Mapping supply and demand of a provisioning ecosystem service across Europe

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Abstract

Human welfare is dependent on the availability of ecosystem services (ESs). There is an urgent need to explore the balance between ES production and consumption areas to ensure the sustainable use of the natural capital. Here, we present a spatial accessibility analysis to explicitly evaluate the balance between ES supply and demand across Europe. We used a central food product (crop) as an example of provisioning ES, where transportation is required to satisfy the demand. Our results show large differences in a country's ability to produce food in relation to its demand, leading to significant risks of over- and underproduction on a regional scale. An ecosystem's capacity to provide services exceeded especially in the middle of Europe. The majority of the countries would benefit significantly by balancing the supply and demand at international level, even at close distances. Our results demonstrate how the situation in Europe can change if the international distribution of the food ES is prevented. By using a state-of-the-art accessibility method instead of commonly used overlay analysis, it is possible to identify where to invest in transportation and enhance natural capacity to respond to the possible changes in food production or the growing demand of food energy.

Keywords: accessibility, demand, provisioning ecosystem service, spatial flow, supply

1. Introduction

The environment supports human existence and well-being with a number of goods and services. These include products like food, medicine and fiber, which are considered as ecosystem services (ESs) (Costanza et al., 1997; Haines-Young and Potschin, 2010; MEA, 2005). The concept of ESs have become popular in contemporary science and it has potential to become a major tool for environmental policy and decision making (Fisher et al., 2009; Seppelt et al., 2011). However, the rapid progress and complex nature of the ES topic has increased the need for practical applications of the concept (Burkhard et al., 2012; Carpenter et al., 2009; Daily et al., 2009; Daily and Matson, 2008). On that, ES mapping approaches have proven to be an essential tool for bringing the complex spatial information of ES into practical application (Burkhard et al., 2012).

The ES framework is an anthropocentric concept where the utilization has a fundamental role, since ecosystem's conditions and processes become an ecosystem service only when they are consumed by humans (Fisher et al., 2009; Goldenberg et al., 2017). ESs are commonly produced and consumed in different geographical locations (Crossman et al., 2013; Fisher et al., 2009; Serna-Chavez et al., 2014). Goods may be delivered from provisioning to benefiting areas either passively through biophysical processes (e.g. air flow) or through an investment of human capital (e.g. transport) (Serna-Chavez et al., 2014; Villamagna et al., 2013; Wolff et al., 2015). This highlights the importance of a spatial connection e.g. ES flow (Bagstad et al., 2013; Serna-Chavez et al., 2014; Syrbe and Walz, 2012; Wolff et al., 2015) between ES production areas and the corresponding benefit areas (beneficiaries). However, the use of *ES flow* as a term has been ambiguous, referring either to general service provision or to the path of delivery from the providing to the benefiting areas (Bagstad et al., 2013; Schröter et al., 2014; Villamagna et al., 2013). Here, we use a term *spatial flow* to separate it from ES flow to identify the spatial (transportation) connection between provisioning and benefiting areas (Bagstad et al., 2013).

Recently, several studies have investigated ESs delivery processes and made a distinction between ES supply and demand (Burkhard et al., 2014; Schröter et al., 2014; Villamagna et al., 2013). Supply is defined as the capacity of a particular area to provide ESs within a given time (Burkhard et al., 2012). Note that 'capacity' in this case refers to an actually used set of natural services, such as a harvested crop yield. There is weaker consensus around the concept of demand (Schröter et al., 2014; Villamagna et al., 2013; Wolff et al., 2015). Following the definition of Burkhard et al. (2012)

we define demand as “the sum of all ecosystem goods and services currently consumed or used in a particular area over a given time period”.

The assessment and management of ES requires understanding about both supply and demand (Bagstad et al., 2013; Burkhard et al., 2012; Crossman et al., 2013; Goldenberg et al., 2017; Syrbe and Walz, 2012) while the properties of the connecting space between the area of supply and demand have an influence on the provision and the utilization of ESs (Syrbe and Walz, 2012). The spatial flow, which links ES supply to its human beneficiaries, offers an opportunity to recognize how much people can actually benefit from ES at different spatial scales (Ala-Hulkko et al., 2016). Mapping spatial balance between supply and demand can provide a more complete understanding about sustainability of ES, allowing decision makers to plan interventions and policy more precisely at regional, national and inter-national levels (Bagstad et al., 2014, 2013; Syrbe and Grunewald, 2017).

In this study, we quantify and map supply and demand balance of food ES across Europe (see Fig. 1) using accessibility analysis. Throughout the paper, Europe will serve as an example to illustrate the application of the spatial accessibility analysis in the ES framework. Europe is used as an example for two main reasons. First, we wanted to test the approach at the continental scale and second, the availability of food statistics was relatively good from Europe. We used crop as an example of ES, where spatial flows are required to satisfy the demand. Also, other types of ESs may be dependent on the spatial flow (e.g. freshwater, timber or recreation, see e.g. Ala-Hulkko et al. 2016) and can be estimated through the spatial accessibility. However, in this paper, we concentrated testing the applicability of method by using a key provisioning ES, namely crop production.

To model supply and demand we (i) mapped the spatial variation between crop supply and demand across Europe, (ii) assessed the spatial flow between crop production and human consumption using a transport network based accessibility method following Luo and Wang (2003), (iii) estimated how well supply is able to satisfy the demand of crop products in European regions and (iv) explored how barriers such as state borders potentially affect the spatial flow of studied ES. Study of Chen (2004) has shown the importance of national borders as creator of barriers to the free flow of goods. Study evidenced that although, European Union (EU) countries are expected to be highly integrated and should display small border effects, it is observed that EU countries trades more with itself than with a country outside the EU. The effect of borders is detected to be large especially in small countries (Chen 2004). Also study of Salas-Olmedo et al. (2016) highly recommended that accessibility studies should consider the growing role of borders in international trade even within nearly borderless areas, like the EU. Hence, we considered Europe as a single free trade area and illustrate the impact of nation-based trade barriers on accessibility.

Spatial flow is addressed through the concept of spatial accessibility (Páez et al., 2012) which determines the potential to transport food products from the areas where ESs are produced (supply) to areas where these ESs are consumed (demand) through a road network (*see 2. Materials and Methods*). The accessibility method takes into consideration not only the volume of ESs provided relative to the size of demand but the proximity of the provided ESs relative to the location of the demand. In other words, large supply located spatially close to demand does not necessarily equate with satisfied demand. The transportation mechanism determines accessibility of supply to demand. Correspondingly, close proximity may not guarantee good accessibility due to competing demand for an available service (McGrail and Humphreys, 2009). Analyzing the spatial flow between provisioning and benefiting areas receive more exact and useful information on the balance or mismatch of food delivery (i.e. production capacity) and demand compared with more simple approaches, such as overlay analysis which can lead to over-simplification, inaccuracies and misunderstandings in ES mapping (Bagstad et al., 2013). Our study has clear policy relevance by demonstrating the constraints and options to restore the delivery of services to beneficiaries that is also one of the main target of Action 2 of the European Union’s 2020 Biodiversity strategy (European Commission, 2011).

2. Material and methods

2.1 Mapping food supply and demand.

European Union (EU) countries for which data is available except for Malta, Cyprus and overseas territories were considered in this study (Fig. 1). In addition, non-EU countries Norway, Switzerland, Montenegro, Bosnia and Herzegovina and Serbia were included to supplement the study area (altogether 31 countries). The analytical resolution of this study was the administrative boundaries of NUTS3 area (Nomenclature of Territorial Units for Statistics, n = 1379). These boundaries correspond to counties being the most appropriate discrete unit of data for continental-scale analysis. Furthermore, the administrative boundaries correspond well with the accuracy where beneficiaries receive the service (Raudsepp-Hearne et al., 2010; Walz et al., 2017).

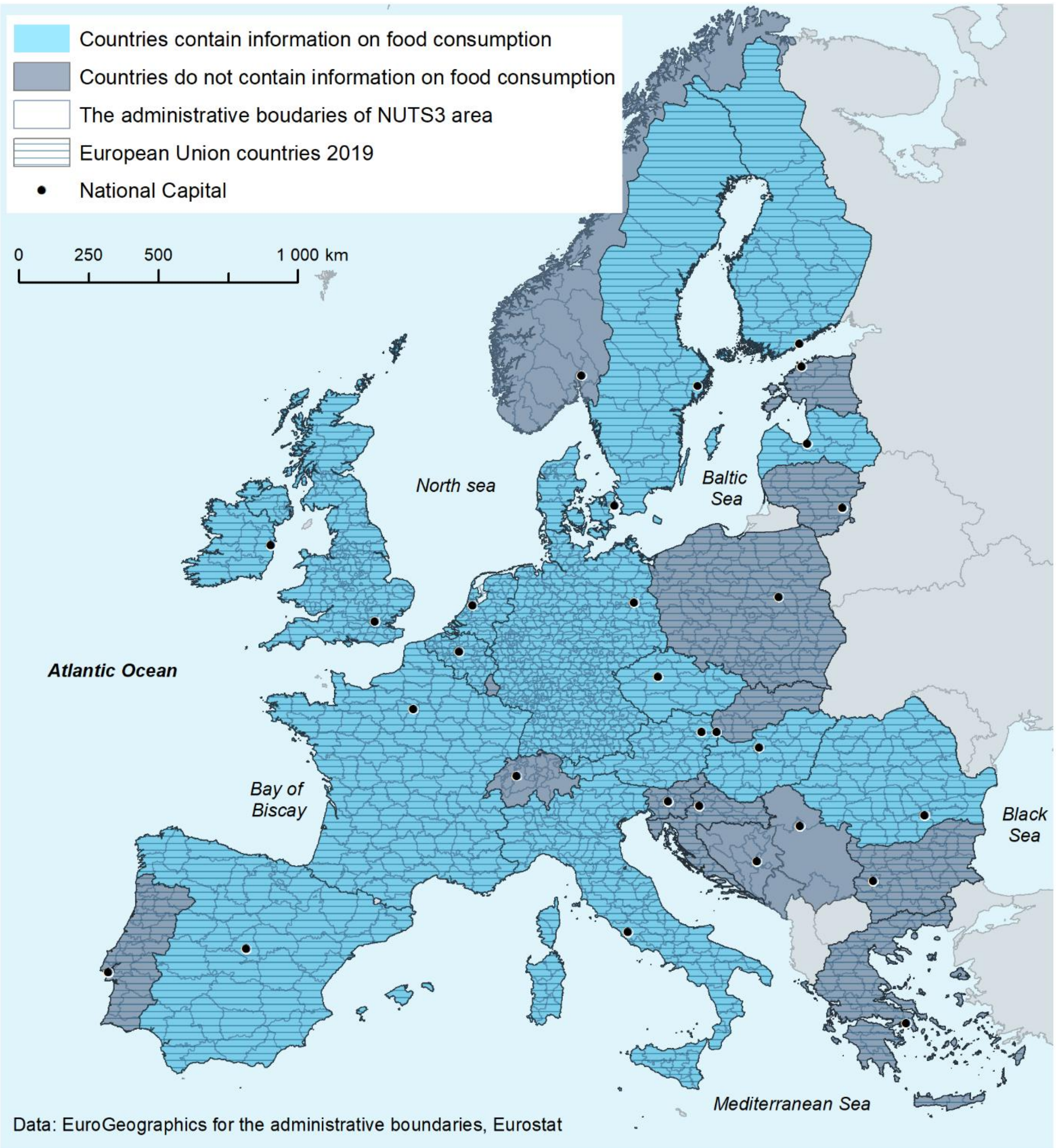

Figure 1. Study area consist altogether 31 countries across Europe. The Comprehensive Food Consumption Database (EFSA, 2011) covers 16 countries around the study area (light blue areas).

To obtain a budget of ES undersupply, neutral balance or oversupply, mapping and assessment of the food balance requires that supply and demand are in the same units of measure: kg per NUTS3 area in a year (Baró et al., 2015; Burkhard et al., 2012; Kroll et al., 2012; Syrbe and Walz, 2012). The location of each ES benefiting area (demand location) is re-set in each NUTS3 area to the centroid of the largest population area. Each ES providing area (supply location) is re-set to the centroid of the largest cultivated area (based on the information on Corine Land Cover) within each NUTS3 area.

2.1.1 Crop supply

In this study, supply is mapped according to the capacity of cultivated fields to provide a food service (see Schröter et al., 2014). First, the capacity to provide crops was calculated based on Corine Land Cover (CLC) 2006 seamless vector data (European Environment Agency, 2016) which contains information of the area of arable lands (class 211 non-irrigated arable land and class 212 permanently irrigated land) in the whole Europe (Fig. S1). In the case of Greece, CLC 2000 seamless vector data were used to calculate arable land area due to lack of the area information of the CLC 2006. The information about the crop yield (kg per country per year) was obtained from FAOSTAT's (2016) Food Balance Sheets, which present a comprehensive picture of the pattern of a country's food supply during a year 2006. All cereals except rice are included in the annual crop yield. Because the majority of the crop yield is used as animal feed and by industry in general, only crop yield for human consumption was included in the analysis. To indicate the food supplies available only for human consumption, the food waste (lost during the food supply chain) is taken into consideration when calculating the ES supply. Food losses take place at production, postharvest and during processing stages in the food supply chain serving to decrease the edible products going to human consumption (Parfitt et al., 2010). In Europe, a total loss of cereals at different food supply chain stages is approximately 30% (FAO, 2011).

2.1.2 Crop demand

Demand is calculated for each NUTS3 area (Fig. S2) from a variety of sources: The major ones being 1x1 km grid cell database of Europe population for the year 2011 (Eurostat, 2016a) and European Food Safety Authority the (EFSA) survey of food consumption across EU area (EFSA, 2011). Other sources included the population information of the Serbia and Bosnia and Herzegovina (ArcGIS ESRI, 2016) and NUTS3 areas (Eurostat, 2016b). Population grid database is used to indicate the population centroid of each NUTS3 area. We select the most densely populated grid from each NUTS3 to represent a location of demand in our analysis. Information of the total population of NUTS3 (Eurostat, 2016c) was then aggregated to the population centroids.

Consumption is based on The Comprehensive Food Consumption Database (EFSA, 2011) which compiled survey data of 16 countries in the EU between 1997 and 2008. The survey statistics on food consumption are based on 20 main food categories and consumption rate is reported in grams per day for different age classes (infants, toddlers, other children and adolescents, adults, elderly and very elderly). Only the food consumption of the adult population is available. In this study, we use data on the average consumption per adult (18-64 years of age) and for the food category of grains and grain based products. For the 15 countries which have no consumption information, we used an average value of all 16 countries to indicate food consumption. To measure supply and demand in similar and comparable units, the consumption is calculated as amount of food consumed (kg per year) per each NUTS 3 area.

2.1.3. Network data

The transport accessibility components of a spatial flow of ES was quantified with a least- cost-path analysis using open-source and publicly available road and ferry network data in standard Geographical Information Systems (GIS)-based formats. The majority of the road and ferry network data was obtained from EuroGlobalMap (2016) which is a topographic dataset of 1:1 million scale with a few exceptions in the Balkan Peninsula. Primary and secondary class roads from Balkan Peninsula (Bosnia-Herzegovina and Montenegro) were not available in EuroGlobalMap. Open Street Map (OSM) (OSM, 2016) is used in those locations. The topology errors of OSM were corrected manually. The national boundaries of NUTS3 data (Eurostat, 2016b) were used to produce national road networks for the analysis area where borders are considered.

2.2 Analyzing the spatial flow between supply and demand of food ecosystem service

To model the transport accessibility of supply and demand neighbouring effects, a wider spatial continuum may be included in a single index. As a joint network-integrated measure, floating catchment area techniques are the most advanced available in the field of transport geographic analysis. The two-step floating catchment area (2SFCA) was developed to analyse the accessibility of primary care physicians, and it has ability to include supply and demand attributes together with transport cost-distance in a single index (Luo and Wang, 2003). The technique was developed further to include a distance decay parameter for the service-to-demand allocation. This enhanced 2SFCA (E2SFCA) (Fig.2) has been popularized in measuring accessibility to health care service attributes. The accessibility method also addresses the classical modifiable areal unit problem (Langford et al., 2016) effectively. The areal unit problem is a source of statistical bias when scale (i.e. the size of container object) and zone (i.e. the location of tract boundaries) may have an influence on the results. Finally, the accessibility method enables supply and demand data resolutions to be at different or even varying scales in the analysis.

For this study, E2SFCA was applied following Luo and Qi (2009). The analysis consists of two steps. At the first step, demand was derived for supply nodes within the catchment area as production-to-consumption shares R_j in location j:

$$R_j = \frac{S_j}{\sum P_k W_r} \mid k \in \{d_{kj} \in D_r\} \quad [1]$$

Where S_j is the amount of production at location *j*, P_k is the demand at location *k* whose centroid falls within catchment *j* ($d_{kj} \in D_r$), and d_{kj} is the travel time between *k* and *j*. In other words, this first step counts what population (demand centroids) falls within the threshold travel distance zone (catchment) of each ES provider (supply centroids). W_r is the distance weight function with linear form for rth catchment zone. Calculations are weighted 1.0 at zero distance from the supply or demand point and this weighting decays linearly to reach 0.0 at the set threshold distance. This means that people become less inclined to utilize a service as their distance to it increases. In this study, we used three different transportation distance thresholds (250, 500 and 1000 km) to exemplify how far crop products are transported through road network. At the second step, production-to-consumption shares (R_j), are derived for population nodes and summarised to accessibility to production ratios A_i^F in a location j:

$$A_i^F = \sum R_j W_r \mid j \in \{d_{ij} \in D_r\} \quad [2]$$

Where R_j is the production-to-consumption share at location *j* within the catchment at population location *i* (i.e., $d_{ij} \in D_r$), and d_{ij} the travel time between *i* and *j*. This step allocates available ES to population, by deriving the share of the ES that falls within the catchment of each population.

E2SFCA was executed with the ESRI ArcGIS Desktop and USWFCA (Enhanced Two-Step Floating Catchment Area Accessibility Add-In tool) (Langford et al., 2014). To keep the origin-destination matrix in reasonable size and spatial resolution at needed accuracy in computations, the NUTS3 was selected for reference scale. As network analysis connects origins and destinations to point type nodes, the supply and demand centroid of each NUTS3 areas applied as reference points. To explore how barriers, such as state borders, affect the spatial flow of studied ES we restricted the transportation of food to within nation-state borders. Salas-Olmedo et al. (2016) have pointed out that country borders may still form barriers that produce unexpected changes in international trade flows even international food trade has opened remarkably during past decades. To illustrate the effects on borders to the spatial flow we used both borders and borderless aspects in assessing the opportunities to transport food ES to beneficiaries. In addition, to further highlight the accessibility results, we calculated nonparametric Spearman's bivariate correlations (R_S) between the results of a regional overlay (subtraction between crop supply and demand) and accessibility scores for all studied distance thresholds to explore the relationship between those two approaches at NUTS3 level.

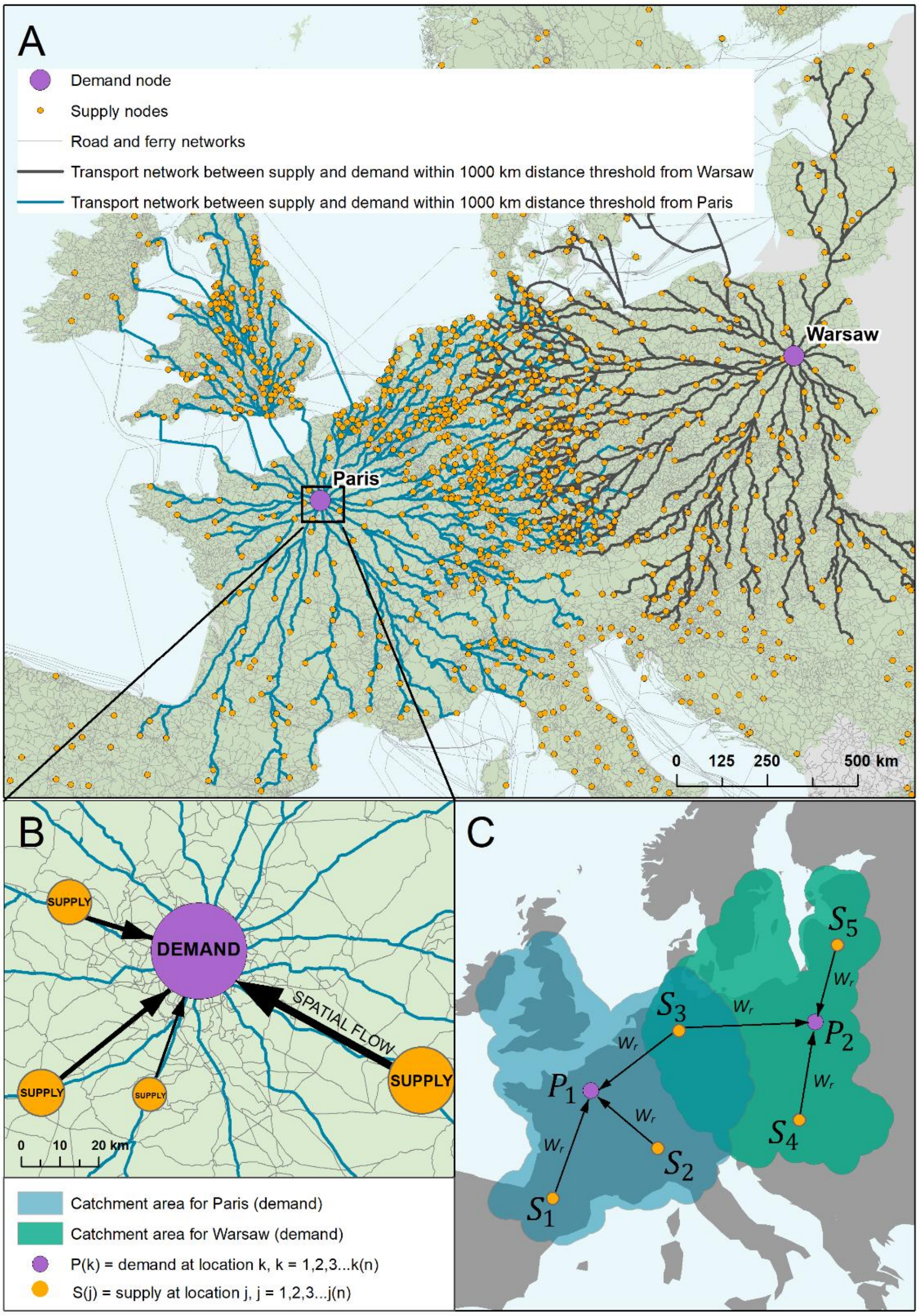

Figure 2. A schematic figure illustrating the enhanced two-step floating catchment area (E2SFCA) accessibility calculations for 2 location: Warsaw and Paris. Purple dots represent crop demand. Orange dots represent crop supply (A). The size of dots (B) indicate the volume of supply and demand. Competition between the spatially

distributed demand dots does not appear. As a result, the spatial flow between supply and demand is simplified to illustrate only the principle of accessibility analyses. (C) describes the analysis first step and correspond to the formula of E2SFCA in *Material and method*.

3. Results

Our analysis reveals the substantial spatial variation in crop supply and demand across Europe (Fig. 3. A and B). Spatial variation of supply is caused by quantitative and qualitative agricultural factors (land use, the arability of land, climate conditions) which vary greatly from region to region. Within Europe crop cultivation (supply) concentrate mainly in France, parts of Germany, Poland, Hungary, Romania and the British Isles (see Fig 3. A), whereas low shares of crop products is mainly found in northern Europe and the Iberian Peninsula. The key source of demand was located around the largest population concentrations in central and southern Europe, and particularly in the belt from Brittain to Italy (Fig. 3 B). An overlay map (Fig.3 C) between supply and demand illustrates how large cities, such as London, Paris and Berlin have focal peak in demand in relation to surrounding crop production.

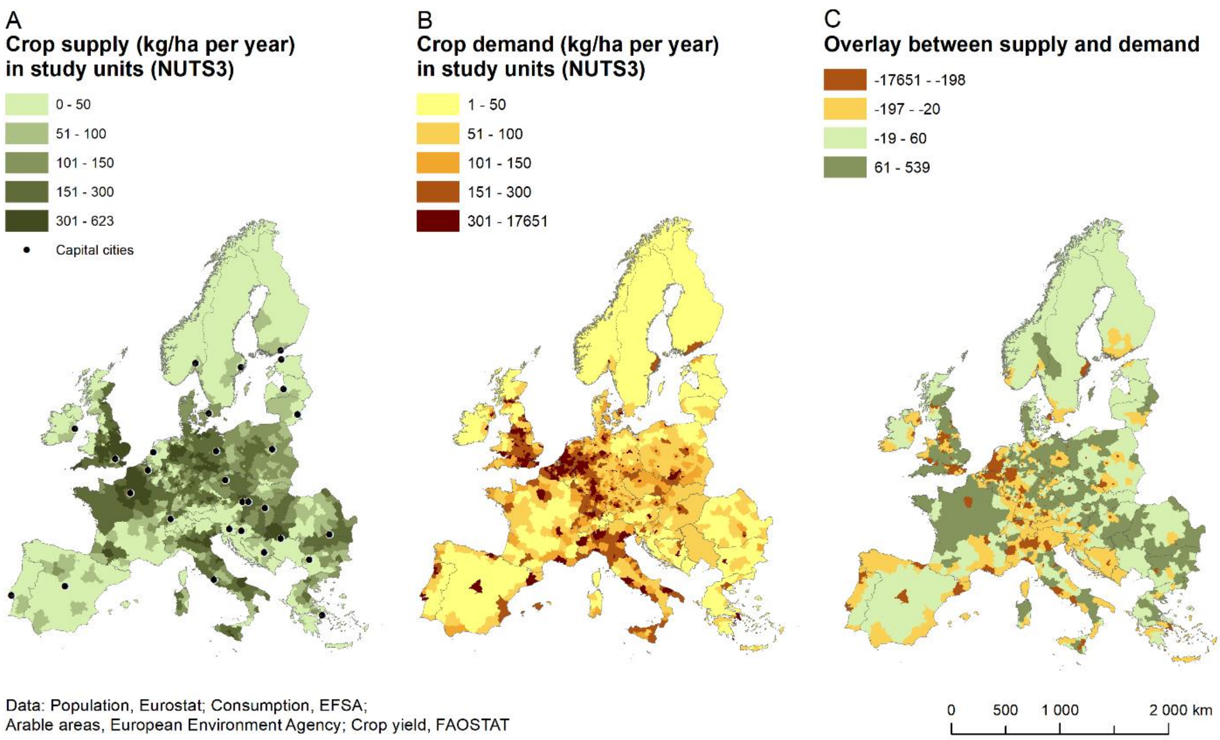

Figure 3. Supply and demand of food ecosystem service (ES) at European level (A-B). Graduated colors indicated how much crop ES (kg/ha per year) are provided or consumed in each study unit (NUTS 3 areas). Overlay of two first maps (C) describe the subtraction between crop production and consumption. An overlay map is classified based on quantiles.

If we consider Europe to be a single free trade zone (Fig. 4 A-C), demand can be served across the nation's borders. Figure 4 depicts how accessibility will change as travel distances increase. If food is delivered locally (within 250 km of supply), clear differences between oversupply and undersupply areas are distinguished across Europe (Fig. 4 A). Oversupply areas follow the location of the main crop production centroids and the shortage areas are located mainly in the mountainous areas, densely populated areas or along the edge of the study area. Especially, the area from the Netherlands to Italy is clearly distinguished of a low food supply in relation to demand. Increasing the travel distance from 250 km to 500 km and 1000 km (Fig. 4. B and C respectively), food consumption is able to satisfy more evenly around Europe. At these distances, parts of the Hungary and Balkan Peninsula are still producing more food than is needed. Spearman's bivariate correlations (R_S) between overlay results (Fig 3. C.) and accessibility scores (Fig.4 A-C) varies between 0.44 and 0.12 decreasing from local delivery to long transportation distance (Table 1). The differences between those two approaches are particularly apparent around the large cities, where demand has been able to take better into account with the help of accessibility analysis.

Table 1. Spearman's bivariate correlations (R_S) between overlay and accessibility results (Fig. 3).

	Nat 250	Nat 500	Nat 1000	Eur 250	Eur 500	Eur 1000
Overlay	0.42***	0.37***	0.29***	0.44***	0.33***	0.12***

*p <0.05; **p <0.01; ***p<0.001; n=1379

Abbreviations: Overlay = overlay between supply and demand; Nat = National borders are included in accessibility analysis; Eur = Whole Europe is one single study area in accessibility analysis; values 250, 500 and 1000 = describe the different distance thresholds (km) used in the analysis.

In this study, we investigate the impact of national borders to ES flow by restricting the transport of food ES within nation-state borders. Results are depicted in Figure 4 D-F. There are large differences between the countries ability to produce food in relation to the demand, and again remarkable variation of regional overproduction. For example, France and the Baltic states have clear national overproduction, which could be balanced with close distance cross-border consumption. Also, Hungary, Romania, Serbia and Bulgaria have surpluses of crop production available which need to travel over 1000 km to reach demand markets in Europe. In contrast to this, the Iberian Peninsula, mountainous areas in northern and central Europe, densely populated areas in the middle of Europe and several coastal areas are characterized by undersupply at all threshold distances. R_S between overlay map (Fig 3. C.) and accessibility maps (Fig. 4 D-F) follows the same trend as in the borderless European case study (see Table 1). Taking transportation and national trade barriers into account significantly impacts the spatial flow of ESs across Europe. A majority of the states clearly benefit from balancing the supply or demand at international trade, even at relatively close distances.

In addition to the geographical overview of the food delivery, our results show that almost same proportion of the population is located in the areas of underproduction and overproduction across Europe (Table 2). The amount of people living in oversupply areas will increase slightly if Europe is considered as a single free trading area. However, at country level, the benefits of international delivery of food are significant. For example, Belgium, Switzerland, Luxembourg, Netherlands and Slovenia clearly benefit from cross-border flows of ES. Demographic inspection of the results also supports geographical overview, showing the strength of the accessibility analysis particularly at the densely populated areas. According to the overlay analysis, for example, more than 60% of the population lives in the area of low food supply in Europe (Table 2). Whereas, delivering the food through a road network, the proportion of people living in the deficit area falls to 36% at 1000 km travel distance.

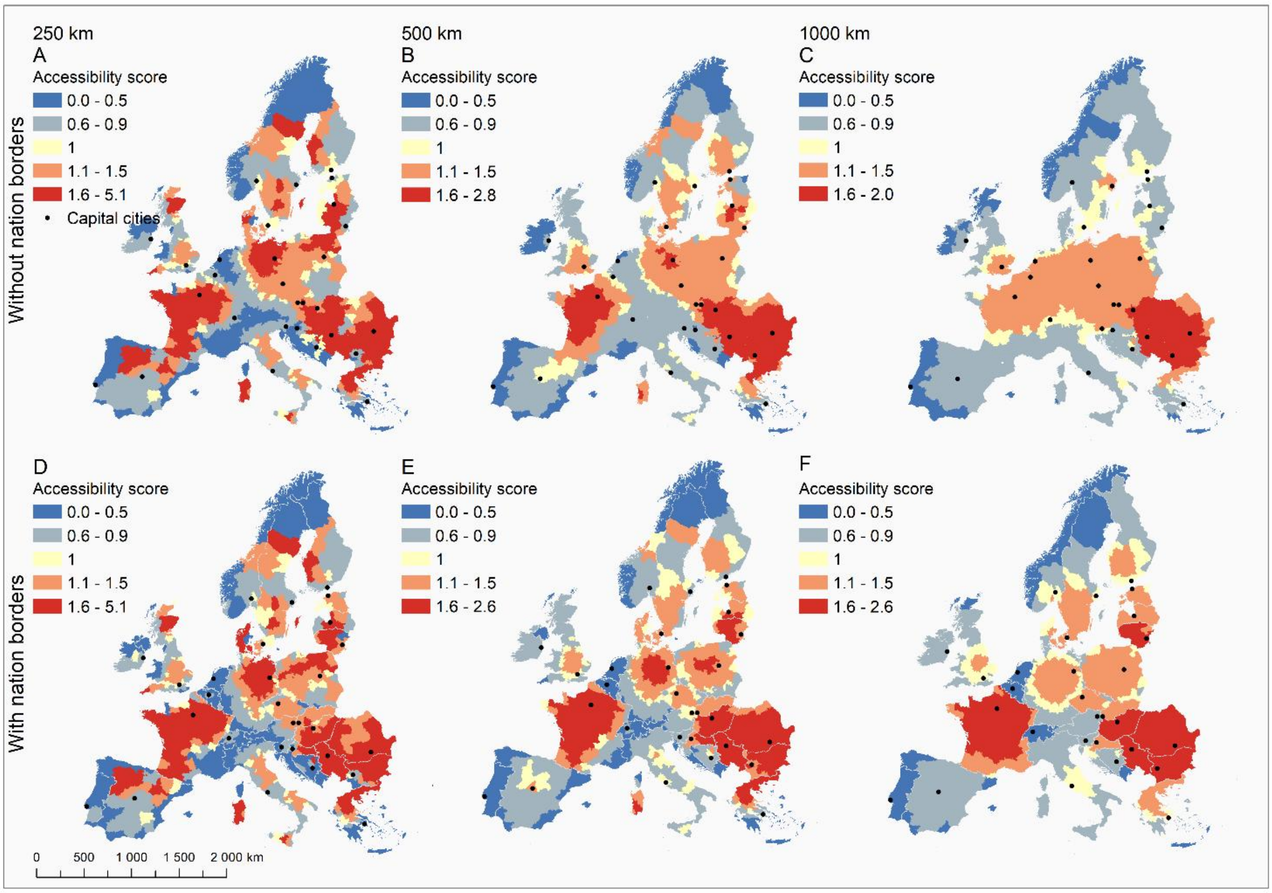

Figure 4. The balance between supply and demand of crops across Europe using 250 km (A, D), 500 km (B, E) and 1000 km (C, F) distance thresholds. A-C describe Europe as a single free trade area and D-F illustrate the impact of nation-based trade barriers on accessibility. The analysis assigns an accessibility scores determined

by the supply to demand ratio. Values less than one (blues) indicate less supply than demand within the threshold distance. Value one (yellow) indicate a balance between supply and demand while values greater than one (reds) represent more supply than demand.

Table 2. Amount of population (%) in undersupply, balance and oversupply areas.

COUNTRY	Nat250			Nat500			Nat1000			Eur250			Eur500			Eur1000			Overlay		
	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+
Austria	58	0	42	58	17	25	100	0	0	57	2	40	45	15	40	0	6	94	61	8	31
Bosnia and Herzegovina	85	0	15	62	22	15	85	15	0	49	36	15	85	0	15	62	22	15	95	2	2
Belgium	100	0	0	100	0	0	100	0	0	94	5	0	61	34	5	0	0	100	85	1	14
Bulgaria	11	2	87	0	0	100	0	0	100	11	0	89	0	0	100	0	0	100	29	16	55
Switzerland	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	8	73	19	81	12	7
Czech Republic	32	5	63	20	19	61	12	16	72	12	0	88	0	0	100	0	0	100	23	24	53
Germany	56	3	40	50	8	42	26	30	43	56	5	39	57	7	36	1	4	95	71	2	27
Denmark	16	13	71	1	15	84	13	18	69	16	25	59	36	19	45	54	45	1	35	0	65
Estonia	11	11	78	11	11	78	0	11	89	55	21	24	45	0	55	56	44	0	44	36	21
Greece	62	2	36	63	2	36	19	42	38	64	0	36	64	2	34	72	3	25	71	3	25
Spain	89	2	9	82	3	15	100	0	0	90	1	9	78	19	3	100	0	0	78	9	13
Finland	64	4	32	51	16	33	18	53	29	35	33	32	26	11	63	49	51	0	51	33	16
France	25	5	70	20	6	74	1	1	99	29	7	64	29	1	70	25	11	64	48	8	44
Croatia	72	0	28	33	0	67	25	8	67	82	0	18	83	0	17	89	11	0	71	6	23
Hungary	0	2	98	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	33	3	64
Ireland	94	6	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	91	9	0
Italy	65	10	25	68	27	4	76	24	0	67	7	25	84	13	3	86	14	0	76	3	20
Lithuania	5	0	95	0	0	100	0	0	100	32	11	56	0	5	95	74	26	0	47	21	31
Luxembourg	100	0	0	100	0	0	100	0	0	0	0	100	0	100	0	0	0	100	100	0	0
Latvia	27	0	73	0	27	73	0	0	100	14	13	73	0	27	73	56	44	0	32	18	49
Montenegro	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0
Netherlands	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	2	9	89	92	1	7
Norway	68	24	9	91	3	6	57	38	5	62	29	9	75	17	9	100	0	0	56	34	9
Poland	28	10	62	21	18	60	2	10	87	27	10	63	4	11	86	4	4	91	45	7	48
Portugal	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	91	5	4
Romania	0	0	100	0	0	100	0	0	100	3	5	91	0	2	98	0	0	100	21	13	67
Serbia	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100

Sweden	39	32	28	36	9	54	16	25	59	39	16	45	14	35	51	34	37	29	40	16	43
Slovenia	100	0	0	100	0	0	100	0	0	94	0	6	94	0	6	0	19	81	89	0	11
Slovakia	0	0	100	0	0	100	0	0	100	55	11	34	0	0	100	0	0	100	27	0	73
United Kingdom	43	19	38	38	34	28	30	53	17	44	22	34	28	20	51	42	18	39	68	1	31
TOTAL	51	7	42	47	13	41	40	18	43	51	8	41	47	10	43	36	10	54	62	6	32

Abbreviations: **Nat** = National borders are included in the accessibility analysis; **Eur** = Whole Europe is one single study area in the accessibility analysis; values **250**, **500** and **1000** = describe the different distance thresholds (km) used in the analysis. **Overlay** = the subtraction between crop production and consumption. **-** = less supply than demand within the threshold distance; **0** = a balance between supply and demand; **+** = more supply than demand.

4. Discussion

Understanding the relationship between ES supply and demand is one of the key issues in the framework of ES (Burkhard et al., 2014; Goldenberg et al., 2017; Syrbe and Grunewald, 2017). The appropriate evaluation of ESs requires the assessment of the quantified usage opportunities of human societies to utilize accessible ES supply through the spatial flows. It is essential to estimate the pathways of spatial flow when determining the relationship between supply and demand. Because ESs have complex flow dynamics that operate at different spatial and temporal scales, finding the relevant indicator to describe this complex relationship across different scales is not a simple task. Especially, origins and transport paths complicate the assessment substantially in today's globalized trade systems, which include intercontinental trade routes (Burkhard et al., 2012). In this study, spatial accessibility analysis has proven to be promising framework in modeling spatial characteristics of supply and demand availability, proximity and trade barriers in Europe.

Accessibility analysis adds further detail to the delivery of food ES compared with studies where supply and demand have been estimated using simplistic overlay of two or several map layers (Burkhard et al., 2014; Nedkov and Burkhard, 2012). Using a simple regional overlay analysis, spatial mismatch between supply and demand would not have been identified appropriately in large demand centroids (compare Fig. 3 and 4, Table 2), and significant regional level spatial variation would be lost at a state level overlay. Accessibility of ESs identify not only the balance of supply and demand but also areas where additional investments (roads network or management of food production) are needed to meet demand. Conversely, accessibility analysis may be used to identify suitable areas where promotion and investment in local-scale food production could decrease the need for transportation. Another interpretation of the results can be used to evaluate the sustainable use of ESs. In that case, the ES provision (supply) can be considered sustainable when demand is met without increasing the capacity of food production.

Based on our results, it seems that demand exceeds ecosystem capacity to provide food in many regions in Europe at all studied distance thresholds. This unbalanced use of food ES requires society to invest in transportation, to enhance natural capacity of ecosystems to produce services, decrease demand or to invest in a technological substitute to balance the gap between supply and demand (Villamagna et al., 2014). The results help quantify and visualize the current state and use of food ES, making information easily to access and understand for decision-makers. Realizing this spatial flow of ES provides a practical policy-relevant measure of sustainability of ecosystem use as well as to improve the development of ecosystem accounts with the aim to reach sustainable development goals for feeding people and minimizing the impact to planet (Griggs et al., 2013; United Nations, 2015). In addition, the method can be utilized when assessing changes in the balance between food production and consumption. This is especially important when considering future food security. For example, European crop production is predicted to decline in most scenarios as a result of climate change (e.g. Pirttioja et al., 2015). At the same time, crop demand is expected to grow. The study of Vásquez et al. (2018) have shown that demand of food energy has increased more than 100% during the last decades globally and same trend is expected to continue in the future. When the expansion of agricultural land is restricted, the balance between crop production and demand become particularly important question (Ewert et al., 2005). Accessibility analysis can provide a powerful tool to identify future risks or realize how the balance between supply and demand can be maintained through reasonable cross-border delivery of food ES within Europe. For carbon dioxide emissions accessibility analysis can be applied to estimate transportation costs and by optimizing the delivery of food ESs from areas of oversupply to the areas of high demand it may be possible to reduce greenhouse gas emissions, a contributing factor to global climate change (IPCC, 2014).

This present example focused on the food ES, but also other types of ESs may be dependent on the spatial flow and can be estimated through the spatial accessibility. Some types of ESs are strictly dependent on the presence of people. For example, to benefit from the cultural ES, such as recreation, people need to be able to reach those areas (Ala-Hulkko et al., 2016; Paracchini et al., 2014), which again requires traveling between the place of residence and the ES area (see Ala-Hulkko et al., 2016). Otherwise, many provisioning ES, such as freshwater, timber or energy resources are transported actively to consumption site either through the road network or other human-managed flows (e.g. artificial watercourses and pipelines). The spatial flow can also consist of various types of natural flows (Burkhard et al., 2014; Goldenberg et al., 2017), where services are carried, for instance by natural watercourses or gas circulation paths to the beneficiaries. Spatial flow also occurs at landscape scale where the links between ES providing and benefiting areas do not follow existing human-managed or natural network. For example, connections between pollination supply areas (suitable habitats for pollinators) and benefiting areas (plants demanding pollination) can be estimated using a cost surface that represents the resistance to an organism's movement across landscape (Heino et al., 2017). Overall, accessibility analysis provides a useful tool for exploring different ESs from local to global scales depending on available data.

However, despite the presented promising results and applicability examples, questions remain. The accurate measurement of spatial accessibility between supply and demand of provisioning ES (here food) is chiefly problematic due to complex market systems, the economic supports of agriculture and long production chains that goods and services pass through before final products reach the consumers (Burkhard et al., 2014). Instead of using the actual ES, people benefit from a final processed good that are the result of whole production chains (Burkhard et al., 2014; Schröter et al., 2012). Thus, it will be highly complex to define where exactly the goods and services originally come from. Again, in the current globalized economy, trade allows states and regions to have considerably higher ES demand than that provided by ecosystems in the same areas, which are deeply connected to the global reduction of ESs (Burkhard et al., 2012). An assessment of available services relative to the needs of the population is challenging. Access to ES resources varies across space because neither production nor population are uniformly distributed. Potential accessibility signifies the probable entry of ES products, but does not ensure the automatic utilization of the offered services (Luo and Wang, 2003). That said, because we do not have exhaustive measures of the demand including marketing, demographic changes or behavioral norms, we cannot completely map the balance of food ES in Europe. However, we illustrated how different transportation distances and borders between nations affect the relationships of production and consumption of food ES, as suggested when studying the potential accessibility to markets (Salas-Olmedo et al., 2016). Our results demonstrate how the balance between supply and demand in Europe can change if the international distribution of the food ES for one reason or another is prevented.

5. Conclusions

The accessibility method provides a good practical application in modeling spatial characteristics of supply and demand availability, proximity and trade barriers in Europe. The strongest applicability of the accessibility analyses is not only that it combines the state of the network and ES but also how they are perceived and effectively utilized by people with different characteristics. Our results showed that in Europe, several countries would benefit from balancing supply and demand of food ES at international level. Compared to simplistic overlay analysis, this approach increases our capability to provide more meaningful, realistic and easy-to-read quantifications and maps of ES. The strengths of the accessibility analysis are evident particularly at the densely populated areas where mismatch between supply and demand was identified more appropriately. Results can also be used to identify where to invest in transportation and enhance natural capacity to respond to the possible changes in food production or the growing demand of food. Concomitantly, the approach can help us to meet the requirements of different strategies, such as Action 2 of the European Union's 2020 Biodiversity strategy and Goal 2 of sustainable food production, distribution and consumption. The spatial restrictions such as accessibility and proximity of ES has rarely been demonstrated at the continental scale before.

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Data availability. The ES supply data are available at: https://www.eea.europa.eu/data-and maps/data/clc-2006-vector-data-version-6#tab-gis-data%3E. and http://www.fao.org/faostat/en/#data/FBS.

The ES demand data are available at: http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography; EFSA. Use of the EFSA Comprehensive European Food Consumption Database in Exposure Assessment. EFSA J. 9, 2097 (2011) and http://www.arcgis.com/home/item.html?id=cf3c8303e85748b5bc097cdbb5d39c31.

The network data are available at: http://www.eurogeographics.org/products-and-services/euroglobalmap. and https://www.openstreetmap.org/#map=5/65.453/26.069.

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