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Intermodal transport of windmills

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Abstract

Special goods can be difficult to handle due to fragility, weight or size and therefore require special treatment when transported. Windmills are examples of special goods with challenges both with respect to high weight and large size. At least in Europe, the focus on green energy entails rapid development of windmill projects where components needing special handling is transported over great distances. This paper studies the transport of windmills from Continental Europe to Norway where challenges are related to the long-transport distance, low road standard and rough climate. Different transport strategies are presented and discussed in relation to a theoretical model aiming to minimize the generalized transport costs. It is argued that unimodal transport by truck is not practically possible due to many insuperable barriers. Therefore, two types of intermodal transport are suggested of which the benefits of reduced handling at terminals are weighted against lower capacity utilization at the water based long-haul distance. Despite being part of a political strategy aimed at developing green energy, the companies transporting windmills are rarely imposed any environmental requirements by the shipper.

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Keywords: Generalized transport costs; handling costs; intermodal transport; ship; truck; windmill

1. Introduction

Wind is a source for renewable energy that has received considerable attention the last decades. Wind power can to some degree contribute to the production of energy and many countries have access to wind that can be utilized for such purposes by wind mills (e.g. Aman et al., 2013). The global windmill industry, dominated by the markets in Europe, North America and Asia, grew by about 29% in 2008 and exceeded 120 GW by the end of the year (Saidur et al., 2011). In Europe, this rapid growth could be a consequence of the target of increasing the proportion of

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renewable energy to 20% in 2020 (European Commission, 2008). During the last decade, wind mills have been constructed also at sea (offshore) where the wind resource is more abundant and of better quality (van der Tempel, 2006).

It is the goal of the transport policy within the European Union to establish a sustainable transport system (European Commission, 2009) and the successful promotion of intermodal transport has been identified as the most critical action in order to achieve this (Tsamboulas et al., 2007). Thus, intermodal transport is promoted through policies that are addressed at all political levels (Macharis et al., 2011). To make intermodal transport a preferred alternative to road haulage, generalized transport costs would have to be equal or lower (Hanssen et al., 2012), thus the extra costs due to pre- and post-haulage (PPH) as well as transshipments at the intermodal terminals must be offset by the lower costs of the long-haul transport (Bärthel and Woxenius, 2004).

Transport of windmill components from production to assembly site can be challenging due to large scale and high weight. Windmills are made up of large sections, and transports can be 50 meters long and 5 meters wide. Hence, this is classified as special goods with challenges that often can be met only by special preparing of infrastructure. The parts of the transport chain carried out by road must meet national rules and restrictions. This implies for example that bridges must have sufficient carrying capacity which can require that they are closed down while special transport is in progress. Additionally, for such oversized transports, it can also be required that police and/or public road authorities are present at transport by road. To our knowledge there are few studies focusing on the economic consequences of the challenges related to transport of windmills.

The aim of the paper is twofold. First, the challenges and considerations for a typical transport of windmills are discussed based on interviews with representatives for two companies providing such transport services. Second, a specific case involving transport of oversized windmill parts from the production site in Europe to the assembly site in Norway is presented. Two transport solutions derived from this case is related to a theoretical model of intermodal transport in order to discuss under which conditions each of the alternatives should be chosen.

The paper is structured as follows: Section 2 presents a theoretical framework where generalized transport costs are applied to explain the conditions for making intermodal transport preferred to unimodal solutions. Then in Section 3 the case of transport of windmill components from northern Europe to the middle part of Norway is presented and analyzed in relation to the theoretical model in Section 4. Finally, conclusions and implications are given in Section 5.

2. The Model

The optimal transport solution will depend on the objectives to be maximized. For a shipper this is usually to some degree related to minimizing the generalized transport costs. The choice of transport solution can be studied by the use of generalized costs comprising all cost related to the transport (Button, 2010). For shippers aiming to minimize total costs an intermodal transport solution is preferred to unimodal transport if this gives lower generalized transport costs (Hanssen et al., 2012). In line with the model presented by Hanssen et al. (2012), let us assume that a shipment needs to be transported over a given distance measured in km and denoted by D. An unimodal alternative using road transport only with generalized costs, G_t, is defined in (1) where subscript t indicates truck. In (1) the distance independent part of generalized costs is represented by ρ_{0t}. The distance dependent element is defined by ρ_{1t} comprising both price and time costs per kilometer.

$$G_t = \rho_{0t} + \rho_{1t} D \tag{1}$$

The shipment can alternatively first be transported by truck (pre-haulage) to the distance D_1, then by water (could as well be rail) for the long-haul distance $(D_2 - D_1)$ and, finally, by truck (post-haulage) to the final destination, $\widehat{D}$ (D-hat). Terminal handling costs from truck to water at D_1 and back to truck at D_2 are symmetric and defined by H. Note that these handling costs comprise both pecuniary costs and time costs. The generalized transport costs for this intermodal transport solution using truck and water, G_{Int}, is defined in (2) where subscript w indicates transport by water. Moreover, in (2) the pre- and post-haulage costs are adjusted by the factor $\varphi \geq 1$ taking into account that generalized transport costs are higher per kilometer due to low speed compared to that of long-haul transport.

$$G_{Int} = (\rho_{0t} + \varphi\rho_{1t} D_1) + \left(H + \rho_{1w}(D_2 - D_1)\right) + (H + \varphi\rho_{1t}(\widehat{D} - D_2)) \tag{2}$$

Starting from the left in (2), the first element, $(\rho_{0t} + \varphi\rho_{1t}D_1)$, represents generalized transport costs by truck from origin to the terminal at distance D_1. The second parenthesis, $\left(H + \rho_{1w}(D_2 - D_1)\right)$, represents costs for reloading the cargo to the long-haul transport by water between port terminals at D_1 and D_2. Finally, the last parenthesis, $(H + \varphi\rho_{1t}(\widehat{D} - D_2))$, represents costs for loading the cargo back on a truck and transport by road to the final destination. It is assumed that ρ_{1t} is equal for pre- and post-haul distances and adjusted by φ. Moreover, it is commonly accepted that the marginal increase in generalized transport costs is higher for transport by truck compared to that of transport by water, $\rho_{1t} > \rho_{1w}$. This means that generalized transport costs increase more rapidly with distance for truck compared to water and rail.

The expressions in (1) and (2) defining the generalized costs for unimodal and intermodal transports, respectively, are illustrated in Fig. 1. Unimodal transport is preferred to intermodal transport in Fig. 1 when the long-haul distance is at least $(D_2 - D_1)$. The generalized costs for the total transport distance is defined for intermodal and unimodal transport solutions by $\widehat{G}_{Int}$ and $\widehat{G}_t$, respectively. An increase in the long-haul distance to D_3 renders equal generalized costs for the two alternatives. If the long-haul-distance increases further then intermodal transport will be the best alternative.

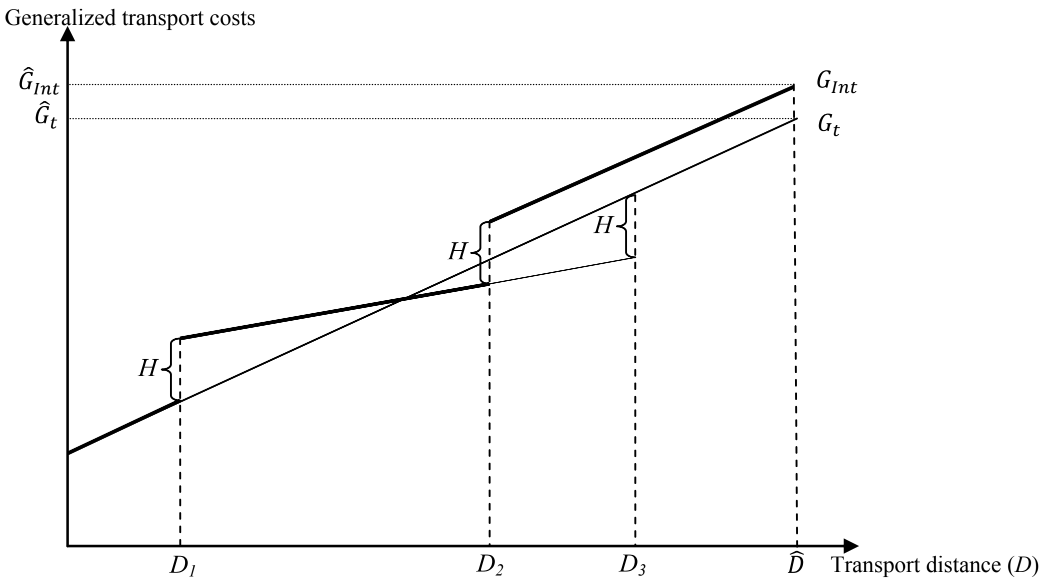

Fig. 1: The relationship between generalized costs and distance for unimodal, G_t, and intermodal, G_{Int}, transport solutions. Source: Hanssen et al. (2012).

An intermodal transport solution is preferred to unimodal if (2) is lower than (1) as defined in (3):

$$G_{Int} < G_t => (D_2 - D_1) > \frac{2H + \rho_{1t}\widehat{D}(\varphi - 1)}{\varphi\rho_{1t} - \rho_{1w}} \quad (3)$$

The condition for preferring intermodal transport is rephrased in (3) to demonstrate how different factors influence the required distance for the long-haul distance by water (could as well be by rail). The partial differentiations of $(D_2 - D_1)$ with respect to $H, \widehat{D}, \varphi$ and ρ_{1w} are positive, while the derivative with respect to ρ_{1t} is negative. This implies that the required transport distance by rail required to make intermodal transport preferable increases when

- the handling costs at terminals increases
- the total transport distance increases
- the adjustment factor of pre- and posthaul costs for trucks increases
- the distance dependent marginal generalized costs for water increases

- the distance dependent marginal generalized costs for truck decreases

In the special case when $\varphi = 1$, meaning equal costs for pre- and post haulage and long-haul by truck, then the numerator and denominator are reduced to $2H$ and $(\rho_{1t} - \rho_{1w})$, respectively. Hence, in this case the required long-haul distance is independent of the total distance, $\widehat{D}$.

3. Transport of Windmills

3.1. The Case

The middle parts of Scandinavia have been identified as areas with great potential for developing wind power and the construction of wind mill parks has already started (Moan, 2012). Currently, the middle part of Norway has an energy deficit amounting to about 10 TWh, where poor infrastructure in the grid makes a major bottleneck. A way to meet the power deficit is to produce electricity locally by utilizing the wind flows in the region. A number of new windmill projects were given concessions by the regulator, Norwegian Water Resources and Energy Directorate (2013), during 2012.

There are several producers of the main parts for the windmills worldwide. With relevance for this case, a total of 14 European producers were identified of which the largest are located in Denmark, Germany, Spain and Finland. The most relevant transport routes involve the use of ship from ports in Germany (Bremerhaven and Rostock) or Denmark (Esbjerg) to the middle part Norway as illustrated in Fig. 2. There is usually a need for transport by truck (PPH) both before and after the long-haul distance by ship and this will be elaborated on in Section 3.2.

Fig. 2: Illustration of routes for long-haul transport by sea from relevant ports in northern Europe to the construction site in Norway.

3.2. The Transport Chain

When it is decided that an area should be developed for windmills the producers buy transport solutions from external companies. Hence, producers of windmills are customers of the transport companies. The relationship between actors in the transport chain for windmills is discussed by Moan (2012) based on information acquired by interviews with representatives for firms commonly in charge of specialized transports. The representatives for two transport firms have been interviewed and their identities are kept anonymous due to company sensitive reasons.

The contracts for transport are usually assigned after rounds of competitive tendering where several transport companies can participate. Transport firms must invest considerable resources in the preparation for the price estimation. They must review the route and map the infrastructure conditions. This includes facilities at the harbours, loading and unloading, availability and properties of the road network. Since so much is at stake, there is always a test run of the route prior to starting the actual transport. It is a tendency that producers leave larger parts of the transports to external companies. Hence, the transport companies take on the responsibility and coordinate the transport. The fact that most transport firms do not own all the equipment that is required for such specialized transports implies that several companies are involved and must interact in the transport chain. Naturally, the properties of transports vary according to location and infrastructure for producer and site, but a general chain of events is illustrated in Fig. 3.

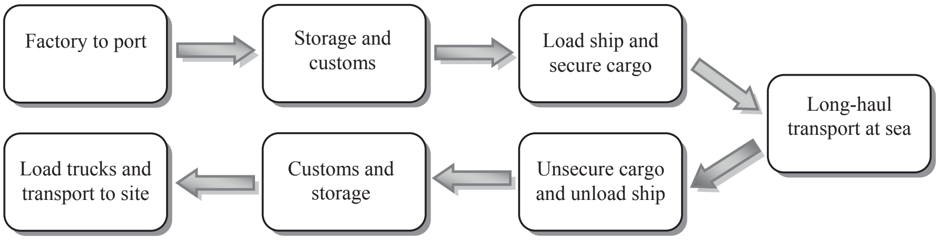

Fig. 3: The transport chain for windmills.

The long-haul transport is often carried out by ship and the first stage is to move the windmill components from factory to port. The transport mode for this stage depends on the characteristics of the region. While barge is common on the rivers in Europe, the use of specialized trucks is more frequently used in the Nordic countries. When the components have arrived at the port, they are stored before being loaded on ship. While waiting at the ports there are inspections and controls of formal documents (see e.g. Lowe, 2005). When loading the ship the capacity at the harbor is a critical factor. There is usually a need for renting equipment such as cranes and a spacious environment is required for storing and handling the large windmill parts. More specifically, a complete windmill usually consists of ten components comprising (see also Manwell et al., 2009):

- tower consisting of three or four elements with lengths of 30 meters
- blades with a length of 45 meters
- hub where the blades are attached and the nacelle (wind mill turbine) with a combined weight of about 78 tonnes

The loading process includes securing of the cargo usually by welding the components to the deck of the ship. When the ship is loaded, the cargo is secured, and all inspections and documents are approved, the transport can sail towards the destination harbour. At arrival the cargo is inspected prior to releasing the security measures. The components are then unloaded to the harbour or directly on trucks. Also at the destination harbour there is a need to rent specialized equipment such as cranes. When unloaded there is a need for another round of inspections and control of documents (e.g. customs). There is now a need for coordinating the transport to make the components arrive at the site in the desired order.

The transport from harbour to site is typically carried out by large specialized trucks. Since the components have different characteristics there is a need for separate types of vehicles for towers, hubs/nacelles and blades. For the large windmills, one truck usually carries one component, except for blades of which several can be transported simultaneously. For smaller windmills it can be sufficient with one or two types of vehicles. To avoid renting too many vehicles and due to shortage of specialized vehicles it is often necessary with several trips using the same trucks.

In Norway it is decided by law that specialized transports must be escorted and this often also involves participation by police and road authorities. The escort is a considerable driver of costs. When the components arrive at site, they are unloaded from trucks and stored. If inspections do not reveal any damages the job for the transporting firm is completed. Equipment for assembly is usually the responsibility of the installation crew.

4. Analysis

When deciding on transport solutions, all advantages and disadvantages for the relevant alternatives must be assessed. Moan (2012) discusses both unimodal and intermodal transport solutions for the case in point. It is generally concluded that unimodal transport by truck is not a feasible alternative due to the long distance and topographic challenges caused by sea and mountain. Moreover, for this particular case it does not satisfy typical requirements from the customers with respect to delivery time, price, probability for damage and impact on the environment (external costs). The general characteristics of transport by truck compared to other transport modes is discussed e.g. by Ballou (2004).

For the intermodal transport solutions there two main alternatives are identified of which both involve truck for pre- and post haulage and ship for long-haulage. The difference between the two approaches is related to the handling at terminal and the long-haul transport. Hence, cost for pre- and post-haulage, ρ_{1t}, is assumed to be equal for the two alternatives. An illustration of the two intermodal transport solutions is given in Fig. 4. It should be noted that some of the suppliers, e.g. in Germany, would use rail or barge for the transport to terminal at the North Sea. However, such a separation of the long-haul distance is not considered in the transport solution illustrated in Fig. 4.

First, a traditional approach follows the transport chain illustrated in Fig. 3 where the components are handled at the port terminals. This involves loading between truck and ship and securing by welding. Second, an alternative approach a form of piggyback where already loaded trailers are placed directly on the ship deck. These two approaches inherit several properties that influence the generalized transport costs of which the principles are discussed in Section 2. The generalized costs for the traditional and alternative transport solutions are defined in Fig. 4 as G_{Int-I} and G_{Int-II}, respectively. In this illustration the handling costs for G_{Int-I} is outweighed by higher marginal costs for G_{Int-II} giving equal generalized transport costs for the two alternatives, $\hat{G}_{Int-I} = \hat{G}_{Int-II}$.

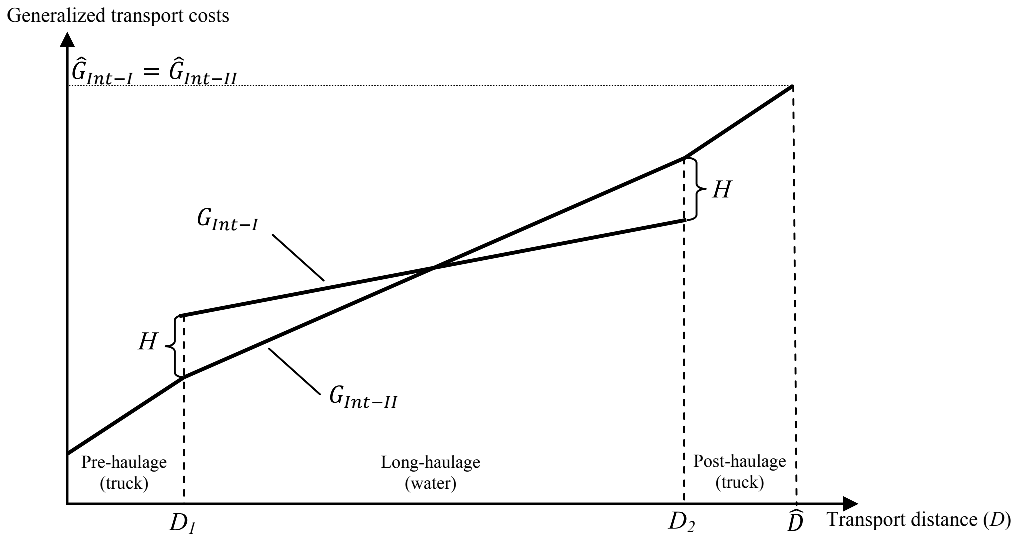

Fig. 4: Illustration of two intermodal transport solutions where G_{Int-I} includes handling at terminals and G_{Int-II} place trailers directly on ship.

The advantage of the first approach is that the ship can be loaded by more windmill components. It is therefore a more efficient solution since it utilizes available capacity in a better way. Hence, the increasing slope with distance, ρ_{1w}, is least steep for G_{Int-I}. However, handling at the terminal, H, takes time and is also related to a probability of damage. Evidence suggests that by avoiding handling at port it is possible to reduce transport time by two days for each windmill. This reduction is most important for shorter trips where handling makes a relatively higher proportion of total time use.

The second approach involves the use of a ship more similar to a car ferry where the fully loaded trailers can be driven directly onboard. Hence, handling is avoided at harbours both at origin and destination, meaning that $H \approx 0$. The informants agree that this would both reduce costs and save time, provided that necessary equipment and capacity are available. A disadvantage of the second approach is the demand for relatively large areas of free space in specific angles to enable the trailers to be successfully unloaded from the ship.

Unfortunately, the development of the windmill park has been slow and currently the plan is to make the investment decision during the first part of 2015. According to the informants, the project must be operative by 2020 in order to take part in the regime of green certificates. An indication that the project is getting closer to realization is that suppliers are visiting the area to prepare for the coming tendering of contracts. For example, in May 2014 representatives from the windmill producer Vestas and the transport supplier Wilhelmsen Ships Service studied the port facilities and assessed the logistical challenges (Fosen vind, 2014).

Since the project is still under development, we are not able to provide parameter values that enable us to calculate the generalized costs for the transport alternatives. Still, based on the statements provided by the respondents at the initial stage we have some indications of the magnitude of costs, time use, damage and environment. Hence, for these four dimensions the three transport alternatives are ranked from highest to lowest. Such an ordinal scale does have limitations with respect to analysis since it does not say anything about the distance between the grades. The comparison of the consequences for the three transport solutions is presented in Table 1. We emphasize that the comparison relates purely to the case of transport from northern Europe to the middle part of Norway and the total assessment could be different in other situations.

It is suggested in Table 1 that an intermodal transport chain using long-haul by sea is preferred to unimodal by truck both with respect to costs for the transport company and external costs. Even though we cannot state exactly the difference between generalized costs the for three alternatives, it is clear in this case that truck only will be considerably more expensive than the two transport solutions using sea for the long haul. This is supported by the fact that the visiting suppliers mentioned above studied the port facilities which could indicate that an intermodal transport solution using sea for the long-haul will be proposed.

Table 1: Comparison of the studied transport solutions.

	Unimodal by road	Intermodal with terminal handling	Intermodal with direct load of trailers
Long-haul	Road (truck)	Sea (ship)	Sea (ferry)
Total costs	Highest	Middle	Lowest
Time use	Highest	Middle	Lowest
Probability for damage	Highest	Middle	Lowest
Environmental impact	Highest	Middle	Middle

In order to rank the two intermodal transport solutions it is necessary to study in detail how the reduced time use and damage costs by placing the trailers directly on ship will be valued against the lower capacity utilization at the long haul distanceWhen this information is available, the supplier of transport services will assess which alternative is most suitable depending on the requirements imposed by the shipper. Such company sensitive information will only be publicly available when the tendering is completed and the supplier for the contract has been chosen. Unfortunately, the case at hand has not reached this stage yet. However, studies of costs in intermodal transport solutions using sea argues that loading costs at ports makes a large proportion of total costs (e.g. Sauri, 2006). Hence, the reduced loading time at ports in the case of direct load of trailers suggests that this alternative would deliver the lowest generalized costs.

5. Conclusions and Implications

This paper focus on challenges related to transport of oversized windmill components from production site to assembly site. The case is a windmill park to be developed in the middle part of Norway and information is retrieved by interviews with two firms operating in the business for transport of specialized cargo. The respondents are treated anonymously due to possible business sensitive information. It is argued that the transport route from continental Europe to Norway should be intermodal with the use of sea for the long-haul leg. Moreover, the case is discussed in relation to a theoretical model developed by Hanssen et al. (2012) to assess generalized costs for intermodal transport compared to that of truck only (unimodal transport).

Two questions are specifically addressed in this paper. First, there is a description of a typical transport of windmill components with emphasis on the challenges that are specific for this type of specialized transport. This review is a contribution in itself since we have not seen published before such information specifically related to transport of windmills. Second, a recommendation is given on which transport solution would be the best for the case in point. After having rejected unimodal transport by truck, pros and cons for two intermodal transport solutions are discussed of which one involves traditional handling at terminals and the other suggests a type of piggyback meaning that fully loaded trailers are placed directly on the ship. Relative to the use of piggyback, the traditional alternative implies higher capacity utilization for the long-haul trip, but handling at terminals takes time and is associated with risk for damage of which both are related to higher costs.

To conclude, it suggested that the alternative approach where handling at the port terminal is avoided is the best alternative for the case in point. Both intermodal alternatives are argued to be better alternatives than the unimodal alternative with respect to environmental issues (external costs). Still, external costs are rarely important criteria when choosing transport solution. It is perhaps a paradox that windmill transport is not subject to environmental requirements even though it is considered a “green industry”.

A weakness is that the discussions are based on the information from only two firms and regarding a single wind energy project still to be developed. A topic for future research would be to study which transport solution that was actually chosen and to enlighten the considerations that prepared for the decision. For such a retrospective study, it would probably not be necessary to treat the informants anonymously since most business specific information will be known when the tendering of contracts has been completed.

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