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DELIVERABLE 4.1

The intermodal connectivity indicator

Summary report

This deliverable presents in detail the development of the intermodal connectivity indicator. Furthermore, this deliverable presents an analysis of the links between this indicator and policy objectives as well as other (inland) port performance indicators. Next, this report presents meaningful benchmarking methods on intermodal connectivity. Finally the report discusses the next steps in terms of data collection.

DELIVERABLE 4.1

The intermodal connectivity indicator

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1 INTRODUCTION[1]

Intermodal freight transport has received substantial attention in transportation research (see Bontekoning et al, 2004). Indicators of the quality of transport networks have been developed, however, such indicators have not been applied to intermodal connectivity.

Two broad classes of measures are used to describe the transport networks: the *connectivity of a network* and the *accessibility of a node*. While the connectivity is an attribute of a network that indicates whether it is possible to reach all nodes from all other nodes, the accessibility is an attribute of a node that indicates whether it is possible to reach all or certain nodes from a specific node.

In comparison, connectivity analysis for airports is more advanced than for seaports, partly because of better data availability. For instance, Kim at al. (2012) investigate the interconnectivity of airfreight networks taking into account temporal wave structures (i.e. the quality of connections is related to their time slots).

Connectivity analysis of maritime container networks is in its initial stages. Recent studies have advanced this theme. Ducruet et al. (2011) provide an overview of main network and node measures and examine their usefulness for understanding maritime transportation networks. Hu et al. (2009) present an empirical study of the worldwide maritime transportation networks with ports (nodes) and links (liner shipping services). They study statistical properties of such networks including centrality measures. Deng et al. (2009) point to the strong relation between the container throughput of a port and its position in a maritime network. Their empirical analysis is based on data for 676 large seaports and 3060 sea routes. Ducruet et al. (2012) provide an analysis of global liner shipping networks in 1996 and 2006. They implement conventional indicators of centrality to analyze the relative position of ports in the global network. The results reveal a quite strong robustness in the global shipping network. While flows shift between nodes in the network, the network properties remain rather stable in terms of the main nodes of the network.

Cullinane et al. (2009) present a thorough classification of accessibility measures as infrastructure-based, activity-based and utility-based factors. They propose a new accessibility measure relevant to evaluate port global competiveness. Instead of using

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[1] This paragraph is largely based on a paper on the intermodal connectivity indicator that was written based on the research results from PPRISM. See de Langen, P. W., & Sharypova, K. (2013). Intermodal connectivity as a port performance indicator. Research in Transportation Business & Management, 8, pp. 97-102.

distances as a link values, the authors associate these values with container carrying capacity. The method was visualized with data for the ten top ports throughout for 2004. Finally, Lam et al. (2011) examine calling patterns of container shipping services in order to understand ports connectivity and port inter-relations in supply chains. The connectivity of ports is analysed through a linear relation between vessel capacity of container liner services and frequency of liner services. This measure explicitly quantifies the connectivity of ports and implicitly assesses the competitiveness of the ports and their inter relationships from a liner shipping network's perspective. The empirical data cover four major ports in East Asia: Shanghai, Busan, Kaohsiung and Ningbo.

To conclude, connectivity measures have increasingly been applied to maritime networks, with various interesting results and substantial potential for further advances.

In contrast, virtually no attention has been paid to intermodal connectivity to/from ports. Intermodal connectivity is relevant, as many ports are confronted with growth prospects while the highway infrastructure around many port areas is congested. Thus, many ports, as well as policymakers have the ambition to handle a larger share of the volumes with intermodal transport. For instance, the three largest ports of Europe, Rotterdam, Antwerp and Hamburg have all announced modal split targets (Van den Berg and De Langen, 2011) for the container segment. In the US and many other ports around the world, ports also focus on increasing the share of rail (and where available, barge). Many port authorities also use intermodal connections in marketing efforts for attracting customers.

Achieving a higher share of intermodal transport requires a better connectivity between ports and intermodal terminals in the hinterland. Tracking the development of intermodal connections is an important part of port's global and regional network development. Therefore, the introduction of *an intermodal connectivity* measure that allows for assessing the evolution of the quality of intermodal networks helps ports and policymakers.

2 AN INTERMODAL CONNECTIVITY INDICATOR

We propose two new intermodal connectivity measures, whose objective is to quantify the transformations of the hinterland connectivity ports compared to the state of networks in a reference year. Given the fact that container services are scheduled, while bulk flows simply follow the cargo, we focus on the intermodal container connectivity measure.

The proposed intermodal connectivity measures assess the level of connectivity of deep-sea ports with inland intermodal terminals via barge and rail connections. The first measure is the indicator of intermodal connectivity of a *specific port*. It reflects the development of its barge and rail connections network. The second indicator of intermodal connectivity is defined for a *group of ports* and reflects the development of the overall barge and rail connections network. The latter indicator can be developed at various geographical scales, including the European scale.

For the calculation of the proposed indicators the following 'rules' are considered:

1. A service is defined as a regular transport service linking a port to an intermodal terminal. An intermodal service can be further described through its operating company, type of mode (rail or barge) and frequency.
2. We consider only those services of which frequencies are at least one departure per week. A service is counted only once, even if its frequency is more than once per week.
3. If two (competing) operators have different services to the same inland terminal from the same port, this is counted as two separate services.
4. Services from inland rail hubs in the proximity of the port (instead of services directly to the deep sea terminals of the common user terminal in the port area itself) are not considered. Intra-port services (e.g. a barge service from one deep-sea terminal to the other) are also not counted.

Each service defined according to the rules (1) - (4) represents a single connection between a port and an intermodal terminal. Figure 1 shows the basic concept of the intermodal connectivity indicator.

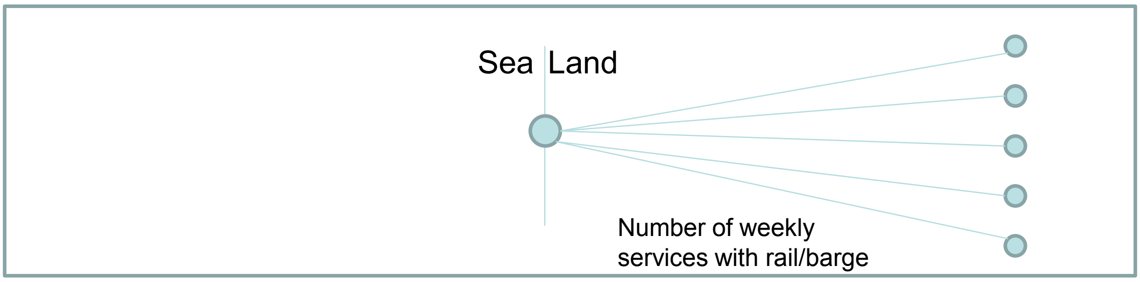

Figure 1: basic concept of the intermodal connectivity indicator

Ports can have intermodal connections by rail and barge. First, an indicator of intermodal connectivity for each mode of transportation separately is developed. These indicators are combined in one intermodal connectivity indicator.

For a port with b weekly barge connections in the current year and b^R weekly barge connections in the reference year, the indicator of intermodal connectivity via barge can be calculated as follows:

$$r^B = \begin{cases} \frac{b}{b^R} \; if \; b^R > 0 \\ 1 \; if \; b^R = 0, \qquad b > 0 \\ 0 \;\; Otherwise \end{cases}$$

In case the considered port did not have any barge connections established in the reference year, b^R = 0, and has developed at least one barge connection in the current year, b > 0, then, r^B = 1. In case the considered port did not have any barge connections established in the reference year, b^R=0 and did not develop at least one barge connection (b=0) than r^B=0.

The rail connectivity can be calculated in the same manner:

$$r^R = \begin{cases} \frac{c}{c^R} \; if \; c^R > 0 \\ 1 \; if \; c^R = 0, \qquad c > 0 \\ 0 \;\; Otherwise \end{cases}$$

The cumulative intermodal connectivity indicator for a group of ports evaluates the development of the hinterland network of these ports. Both barge and rail connections are considered.

Let us consider a set of ports P, and denote by P^B the subset of ports that have established barge intermodal connections and by P^R the subset of ports that have established rail intermodal connections, $P = P^B \cup P^R$. Note that the same port can have both rail and barge connections. We also denote by m_r^B and m_r^R the number of ports in P that have barge and rail connections in a reference year, respectively.

The calculation formula of intermodal connectivity indicator for the group of ports P is defined as follows:

$$r = \frac{1}{m_r^B + m_r^R}\left(\sum_{i \in P^B} r_i^B + \sum_{i \in P^R} r_i^R\right)$$

Note that indicator (3) can be used to estimate the cumulative (for both barge and rail transportation modes) growth of the intermodal connectivity of a single port. In this case the set of ports P will consist of only one port. Both the expansion of the number of existing rail or barge connections, as well as the development of a first intermodal connection are incorporated in formula (3). The latter has a larger impact on the topological network connectivity, as it increases the number of nodes in the network. We illustrate this intermodal connectivity indicator with the following example.

Example 1. Consider a network with four ports. In Table 2 we define the number of barge connections for each port in the current and the reference years. For simplicity of representation we take into account only the weekly barge connections. In the reference year three ports have established barge connections with intermodal terminals (port 4 has not).

	Number of weekly barge connections			
	Port 1	Port 2	Port 3	Port 4
Reference year	10	6	5	0
Current year, scenario 1	11	6	5	0
Current year, scenario 2	10	6	5	1

Table 2. Input data on the number of weekly barge connections.

The first scenario considers the situation when the port 1 expands the number of weekly barge connections from 10 to 11 in the current year. The indicator of intermodal connectivity of this group of ports for this scenario is r=1.03. Note that the intermodal indicator is unweighted: one of the three ports has an improvement of the intermodal connectivity of 10% (11 vs. 10 connections). The other ports have the same connectivity as the previous year. The overall connectivity of the group of these three ports is 1.03 (the unweighted average of 1.1+1+1). The underlying logic is that the quality of the network improves more with an additional service of a port that has only a limited number of connections than an additional service of a port that has a large number of connections.

The second scenario considers the situation where a fourth port, that did not have any barge connections with inland terminals in the reference year, has developed one barge connection. For the second scenario, the indicator of intermodal connectivity of this group of ports is r=1.33, (1+1+1+1 divided by the three ports that had intermodal connections in the reference year). This is much higher than in the first scenario, even though the total number of intermodal services is the same (22). The justification for this is the fact that a new port that develops intermodal services leads to a better network of intermodal connections. It is also relevant to note that the larger the number of ports that have intermodal services, the smaller the effect of a new port that has developed a first intermodal service. This is justified with the same logic: the value of one additional port for the quality of the intermodal network depends on the number of ports already included in this network.

Both proposed indicators quantify the number of connections in a port's (group of ports) hinterland network in the current period compared to the reference year. In this way, one can draw conclusions on the development of the intermodal accessibility of individual ports as well as of the intermodal accessibility of a group of ports. Moreover, such measures are valuable indicators the attractiveness of ports (or regions) for end-shippers and freight forwarders, as these benefit from better intermodal connectivity.

An example can be found in the Annex[2].

[2] This Annex is confidential due to the use and publication of individual port data.

3 INTERMODAL CONNECTIVITY, OTHER (INLAND) PORT PERFORMANCE INDICATORS AND POLICY OBJECTIVES.

The intermodal connectivity indicator is related to policy objectives and other port performance indicators. Figure 2 shows these relations.

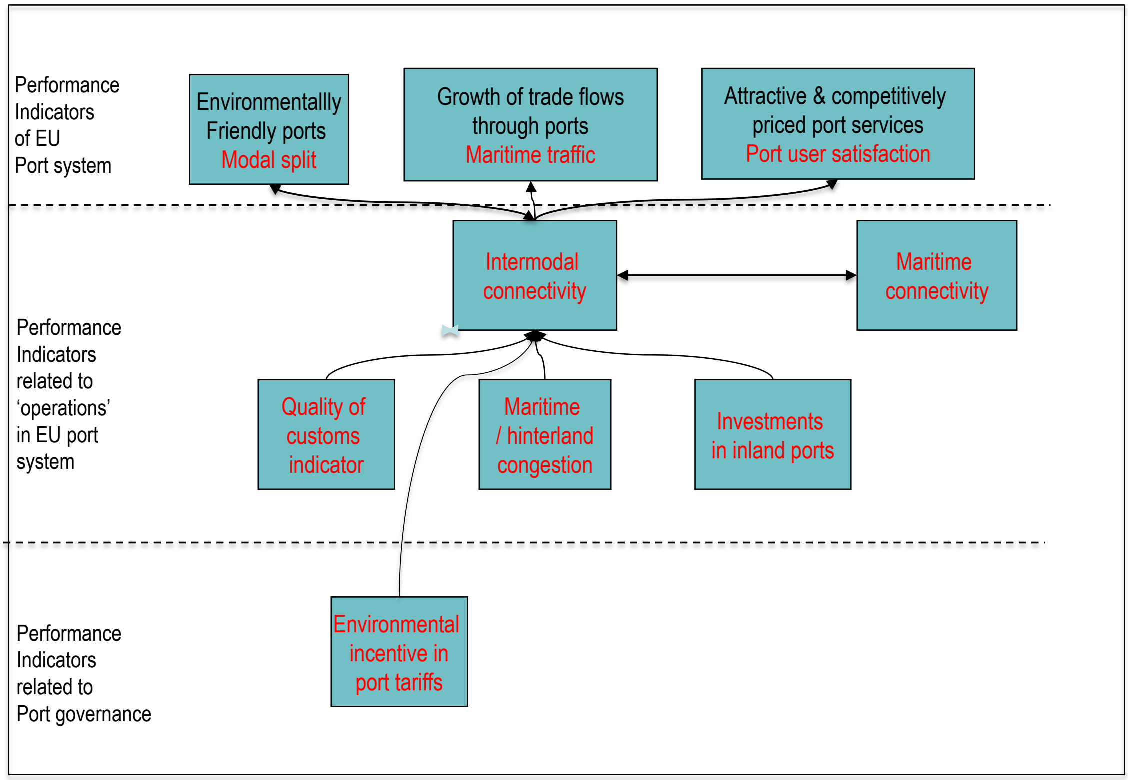

Figure 2: main relations between intermodal connectivity and other port performance indicators.

In the first layer of figure 2, some relevant policy objectives are listed (in black), as well as some potential performance indicators. Figure 3 only included the policy objectives that are directly impacted by an increased intermodal connectivity:

1. The policy objective to increase the environmental performance of transport, by reducing the carbon footprint is directly linked to intermodal connectivity. The higher the quantity of intermodal connections, the higher the share of the environmentally friendly modes rail and barge will be.
2. Intermodal connectivity contributes to the policy goal of growing trade flows through ports. Intermodal connectivity leads to lower trade costs between regions in Europe and overseas markets / suppliers.

3. Intermodal connectivity contributes to efficient and well-priced port services. The quality of hinterland connections is a relevant 'quality attribute' of the quality of a port. The port user satisfaction is expected to be higher for ports where more intermodal options are available.

Intermodal connectivity is also related to other port performance indicators that are planned in PORTOPIA:

1. First, intermodal connectivity and maritime connectivity and positively related. A port can be regarded as a platform with maritime connectivity as well as hinterland connectivity. Improvements in both are likely to have a 'spill-over effect' to the other.
2. Intermodal connectivity is positively related to the quality of custom procedures. Custom procedures that enable the immediate carry on of goods to inland nodes improve the attractiveness of the intermodal service vis-à-vis road transport.
3. Hinterland road congestion is likely to be positively related to intermodal connectivity, as it would induce a shift of cargo from road to rail and barge.
4. Investments in inland ports can also be expected to have a positive effect on intermodal connectivity.
5. Finally, environmental incentives in port dues may promote intermodal connectivity, but that is only the case when port dues somehow differentiate between road and rail / barge services.

4 BENCHMARKING OF INTERMODAL CONNECTIVITY

Intermodal connectivity can be analysed for specific ports as well as for groups of ports. Regarding benchmarking, the following benchmarking options are available:

- Ports with the EU average
- Ports with other ports in the same range
- Ranges with other ranges
- Intermodal connectivity in relation to container throughput volumes.

The first and probably most important benchmarking option is to compare a specific port for the EU average. It is important to keep in mind that the relevant EU average benchmark is the average of all ports that have established intermodal connections. Thus, the effect of 'new' ports with intermodal services is to be excluded from the EU average.

In this comparison, ports can compare their intermodal connectivity indices for rail and barge (r^B and r^R) with the European average:

$$r_{EU\ avg}^{B} = \frac{\sum_{i \in P^B} r_i^B}{P^B}$$

Likewise, ports can compare themselves with other ports in the same range. This requires a fairly large number of observations, so this is unlikely to be feasible. Alternatively, ports may be able to compare themselves with 'peers' ports within the same range of (for this specific case) container throughput.

Next, provided that sufficient ports provide data on intermodal connectivity, the ports can be divided in different port ranges, and the intermodal connectivity of these ranges can be compared. However, the value of such a benchmark is expected to be limited given the limited number of observations per range.

Finally, the intermodal connectivity of ports can be related to the throughput volumes that are handled. However, such a benchmark must be handled with care: while some ports may serve one or a few large intermodal destinations (Le Havre that serves Paris may be an example) while other ports serve a larger group of inland nodes (Hamburg may be an example). This will blur the comparison: differences in the number of terminals that are connected to the seaport may be deeply influenced by the economic structure of the hinterland (concentrated vs. dispersed destination patterns).

We thus conclude that benchmarking must be done carefully and may be especially relevant for individual ports that compare the evolution of their number of connections with that of the EU average. Still, in such a comparison one cannot relate a better evolution of intermodal connectivity causally to a better performance. Therefore, such benchmarks may provide port authorities with a 'sense' of how they do compared to other seaports, not more than that. Still, such 'indicative benchmarks' may still be valuable for port authorities.

5 NEXT STEPS IN DATA COLLECTION

This deliverable has detailed the method for the intermodal connectivity indicator. The data collection required to calculate the indicator is also included in PORTOPIA, but has not been done yet. This is because the data has to be provided by the port authorities. In PORTOPIA, a new platform for this will be developed. This will lead to a much more user-friendly tool for port authorities to insert their data.

Nevertheless, securing the cooperation of the port authorities remains crucial, as they have to provide a substantial number of data, not only on intermodal connectivity but also on a range of other indicators. Therefore, the data collection process has to be well managed. The approach is to ask the port authorities to provide a range of data in Q2 each year. That means that the data will become available in that period, so that the connectivity indicator can be collected in line with the method as outlined in this deliverable.

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6 ANNEX

This Annex is confidential due to the use and publication of individual port data

6.1 Example: calculations based on 2010 and 2011 data

Data on intermodal services is not publicly available. However, many port authorities do collect such data. Thus, the data need to be provided by port authorities. As part of the PPRISM project, led by the European Seaports Organisation (ESPO), European ports were asked to provide data on intermodal connections for the years 2010 and 2011, through an on-line survey, administered by ESPO. Overall, due to the fact that ESPO communicated the relevance of this project, a satisfactory response was received[3].

[3] See http://pprism.espo.be/ProjectResults.aspx (WP3 Pilot Project) for a more detailed description of the survey as well as the results.

Country	Number of ports
Albania	1
Belgium	1
Estonia	1
Finland	2
France	3
Germany	3
Ireland	2
Italy	4
Latvia	1
Malta	1
Netherlands	1
Portugal	1
Spain	3
Sweden	2
Total	**26**

Table 3. The geographical distribution of ports that provided data.

A total of 26 ports provided intermodal connectivity data: the geographical distribution of these ports is given in Table 3 and the distribution of their annual throughputs is indicated in Table 4. 9 out of these 26 ports indicated that they do not have weekly intermodal services. The number of ports that provided data is limited. However, these ports handle roughly 70% of all European container volumes. The limited number of ports who provided data is partly explained by the fact that only relatively large ports have sufficient annual container volumes to make intermodal services viable. Given the minimum required scale for intermodal services, such services are very unlikely below a minimum annual throughput of around 200.000-300.000 TEU. The number of European ports with such volumes is about 40 to 50. Nine ports without intermodal services have indicated that they do not have intermodal services, other such ports may not have answered this survey question (instead of filling out two zero's). So the 19 responses of ports that have intermodal services may be a relatively large share of the ports that have intermodal services.

Throughput, million tonnes	Number of ports
> 25	18
10 – 25	3
1 – 10	5
Total	**26**

Table 4. The distribution of annual throughput of ports, which are included in the survey sample.

Name of the column	Value
Number of ports provided data (sample size)	26
Number of observations for the rail connectivity	16
Number of observations for the barge connectivity	4
Number of ports where the first rail service started in 2011	1
Number of ports where the first barge service started in 2011	1

Table 5. Results of the online survey on the intermodal connectivity.

The results of the survey based on the sample of 26 ports are presented in Table 5. The number of port observations for the direct rail connections (which operate at least weekly) is 16 and the number of port observations for the direct barge connections (which operate at least weekly) is 4. Table 6 provides data on the number of rail and barge connections of individual ports for 2010 year (columns II and IV) and for 2011 year (columns III - V), respectively. The total number of ports which provide data on intermodal connectivity is 17, the remaining nine ports indicated that they do not have any data available with respect to the intermodal barge and rail connections, therefore, the corresponding data is not provided in Table 6.

The values of the indicator of intermodal connectivity via barge and rail for each of the seventeen ports are provided in columns VI and VII, respectively. These values are calculated according to formulas (1) and (2), given that 2010 is the reference year. Note that the port P16 has developed one new barge connection in 2011 and the port P17 has developed two new rail connections in 2011, therefore, the values of the corresponding indicators of the intermodal connectivity via barge and rail are equal to the number of connections developed in a current year, i.e., $r^B = 1$ for the port P16, and $r^R = 2$ for the port P17. Ports P2-P3, P5, P7-P10, P12, and P15 have developed rail connections additional to those that have been serviced in the reference year, and ports P9 and P16 have developed barge connections additional to those that existed in the reference year. The increase of the values of indicators of intermodal connectivity for ports P2-P3, P5, P7-P10, P12, P15-P16 is less than the increase of the values of corresponding indicators for ports P16 and P17. As it was explained in section 3, additional connections have a smaller impact on the development of the connectivity of the analysed group of ports than the newly developed connections. This is reflected in different growth rates of the values of indicators for individual ports.

Number of weekly intermodal connections (direct, at least weekly)					Indicator of intermodal connectivity (individual port)	
	via rail		via barge		via rail	via barge
I	II	III	IV	V	VI	VII
	2010	*2011*	*2010*	*2011*	*2011*	*2011*
P1	0,00	0,00	45,00	48,00	0,00	1,07
P2	9,00	10,00	0,00	0,00	1,11	0,00
P3	4,00	5,00	0,00	0,00	1,25	0,00
P4	15,00	15,00	0,00	0,00	1,00	0,00
P5	690,00	700,00	0,00	0,00	1,01	0,00
P6	2,00	2,00	0,00	0,00	1,00	0,00
P7	5,00	6,00	0,00	0,00	1,20	0,00
P8	126,00	141,00	0,00	0,00	1,12	0,00
P9	10,00	12,00	20	23,00	1,20	1,15
P10	22,00	29,00	5	5,00	1,32	1,00
P11	2,00	2,00	0,00	0,00	1,00	0,00
P12	5,00	7,00	0,00	0,00	1,40	0,00
P13	5,00	5,00	0,00	0,00	1,00	0,00
P14	1,00	1,00	0,00	0,00	1,00	0,00
P15	41,00	52,00	0,00	0,00	1,27	0,00
P16	2,00	2,00	0,00	1,00	1,00	1,00
P17	0,00	2,00	0,00	0,00	2,00	0,00
Total					18,88	4,22

Table 6. Connectivity indicators for rail and barge for individual ports.

The value of the indicator for the sample group of 26 ports is calculated according to the formula (3) as follows: $r = 0.056\,(18.88 + 4.22) = 129,$ where $m_r^B = 3$ and $m_r^R = 15$. It is the unweighted sum of all non-zero values of intermodal connectivity indicators (via barge and via rail) calculated for individual ports. Due to the geographical and annual throughput distributions of 26 ports, which participated in the survey, we believe that the value of the group measure of the intermodal connectivity can be used to characterize the intermodal connectivity of all European ports. Figure 3 shows the European intermodal connectivity indicator (expressed in percentage), given the 2010 year is the reference year.

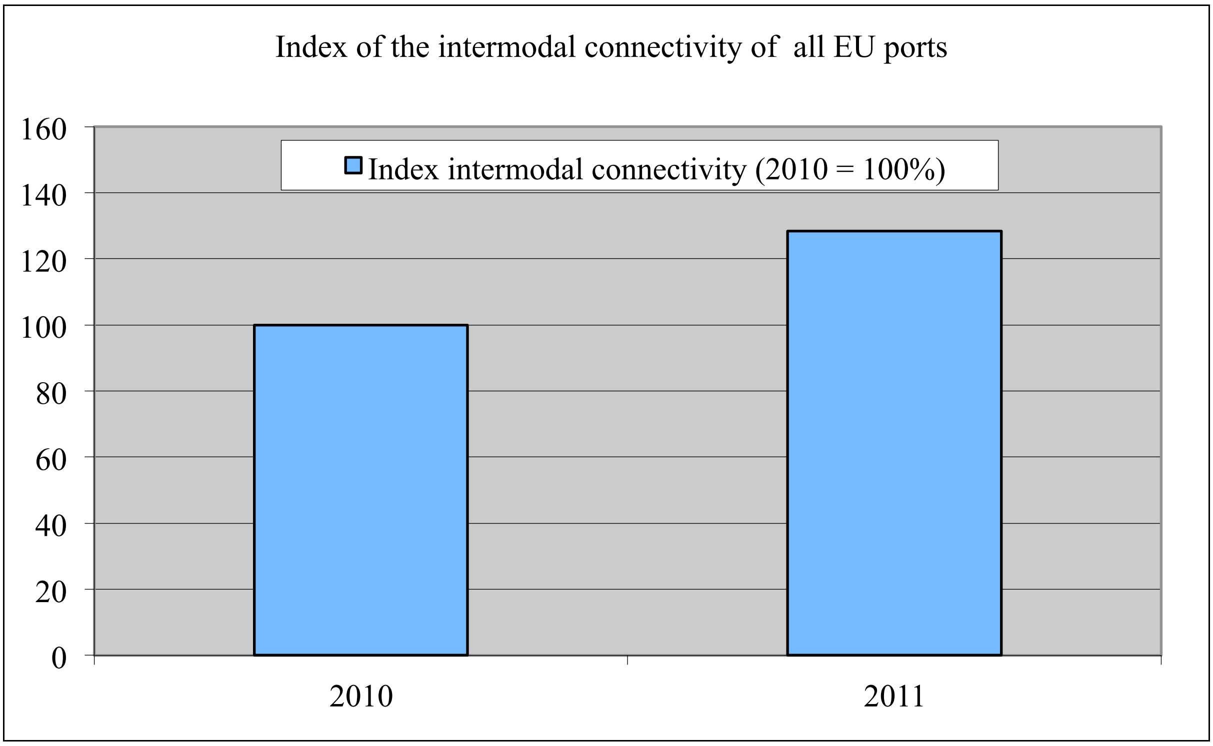

Figure 3: European intermodal connectivity indicator based on data provided by 26 EU ports.

Figure 3 suggests that the intermodal connectivity of the EU port system has increased for 29% in 2011. We acknowledge the weakness that the index currently only covers two years. The index will become more relevant once it can be calculated for a longer period of years. Careful interpretation of this indicator is required. As argued in section 3, a port that previously did not have intermodal services but has developed one service carries a stronger weight than a port that has expanded weekly intermodal services from 10 to 11 destinations. Thus, the fact that the intermodal connectivity has gone up with 29% does not suggest that the intermodal *volumes* have gone up with 29%. As argued in section 3, we think that this connectivity formula has its advantages: increased intermodal connectivity creates value for importers and exporters, even when it does not directly lead to higher intermodal volumes.