Towards an Index for Sustainable Regional Food Provision (i-SRFP) by linking Global and Regional Food System Assessment Tools

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1. Introduction

Project objectives

The concept of developing an Index for Sustainable Regional Food Supply (i-SRFP) is addressing the need of providing short, rapid and very targeted answers to policy and business questions regarding key characteristics of sustainable urban food supply. The FOODMETRES assessment tool "*Metropolitan Foodscape Planner*"(MFP) is an hands-on assessment tool for identifying metropolitan supply potentials in the light of urban food consumption (ecological footprint method). The von Thünen-based concept was developed towards a spatial reference scheme in which existing recreational areas and space for biodiversity conservation were brought into a sustainable balance with new regional food growing areas in the wider proximity of the cities. The novel aspect of *this* project was to combine the regional assessment capacities of the MFP tool with of the global market assessment tool of the Global Metropolitan Detector (GMD) in terms of geo-spatial scope and applicability for building an Index for Sustainable Regional Food Provision (i-SRFP). These capacities can be summarised as follows:

- MFP: applies high resolution European data for assessing food security as a function of demand (urban food consumption) and supply (available agricultural areas and commodities) in forms of 'local hectare'-footprint calculations at the level of metropolitan land use units (1ha resolution).
- GMD: based on a large number of indicators deriving from global data sets at the level of UTM grids (5'x5' resolution, about 10x10km around the equator), this tool allows identifying suitable locations for a wide range of agricultural production regimes and conditions.

With regard to developing an i-SRFP, the two tools are considered to generate essential information addressing the question of regional food security in the light of biophysical conditions, environmental impacts and socio-economic opportunities of interest for both the agricultural sector as well as for policy makers and planners.

Together, GMD and MFP can hence be considered to offer powerful assessment capacities across a wide range of scales making use of complimentary indicator-models that allow interesting cross-comparisons and further contextualisation. In order to allow such in- and out-scaling, we applied both tools to the city-triangle of Antwerp – Rotterdam - Düsseldorf (ARD-Region). This region seemed interesting since it forms the heart of the wider Rhine-Maas-Schelde delta-metropole encompassing a large segment of the Germany's Ruhrgebiet including the rapidly developing agro-innovation regions around Venlo and Niederrhein, most of the Dutch Randstad-area with its central Metropolitan Region Rotterdam-DenHaag boasting Europe' largest harbour (mainport) and greenhouse production centre (greenport) and across the border in Belgium, the metropolitan region of Antwerp, the 'Flemish Diamond'.

Using the example of the ARD Region procedure, we will illustrate the following sequence of steps that are required:

- Undertaking an account of the urban food consumption patterns in the study region (demand)
- Developing a dynamic footprint-driven spatial zoning framework (von Thünen) on the basis of available agricultural lands (supply);
- Identifying regional food provision surplus and deficits on the basis of CORINE land cover at distinctive for 9 commodity groups (based on HSMU);
- Undertaking a spatial-contextual analysis of these results by comparing with GMD-output for 5 different cases.

The results are expected to provide a framework for supporting spatial regional planning schemes in which existing, agricultural systems, recreational areas and space for biodiversity conservation is brought into a sustainable balance targeting at a stronger integration regional food systems into the overall agro-food supply network of cities. The assessment takes into account the aspect of food import, food production, food consumption, and food export to point at solutions for lowering the impacts of urban food consumption on both the surroundings as well as at the global scale.

MFP: a stripped down approach
Building the *Metropolitan Foodscape Planner tool (MFP)* requires a series of data management and GIS operations to be performed in Excel and ArcGIS. The objective to spatially analyze the footprint of metropolitan food supply implies two specific challenges, which require the application of essentially two methodological approaches:

(i) The analysis of the spatial extent of the agricultural area required for food production ("For whom and how much?"); and
(ii) The distribution of the various land use types, which are required for food production ("What and where"?).

The original *Metropolitan Foodscape Planner (MFP)* approach offers (1) hands-on impact assessment tool for balancing commodity surpluses and deficits, (2) a visual interface that depicts food zones to make impacts spatially explicit, (3) landscape-ecological allocation rules to base land use decisions on sustainable principles, and (4) European data such as EFSA, LANMAP, HSMU and CORINE Land Cover to allow future top-down tool applications for all metropolitan regions throughout the EU.

For the purpose of this i-SRFP-project we have stripped-down the above approach by focussing mainly on two zones, namely the Metropolitan Food Ring (MFR) and the Transition Zone (TZ). We hence did not develop the full-blown FOODMETRES assessment that takes into account a green buffer around cities, separates the MFR into a protein and plant-based supply zone and offers landscape-ecological allocation rules. The latter did not seem necessary because we did not prepare the tool for using the Digital Maptable and interactive serious gaming software. The details specifying further sub-zones did not seem to match both the type of research questions associated with linking up to the global level (GMD) and would have been rather resource intensive by increasing the level of complexity.

GMD: selected cases
For establishing links with the results of the GMD, we focussed on the following agricultural production cases:

- Urban agriculture
- Intensive pig and poultry meat production
- Vegetables and fruit production
- Arable crops
- Grassland and other areas suitable for cattle, sheep and goat (meat and milk production)

These assessments have been super-imposed onto the MFP-results allowing contextual interpretation and strategic recommendation with regard to building the i-SRFP.

In a further step we organised an intra-WUR work session ('Deep-Scan' on 12 October 2016) during which we identified a range of indicators for building the i-SRFP.

2. The Metropolitan Foodscape Planner

2.1 Data and method MFP

Taken the population figures from each of these metropolitan regions we calculated the 'Transition Zones' which overlap with each other and where the people living in the MFR-zones are included.

Table 1 : Data Layers applied in the MFP model.

Data Layer	Source
EFSA European Food Safety Authority	https://www.efsa.europa.eu/en/food-consumption/comprehensive-database
Corine Land Cover 2006	http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-3 version 8 april 2014, download 13 jan 2015 in arccat export .tiff als esrigrid in MFT.gdb
Natura 2000	http://www.eea.europa.eu/data-and-maps/data/natura-5#tab-gis-data shapefile Natura2000_end2013_rev1.shp
HSMU Homogenous Soil Mapping Units	Modelled by CAPRI (Kempen et al. 2005) and Eurostat crop area data desaggregated to hsmu's by CAPRI. Year per country: NL 2008, BL 2008, DE 2008.
LGN7 (the Netherlands only)	http://content.alterra.wur.nl/Webdocs/PDFFiles/Alterrarapporten/AlterraRapport2548.pdf

Though less accurate as the national land use survey data, HSMU is available for the whole of Europe, allowing direct top-down assessments without resource-consuming data gathering procedures. The concept of spatially allocating specific food groups for which a certain supply deficit has been recognised – e.g. vegetables or oil seeds are typically underrepresented in the metropolitan surroundings of cities – to areas with clear food supply surplus coverage, for example grasslands, points at the need to guide such stakeholder decisions by offering additional land use related references. MFP is doing so by the means of two support mechanisms:

- a metropolitan zoning concept that suggests an agreed-upon sequence of food-zones following each other inspired by von Thünen (1826);
- a series of food group allocation rules specifically designed for each metropolitan region on the basis of landscape-ecological references (LANMAP)

Table 2: Ecological footprints in global and local hectares based on the population figures for the three case study areas (Wascher, 2016)

	Inhabitants (millions)	Global hectare per capita*	Global area (km2)	Local hectare per capita**	Local area (km2)
Antwerp	1.4	1.75	24500	0.134	1876
Rotterdam	2.2	2.21	48620	0.102	2244
Düsseldorf	5.1	2.05	104550	0.117	5967

Sources:

* *EUREAPA online scenario modelling and policy assessment tool (Briggs 2011)*

** *National references and estimates based on EFSA (2011)*

Assessing the food demand

Starting point of an ecological footprint assessment is the data food demand – thus the consumption patterns of people. Though preferences and needs differ of course across the different regions of the world and also within Europe – even within countries – census data is in principle available at most national levels. Key to the assessment, however, is not the availability of food consumption data, but its transfer to 'global hectares' of productive agricultural lands. Here another complicating factor comes into the picture: regional productivity ('yields') depends on many factors such as soil, climate, technology and culture. Due to a rather fragmented research history with simultaneous and largely uncoordinated efforts across sectors, research institutes and regions, ecological footprint calculations are manifold and differ substantially in terms of underlying data and methodologies (see Table 2). While the ecological footprint is still considered as a key reference and communication tool when comparing environmental impacts at highly aggregated levels, the above mentioned inconsistencies have been a matter of concern for both research and policy.

Table 3: Comparison of different and local hectare demand figures with EFSA data

Germany	Seemüller 2000 (conv)	Wakamiya 2010 (eco)	additional foreign demand		EFSA figures (ha)
Wheat	0.0145	0.0230			0.0150
Other cereal	0.0067	0.0070			0.0060
Potatoes	0.003	0.0032			0.0010
Sugarbeet	0.0082	0.0082			0.0003
Oil					0.0010
Vegetables	0.002	0.0020			0.0012
Fruit	0.0001	0.0033			0.0070
Meat/Fodder	0.0623	0.1390	0.0530		0.0410
Dairy products	0.0855	0.0748			0.0450
TOTAL	**0.1823**	**0.2605**	**0.3135**		**0.1175**

Netherlands	Tilburg Study 2009	Gerbens-Leenes 2002	Vermeulen & Krüschner 2009	Jansma et al 2012 (UFPT)	EFSA figures (ha)
Wheat	0.0270	0.0015	0.0195	0.0095	0.0090
Other cereal	0.0030	0.0030	0.0030	0.003	0.0030
Potatoes	0.0007	0.0031	0.0049	0.001	0.0010
Sugarbeet	0.0058	0.0026	0.0010	0.003	0.0010
Oil	0.0130	0.0710	0.0040	0.0003	0.0003
Vegetables	0.0015	0.0049	0.00123	0.0015	0.0100
Fruit	0.0130	0.0077	0.00456	0.001	0.0010
Meat/Fodder	0.1780	0.0746	0.0556	0.028	0.0290
Dairy products		0.0470	0.0480	0.014	0.0480
TOTAL	**0.2420**	**0.2154**	**0.1417**	**0.0613**	**0.1023**

Belgium	national ref. 1	national ref. 2			EFSA figures (ha)
Wheat	?	?			0.0170
Other cereal	?	?			0.0070
Potatoes	?	?			0.0010
Sugarbeet	?	?			0.0010
Oil	?	?			0.0010
Vegetables	?	?			0.0020
Fruit	?	?			0.0080
Meat/Fodder	?	?			0.0300
Dairy products	?	?			0.0670
TOTAL	**?**	**?**			**0.1340**

Though the emergence of the European Footprint Tool EUREAPA (Briggs 2011) has clearly helped to improve the situation by offering a harmonized methodology for 27 EU countries plus another 16 countries, its output is restricted to calculating *global hectares* only. Global hectare calculations translate all dimension of our current food system – thus all aspects of (fossil) energy and waste production around food production, transport and retail – the lion's share of the footprint – into the required land size that is needed to produce the required resources. Local hectares, on the other hand, address only those pieces of land which are needed to factually produce the required good. Differences between global and local hectare footprints – depending on the size of the urban population - and between urban consumption patterns are illustrated in Table 1. It shows that on average local hectares take less than 10% of global hectare demands.

The discrepancy in total global hectare demand figures in Table 2 derives obviously from the different methods that are being applied. Based on the average Dutch diet and the average agricultural Dutch production capacity Jansma et al (2012) developed the internet based Urban Footprint Tool (www.stedelijkefoodprint.nl). The authors point out that the tool does not thrive for a high level of quantitative accuracy but has primarily been designed to provide a rough approximation of food consumption impacts at the national level. The tools estimated area demand amounts to only 0.061 global hectares per person. Other sources such as Rood *et al.* (2004) put forward 0.31 local hectares, the study of Wageningen UR in cooperation with the Brabantse Milieufederatie "How to feed Tilburg" (2009) suggests 0.24 local hectares, while Gerben-Leenes (2002) calculated 0.21 local hectares as a standard reference. Jansma et al. (2013) explain the tool's underestimation as a result from (1) the selection of mainly locally available food types, and (2) the conversion of imported food to notoriously high Dutch yields.

Because of these differences in the calculation methods we decided to exclusively focus on EFSA data which are considered as being internationally harmonised. One obvious characteristic is that EFSA is putting forward demand data which is substantially lower than most national assessments. This study did not allow to develop understand the background for these differences. Other reasons for selecting EFSA included the following reasoning:

- ecological food production such in the case of Wakamiya must be considered to result in substantially high hectare demands
- EFSA data ranges between the conservative assumptions of Jansma et al. (2012) and the more high-level data by other authors;
- We also felt that the recent Amsterdam assessment by Vermeulen & Krüschner can be considered as case-specific and hence trust-worthy
- Using more conservative data such as from EFSA is likely to reflect more an institutional setting related to the development of European standards

*The differences between countries derive from the different consumption patterns. It should be noted that Belgium is also taking a lead role in terms of high ecological footprint results in other sources (Bru*ers & Vandenberghe 2014). The Metropolitan Foodscape Planner tool (MFP) uses the EFSA demand statistics for identifying 12 categories of crops/land use, namely: (1) wheat, (2) other cereals, (3) rice, (4) oil crops, (5) pulses, (6) potatoes, (7) sugar beet, (8) vegetables, (9) fruits, (10) wine grapes, (11) food crops and (12) grasslands.

Making use of ecological footprint calculation that is based on yearly food demand, we calculate the available supply of agricultural land based on the population number per metropolitan region in all three countries, namely:

- Regierungsbezirk (district authority) Düsseldorf with Krefeld-Rhein (5.1 million inhabitants/TZ: 12.2 million inhabitants)
- Vlaamse Ruit (Flemish Diamond) around Antwerp, Ghent and Leuven (1.4 million inhabitants/ TZ: 5.1 million inhabitants)
- Metropolregio Rotterdam-DenHaag (MRDH) in the Netherlands (2.2 million inhabitants /TZ: 6.8 million inhabitants)

Assessing the food supply

Making use of the figures for urban food demand, MFP projects the corresponding land demand figures in the form of 'local hectares' to those areas of land that can be considered to be eligible for farming. We hence excluded the urban areas, waterbodies (sea, lakes & rivers), nature and landscape conservation sites, forests and other non-farmlands such as rocks, beaches and swamps from the analysis. The total area available for agriculture is the area classified in Corine Land Cover as agricultural areas, sport and leisure facilities, green urban areas, natural grasslands and sparsely vegetated areas, minus the protected areas in Natura2000.

The radii of the "Metro-Food-Ring" and the "Transition Zone" are calculated based on the total demand in ha for the population and the total area available for agriculture per ring.

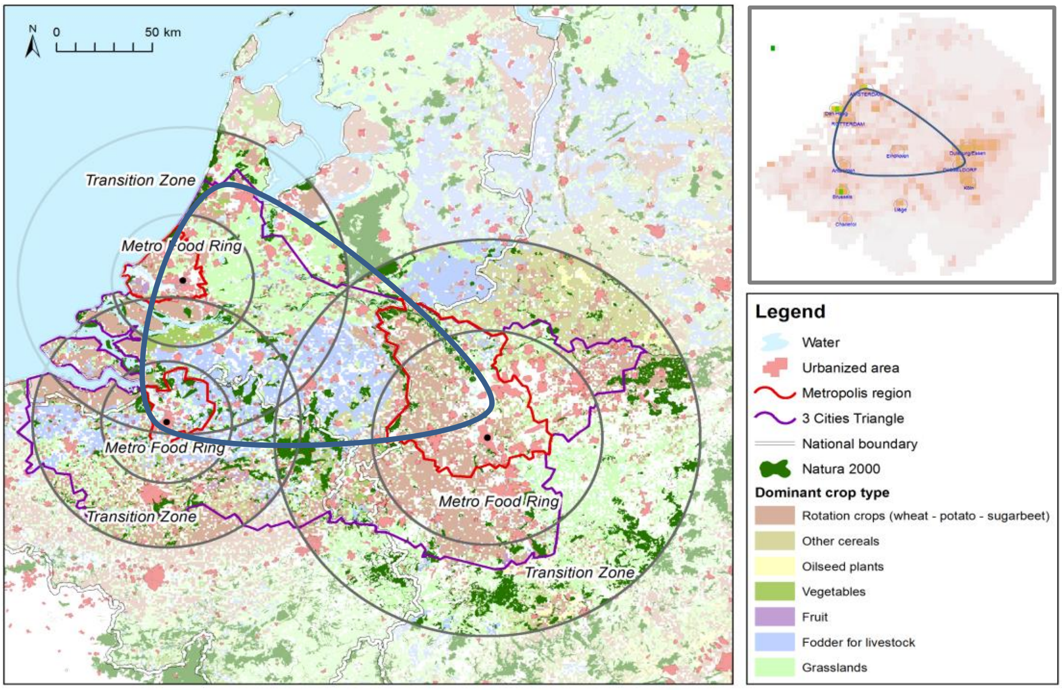

Figure 1*: The ARD-Region in both the Metropolitan Footprint Planner with dominant crop types and in the Global Metropolitan Detector (see inset at top right) mapping context*

Figure 1 shows the results of the area demand calculation with the subsequent spatial projection onto the HSMU-Land use supply areas. Here we see for each metropolitan region (1) the Metropolitan Food Rings as the inner ring around the central cities which already include adjacent large cities such as Cologne and Dortmund in the case of Düsseldorf, followed by (2) the Transition Zones which are partially overlapping. We see that the Transition Zones include other large metropoles such as Brussels in Belgium as well as Bonn and Hamm in Germany. Based on NUTS3 regional boundaries we show the outline of the 3-Cities Triangle as well as a virtual triangle connecting the three regions. Natural 2000 sites are shown in green, water areas in blue, urban settlements in light red and forested areas as well as other non-qualified land use types are shown in white.

A first-hand interpretation of the Figure 1 leads to the conclusion that Natura 2000 sites are mainly located in the Transition Zone – with the Ardennes and Rhön landscapes between the Ruhrgebiet and Belgium Metro-Food Ring. Other Natura 2000 sites are located exactly at the Western periphery of the Regierungsbezirk Düsseldorf along the natural boundary Maas between Nijmegen and Roermond, equally along the Rhine between Duisburg and Emmerich. Large proportions of the Metropolitan Food Rings of all three regions are dominated by crop-rotation food types wheat-sugarbeet-potato; e.g. the Western part of the Met-Region Düsseldorf, the South of Rotterdam (Hoekse Waard) and the Flemish region in the West of Antwerp. It is interesting to see that feed crops for livestock rearing ('fodder') dominates the central region in the overlapping Transition Zones of all three Met-Regions. The MRDH-region takes an exceptional position with regard to the extent of grassland dominating major proportions of both the Metro Food Ring and TZ in the landscapes to the East. It can be seen how the spatial planning concept of the Dutch Green Heart has resulted in open grassland dominated space reaching right up to the MRDH-boundary. But also in the East of the Met-Region Düsseldorf grasslands are a dominating factor. Belgium, on the contrary lacks these types extensive grasslands regions. Another specific land use case is the fruit growing region stretching South from the Hollandse Diep which is still part of the MRDH's Metro-Food-Ring.

2.2 Results MFP

The statistical assessment on the basis of the ecological footprint data for all three metropolitan sites in the ARD-region is depicted in one conclusive graph (see Figure 3). These calculations provide interesting insights to the demand-supply relationships that can be found in both the Metro-Food-Rings as well as in the Transition Zones of each case. In the following we offer a short summary of these findings.

Metropolitan Region Flemish Diamond (1,300 km^2, 1,4 million citizens)
In both the MFR and Transition Zone, there is to recognize a severe deficit of grassland supply compared to demand, the latter being more than twice as high. Within the MFR-Zone, there is a clear over-supply (about 200%) with land use dedicated to fodder plants. Thefruit supply is falling short of meeting the demand, whereas there are more than three times as much veggetables as needed. This supply is especially thanks to the region around Sint-Truiden in Flemish-Brabant with more than 3000 ha apple and pear trees. The supply with both rotation crops (potatoes-sugar beet-wheat) and 'other cereals' is clearly larger than the demand in both MFR and TZ.

Metropolitan Region Rotterdam Den Haag (1,130 km^2, 2,2 million citizens)
The MFR agricultural land requirement is approximately twice as large the total surface area of the metropolitan region. This region includes at total of 6.8 million people which require a TZ that is about three times as large as the MFR. As mentioned earlier, grassland demand and supply are in a reasonable balance – mainly due to the spatial policies protecting the Green Heart and Delfland which is dominated by grazing land. Not included in this assessment is the production volume of the greenhouse areas, e.g. Westland en Oostland. In Westland-Oostland, the net production area for vegetables is around 1.900 hectares, which is about two thirds of the total vegetable-greenhouse surface area of the Netherlands. With the dominant vegetable products tomatoes, cucumbers and paprika making just about one third of the yearly vegetable diet, the greenhouse production supply capacity can be estimated to cover the yearly demand of more than 23 million people – so much more than the total Dutch population (17 million). However, 95% of the tomatoes, 90% of the paprika and 80% of the cucumbers are being exported to other European and global location. In order to capture this part of the assessment please see Figure 2 with specifications for the greenhouse production taking into account Westland-Oostland production capacities (Must 2015).
With regard to the other food crops, livestock feed is in deficit in MFR, but in approximate balance in TZ. There are clear over-supplies for rotation crops in both zones of MRDH. Fruit supply is smaller than demand.

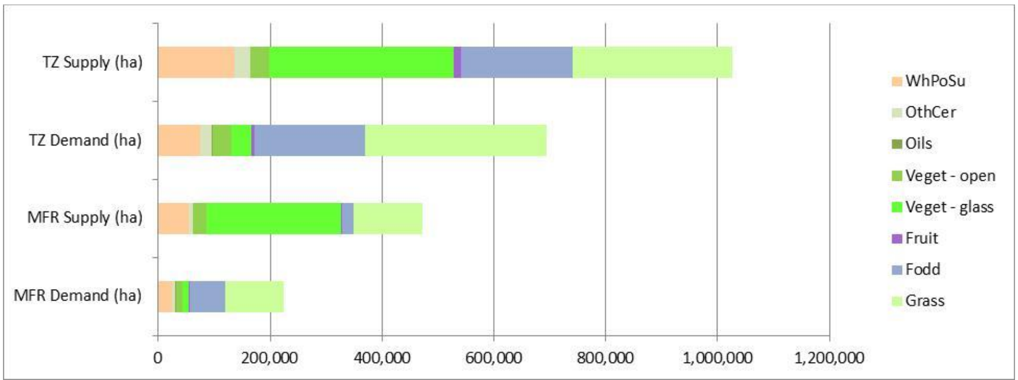

Figure 2: Food Supply-Demand balance sheet for the MRDH region taking into account the Westland-Oostland greenhouse production of vegetables ('Veget – glass')

The Metropolitan Region Düsseldorf (5,300 km^2, 5,1 million citizens)
The difference between the metropolitan area's surface and the MFR is relatively small: only 70.000 hectares of additional production land is needed. This is undoubtedly linked to the more fragmented and diverse land use within the metropolitan zone allowing for agricultural production.
Here we see that the existing supply with grassland is almost matching the demand side to the full extent, at least in the Transition Zone. There is a substantial over-supply for 'rotation-crops' within the Metro-Food-Ring and also a clear oversupply of the category '0ther cereals' in both MFR and TZ. Interestingly there is almost a match between supply and demand for vegetables, but clearly a deficit of

fruit production in both MFR and TZ. The demand for livestock feed production is twice as high in the TZ and even about three times as high in the MFR. With regard to the regional supply potential of the MFR-zone it can be stated that fruit and vegetable production in a relative balance, especially when taking into account the TZ

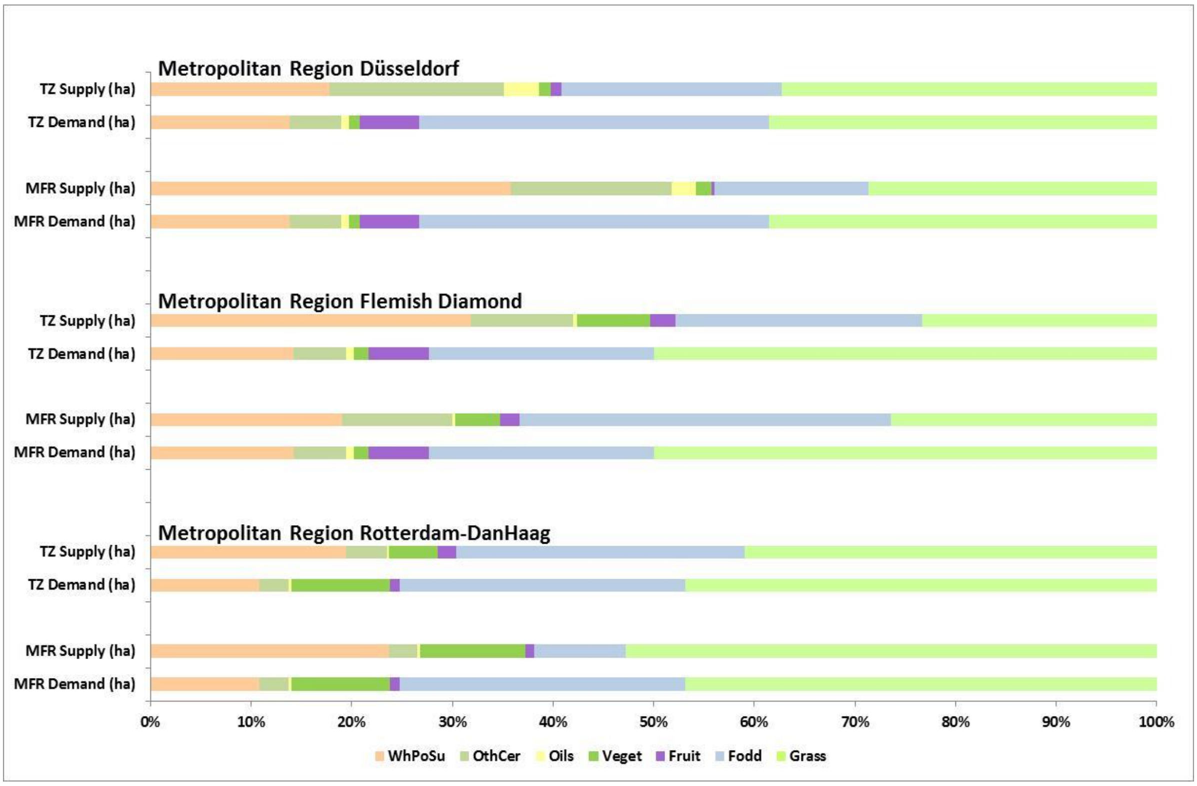

Figure 3*: The regional food demand-supply balance assessment on the basis of the ecological footprint calculations for the three metropolitan areas in the ARD-region.*

2.3 General observations

The above assessment based on metropolitan footprint calculations and GIS-based identification of current food supply in terms of existing land use areas allows the following observations:

- Beside depending on the size of the population and their region-specific consumption patterns, the size of MFR and TZ is strongly depending on land use structure within the metropolitan areas – thus the density of the urbanisation.
- Grasslands and Crop-Rotation take the largest shares with regard to supply, matching the demand in the German and Dutch case, but not in the Flemish Diamond region.
- For livestock feed products ('fodder') and openland vegetables the Flemish Diamond is also different: it is the only region where the supply is larger than the demand.
- The inclusion of the Dutch greenhouse ('glastuinbouw') areas of Westland and Oostland change the picture for potential supply dramatically, pointing at regional alternatives;
- Fruit demand is notoriously undersupplied with exception of the TZ in the Dutch region.

3. Comparison of Metropolitan Foodscape Planner with the Global Metropolitan Detector

3.1 Background and case selection

The results of MFP assessments are considered to provide valuable contextual information for sites of interest as identified by the low-resolution tool Global Metropolitan Detector (GMD) developed by LEI at the level of UTM grids (5'x5 resolution). At any spot on the world, GMD is able to undertake a wide range of indicator assessments making use of expert-driven knowledge-based models. The result of GMD is reported as a map which indicates the potential of suitable production areas for the crop group under consideration. The areas with the darkest colour are thought to have the highest potential. An example of the GMD is provided for the case of identifying Tilapia production locations in Kenya and surrounding countries (see Figure 4). Dark squares show the sites with the highest potential with favourable production conditions. However, the large size of the squares (about 100 km^2) implies the high probability that these sites are actual rather heterogeneous and that substantial differences within and between squares must be expected. Furthermore, GMD should be regarded as a "quick scan" since not all factors are taken into account, e.g. cultural and detailed infrastructural factors.

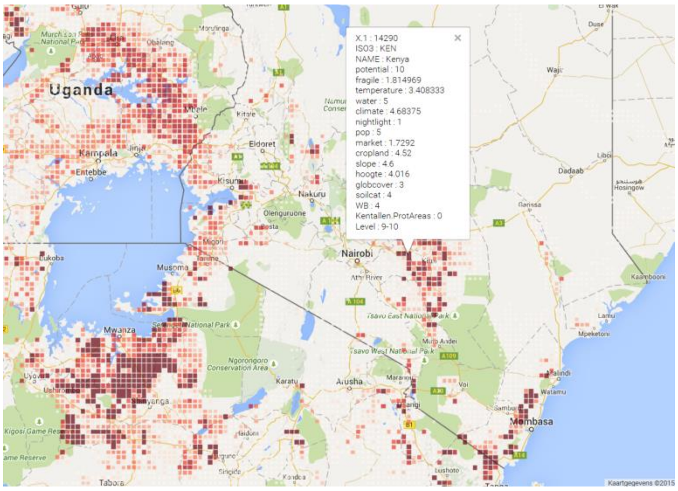

Figure 4: *Example of a presentation of the result of Global Metropolitan Detector (case potential Tilapia production)*

The selected modelling cases for the use of contextualisation are as follows:

- Urban agriculture
  For the calculations it is assumed that the production of fresh vegetables should be produced near cities on areas currently used for cropland and grassland. Especially in regions where perishable products have to be on the market with no delay (tropical regions with bad or expensive transport facilities).
- Intensive pig and poultry meat production
  Areas that are far from densely populated areas may be attractive for intensive meat productions. The derived map "Far from urban regions" is used for this. In rural areas there might be smaller cities, areas nearby are made less attractive. Additionally the map "Population radius 250" is used in a positive way to make sure that production is not "in the middle of nowhere".
- Arable crops
  Cropland not intended for vegetable is used for arable crop production. Production is further away from urban areas than vegetable and fruit production.
- Grassland and other areas suitable for cattle, sheep and goat (meat and milk production)
  Derived grassland not intended for fruit is used for cattle, sheep and goat. Maize, alfalfa or other crops used as animal feed is assumed to be produced in areas with arable crops.
- Vegetables and fruit production

It is assumed that the production of vegetables and fruit should not be too close to urban areas (because of production fresh products) and not too far away (because of logistics and processing). The derived maps "Far from urban regions" and the area cropland and grassland (for a small part) are used for this.

3.2 Method

For explanation on the methodology and output results of the GMD, see the corresponding technical report (Hennen 2016).In order to allow a spatial comparison between the two tool results it was necessary to project the resulting layers on top of each other. The GMD data are in the WGS84-format (5'x5'). We transferred them to ETRS1989_LAEA used in the MFP tool in the FOODMETRES approach, which causes rectangular cells.
In the comparison with the MFP results we focussed on the areas with the highest density in the GMD. Therefore we identified for each GMD output map the 20% grid cells with the highest density values (the 0.8 quantile). In the maps in this report these areas are indicated by red boundaries. In case of urban agriculture the density limit value is 151 ha per grid cell, for intensive pig and poultry meat production 5.4 ha, for arable crops 2034 ha, for grassland 1463 ha and for vegetable and fruit production the limit is 498 ha per grid cell.

3.3 Results

In the following we show the results of projecting the high-density grid cells of the GMD onto the ecological footprint balance maps of the MFP-tool output.

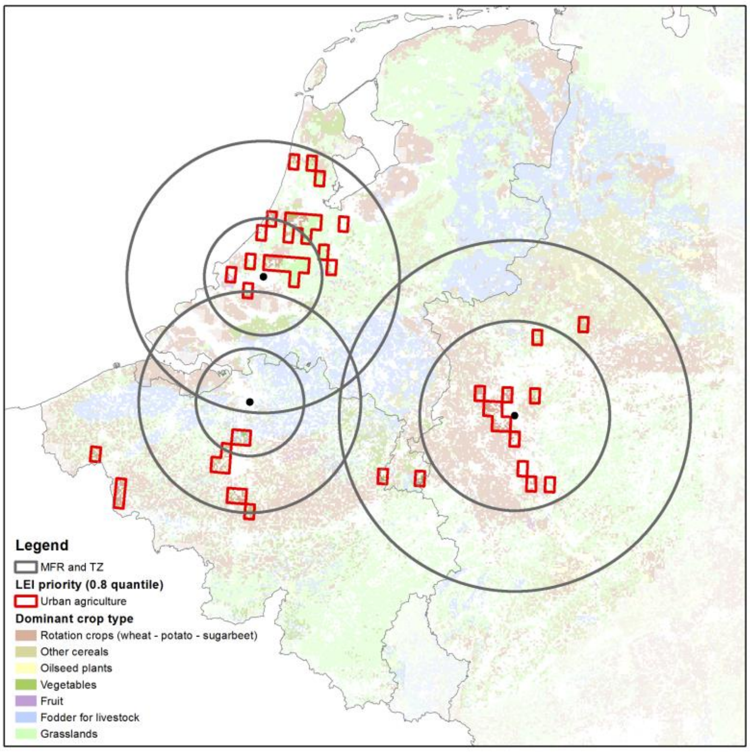

Figure 5: ***Metropolitan Foodscape Planner comparison with Global Metropolitan Detector for the topic of favourable sites for Urban Agriculture***

Figure 5 shows the results of the overlay for the detection of favourable sites for urban agricultural locations. With regard to the selection criteria applied by the GMD it should be noted that it had been programmed to search outside the city boundaries. Given the overall high density of urban settlements in the ARD-Region these results might at first glance surprise: urban agriculture should be possible in virtually all urban and peri-urban locations. However, it should not be forgotten that the originally identified areas have been reduced to only the 20% top-scoring high density grids. So we see indeed crop-grassland location next to larger urban centres of which most are situated in the very proximity of the three selected case study cities Rotterdam and Düsseldorf. Only in Belgium the identified priority sites are not around Antwerp, but North and West of Brussels, as well as near Charleroi and Tournai. Other sites are related to neighbouring urban centres of Lille (France) and Maastricht (Netherlands).

In the Netherlands most priority urban agricultural clusters are located exclusively in the Randstad around Rotterdam and in the Triangle of Amsterdam-Leiden-Utrecht. It should be noted that the GMD tool-allocations for areas within the Green Heart of Holland need to be critically reviewed since urban agricultural land use is likely to conflict with these sites traditional role as large open grasslands. On the other hand, croplands are taken into account while protected areas have been excluded.

In the Regierungsbezirk Düsseldorf, most site proposals follow the Rhine lowlands West of Düsseldorf down towards Leverkusen. But also sites near Wuppertal and Essen are indicated. Also here it will be important to carefully examine the role of nature conservation as a prominent site designation.

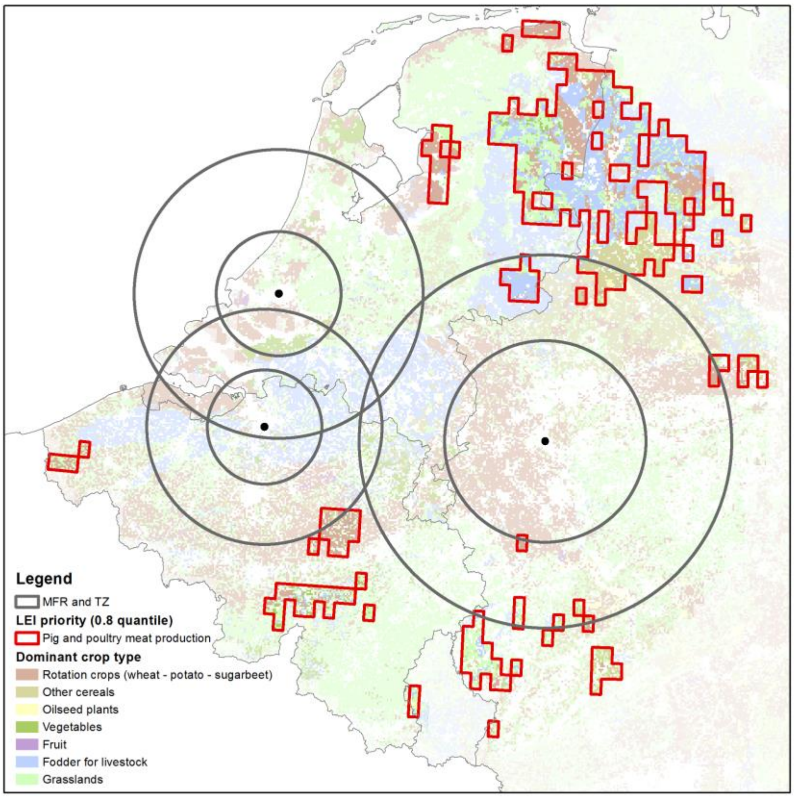

Figure 6*: Metropolitan Foodscape Planner comparison with Global Metropolitan Detector for the topic of favourable sites for intensive pig and poultry production*

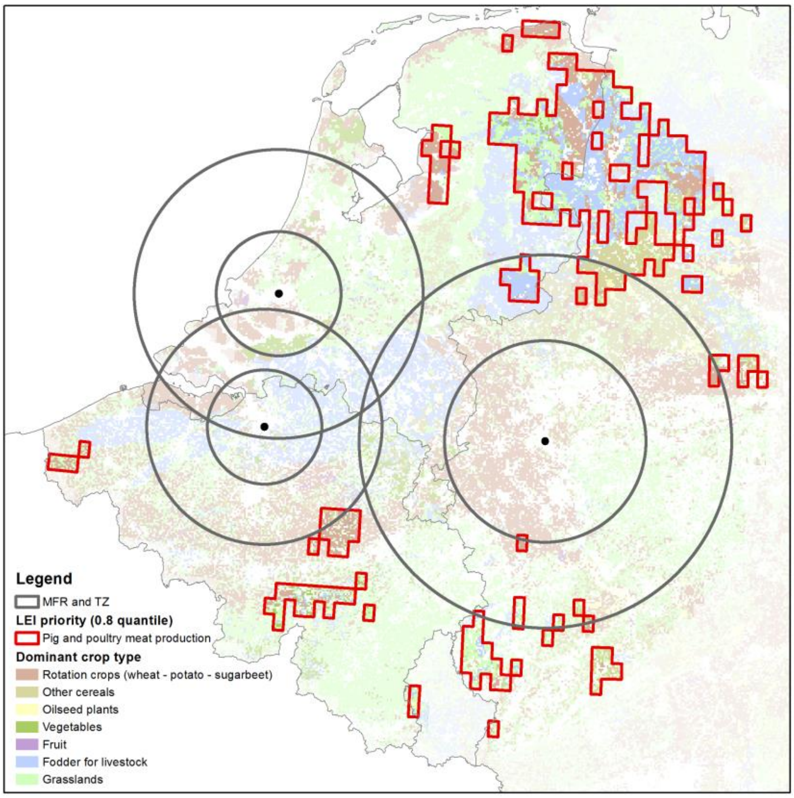

Figure 6 shows the GMD-allocations for proper siting of intensive pig and poultry production, especially taking into account the perception and sensitivities of local populations. The most conspicuous finding is the large area North of the Düsseldorf Metro-Region across the Dutch-German border between the Dollart and Nijmegen. This location appears to make sense since cross-border regions are traditionally less densely populated. In the case of the German side, population number of this part of the Bezirk Weser-Ems are relative low, there are large peatlands and livestock farming is already quite widespread.

In the Netherlands there are areas with high density of pig and poultry farming in the province of Noord-Brabant - especially the Peel-Region - and the provinces of Gelderland and Overijssel. The combination of high density of animals and human population may give rise to various environmental, social and health problems. So, the fact that these areas don't have high priority in the GMD corresponds to this.

Also the proposed sites in Belgium and Germany are clearly located outside the MFR-Zones and even the Transition Zones which support the rationale behind a more evidence-based spatial planning approach towards industrial livestock farming.

Figure 7 shows extensive area allocations for general crop lands. Also here distance to urban settlements has been a factor which can be debated. However, the assessment shows that large proportions of the allocated areas are situated on what are now 'livestock feed production' (fodder), indicating that much more crops for direct human food production and processing could be grown – probably also closer to the cities. Most other areas match existing crop-rotation and other cereals. The impact of this GMD-output needs to be further studied.

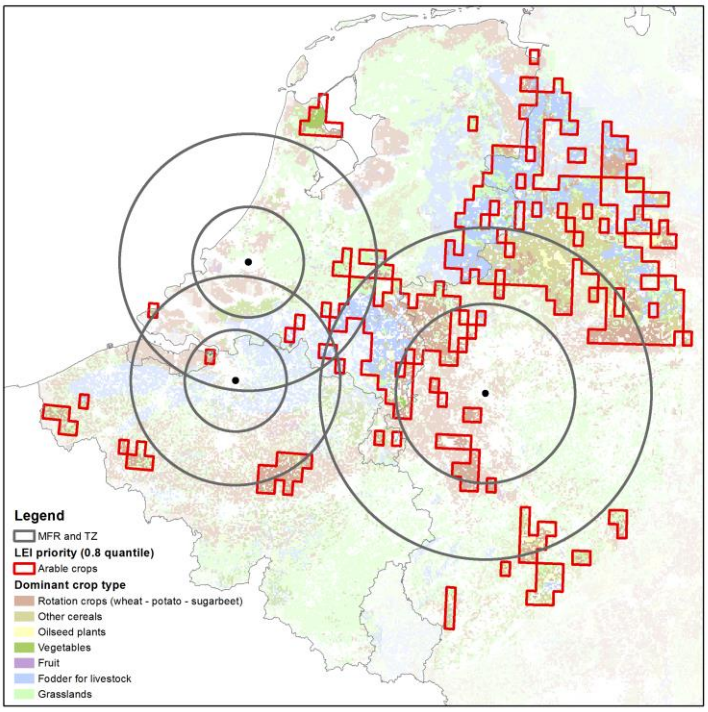

Figure 7*: Metropolitan Foodscape Planner comparison with Global Metropolitan Detector for the topic of favourable sites for Arable Crop production*

Figure 8 illustrates possible areas for dairy farming grassland production. It is immediately obvious that there is close match with large stretches of existing grassland use – especially in the Netherlands. We also see, e.g. in the north-east of the Netherlands, Germany and Belgium, that there are numerous allocation for food-crop regions to qualify for possible grassland production.

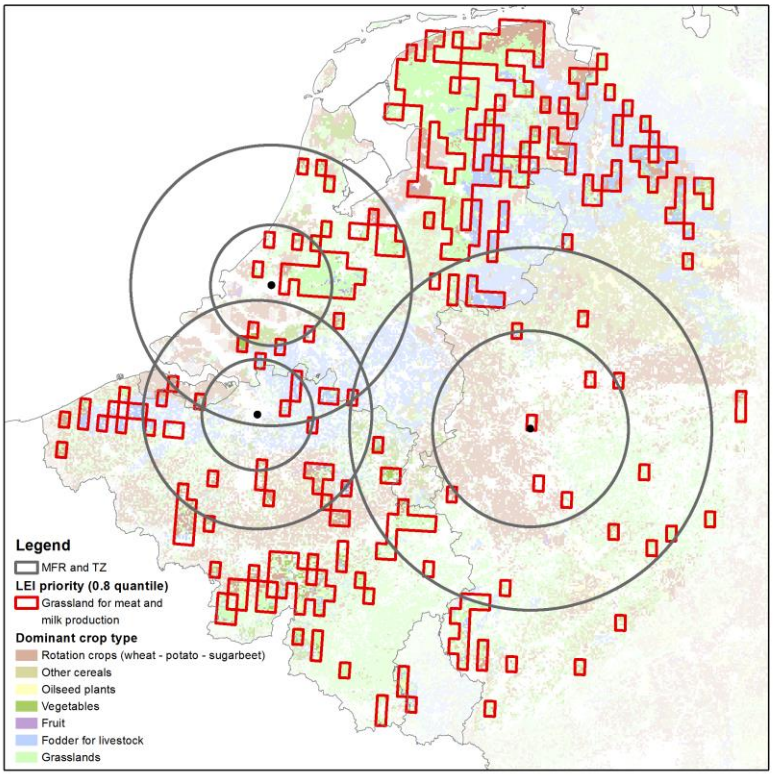

Figure 8*: Metropolitan Foodscape Planner comparison with Global Metropolitan Detector for the topic of favourable sites for Grasslands for Meat and Milk production*

Figure 9 depict the results for identifying suitable sites for vegetables and fruit production. From the viewpoint of the FOODMETRES approach we actually do not fully agree on the chosen selection criteria. This is because (1) vegetable and fruit freshness should not be in a negative correlation with close distance to urban settlements, and (2) these land use types are actually quite attractive for urban recreation purposes. It should be noted that GMD does not choose among the different land usages. For a grid near a city it is possible to have a part of the area for urban agriculture, a part for vegetables and fruit and a part for grassland and recreation. So a grid has more functions combined.

At the same time, vegetable and fruit re-allocations or production increase in close proximity to the city are at the core of the Metropolitan Foodscape Planner / FOODMETRES approach. We used this case as an example to demonstrate the down-scaling capacities of this approach when making use of high resolution data such as LGN7 at the scale of 25x25m grid cells (Hazeu 2014). Figure 10 shows the location south of Hollands Diep between the villages of Moerdijk, Zevenbergen and Klundert at different scales with the corresponding data layers. Map 11a shows the distribution of GMD priority grid cells for vegetables and fruit over the whole test areas without MFP-rings. Map11b zooms into the details South of Hollands Diep. We see cities left out as white patches and mainly two dominant food groups: fodder and vegetables – with one cell of fruit (top center). Map 11c shows the same area section as 11b, but with the details of LGN7. Map 11d zooms into this high resolution map allowing a closer view on the different land use types. Here we mainly see sugarbeet, cereals and potatoes (*'bieten', 'granen' en 'aardappelen'*) – i.e. rotation crops. This part does hence not clearly correspond with the HSMU-based assessment, which indicates fodder as the dominant crop type. Closer to the river we see different kinds of grasslands and fruit orchards. In LGN7 there is no discrimination to vegetables. Other crops (*'overige gewassen'*) contains also vegetables.

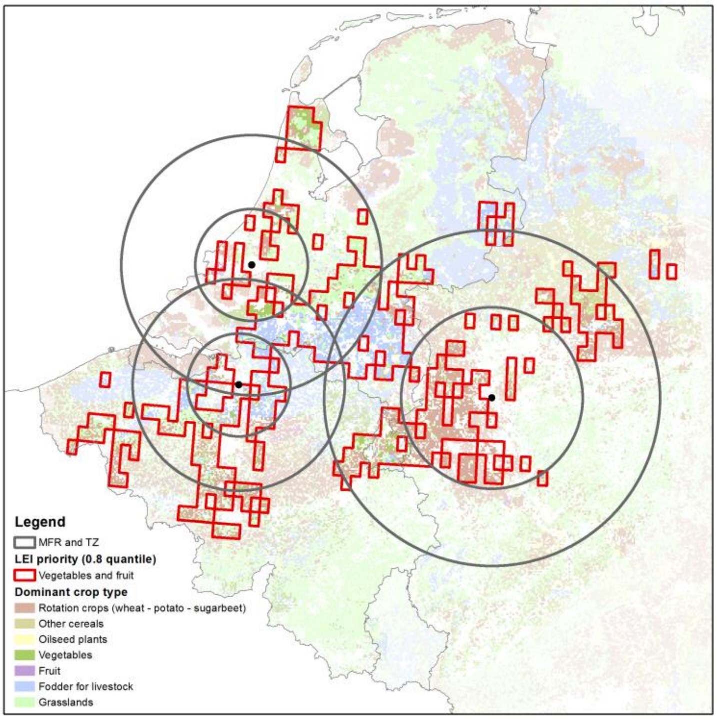

Figure 9*: Metropolitan Foodscape Planner comparison with Global Metropolitan Detector for the topic of favourable sites for vegetables and fruit production*

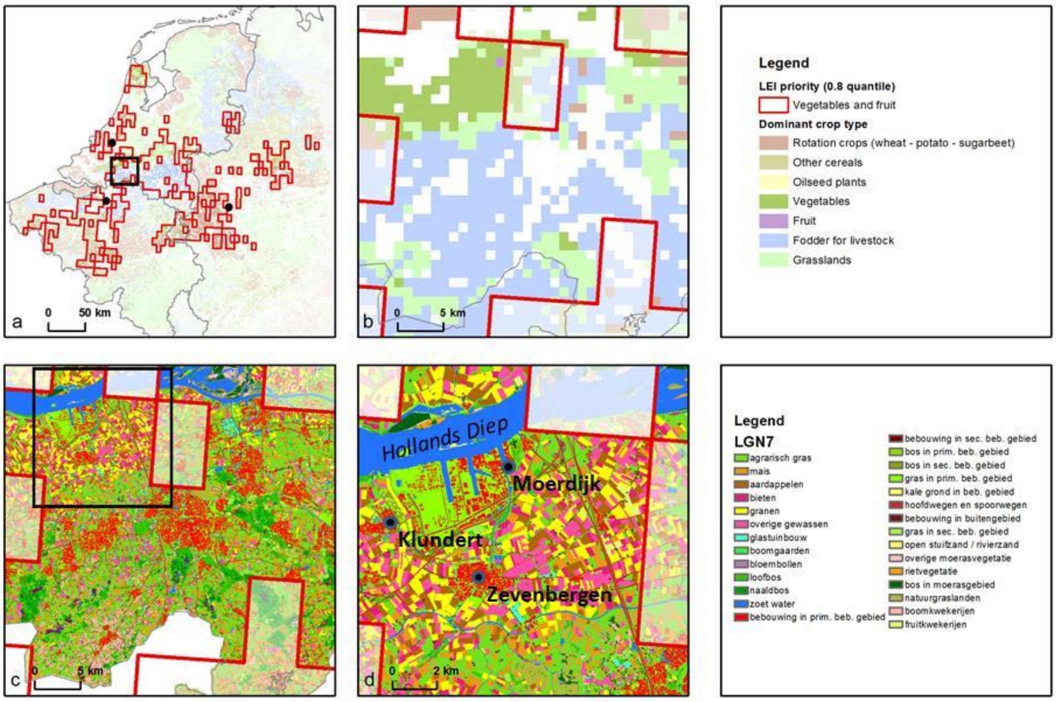

Figure 10*: Downscaling of the food security assessment for the topic of vegetables and fruit production at the example of Metro-Food Ring around the Metropolitan Region Rotterdam Den Haag – here with focus on an open land vegetable production South of Hollands Diep.*

4. Discussion

Applying the MFP tool to the ARD-Region between Antwerp, Rotterdam and Düsseldorf has demonstrated that self-sufficiency of these metropolitan regions is in principle possible and that dependencies from food import vary considerable between the regions. It also shows that regional food supply does not only depend on existing agricultural land use, but also on issues such as site designation in favour of nature conservation and recreation, urban development trends, flood protection as well as other aspects of national security. Depending on whether a city is located close to non-food zones such as lakes, oceans, mountains, sand dunes or protected areas, the eligible areas for regional food production can be close by or relatively far away. Accessibility of these food zones is another limiting/enabling factor (Wascher et al. 2016). All these factors are of high impact on metropolitan food supply capacities and ultimately on food security of cities. With an export volume of €82 billion in 2015 (LEI 2016), The Netherlands is further expanding its position as Europe's leading global player in both trade and production. In comparison: North-Rhine-Westphalia has a total agro-food export of €7.8 billion in 2016 from a German total of €68 billion (IT.NRW, 2016), and the Flemish region holds with €30 billion about 80% of the total Belgium export volume in 2013 (Wikipedia). Because of the leading role of The Netherlands as a global champion in agricultural trade we discuss critical aspects of the global agro-food system mainly by using Dutch examples:

- Land use change: though the global agro-food sector points at the benefits of innovation and intensification in terms of reducing the demand for land, the total agricultural area has not decreased (Ausubel et al. 2013). This is because the global ecological footprint of agriculture is roughly ten times as large as the local footprint – hence the area needed for producing the demand (see Table 4). Assessing normalisation references and factors for human meat consumption in EU27, JRC (2008) found that impact associated with *terrestrial eutrophication* – to just quote one of the 17 impact indicators – is 0.21 ha per person and year as compared to 0.15 global hectares needed for producing meat and dairy products. Of course, food self-sufficiency based on metropolitan supply will not automatically reduce the large area impact of meat consumption. However, the large land demands and partial over-supply for areas reserved to livestock farming – especially feed – point at regional misbalances that goes potentially on the expense of food groups such as vegetables, fruit and natural grasslands.
- Competition for space: here we see that urban development is increasingly conflicting with agricultural intensification. The current rate of soil loss by sealing through urban expansion and infrastructure in the Netherlands amounts to ca. 36 ha per day. In other countries of Europe, like Germany (120 ha per day), Austria (35 ha per day) and Switzerland (10 ha per day), similar soil losses by sealing through infrastructure and buildings have been observed. According to the EU, this development is in direct competition with agricultural land uses and is threatening valuable agricultural soils all over Europe (Montanarella 2015). But also nature conservation, recreation and the increasing popularity of horse riding are factors that are substantially limiting agricultural land use. Both the Flamish as well as the Randstad region face severe land use pressure on valuable agricultural grounds. Given the high land prices near cities, agriculture has to be extremely competitive to survive. Such areas would be highly qualified for new value chains that make use of urban waste streams (bio-refinery) and waste heat for producing a variety of horticultural products in close proximity to the consumers.
- Biodiversity: Lenzen et al. (2012) have shown that trade contributes to biodiversity threats, especially in developing nations. Similarly to tropical deforestation, biodiversity threats are often higher in mid latitudes, developing countries, where specific food commodities are produced for export to higher latitudes, to the more developed countries that do not have a suitable climate to make these commodities (e.g. palm, cocoa, bananas). Thus, even though overall land productivity seems higher in exporting nations than importing ones (Fader et al. 2011), specific frameworks are required to mitigate biodiversity loss and forest threats due to commodity specific South–North trade. Some of such frameworks are currently in place, for example for soybean and palm oil. In metropolitan areas such as the ARD-region we encounter the situation that local biodiversity is under severe pressure by both urban development and agriculture, with only little benefits for local urban food consumption. So while the pressure is high on regional and remote biodiversity values, economic revenues are restricted to farming and food processing business that contributes only little to regional employment, social inclusion and urban food consumption.
- Climate Change: According to Dalin and Rodríguez-Iturbe (2016), trade of bulk agriculture (i.e. raw crops) reduces emissions in 41.6% of the trade flows (i.e. trade links from a specific country to another), in many cases substantially, due to a difference in emission intensities overcoming transportation emissions (Cristea et al. 2013). However, the remaining links represent significant increases in emissions, so that the average effect of bulk agriculture trade is to increase emissions by 359 g of CO_2 per dollar of trade. The effect of processed agriculture trade (including fruits, meats and dairy products) on global emissions is not provided, but Dalin and Rodríguez-Iturbe (2016) note that this type of trade is more likely to rely on carbon intensive air transport than that of raw crops, thus potentially increasing global emissions further.

5. Conclusions

With regard to the MFP tool we can conclude that the assessments point at strategic opportunities for enhancing the regional supply with agricultural products in at least two ways:

(1) Proposing land use changes in the case of production-surplus towards production-deficit crops where possible

(2) Using existing zero-balances as well as supply surplus to reduce food export to the benefit of a targeted increase of regional supply.

The underlying guiding principle for such an interpretation is the consideration that regional food security will become

GMD is a model intended as to be used as a less-detailed first step "quick-scan" assessment. The model can be used for each region in the world without much additional effort. Since GMD cannot account for very detailed conditions and circumstances, a second more detailed step by the MFP-tool, or another tool with additional high resolution information, is required.

In poly-centric urban agglomeration areas such as in the ARD-Region between Belgium, The Netherlands and North Rhine-Westphalia in Germany food supply is competing with space for urban development, recreation, biodiversity, urban development and demand competition from adjacent metropolitan regions. In the discussion we compare the potential benefits of a metropolitan food supply for feeding the cities with the currently dominating export/import driven industrial agro-food system on the one hand and with regional urban food supply on the other hand. The comparison suggests that current urban food security could be more sustainable and less vulnerable to external impacts if considering more region-oriented concepts of 'resource efficiency' and 'food innovation' targeting at a maximum of social inclusion (regional job opportunities), environmental benefits and regional identity.

Both the MFP and the GMD are tools that can help both policy makers as well as the entrepreneurs from the agro-food sector to take into account the wider spatial and functional dimensions of metropolitan regions when deciding on long-term strategic planning and business opportunities.

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