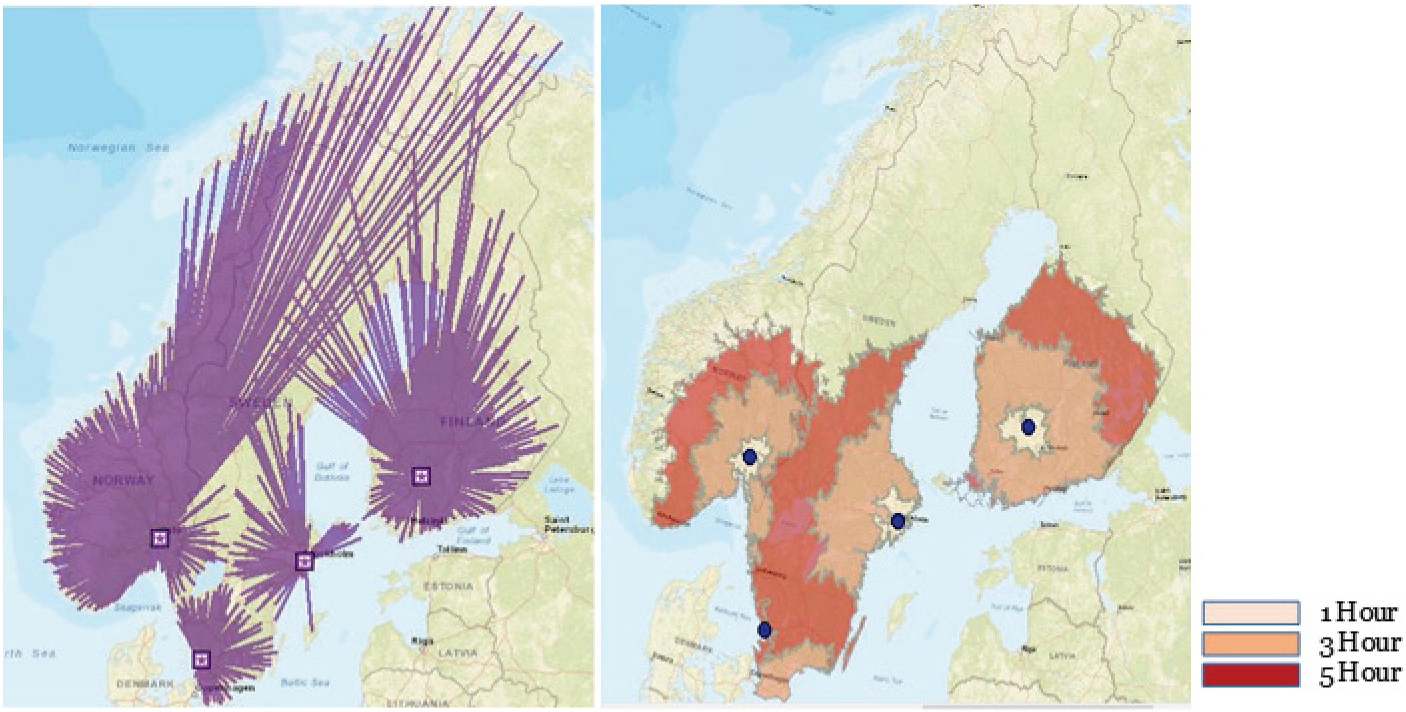

Figure 19. Nordic level 4 DC location and service areas

Table 21. Nordic level 5 DC Information

Location	Allocated Demand
Stockholm, SE	4,747,991
Hämeenlinna,FI	5,858,537
Oslo, NO	4,456,798
Halmstad, SE	4,128,914
Steinkjer, NO	1,556,458

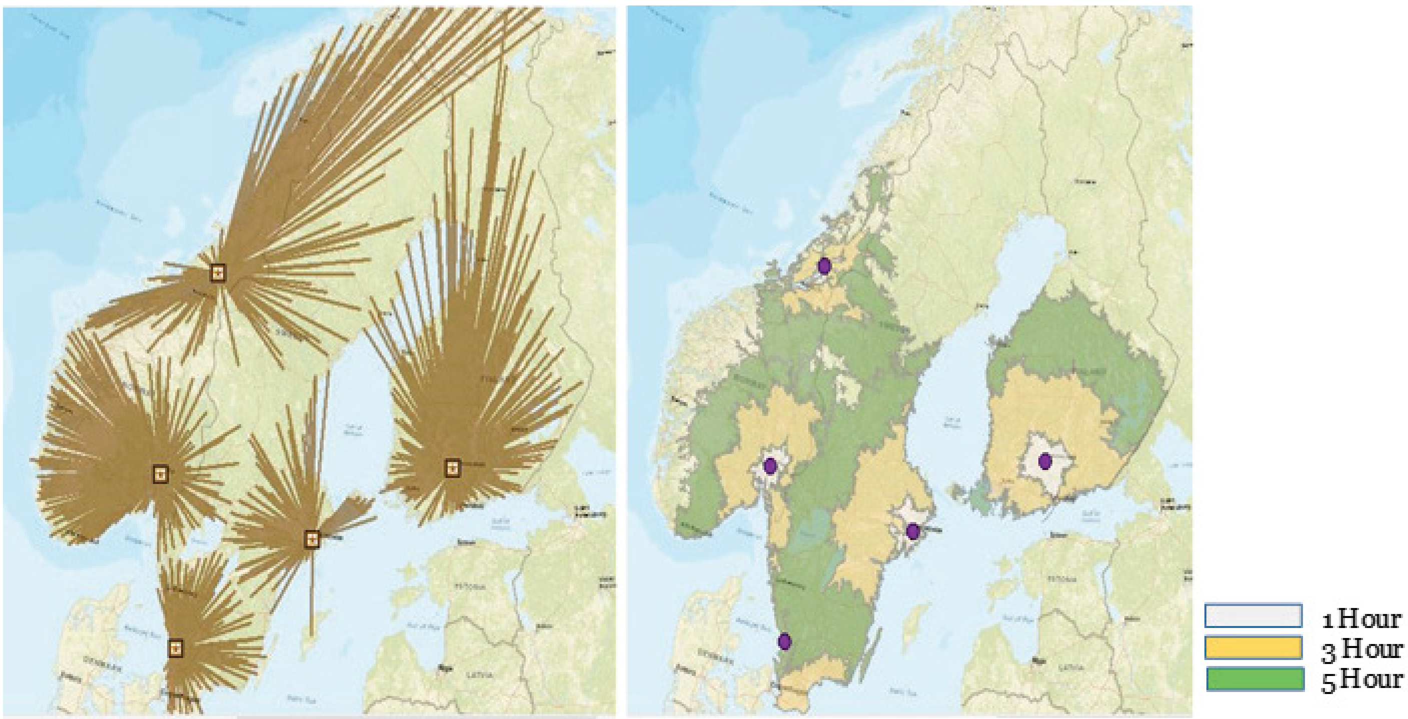

Figure 20. Nordic level 5 DC location and service areas

4.5 Distribution centers in the Nordic level including Denmark

In this scenario, Denmark is added to the optimization of distribution center locations. Additionally, demand nodes of over 10000 population are only considered in this analysis.

Table 22. Nordic Level with Denmark 1 DC information

Location	Allocated Demand
Jönköping, SE	23,925,374

Figure 21. Nordic Level with Denmark 1 DC location

Table 23. Nordic Level with Denmark 2 DC information

Location	Allocated Demand
Göteborg, SE	18,316,758
Tampere, FI	5,608,616

Figure 22. Nordic Level with Denmark 2 DC location

Table 24. Nordic Level with Denmark 3 DC Information

Location	Allocated Demand
Hämeenlinna , FI	5,043,784
Vallensbæk , DE	7,622,931
Kristinehamn , SE	11,258,659

Figure 23. Nordic Level with Denmark 3 DC location

Table 25. Nordic Level with Denmark 4 DC Information

Location	Allocated Demand
Hämeenlinna , FI	4,976,255
Stockholm , SE	5,004,766
Oslo municipality, NO	6,023,591
Vallensbæk , DE	7,920,762

Figure 24. Nordic Level with Denmark 4 DC location

Table 26. Nordic Level with Denmark 5 DC Information

Location	Allocated Demand
Hämeenlinna , FI	4,976,255
Stockholm , SE	4,765,284
Oslo municipality, NO	4,210,410
Göteborg, SE	4,154,322
Glostrup, DE	5,819,103

Figure 25. Nordic Level with Denmark 5 DC location

5 POPULATION SENSIVITY ANALYSIS

Scenario 1: How much population is required in Umeå and Vaasa to be considered as one of the top five distribution centers at the Nordic level?

The analysis is performed based on the population of the municipalities in Nordic countries. The number of inhabitants in Umeå municipality is approximately 120000. In order to define the required population, different scenarios based on the population size are generated. The following result is obtained by executing scenarios.

Table 27. Required population of Umeå at the Nordic level

Location	Population	Allocated Demand
Denmark Vallensbæk	16,280	7,484,400
Norway Sandefjord	62,019	6,106,579
Sweden Stockholm	935,619	4,635,718
Finland Tuusula	38,588	3,786,126
Sweden Umeå	500,000 – 1,000,000	2,912,551

Figure 26. Umeå as one of the top five DCs at the Nordic Level

Scenario 2: How big should the Umeå population be to be considered as one of the top five distribution centers in Finland and Sweden?

The analysis is conducted based on the population of the municipalities in Finland and Sweden. By executing various scenarios based on population size of Umeå, the following result is acquired.

Table 28. Required population of Umeå for Finland and Sweden scenario

Location	Population	Allocated Demand
Sweden, Stockholm	935,619	4,871,076
Sweden, Halmstad	98,538	4,257,654
Finland, Nurmijärvi	42,010	3,696,747
Finland, Kärsämäki	2,655	1,514,805
Sweden, Umeå	250,000 – 350,000	1,403,453

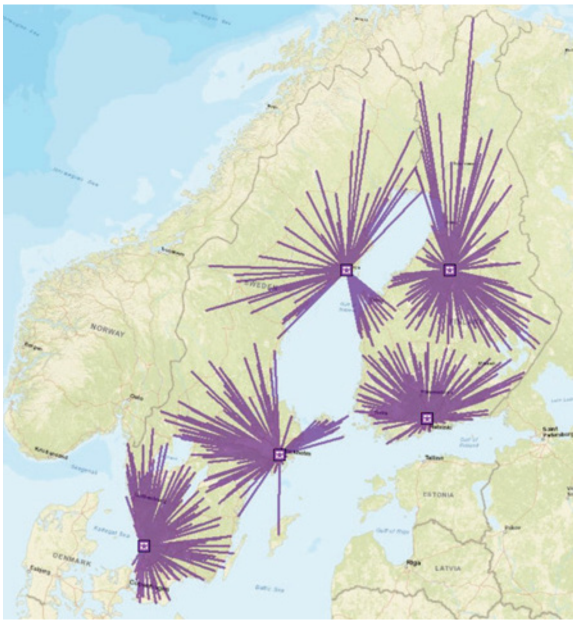

Figure 27. Umeå as one of the top five DCs in Finland and Sweden

Scenario 3: How much population is required in Vaasa to be considered as one of the top five distribution centers at the Nordic level?

The number of inhabitants in Vaasa municipality is approximately 65000. In order to define the required population, different scenarios based on the population size are generated. The following result is obtained by analyzing scenarios.

Table 29. Required population of Vaasa at the Nordic Level

Location	Population	Allocated Demand
Denmark Vallensbæk	16,280	7,547,039
Norway Rygge	15,747	6,123,576
Sweden Stockholm	935,619	4,624,648
Finland Tuusula	38,588	3,613,209
Finland Vaasa	1,000,000 – 1,500,000	3,516,902

Figure 28. Vaasa as one of the top five DCs at the Nordic Level

Scenario 4: How much population is required in Vaasa to be selected as one of the top five distribution centers in Finland?

The analysis is conducted based on the population of the municipalities in Finland. Different scenarios based on the Vaasa population size are created to determine the required population of Vaasa.

Table 30. Required Vaasa population as one of top five DCs in Finland

Location	Population	Allocated Demand
Helsinki	635,181	2,141,218
Huittinen	10,403	1,281,030
Pieksämäki	18,475	967,033
Oulu	200,526	675,125
Vaasa	170,000 – 200,000	573,632

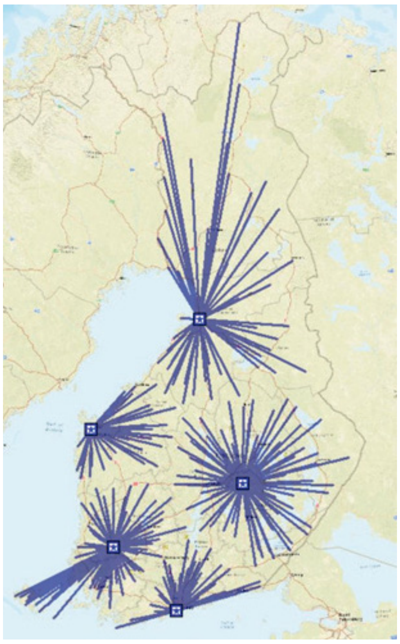

Figure 29. Vaasa as one of the top five DCs in Finland

Scenario 5: How much population is required in Mo i Rana to be selected as one of the top five distribution centers in Norway?

The population in Mo i Rana is approximately 26000. In order to find the required population number, different population levels for Mo I rana are experimented with and the following result is obtained.

Table 31. Required Mo i Rana population as one of top five DCs in Norway

Location	Population	Allocated Demand
Oslo municipality	666,759	2,880,398
Stord	18,821	1,133,336
Trondheim	190,464	763,347
Mo i Rana	226,000 – 326,000	462,100
Balsfjord	5,685	311,566

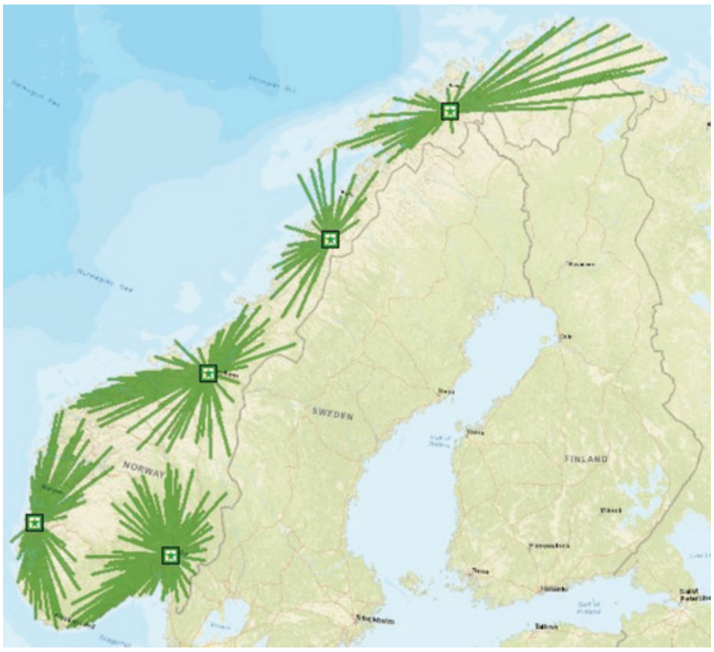

Figure 30. Mo i Rana as one of the top five DCs in Norway

Scenario 6: Does the location of the top five selected distribution centers in Sweden change if we are required to choose the top six, seven or eight distribution centers?

As can be observed from Figure 10 and Table 11, Umeå, Örebro, Göteborg, Stockholm and Eslöv are chosen as the top five DCs in Sweden. We experiment with scenarios ofsix, seven and eight distribution centers to discover whether the top five DCs still remain between the chosen locations. The results of the scenarios are presented in Tables 32, 33, and 34.

Table 32. Sweden top six DCs

Location	Population	Allocated Demand
Stockholm	935,619	3,089,431
Växjö	89,500	965,638
Lund	118,542	1,437,649
Göteborg	556,640	1,731,790
Örebro	146,631	1,887,719
Umeå	122,892	882,926

Table 33. Sweden top seven DCs

Location	Population	Allocated Demand
Stockholm	935,619	2,974,288
Växjö	89,500	965,638
Lund	118,542	1,437,649
Göteborg	556,640	1,731,790
Örebro	146,631	1,865,888
Sundsvall	98,325	506,168
Skellefteå	72,266	513,732

Table 34. Sweden top eight DCs

Location	Population	Allocated Demand
Stockholm	935,619	2,803,753
Växjö	89,500	965,638
Lund	118,542	1,437,649
Göteborg	556,640	1,731,790
Örebro	146,631	1,547,547
Falun	57,685	533,292
Sundsvall	98,325	461,752
Skellefteå	72,266	513,732

6 SUMMARY TABLES OF DISTRIBUTION CENTERS IN NORDIC COUNTRIES

Table 35. Finland distribution centers and allocated demands

Location	1 DC	2 DC	3 DC	4 DC	5 DC
Häme	5,416,797	-	-	-	-
Helsinki	-	3,993,520	2,401,678	2,239,028	2,119,991
Oulu	-	1,423,277	1,101,048	748,918	748,918
Tampere	-	-	1,914,071	1,620,633	1,155,869
Kuopio	-	-	-	808,218	808,218
Turku	-	-	-	-	583,801

Table 36. Sweden distribution centers and allocated demands

Location	1 DC	2 DC	3 DC	4 DC	5 DC
Kumla	9,995,153	-	-	-	-
Sollentuna	-	5,724,778	-	-	-
Halmstad	-	4,270,375	4,257,654	-	-
Umeå	-	-	893,126	893,126	882,926
Stockholm	-	-	4,844,373	4,584,207	3,089,431
Göteborg	-	-	-	2,541,352	2,062,856
Eslöv	-	-	-	1,976,468	1,949,462
Örebro	-	-	-	-	2,010,478

Table 37. Norway distribution centers and allocated demands

Location	1 DC	2 DC	3 DC	4 DC	5 DC
Oslo	5,250,747	4,758,565	3,404,049	2,880,398	2,713,060
Lødingen	-	492,182	492,182	-	-
Bergen	-	-	1,354,516	-	624,795
Sørreisa	-	-	-	397,035	397,035
Stord	-	-	-	1,133,336	-
Trondheim	-	-	-	839,978	805,722
Sandes	-	-	-	-	710,135

Table 38. Nordic countries distribution centers and allocated demands

Location	1 DC	2 DC	3 DC	4 DC	5 DC
Kungsör, SE	20,748,698	-	-	-	-
Kangasala , FI	-	6,095,059	6,050,631	6,048,981	-
Kristinehamn, SE	-	14,653,639	-	-	-
Oslo, NO	-	-	6,688,914	5,673,097	4,456,798
Katrineholm, SE	-	-	8,009,153	-	-
Stockholm, SE	-	-	-	4,897,706	4,747,991
Halmstad, SE	-	-	-	4,128,914	4,128,914
Hämeenlinna,FI	-	-	-	-	5,858,537
Steinkjer, NO	-	-	-	-	1,556,458

Table 39. Nordic countries distribution centers including Denmark and allocated demands considering points with at least 10000 inhabitants

Location	1 DC	2 DC	3 DC	4 DC	5 DC
Hämeenlinna , FI	-	-	5,043,784	4,976,255	4,976,255
Stockholm , SE	-	-	-	5,004,766	4,765,284
Göteborg, SE	-	18,316,758	-	-	4,154,322
Oslo municipality, NO	-	-	-	6,023,591	4,210,410
Glostrup, DE	-	-	-	-	5,819,103
Vallensbæk , DE	-	-	7,622,931	7,920,762	-
Kristinehamn , SE	-	-	11,258,659	-	-
Tampere, FI	-	5,608,616	-	-	-
Jönköping, SE	23,925,374	-	-	-	-

7 CONCLUSIONS

The problem of facility location has been a well-established research area, and the applicability of location models has always been under discussion. Facility location decisions play a significant role in logistics operations involved in supply chain management. Tactical decisions on defining facility locations have a significant influence on the success of supply chains.

In this paper, we have utilized the GIS concept and tools to identify the most cost-effective facility locations in both the level of Nordic countries and then each country including Norway, Finland, Sweden and Denmark. The scenarios are hypothetical, but as with many consumer related products this assumption is often realistic, and we believe that the optimized solutions may give some insight into how distribution centers are attractive when demand volume is increasing.

For estimating the potential facility locations and demand points, population information and the road dataset of each country are used, and the distance between facility and demand points is calculated based on road information. For defining the most optimal facility sites, the geographical location of population points is considered as both demands points and candidate facility locations. In addition, analyses were performed at the Nordic level and for each country with scenarios of selecting 1 to 5 optimized facilities from candidate locations. The merged Nordic scenario is also typical for many larger companies: a good transport network enables reasonably fast and cost-effective delivery of goods from a single location. By merging distribution centers together, companies can benefit from reduced demand uncertainty and lower stocks due to the effect of risk pooling on safety stocks; on the other hand, however, direct transportation costs will increase to some extent.

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