Transport of fish from Norway: energy analysis using industrial ecology as the framework

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Abstract

In this article, industrial ecology is used as a framework for analysing transport energy and its implication for products. The importance of the energy use for transport in a natural resource production system is analysed. By using fish as a case study, it is shown that the amount of energy for transport is highly dependent on the transport mode used. When applying industrial ecology principles for making assessments of the environmental impacts of products, the whole product chain is examined. This is an extended life-cycle approach, which also includes the transport of the finished products from the exporter to the importing country. This last part of the transport chain can be extremely energy demanding, as is shown for the case of fish transport. This finding has implications for the products, and for the form in which the products should be transported. Increasing the energy efficiency of production systems is an important industrial ecology principle, and must be taken into consideration when analysing product chains. A revision of today’s practice of transporting large quantities of fresh whole fish by transcontinental airliners is bound to be necessary. This is a consequence of the demands for increased energy efficiency of tomorrow’s industrial production systems.

Keywords: Industrial ecology; Energy analysis; Transport of products

1. Introduction

Industrial ecology encompasses a wide range of issues connected to the relations between industrial production systems and the environment. Included are energy and material resource use, emissions to air, water and land, during the whole production chain. The whole chain in this respect consists of extracting and processing of raw materials; manufacturing, transportation and distribution; use/re-use/maintenance; recycling and final disposal [1]. There is, however, not equally emphasised on the various aspects of the chain in the industrial ecology field. First of all, the energy use considerations are not well focused upon compared to what is the case for material resource use. This has been pointed to earlier by O’Rourke et al who states that:

…It is rather odd that energy flows in natural ecosystems are largely neglected. In an introductory text on ecology, Kormondy writes, “…a one-way flow of energy constitutes one of the most important if not the cardinal principle of the ecosystem” [2]. If energy flows — not material flows — are “one of the most important” principles of a natural ecosystem, then industrial ecology should place at least equal emphasis on energy flows and how they change as ecosystems evolve [3].

Secondly, there is strong focus on issues connected to extraction, processing, manufacturing, waste utilisation and recycling. Transport, in connection with the various segments of the production chain, is only scarcely considered. Analyses of the energy use and environmental effects of distributing the products are missing in particular. The perspective on products in industrial ecology is however quite strong, and integrated with the energy and material flows. The design and manufacturing of environmentally friendlier products are highly relevant, as the statement by Robert Frosch points to:
A product is a transient embodiment of material and energy occurring in the course of material and energy process flows of the industrial system (Quoted in [4]).

Product Life-Cycle Assessment (LCA) is an important tool in industrial ecology. However, the LCA approach often fails to include the trans-national transports from producer to the customer. The wide approach that is represented by industrial ecology should have focus on all the life-cycle stages of the products and the environmental demands along the whole product chain. If transport in the product chain is not included, important environmental effects of the products are omitted. This is problematic when facing transport’s contribution to major environmental problems [5]. Including the transport considerations in the product chain might result in other demands upon the products. Hardly any of the concepts of industrial ecology include the transport considerations along the complete product chain. If these considerations were included, other answers to the question of environmental impacts might be obtained. Fish is the product case used in this article to elucidate this issue.

There is particular reason for concern regarding the energy use for transport of raw materials and finished products. The increased globalisation of the economy causes raw materials and particularly finished products to be transported over greater distances, resulting in steadily higher energy use for these parts of the industrial production chains. This serves as a background for this article’s focus on the products being produced. The connection between the main issues dealt with in this article are summarised in Fig. 1. The figure illustrates that the article discusses issues along two dimensions:

1. The transport-energy use dimension;
2. The production-product dimension

In the transport-energy use dimension (1) a discussion of the energy use in transport is carried out (a). This is based on an analysis of the energy use in the various transport activities in the production chain. The energy use in the production chain also includes stationary energy uses (b). This is also dealt with in the article, but seen in light of the relative higher importance of the energy use for transport. The type of production considered has implications for transport choices (c), while the transport itself has implications for the product type (d). This brings us over to the production-product dimension (2). The energy use for transport in the production chain has implications for the products being produced (e). Particularly the transport of finished products to the customers can require excessive energy inputs if the product is in a form not suited for transport by energy-efficient transport modes.

The research presented here is based on the hypothesis that the environmental impacts in the form of increased energy use and emissions from the transport of raw material and finished products, in most cases, are underestimated. The empirical data are from research in energy use of natural resource based industries. Transport of goods is large in the natural resource based industries and particularly the strong increase in air- and truck-based transport is problematic for many reasons — in terms of energy use, emission of CO₂ and congestion of the air space and the European road network — this increase is undesirable. Changes in transport modes are necessary to combat these problems. Transfer of today’s road based goods transport to more energy efficient rail and sea-based transport will be required in the future. Likewise will limitations on goods transport by air be required. The application of a wide range of measures and actions are necessary in order to obtain these changes in the systems for transport of goods. Substantial environmental gains will however, only be obtained after major changes in the production systems, particularly regarding form and where the products are transported.

The theoretical framework applied in the research presented here is industrial ecology, while fish is the case product. Some aspects of this choice of case product are described in the following. The historical development in Norway points to the problem that while the total volume of fish catch is approximately at the same level in 1990 as in 1960, the energy use in the fisheries has increased 6-fold over the same time period [6]. This is partially explained by longer transport distances for each boat to the fish-rich waters. This emphasises the development towards a steadily more energy-demanding fishery where increased transport is an important component responsible for this change.

The change in the energy use in the production segment of the product chain highly significant. For the fish sector, a wide focus on the production segment implies that not only the activities of the fishing boats and the fish farms are included, but also the transport of the raw materials (fish feed) and finished products (fish for sale). This wider approach also has relevance in the discussion.
of sustainable development. There have been tendencies, both in politics and research, of a narrow understanding of the term ecological sustainability. In fisheries, this is made into a question of staying within the maximum sustainable yield for the species. In principle, then, it may be ecologically sustainable to establish a fishery consisting of a small fleet of energy-demanding trawlers, which ensures that the catch is kept within the sustainable yield. Similarly, a sustainable aquaculture can be defined, as long as certain criteria, such as minimal pollution from the facilities, are fulfilled. Consequently, there is, in principle, nothing to prevent the export of fish by jet plane from Norway to Japan. It is evident that this is not consistent with the understanding of ecological sustainability that ensues from the term sustainable development, for example in the way it is described in the Brundtland Commission report [7].

A wider ecological sustainability perspective of the whole product chain must also be applied in industrial ecology considerations. This is necessary when making efforts to determine the magnitude of energy input into products. The energy use of both upstream and downstream industrial activities must be considered. It is necessary to include the energy use for production and transport of fish feed for aquaculture. Also, the transport system for the finished products is included. This is of particular importance since the energy use for transport contributes greatly to the total life-cycle energy input in products [5].

2. Method and data material

The data material forming the empirical base for this article is mainly drawn from two research projects carried out at Western Norway Research Institute. The first research project is Local and global environmental challenges as conditions for rural development. The project was part of the programme for research on rural development in the “Department for bio-production and breeding” at Norwegian Council for Research in the period 1992–1995. One of the core questions that was asked was: how large is the energy use for transport in fisheries and aquaculture (fish farming)? Data on energy use were obtained for the segments of the fish product chain that was assumed to be the most important. For the calculation of energy use in the aquaculture fish feed production chain in Norway in 1980 and 1994, data were obtained from Norwegian fish feed producers and the Norwegian Herring Oil and Meal Industry Research Institute. The segments of the aquaculture fish feed production chain and their specific energy use (in parenthesis) are: (1) Catch of fish feed raw materials (1552 kW h/t), (2) production of fish flour (3210 kW h/t), (3) import of fish flour (148 kW h/t) and (4) production of feed-pellets (249 kW h/t). The origin of the imported fish flour material is assumed to be as follows: 50% from Iceland, 25% from Denmark and 25% from Chile. The energy use for production of fish flour is assumed to be the same in these countries as in Norway.

In the calculations of the energy use in the distribution of the exported fish, three main categories of fish are analysed: (1) fresh and frozen fish to Europe, (2) frozen fish to East Asia¹ and USA and (3) fresh fish to East Asia and USA. The Norwegian Seafood Export Council supplied the data on the amounts in each of the three categories in 1995.

The data on energy use, load capacity and load factor (utilisation of load capacity) are based on data for the boats to East Asia operated by Maersk Line.²

The calculations of the energy use in feed-production and transport of frozen and fresh aquaculture fish overseas are based on a total of 222,000 t harvested aquaculture fish in 1994. This number was provided by Kontali Analyse AS (www.kontali.no).

The other research project from which the empirical base for this article is drawn is Energy saving in transport of goods — a pilot project in rural natural resource based industries. The project was part of the programme for research on “Specific Actions for Vigorous Energy Efficiency” (SAVE) in the European Commission Directorate-General for Energy, DGXVII and was performed during the period 1998–2000 [8]. The main objective of this project was to develop and implement actions, strategies and measures for improved energy efficiency in transport of goods. The project covered rural natural resource based industries from three different branches. All ‘cases’ were transport in connection to rural natural resource based industries in the three Nordic countries; Finland, Norway and Sweden. The three branches were transport in forest industry (Finland), fishing industry (Norway) and agriculture industry (Sweden).

The data included in this article is on the transport of fish from Western Norway to the European continent. A total of four different cases for transport of fish, which were used in 1998/99, were analysed, in detail, in this project. All four cases were operated by one transport company and the cases were mainly based on truck

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¹ Japan, Taiwan, Hong Kong, Singapore and Korea. This constitutes 98% of fresh fish exported from Norway to USA and other overseas countries in 1994.

² For the calculation of energy use in the export of frozen fish to East-Asia and USA it is assumed that the transport is carried out by 60,000 dwt container boats, with a capacity of 7500 t frozen fish total, in 300 containers with 25 t fish each. It is further assumed a fuel consumption of the ships of 150 t heavy oil per 24 h. The energy content of the heavy oil is 11.65 kW h/kg and the boats travel at a speed of 24 knots. The energy use per 24 h with full load capacity is 32.5 kW h/t fish transported. This includes 3.8 kW h for the operating the freezing aggregates during the transport. Average load factor is 52.5% (80% to East-Asia, 25% on the return trip).
transport. One of the four cases is analysed in detail in this article. The main results of the other three cases are however, discussed for generalisation purposes. All the analysed cases included a segment where the trucks were transported by ferries. The case which is presented, in detail, in this article is the transport of dried cod to Italy (Torino/Foligno) truck from Ålesund to Oslo, ferry to Copenhagen, truck to Gedser, ferry to Rostock, truck to Manching, rail (truck on rail) from Manching to Brenner, and truck on the last distance to Foligno.

For the calculation of energy use for the case route in 1998 it is assumed that an energy content of 9.76 kW h/l diesel fuel was used by the trucks. The ferries are assumed to travel with an average speed of 37 km/h. The specific energy use for each of the two transport modes ferry and truck-on-rail is 0.50 and 0.11 kW h/t km, respectively.

The case routes are compared with a scenario for 2015. This scenario presupposes major changes in the transport systems in Europe, such as increased capacity of the rail systems, and increased efficiency of harbour operations [9]. The energy use factors applied in the calculations for 2015 and changes since 1998 are shown in Table 1.

Table 1
Energy use factors applied in the calculations for 2015

<table>
<thead>
<tr>
<th>Transport mean</th>
<th>Energy use (kW h/t km)</th>
<th>Change since 1998 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boat&lt;sup&gt;a&lt;/sup&gt; (at 70% load factor)</td>
<td>0.08</td>
<td>0</td>
</tr>
<tr>
<td>Truck&lt;sup&gt;b&lt;/sup&gt; (at 60% load factor)</td>
<td>0.36</td>
<td>-10</td>
</tr>
<tr>
<td>Train&lt;sup&gt;c&lt;/sup&gt;, electric (at 70% load factor)</td>
<td>0.06</td>
<td>-25</td>
</tr>
</tbody>
</table>

<sup>a</sup> The lack of improvement in total energy efficiency since 1998 is caused by the need to cool the fish during the transport, which outweighs the improvements in energy efficiency of engines.

<sup>b</sup> Trucks are assumed to mainly be used for shorter distances in distribution- and supply transports. This explains the small improvement of only 10%.

<sup>c</sup> Trains are assumed to be powered by electricity only. The trains for goods transport are assumed to have maximum speed of 120 km/h and with carriages for transport of containers/semitrailers on two floors. Already at the end of the 1990s did Swedish and Finnish rail transport average 0.03–0.04 kW h/t km (load factor 60–70). A higher energy use factor than this is used to compensate for the weight of containers/semitrailers and the need for cooling of the fish during the transport.

The empirical data presented from the project Local and global environment challenges as conditions for rural development is previously published, in the Norwegian language, in one of the reports from the project [6]. The report covers both what can be termed mobile fisheries (by boat) and stationary fisheries (aquaculture). The main focus in this article is aquaculture, which is the faster growing of the two forms of fisheries. Both upstream and downstream energy use is included in the analysis.

The energy use in the production chain of feed for aquaculture is analysed first. The Norwegian energy use for this segment of this form of fish production in the years 1980 and 1994 is shown in Table 2. From the table, it is obvious that the energy use for catch of fish flour raw material dominates the picture. This can be explained, in part, by the large amount of raw material that is needed for fish flour production. Approximately five kg of fish are needed for the production of one kg fish flour. Table 2 also shows the tremendous increase in the energy use for the aquaculture industry in Norway during the last two decades. The increase in energy use in the feed production chain between 1980 and 1994 is actually more than 24-fold. This underlines the importance of considering the environmental aspects of this industry.

The energy use in the distribution of the exported of aquaculture fish from Norway in the three main categories of fish is shown in Table 3. It is evident from the table that the transport of fresh fish to East-Asia and USA dominates the energy use in the export of aquacul-
Table 4
A detailed look at the energy use in the transport of fresh and frozen aquaculture fish from Norway to East-Asia and USA (1994)

<table>
<thead>
<tr>
<th>Product form, transport means and route</th>
<th>Total energy use (GW h)</th>
<th>Energy use per product unit (kW h/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frozen fish:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>— Truck Bergen-Oslo</td>
<td>2.7</td>
<td>0.2</td>
</tr>
<tr>
<td>— Boat Oslo-export country</td>
<td>29.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Fresh fish:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>— Truck Bergen-Frankfurt</td>
<td>10.6</td>
<td>0.6</td>
</tr>
<tr>
<td>— Aeroplane Frankfurt-export country</td>
<td>368.6</td>
<td>21.0</td>
</tr>
</tbody>
</table>

Fresh fish from Norway, comprising more than 70% of the total energy use.

In order to compare the different forms of fish transport in terms of energy efficiency, it is necessary to also consider the amount of fish transported for each of the two product categories, frozen and fresh fish, which are exported to East-Asia and USA. The amounts transported in 1994 were 15,751 t frozen and 17,575 t fresh fish, respectively. It is then possible to compare the energy efficiency between the transports of the two product forms. An energy efficiency of 2.1 kW h/kg fish is obtained for the transport of frozen fish, while the transport of fresh fish requires 21.6 kW h/kg, thus a factor of more than 10 times difference in energy efficiency of the transport of two different forms of the same product. This large difference can be explained by analysing the energy use in the different segments of the two transport chains. This is presented in Table 4, where the energy use in the different transport means and routes for the two forms of the fish product is shown in more detail. It is obvious from Table 4 that it is the air transport that is the major reason for the high energy use of the transport of the fresh fish compared with frozen fish.

Transport is the key factor in the calculations of the energy use in the two product chains. This is evident in Fig. 2, which shows the transport’s share of total energy use in the two product forms. The two bars show the energy use for feed production and export of frozen and fresh aquaculture fish. The energy use in the production of fish feed is the same (9.6 kW h/kg fish) for the two product forms. The large difference in energy efficiency between transport by boat and aeroplane results in a total of three times higher energy input in the fresh fish product compared with the frozen.

3.2. Fish transport in Europe

The following results are based on the analysis of the empirical data datethe SAVE-project Energy saving in transport of goods — a pilot project in rural natural resource based industries. The fuel consumption, distances, durations and average loads for the case fish transport route are shown in Table 5. It must be emphasised that a total of four case routes were analysed, in detail, but only the results from one of the routes are presented here. The energy use was calculated from the measured fuel consumption of the trucks and by using the factors for energy content of the fuel, speed of ferries, and energy use for ferries and truck-on-rail presented in Section 2. The results are shown in Table 6. It is clear from the table that the contribution to the total energy use from ferries is relatively large, even though the distance with transport of truck on ferry is short compared with the total transport distance.

To achieve major improvements in energy efficiency, a mode change from today’s road based transport into using more rail and sea transport is necessary. The effects of such mode transfers, on the energy use, are analysed in the work for the Nordic Transport-political Network in the Interreg IIc-programme. In the report from the project “Optimal transport corridors based on

Table 5 Average fuel consumption, distances, time usage and load for the transport of dried cod to Italy. Round trips from Norway to the European continent and back to Norway (1998)

<table>
<thead>
<tr>
<th>Truck fuel consumption(l)</th>
<th>Road distance (km)</th>
<th>Ferry duration (h)</th>
<th>Rail distance (km)</th>
<th>Total duration (h)</th>
<th>Payload (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1659</td>
<td>4622</td>
<td>28</td>
<td>440</td>
<td>158</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 6 Average energy use for transport of transport of dried cod from Western Norway to Italy and back to Norway (1998)

<table>
<thead>
<tr>
<th>Energy use (kW h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
</tr>
<tr>
<td>Ferry</td>
</tr>
<tr>
<td>Truck on rail</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
Table 7
Energy and time use in the transport of dried cod to Italy. Round trips from Norway to Italy and back to Norway (2015)

<table>
<thead>
<tr>
<th>Main mode</th>
<th>Truck distance (km)</th>
<th>Rail distance (km)</th>
<th>Boat distance (km)</th>
<th>Total duration* (h)</th>
<th>Energy use (kW h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail</td>
<td>226</td>
<td>5274</td>
<td>0</td>
<td>166</td>
<td>8752</td>
</tr>
<tr>
<td>Sea</td>
<td>814</td>
<td>0</td>
<td>10,686</td>
<td>438</td>
<td>25,254</td>
</tr>
</tbody>
</table>

* An average speed of 80 km/h is assumed for trains. In addition is six hours waiting time at each of the loading/recoupling locations assumed. The average speed of boats is assumed to be 14 knots. In addition comes a loading and unloading time of four hours at each port. This might appear to be very low, but it is due to the much-improved efficiency of the port operations. The average speed for trucks (including rest hours) is assumed to be 60 km/h. This might appear to be low, but as pointed out earlier, the trucks are assumed to be used only for short distances in connection with the two main transport modes, at the beginning and the final segment of the case routes.

Table 8
The energy and time use for the transport of dried cod to Italy. Round trips from Norway to Italy and back to Norway. Actual data from 1998 and calculated data for rail and sea transport in 2015

<table>
<thead>
<tr>
<th>Energy use (kW h)</th>
<th>Time use (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998 (truck based)</td>
<td>27,861</td>
</tr>
<tr>
<td>2015 Rail</td>
<td>8752</td>
</tr>
<tr>
<td>2015 Sea</td>
<td>25,254</td>
</tr>
<tr>
<td>% Change 1998–2015</td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>–69%</td>
</tr>
<tr>
<td>Sea</td>
<td>–9%</td>
</tr>
</tbody>
</table>

From the other three cases analysed similar results were obtained, with significant energy saving effects (ranging from 9% to 79% reduction) for changing from truck to rail and sea transport. Increased time use is not an important barrier, and in some cases the time efficiency is actually better with rail than with truck.

4. Final discussion

A central principle of industrial ecology is a transition to more energy efficient industrial production systems in the future (see e.g. [1]). In this article, the importance of the energy use for transport in natural resource production systems has been analysed. By using fisheries as a case, it is shown that the energy for transport dominates the picture. Particularly the transport of the finished products is extremely energy demanding.

When using industrial ecology principles for making assessments of the environmental impacts of products, the whole product chain must be considered. The energy input into products should also include the transport of the finished products to the customers. This has implications for the products, and for what form the products should be in when they are transported.

One production system that has increased rapidly in the last few decades and is seen by many as promising for the future, is aquaculture. Regarding its energy usage, there are reasons for major concerns with this system. It has previously been shown that the energy use per produced unit of fish for traditional aquaculture (cage farming) is ten times higher than free ranching at sea [11]. The transport component of the aquaculture production system contributes to this problem. An example of this is that a large part of the fish feed used in Norway is produced in South America. The problem of high energy use for aquaculture is further amplified when taking into consideration what happens with the fish after it is harvested. Most of the fish that is transported in its fresh state on transcontinental air flights are produced by aquaculture production techniques. As is shown in this article, the energy use per unit of product is 10 times higher for this transport compared to when the product is transported in its frozen state by boat. The dominating trend in the last few decades has been to transport whole fresh fish, consisting of more than 90% (w/w) water. However, further back in history, it was common to transport the fish with less water, processed and preserved in the form of dried or smoked products. Intercontinental flights carrying whole fresh fish is an
extremely energy demanding way of transporting a product consisting mainly of water. This is not an activity that is compatible with the industrial ecology principles.

If the energy efficiency of industrial production systems is to be improved, more of the goods will have to be transported with energy efficient transport modes. This realisation has implications for what type of products can be transported over long distances, in the future. The example taken from fish transport by air illustrates this by showing that in an already energy demanding production system, the energy use must not be increased additionally by transporting the product over long distances in a form requiring the use of excessive energy. Instead, if the product is to be transported long distance, the transport should be carried out in a product form suitable for transport by an energy-efficient transport mode. For the case of the industrial product fish such a product form is the frozen, dried or smoked product, which can be transported by rail or boat. Without these considerations being applied in industrial ecology, the concept’s value is reduced as a useful framework for improving the industry–environment relations.

For transport shorter than transcontinental, such as within Europe, it is possible, at least in principle, to continue to transport a product consisting of mainly water in an energy efficient way. This is however, dependent on the mode changes from today’s road based transport to the more energy efficient sea and rail transport modes. The cases analysed show that the same product types can be transported more energy-efficiently by sea and rail, without increasing the time use correspondingly. In those cases of fish transport where the time use is increased, this is of little importance for the quality of the product, if it is in a form (frozen or preferably dried or smoked) that is suited for long periods in transport. This illustrates the importance of transport mode change for improving the energy-efficiency of the fish production system.

Transportation of whole fresh fish implies that also large amounts of potential waste material are transported. When the product is transported in the unprocessed form, the waste is dealt with in the destination country, far from the origin of the product. The utilisation of waste as useful raw materials and products is an essential principle in industrial ecology. However, the practice of dumping fish waste at sea, which is commonly done by factory freezer trawlers, can be considered a way of reducing the environmental impact of the waste. This is the same principle used when chipping branches and bark in the forest and spreading it to recycle some of the nutrients. Since the fish waste is a source of nutrient for life in the ocean, it is recycled locally which also reduces the total volumes to be transported to land. The principle of processing the waste locally, before it is transported, should also be adhered to when considering the environmental aspects of fresh whole fish transport vs. processed (frozen, dried, smoked) fish. The proximity principle, which states that the products should be produced close to the customer, is highly applicable in this context. If the proximity principle is not adhered to, more transport is generated, resulting in more negative environmental effects. These are principles that should be applied within the industrial ecology framework.

Finally, a discussion of the advantages of using industrial ecology as a framework for the analysis of energy use in production chains might be of value for the understanding of the major issues elucidated in this article. As pointed out in the introduction, both life-cycle analysis and LCA tools are useful within the wider conceptual frame of industrial ecology. Both LCA-based methodologies and industrial ecology analyses can give important data for energy use along production chains. There are however, major differences between the two approaches. LCA is a much more limited approach than industrial ecology. LCA can give data on the environmental impacts such as energy use, but industrial ecology goes much further, and points additionally to implications for products and production processes, within the industrial systems. Two major implications are pointed out in this article. They are the implications for the form of the product fish (less whole fresh, more processed such as frozen, dried or smoked) and implications for transport mode (less air and road, more rail and sea).

References

