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Trade Liberalisation and Sustainability: A Case Study of Agro-Food Transport Optimisation

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Abstract:

Purpose: *The aim of the article is to describe the characteristic features of the international trade in agricultural products, and to determine how the optimisation of international flow of goods could contribute to reducing the environmental burden of transport.*
Design/methodology/approach: *The research is based on a combination of three key databases - FAOSTAT bilateral commodity trade matrices, CEPII distance tables and the EcoTransIT.*
Findings: *It has been proven that the current international trade relations form dense, scale-free networks, shaped under the influence of both bi- and multilateral historical, cultural, political and economic relations is approved. By the application of linear optimisation for the minimisation of total greenhouse gas emissions it can be proven that the trade in wheat is far from optimal. Theoretically, concerning 2016 is possible to reduce environmental pollution by 38%. In the case of maize the re-organisation of the global trade network could reduce pollution by 18%, and in the case of soya beans by 8%. Comparing the difference between actual and optimal transportation networks based of historical data (2007-2016) it could be proven, that the average additional environmental burden, caused by suboptimal international transport were in case of wheat 36%, in case of maize 11% and in case of soya beans 10%.*
Practical implications: *The optimization of the global trade and international transport of these three commodities offers a more than 500 kt/year decrease in greenhouse gas emissions. Comparative analysis of current and optimized trade networks highlights the increasing importance of the role of regional hubs in key exporting states.*
Originality/value: *This fact underlines the importance the efforts for liberalisation of international trade system.*

Keywords: *EcoTransIT, globalization, international trade, linear programming.*

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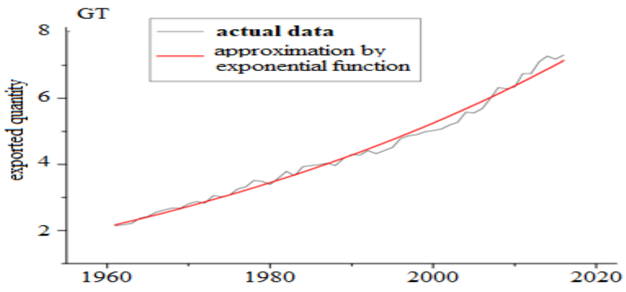
1. Introduction

It is well documented that since prehistoric times agricultural and food products have been the most universally traded commodities (Mauss, 1934). In the opinion of Zimmerman (1933) *"no other commodity has left as definite an impress on the transportation map of the world as wheat".* In the last half century, global agricultural trade has been increasing at an exponential rate (Figure 1). This fact can be explained by relatively low fuel prices (Abadie *et al.*, 2017), as well as the rapid development of communication, financial and transportation infrastructure and technology (Desrochers and Szurmak, 2017; Slusarczyk, 2017). Borchert and Yotov (2017) have proven, that the effects of proximity have fallen and the importance of trade agreements has increased over time. Cairncross (1997) considers the decreasing importance of transportation costs as a positive development, because "the death of distance will not only erode national borders; it will reduce the handicaps that have up until now bordered fringe countries". At the same time, the adverse ecological consequences of long-distance transportation are widely analysed and documented (Jiang and Green, 2017; Liano *et al.,* 2018; Rajiani and Kot, 2018; Zhou and Lee, 2017).

Shipping is the dominant transport mode for long-distance trade in food and agricultural products (Rodrigue and Notteboom, 2015). It is a relatively energy efficient form of transport (Rehmatulla and Smith, 2015), but can be considered an important environmental burden (Walker *et al.*, 2018), due to air pollution (Matthias *et al.,* 2010), vessel oil spills (Nagarajan, 2018), ballast water disposal (David *et al.,* 2018), dry bulk cargo releases (Seebens *et al.*, 2013) anti fouling pollution (McNeil, 2018), and waste disposal at sea (Tornero and Hanke, 2016) and at ports (Pérez *et al.,* 2017), as well as the effects of work carried out in harbours (Davarzani *et al.*, 2016; Oláh *et al.,* 2018a; Oláh *et al.,* 2018b; Romeo *et al.,* 2015; Sánchez-Arcilla *et al.,* 2016).

The international trade in such food, as honey can be described by a few hubs, around which there are various, relatively peripheral states to be considered a scale-free network (Popp *et al.,* 2018). The edges of the networks are the trade flows of honey, and the hubs, as nodes of the network are the differ states. Moreover, the network cooperation can support substantial not only cost-effective, but environmental benefits, especially in the case of trading of highly-controlled fresh and frozen food (Stellingwerf *et al.,* 2018). Hricko (2006) and Poliačiková (2016) offers some easily understandable case studies on the adverse health effects of long-distance trade, noting that *"air pollution from international trade and goods movement is a major public health concern at the state-wide, regional and community level. Adverse health impacts from the pollutants associated with goods movement include but are not limited to premature death, cancer risk, respiratory illnesses and increased risk (Kliestik et al., 2018) of heart disease adverse birth outcomes, effects on the immune system, multiple respiratory effects, and neurotoxicity are additional potential health effects"* (CARB, 2005).

Figure 1. *Increase in the international trade in crop products (in 10^9 metric tons [GT]), and its approximation by an exponential function ($Q=0.0005341^{-t/66.24}-1.6648$), where t denotes years ($r^2=0.982$).*



Source: Authors' own calculations, based on FAOSTAT database (FAO, 2018).

The aim of the current article is to describe the basic characteristic features of the international trade in agricultural products, and to determine how the optimisation of international flow of goods could contribute to reducing the environmental burden of transport. We will test the hypothesis that (H_1) the current structure of international agricultural trade is far from optimal, because it has developed under the influence of a complex set of socio-economic forces, which is why (H_2) there is a wide scope to reduce the sum of the transportation distances of different goods, and consequently the environmental burden caused by the international transportation of goods.

The article is structured as follows: in the methodological part we offer a brief summary of the tools applied to analyse and optimise the flows of agricultural products, and present the databases of various investigations. The results and discussion part highlights some characteristic features of current agricultural trade networks, and demonstrates that the optimisation of international agricultural trade could be an important step towards reducing the environmental burden. The article ends with some conclusions and suggestions for enhancing the sustainability of agro-food supply chains.

2. Theoretical Issues

The network paradigm helps us understand and model the flow of goods in agricultural trade systems, "network" is a generic term for graphs (Albert and Barabási, 2002) which represent a set of nodes lined by edges. That is why complex systems in general, and transport systems in particular, can easily be represented by graphs whose nodes are the actors (in our particular case, countries) and whose edges represent the flow of goods (in our case, agricultural products) between them (Ruzzenenti and Basosi, 2017). In the opinion of Cumbo *et al.* (2014) the structure of the network allows for a combination of different characteristic features and scales, each node inherits its role in the system by its position in the network, while the global features of the network as an organic entity depend upon its edges. It should be, however, noted that any network is combined with the likelihood that certain negative phenomena may arise, i.e., pathologies which reduce the attractiveness of this type of activity. Some of these pathologies are similar to those occurring in any organization, while the others are a specific feature of network organizations (Cygler and Sroka, 2014). The flow of agricultural products between different countries (nodes) can be considered as a weighted network, because the exported quantities reflect the intensity of transport between these entities.

A key property of a node in a network is its degree, representing the number of links it has to other nodes. The degree distribution - p_k - provides the probability that a randomly selected node in the network has degree k. According to the theory of (Barabási and Albert, 1999), the majority of social (Shpak et al., 2017) and economic systems can be characterised by a heavy-tailed distribution. These networks are characterised by local hubs, and are called scale-free networks. Betweenness centrality is a measure of the extent to which a node lies on paths between two other nodes (Newman, 2005). A similar, but more complex measure of the embeddedness of the different nodes in the network is the bridging centrality, expressing the brokerage role of different nodes, based on the classic work of (Granovetter, 1983).

In the last few decades there has been a mushrooming of the different tools developed to understand the structure of networks, but a major limitation of analytical methods stems from the fact that the strength of edges (ties) is not taken into account, which is why we have applied specific indicators which are able to grasp and mirror the differences in the intensity of relations between the states investigated (Opsahl *et al.*, 2010). We have applied the CentiScaPe collection of algorithms for an analysis of the characteristic features of weighted networks (Su *et al.*, 2014). Based on this methodology, originally developed and applied for the analysis of biological systems (Scardoni *et al.*, 2009), we have been able to determine the most important indices of the centrality of different nodes. To characterize the position of individual nodes in large, complex networks of international trade flows of agricultural goods, we have applied Guimera and Amaral (2005)'s network topology approach. Further characteristic features of networks, based on similarities of node positions, have been analysed by an Incremental Principal Component Analysis (IPCA) algorithm. This method - originally developed for the identification of protein complexes - is a density based clustering method which is able to identify the dense subgraphs in directed, weighted networks (Li *et al.*, 2008; Li *et al.*, 2017).

The visualisation of the network configurations has been made by the clustered circular layout (McGuffin, 2012) and the edge-weighted, spring-embedded algorithms (Fung *et al.*, 2010) of Cytoscape software (Franz *et al.*, 2015). The optimisation of the international trade flows of agricultural products has been realised by linear programming. This method is a well-known tool for optimizing transportation systems (Charnes and Cooper, 1954). In general, the objective function is the minimisation of transportation distance (Lévy and Schwindt, 2018), but in our case we will focus on the minimisation of the environmental pollution caused by the transportation of different agricultural commodities. The canonical form of our model is as follows:

Minimise $c^T x$
subject to $\Sigma x_{ij} \leq a_i$ and $\Sigma x_{ij} \geq b_j$,
and $x_{i,j} \geq 0$

where **x** represents the vector of distances between different nodes, **c** is the vector of the environmental burden of the transportation of a unit of goods from *i* to *j*, c_{ij} is an element of matrix **C** containing the environmental burden of transportation of goods between *i* and *j* nodes, **a** is the vector of supply for each country, and **b** is the vector of demand for different countries. We have applied the Lindo software (Lin and Schrage, 2009), which is widely applied in the optimisation of transport processes (Chanda, 2018; Kovács and Kot, 2017).

We have analysed the world trade in agricultural products on the basis of three typical products: wheat, maize, and soy. These products make up more than one third of world trade in agricultural goods in quantitative terms. Wheat can be considered a widely produced crop, while maize and soy production is dominated by a smaller set of exporters.

Data on the international transport of agricultural commodities have been obtained from the trade matrices of the statistical database of the Food and Agricultural Organisation of the United Nations (FAO). This database reports yearly data. The latest available data concern 2016, which is why we have applied this dataset.

In the case of the optimisation of trade flows between different countries, two questions have emerged: (1) how can the distance between different countries be determined, and (2) how can we quantify the environmental burden caused by the transport of goods.

Based on the classic work of Tinbergen (1962), the calculations in trade economics have been founded on great-circle (crow flies) distances, but these data do not represent the real transport distances between different locations. There is a wide choice of harbour-distance tables, but these do not offer a real picture of the importance of different ports. Based on a combination of databases on maritime shipping, Mayer and Zignago (2012) offers a comprehensive table of distances between 227 countries and territories. The importance of ports has been determined on the basis of existing maritime routes. In the case of three countries (CAN[5], RUS and USA), the database has taken into consideration not one, but two ports, and the smaller distance between the given port and the port of the partner country has been calculated. The distances between landlocked countries and their counterparts (if they have access to a sea harbour) has been determined on the basis of the minimum

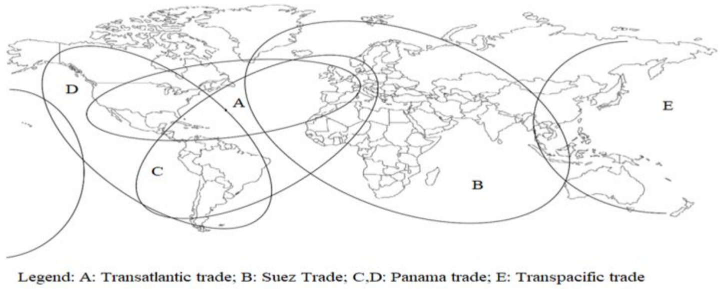
[5] *In this article countries are indicated by their three digit codes, according to the ISO 3166 standard.*

road distance between the capital of a landlocked country and the nearest foreign relevant port. The distance between two landlocked countries has been calculated on the basis of the road-distance between the two capitals. We have not considered the distance between the production area and the logistical centre (harbour or railway station) because this transportation activity should be realised in all export activities.

The environmental burden caused by transport has been determined on the basis of greenhouse gas emissions, because this indicator is generally applied to characterize the environmental pollution caused by different forms of transport (Nocera *et al.,* 2015). There is an increasing range of tools available for determining the environmental footprint of transport, including Hapag-Lloyd EcoCalc (Ziegler, 2014), COPERT (Berkowicz *et al.,* 2006), Versit+ (Bask and Rajahonka, 2017; Smit *et al.,* 2007). We have chosen the EcoTransIT database (EWI, 2018). In the opinion of (Auvinen *et al.,* 2013) *"Due to its very detailed and accurate database with worldwide coverage EcoTansIT World is considered as one of the most important items".* This database is widely applied in operations research (Recanati *et al.,* 2018). On the basis of its data, various environmental pollution values have been determined for the different types of ships used on various sea routes. The emissions of different greenhouse gases are converted to CO_2 emissions in line with current European standards (EN_DIN, 2012). Different ship categories are used in marine trade lines: to differentiate the vessels and the environmental pollution they cause when used on different marine trade lines, we have adopted the categorisation of (IMO, 2009), summarised in Figure 2.

The emissions from different ships depend on fuel consumption and the parameters of navigation, which is why the "nominal" values of environmental pollution caused by different ship-types had to be adjusted for speed and cargo utilisation. The ratio of operating speed to design speed and the cargo utilisation have been determined by (IMO, 2014), based on business practices, according to ship type and size classes.

Figure 2. *Division of marine trade lines in the global trade in agricultural commodities.*



Source: *IMO (2009) 2018, authors' own editing.*

The most important characteristic features of the different ship-categories used in the framework of the current research are summarised in Table 1.

Table 1. *Characteristic features of the most important ship-categories used in different sea-routes and their environmental burden.*

Ship category	**Speed reduction (%)**	**Load factor (%)**	**Greenhouse gas emissions in CO_2, calculated to one tkm (t)**
Suez trade (80-200 k deadweight tonnage)	23	49	5.45652E-06
global average world (bulk carrier; 35-120 k deadweight tonnage)	26	58	8.66532E-06
intra continental (bulk carrier; < 35 k deadweight tonnage)	22	57	1.24787E-05
Transatlantic (bulk carrier; 35-80 k deadweight tonnage)	22	55	8.12277E-06
other global trade	22	55	7.30119E-06
transpacific trade (bulk carrier; 35-200 k deadweight tonnage)	23	53	6.66563E-06
panama trade (bulk carrier; 35-80 k deadweight tonnage)	22	55	8.12277E-06

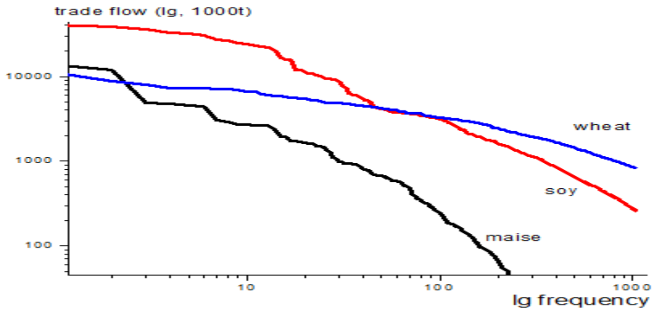
Source: *Authors' own calculations, based on (Initiative, 2018).*

In the case of landlocked countries between which there is no sea, we have approximated the environmental burden caused by transportation on the basis of a 1300 t heavy train driven by a diesel engine (the proportion of electrified lines is globally less than 30%, (UIC-IEA, 203)), with a 100% load factor. The environmental burden of these trains have been calculated on base of current resources of global railway development (Dimoula *et al.*, 2016; Profillidis *et al.*, 2014). The matrices describing the environmental burden per unit distance and unit quantity of products between each pair of countries involved consisted of 10^4 data, because the number of sending nodes were between 50 and 90, and the number of receiving nodes between 90 and 135.

3. Results and Discussion

The structure of networks in different years shows considerable similarity. There is a fluctuation in trade flow values between countries, that's why we have used rank correlations: the average Spearman rank correlation value of edges (different transport flows between the countries) between years for period 2007-2016 have been 0.71 in case of wheat, 0.86 in case of maize and 0.89 in case of soya beans. This fact offers a favourable possibility to generalise our results. For simplicity, we show our results on base of latest available data, 2016. At the same time we emphasise, that the results for another years were similar. There are considerable similarities between the structures of the investigated product-flows. The most important is the fact that all of the networks are rather dense: there is a high ($n<10^3$) number of trade relations between the different states (Figure 3).

Figure 3. *The distribution of trade flows between different countries*



Source: *Authors' own calculations, based on FAOSTAT database (FAO, 2018).*

The majority of these flows are not significant; the distribution of the intensity of bilateral trade relations can be described as a heavy-tail (e.g., lognormal, gamma or Weibull) distribution. The most important trade flows are summarised in Table 2.

Table 2. *The ten most important bilateral trade relations (million t).*

Maize			**Wheat**			**Soy**		
Exp.	Imp.	Quant.	Exp.	Imp.	Quant.	Exp.	Imp.	Quant.
USA	MEX	13.86	RUS	EGY	5.82	BRA	CHN	38.56
USA	JPN	11.89	ARG	BRA	4.17	USA	CHN	35.97
USA	KOR	4.85	FRA	DZA	3.67	ARG	CHN	7.79
BRA	IRN	4.79	AUS	INZ	3.47	USA	MEX	3.64
USA	COL	4.56	USA	MEX	2.76	USA	IDN	2.57
ARG	VNM	4.42	USA	JPA	2.73	USA	JPN	2.36
ARG	EGY	3.07	USA	PHL	2.68	USA	NLD	1.96
BRA	VNM	2.88	RUS	TUR	2.65	CAN	CHN	1.79
BRA	JPN	2.69	UKR	IDN	2.47	BRA	ESP	1.62
USA	PER	2.69	FRA	MAR	2.33	BRA	THA	1.53

Source: *Authors' own calculations.*

The network of trade in different commodities can be described as a scale-free one: the distribution of out-degree nodes follows the power low (Table 3) on example of 2016 data.

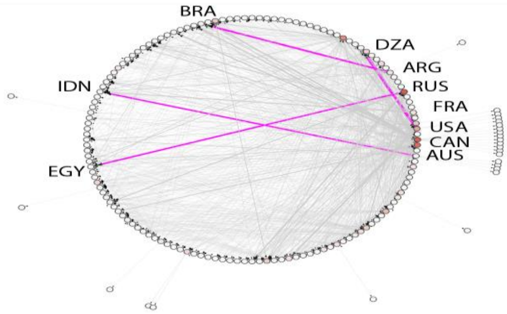
Table 3. *Distribution of out degrees of the nodes in networks of different commodities on base of data 2016*

Wheat (r^2=0.84)
$Y=4.79x^{-0.523}$
Maize (r^2=0.89)
$Y= 8.774x^{-0.565}$
Soy (r^2=0.91)
$Y=6.24x^{-0.577}$

Source: *Authors' own calculations, based on FAOSTAT database (FAO, 2018).*

The networks have been divided into subgraphs by the IPCA algorithm. The number of subgraphs varies from 32 (chicken) to 78 (maize). Analysis of the members of the subgraphs has shown that on average 87% of the members of the same cluster are (1) members of the same regional economic organisation (e.g., EU), or (2) have some common historical background (e.g. former members of the USSR, former colonies), or (3) have some tight military-political relationship (e.g. JAP-USA). An in-depth analysis of the causes of this situation lies beyond the scope of the current research. In the wheat trade RUS, FRA, AUT and ARG are the most important exporters (Figure 4).

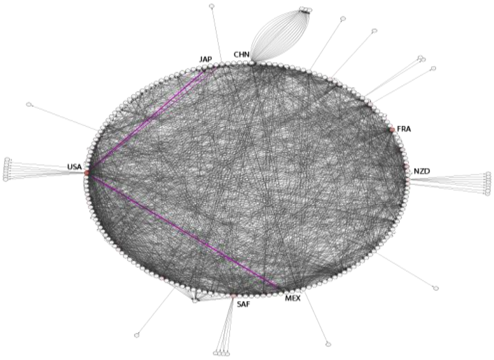
Figure 4. *The global network of the wheat trade, 2016.*



Source: *Authors' own calculations.*

The main supplier of EGY is RUS, of BRA is ARG and of IND is AUS, RUS, CAN and FRA can be characterised by a high level of betweenness centrality. France exports mainly to DZA and numerous North-African countries join the world trade network via this country. The width of the arrows is proportional with trade intensity; the most important trade flows are indicated by pink arrows. The intensity of the fill colours of the different circles representing the states is proportional with their betweenness centrality. The trade in maize is dominated by the USA and ARG. The former country supplies mainly the American, the latter the South-American and African, states (Figure 5).

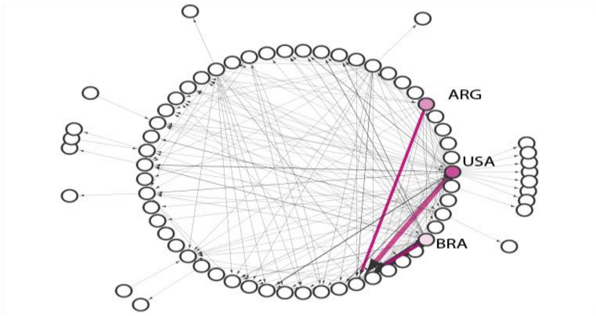
Figure 5. *The global network of the maize trade, 2016.*



Source: *Authors' own calculations.*

The width of the arrows is proportional with trade intensity; the most important trade flows are indicated by pink arrows. The intensity of the fill colours of the different circles representing the states is proportional with out of their centrality. The trade in soy is determined by the USA and BRA. The giant trade flow between these states and CHN is an extremely important part of the global agricultural market (Figure 6).

Figure 6. *The global network of the soy trade, 2016.*



Source: *Authors' own calculations.*

The width of the arrows is proportional with trade intensity; the most important trade flows are indicated by pink arrows. The intensity of the fill colours of the different circles representing the states is proportional with their betweenness centrality. Analysing the centrality of different nodes it is obvious that with exception of certain cases (e.g., USA and BRA in the soy trade), there are no characteristic hubs in the networks.

4. Conclusions

Linear programming offers a feasible global solution for the optimisation of trade flows between different countries. Results of optimisation on base of supply and demand data concerning 2016 are summarised in Table 4. Comparison of the current and optimal solutions highlights that the optimised system offers a considerable reduction in environmental burden.

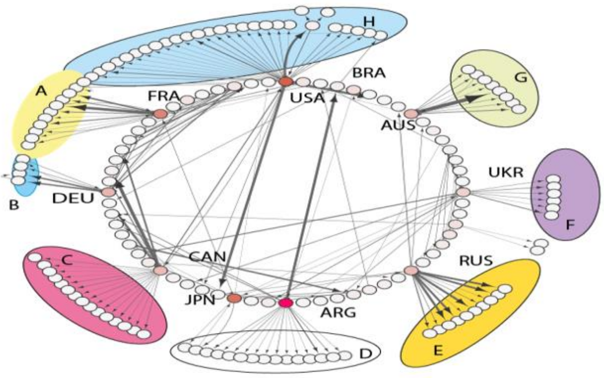
Table 4. *Results of the optimisation of international trade routes for key agricultural commodities.*

Goods	Current CO_2 emissions (kT)	CO_2 emissions according to the optimal scheme (kT)	Ratio between actual and optimal data (%)	Reduction in CO_2 emissions (kT)
wheat	7748.72	4890.64	63.12	2858.09
maize	8763.36	7398.01	84.42	1365.35
soy	13277.28	12343.82	92.97	933.46

Source: *Authors' own calculations.*

As a general rule it can be stated that the environmentally optimal structures are much lesser dense than the actual networks. The importance of local hubs further increases, and according to the nod- categorisation system of Guimera and Amaral (2005), provincial hubs appear in all networks. In the case of the wheat trade (Figure 7) the most important countries which FRA exports wheat to (Figure 7) should be ITA, South-European countries and the North-African countries (Cluster A).

Figure 7. *The optimised structure of the wheat trade, detailed explanation in the text.*



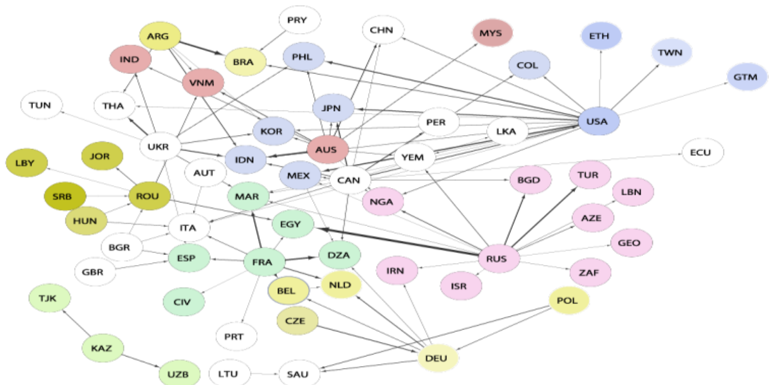
Source: *Authors' own calculations.*

The primary markets of DEU should be the Central-and Northern-European states (Cluser B). Canada and Argentina should be important suppliers of African counties (Clusters C and D). The main markets of RUS should be the Middle-Eastern and Central-Asian countries (Cluster E). The most important partners of UKR will be the countries of the Middle East. The supply of the Pacific region should be based on AUS (Cluster G), together with the USA (cluster F). For the USA, besides the Pacific region, the supply of a part of Central and South America would be optimal. The optimal structure of the maize network can be most plastically depicted by an edge-weighted spring-embedded layout algorithm (Figure 8). Members of the most characteristic clusters are indicated by the same colour. Obviously, the most important centres of trade are FRA, RUS, USA and AUS. In case of soy (Figure 9) the USA should focus its exports only on supplying CHN.

The most important markets for BRA should be CHN and JAP. The supply of EU member states should be covered from other sources. The width of the arrows are proportional with trade intensity; the most important trade flows are indicated by red and blue arrows. The intensity of the fill colours of the different circles representing the states is proportional with their betweenness centrality.

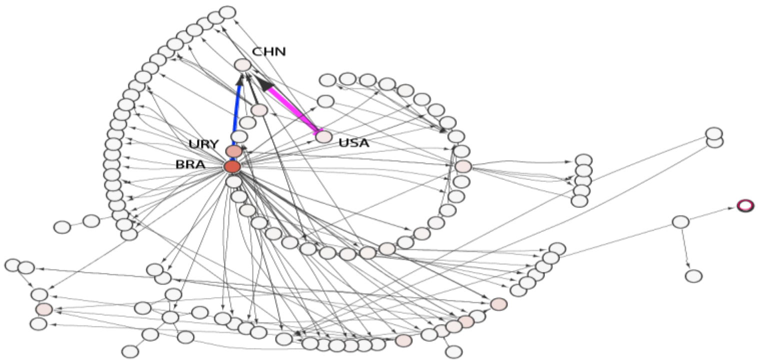
In summary it can be determined that the current trade flow is far from optimal, which is why there is a wide room for improvement. Our results support the estimations of (Eide *et al.*, 2011; Pérez *et al.*, 2017; Rehmatulla and Smith, 2015) on the potential impact of voyage optimisation on possible reductions in CO_2. There are considerable differences in estimations of the average cost of reducing CO_2 emissions. If we apply a (rather conservative) estimation of 20 USD/t CO_2, then the suggested optimisation could be the equivalent of 1.04 mrd USD/year. Reducing the role of import-regulations could be an important step towards reducing the environmental burden caused by this considerable - and as we have seen, unnecessary - trade.

Figure 8. *The edge-weighted spring-embedded layout of the optimised maize trade network.*



Source: *Authors' own calculations.*

Figure 9. *The optimised global network of the soy trade.*



Source: *Authors' own calculations*

If we analyse the distribution of states from the point of view of the environmental burden of supplying these states with different agricultural commodities (Table 5), it is obvious that the majority of these states are in the Far East and Northern Africa. From this it follows that if we could increase agricultural production in these states (especially in CHI and IND), the long-range distances covered by shipping could be considerably reduced.

Table 5. *List of states, the supply of which involves the highest levels of greenhouse gas emissions (kt) on base of 2016 data.*

Wheat		**Maize**		**Soy**	
IDN	484.489	JPN	15341.786	CHN	8567.021
ESP	265,814	MEX	1410.5991	TWN	365.497
BGD	236.126	KOR	978.9907	THA	352.172
NGA	236.064	VNM	808.5151	IDN	318.370
DZA	228.495	CHN	7405.935	NLD	289.370
JPN	225.549	ESP	6019.860	DEU	229.179
BRA	213.248	EGY	5932.617	ESP	202.620
MAR	180.473	IRN	5660.539	IRN	183.781
THA	155.524	COL	4586.084	JPN	182.156
VNM	129.971	ITA	4466.655	VNM	179.718

Source: *Authors' own calculations.*

Linear programming serves primarily the solution of actual problems, but we have been interested, whether our results could be generalised for another year. That's why we have compared the actual and optimal transportation systems for three products to time period 2007-2016 and determined the additional environmental burden, caused by suboptimal transportation systems. Our results have proven, that these differences were 36%, 11% and 10% in case of wheat, maize and soya beans respectively. The facts above highlight the importance of global coordination on international trade of agricultural commodities. This idea in not new. The well-known Hungarian researcher and diplomat, Hevesy (1939) has stated it in his classic book of global world wheat trade: *"all countries, but especially the great wheat-exporting and the great wheat-importing countries, should support a policy of co-operation for maintaining an equilibrium position amidst the highly artificial conditions of the world of to-day"* (Dimoula *et al.*, 2016)

At the same time it should be borne in mind that this is just a relatively short-term solution, because the development of local production capacities could be a further step towards reducing the environmental burden. For example, if meat consumption increases in the developing and relatively lesser developed world, this will involve the increasing use of maize and soy. Without a further development of local production capacities, a considerable increase in agricultural and food miles, and increasing environmental pollution can be expected.

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