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Optimizing agricultural land use options for complying with food demand: evidences from linear programming in a metropolitan area

Assessing the sustainability of urban agro-food systems is strictly linked with food provision capacities. Especially in metropolitan regions, where agriculture is continuosly under pressure, deepening economic and policy implications of structural changes is particularly important. In this perspective, the paper proposes the use of an optimization model to indicate how reconciling agricultural activities and compliance with food demand at regional level. The approach relies on a scenario analysis carried out through a linear programming model. With regard to the Milan metropolitana area, five scenarios are performed, related to either different productive capacities or dietary habits, and the optimal allocation of agricultural resources in response of such modifications is returned.

Keywords: *metropolitan area; land use; scenario analysis; optimization models*
Parole chiave: *area metropolitana; uso del suolo; analisi di scenario; modelli di ottimizzazione*
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Introduction

The interest in issues related to urban food supply is not something new. Major efforts are addressed to deepen this topic in Developing Countries, where the main problem concerns the need to increase and improve food security (Gallaher et al. 2013). However, the theme is continuously on the rise in the Global North, as well. Here the enhancement of productivity is needed to provide high quality food to an increasing number of people (UNDESA 2012); at the same time, it emerges as profoundly related to both resilience (Meerow et al. 2016) and sustainability of the urban model (Allen and Wilson 2008; Alexandros and Bruisma 2012). Food in fact affects the local economy, the environment, the public health, the quality of neighbourhoods (Pothukuchi and Kaufman 1999). Within a regional context, the relations between the productive areas, typically the rural ones, and those where food demand is concentrated – the purely urban zones - reflect the food supply dynamics; therefore their proper and adequate management is the base for a sustainable system. However, the interactions between the two elements is characterized by a profound dynamism (Sali et al. 2014a): the expansion and the spreading of metropolitan areas, in combination with a progressive urbanization (UNDESA 2012), leads to an increase in the demand for goods and services; this in turn represents a key driver that exacerbates land use conflicts between productive areas and residential settlements (Perrin et al. 2013), resulting in a significant change in the relations within the Urban-Periurban-Rural continuum

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(Iaquinta and Drescher 2000; Mazzocchi et al 2013). In particular, the surrounding farmlands suffer from a lower productive capacity, with a growing dependence for resources on global level (Porter et al. 2014) and the disconnection between production and consumption sites (Sonnino 2009). Literature variously deepens the role of urban and peri-urban agriculture in providing food to cities and urban conglomerations, estimating the level of food self-sufficiency and reliance (Timmons et al., 2008; Mok et al., 2014). The dimensions of supply and demand for agricultural products in fact characterize the regional agro-food system, contributing in the assessment of how it would be able to respond to domestic demand, compete in the global context and meet consumers' needs. Concretely, this often results in the increased attention paid to all those initiatives that favour a higher organizational and geographical proximity between food and its source (Watts et al. 2005; Aubry and Kebir 2013), from local agro-food systems, to short food chains (Goodman and Goodman 2009; Sonnino 2009) and Alternative Agro-Food Networks (Murdoch et al. 2000; Renting et al. 2003). They are limited to strengthen the relations between producers and consumers, which actually represents a significant simplification of the many interdependencies amongst the actors involved in the agro-food sector (Lamine 2015). In spite of this, the use of a this kind of conceptual framework, though simplified, provides the chance to investigate the agricultural system itself according to a different perspective. It is therefore possible to analyze the context not only on a global scale - overcoming the limitations of national models - but also on a regional or metropolitan level. This means performing a reverse process and identify the characteristics of autonomy and sustainability related to the local systems, as well as assess the impact of closer proximity between places of production and consumption. This primarily allows the enhancement and the efficient use of local resources, leading the territory to benefit from manifold positive externalities: the promotion of economic vitality and the sustainability of peri-urban areas (Tsuchiya et al. 2015), the creation of favourable conditions for stronger resilience and competitiveness (Kneafsey et al, 2013), the adoption of actions functional to the development of local governance systems and the implementation of urban food policies.

Such as with other fields of policymaking, food policies require a sufficient informational and knowledge base to carry out effective actions (De Smedt 2010). The sustainable use of local resources, as long as the preservation of environmental-valued elements in strongly-urbanized areas, cannot therefore ignore the features of its respective agricultural system. Its characterization thus involve in first instance the quantitative dimension of both food demand and supply – i.e. primary production. This latter component varies according to the suitability of the territory itself and the specialization of the primary sector, or in more general terms, on the available agricultural area and its land use options. In other words, the maintenance of peri-urban areas and its productive capacities would favour the adjustment with local food demand, also creating the bases for the development of innovative local agro-food chains and metropolitan agro-food models.

Preliminary analyses and assessments of the context are essential instruments for providing indications on the potentialities of the system, their strengths and weaknesses, finally allowing to shape proper regulations accordingly and based on the actual needs of the territory. In order to contribute to this discussion, the paper introduces the use of a methodological approach at regional level, where activities of relevant actors in the agro-food sector takes place and where policies, regulations and interventions are effective. The analytical tool adopted refers to optimization modelling, mathematical linear programming in particular. The approach it is adopted to simulate the effects that different productive conditions and dietary habits have on agricultural land use options, in order to comply with food demand.

The use of optimization models

In the wider context of decision making, and especially in the planning and the management of complex interventions, the decisional process can benefit from the use of decision support tools and multiple criteria approaches. In this sense, mathematical programming assumes the role of a privileged instrument for providing general solutions to complex problems. Such method is in fact typically used for solving optimization problems in presence of limited resources, which means allocating them in the most efficient way: a typical example of this, is to consider the limited availabilities of materials and labour for determining the production levels that, under these same conditions, ensure the maximal profits.

In general terms, a linear programming optimization model is aimed at minimizing (or maximizing) a linear function J subject to linear constraints, whether equalities or inequalities:

Minimize or maximize	$J(x) = r^T x$	(1)
Subject to	$Ax \leq q$	(2)
and	$x \geq 0$	(3)

where x represents the vector of decisional variables, q the vector of coefficients used in the function and A the known matrix of coefficients.

On these bases, mathematical programming has been variously applied for the operative research in different branches (e.g. economy, land use planning, ecology, agriculture, biology, nutrition science) and with different purposes, from decision-making support systems (*"what-is-the-best"* approach) to scenario analyses (the *"what-if"* approach). A further utilization of LP models in fact relies on the chance to formulate and analyse different simulated conditions, under the hypothesis of an internal redistribution of resources or a recalibration of the imposed constraints.

With regard to food nutritional adequacy and dietary pattern, linear programming models have been implemented with different purposes in various periods and regions. Ahmed et al. (2011) adopted a linear programming technique to optimize resources use efficiency in North Sudan, where cash and food crops are the main source of household income and poverty alleviation. The authors implemented a model to establish the combination levels of production factors – namely water, land, labour and capital - for a maximization of gross margins from crops. Similarly, Arsenault et al. (2015) have recently determined the optimal mix of crops, while minimizing the use of additional agricultural land, to meet the nutritional adequacy of national food supply in Bangladesh, Senegal and Cameroon. Nutritional requirements that were firstly investigated by Stigler in 1945, when he elaborated a model to determine a combination of food products to comply with nutritional requirements, while minimizing its respective cost. The minimum cost diet model was also implemented by other authors. For instance, Moraes et al. (2012) combined diet formulation for dairy cattle and the presence of environmental policies to examine the effects of these latter on the animal dietary pattern itself. Even more recently, Ward et al. (2014) explored, still through the LP approach, different dietary preferences (i.e. high meat intake and vegetarian diet) and the possibility of urban agriculture in Northern Adelaide, Australia, to contribute to food security, either reducing cost or maximising the dietary contribution.

As better described in the next sections, the paper proposes the application of a linear programming model to a specific case study area, namely the metropolitan area of Milan. Similarly to aforementioned studies, the model aims at identifying the most efficient allocation of regional agricultural resources that better fits with the respective food demand, even in presence of different conditions of either the productive system or dietary habits.

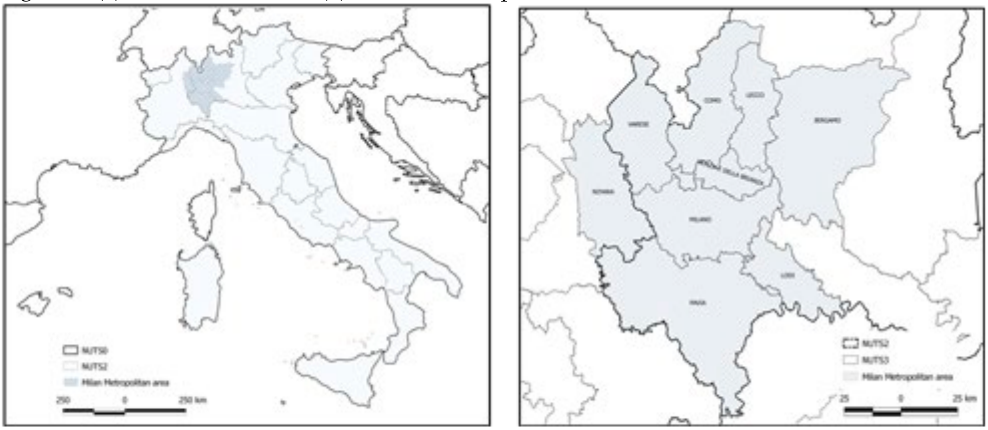
Methodology

The case study area: the metropolitan region of Milan

The metropolitan area of Milan (OECD 2006) (MMA from now on) is one of the most populated conurbation in Europe and ranks first in Italy: the region in fact encompasses a large part of Lombardy region (Figure 1), covering more than 301,000 km^2 with a population of about 7.8 million people.

Provinces included in the spatial delimitation of the area gravitate on the city of Milan, which represents the main fulcrum of the region and extends its influence far beyond its administrative boundaries. Thus the macro-area is characterized by a high population density, especially in its Northern part, which determines the predominantly polycentric structure (Zasada et al. 2013) distributed along infrastructural networks and around the capital city (Sali et al. 2014b). On the contrary, in the Southern part a larger extent of rural areas can be found, where agricultural practices are still deep-rooted. The intensive agriculture typical of this zone is mainly intended for cereal and fodder cultivation, as well as for livestock breeding (Table 1). On one hand, despite rice-cultivated areas in the regions account for most of their extent at national level, the scarcer amount of agricultural land intended for vegetables ensures produced amounts comparable to rice. In addition, the breeding sector is a very important regional activity, es-

Figure 1. (a) Location of MMA; (b) NUTS3 encompassed in the MMA.



Source: own elaboration

pecially for what concerns the dairy sector: as Corsi et al. (2015) pointed out, milk production can meet the regional demand for both milk and dairy products.

Regardless the prominent role played by the agricultural sector, the relations between the rural and the urban environments have become profoundly dynamic (Sali et al. 2014a). In recent years the region has been more and more subjected to a strong aggressive urbanization that represents the major threat to the persistence of farmland and the agricultural system (Mazzocchi et al. 2013), further affected in its productive potential by the diminishment of arable land (Oldeman et al. 1991). The maintenance and the conservation of agricultural areas, especially in the peri-urban context, are strategic actions for contrasting urban sprawl and its related effects on rural areas.

The methodological path

The methodological approach adopted consists of different but interrelated steps. In particular, they can be distinguished as follows:

- Identification of staple foods to be included in the analysis. The choice of foods was carried out in order to ensure a strict connection with the regional context and its agriculture. For this reason, non-agricultural products (i.e. aquaculture products), non-local products (i.e. coffee, tea, cocoa and similar), and non land-based food productions (i.e. cultivated fungi, honey) have not been considered. These products have been used as reference elements to which both supply and demand dimensions have been traced back;
- Quantification of regional food supply and demand at staple food-level. With regard to food demand analysis consumptions expressed by dietary habits (*EFSA 2011*) have been back transformed to the consumed amounts of their correspondent agricultural primary product.

Table 1. Main features of case study area (own elaboration based on OECD 2006; ISTAT 2010, 2011; Corsi et al. 2015).

Feature		MMA	Italy	% of total
Land size (km^2)		25,200	301,340	8.36
Population (Mio. people)		7.89	59.43	13.28
Density (people/km^2)		602	197	
GDP (thousand USD)		35.6	206.9	17.21
Workers in agriculture (n.)		55,265	3,628,208	1.5
UAA (ha)		490,668	12,782,936	3.84
of which	orchards	1,596		0.29
	wheat	44,446		2.27
	barley	2,294		0.88
	oats	77		0.05
	maize	2,153		24.19
	rice	140,190		57.03
	vegetables	4,533		1.51
	pulses	1,042		0.75
	potatoes	380		1.40
	olive yards	425		0.04
	other oil plants	3,341		1.10
	vineyards	15,024		2.26
	sugar beet	6,895		11.76
	fodder maize	109,362		24.18
	temporary grassland	39,030		2.04
	permanent grassland	87,732		2.55
UAA (ha per capita)		0.062	0.047	
Number of farms (n.)		26,289		1.62
Farm dimension (ha/farm)		18.6	7.89	
Animal heads (number)	dairy cows	172,644		23.50
	beef cattle	786,060		59.67
	fattening pigs	2,279,849		26.57
	broilers	1,322,993		3.01
	layers	2,756,754		15.30

On the supply side, the respective productions result from the combination of land extents and yields (for products of plant origin) or, for animal products, of animal heads, productivity per head and the regional productive potential of forages to feed livestock, according to data collected in National statistics (ISTAT 2010).

Both the dimensions can be differently described, as shown in Table 2;

- Modelling the relation between supply and demand (de facto) by a multi-objective model (described in detail in the subsequent paragraph) that measures the gap between the amounts consumed and the quantities produced of each staple food;
- Assessment of adaptations and adjustments of the agricultural production system to a closer compliance with food demand, through the modelling of different scenarios of production or consumption patterns.

Table 2. Features of food demand and consumption patterns in the area.

Staple food	Quantities (metric tonnes)		Calories (.000 kcal)		Production value (Mio. EUR)	
	Demand	Supply	Demand	Supply	Demand	Supply
Fruit	480,641	10,182	374,899,943	7,941,746	495,060	10,487
Wheat	662,370	137,048	2,338,166,704	483,777,958	157,313	32,549
Barley	22,457	11,799	87,588,086	37,637,551	5,718	2,457
Oats	1,588	253	5,924,086	944,540	325	52
Maize	1,588	24,619	5,733,499	88,876,150	315	4,889
Rice	77,791	507,720	248,932,523	1,624,705,182	28,213	184,135
Other cereals	17,195	34,686	59,358,272	119,734,801	4,167	8,405
Total cereals	782,989	716,125	2,745,703,170	3,155,536,182	196,051	232,487
Vegetables	490,376	121,855	142,209,050	35,338,035	328,552	81,643
Pulses	27,401	2,824	80,285,395	8,273,064	38,362	3,953
Total vegetables	517,777	124,679	2,224,794,445	43,611,099	366,914	85,596
Potatoes	145,632	10,897	215,535,548	16,127,450	55,340	4,141
Olives for oil and other oil crops	648,230	990	922,536,805	2,147,748	511,170	383
Wine grapes	265,937	78,901	194,134,142	57,597,623	116,480	34,559
Sugar beet	452,475	31,262	261,088,987	18,038,909	18,099	1,250
Milk	2,484,961	1,964,603	1,202,720,957	950,867,844	991,748	784,073
Beef meat	168,997	1,498	221,386,089	1,961,791	663,917	5,883
Pig meat	79,411	149,348	228,703,749	430,122,361	116,734	219,542
Poultry meat	60,021	4,889	84,629,331	6,893,891	73,225	5,965
Total meat	308,429	155,735	499,719,169	438,978,043	853,876	231,390
Eggs	53,937	67,718	69,039,621	86,679,677	116,864	146,723

The optimization model

The use of mathematical linear programming has allowed to define and model the food supply-demand relation within the case study region. In particular, given D_i and S_i respectively the demanded and the supplied amounts of each i staple food, the production S is defined as a function of the productive factor x assumed as decisional variable, namely agricultural area, animal heads or amounts of animal products:

$$S_i = S_i(x) \tag{4}$$

where the function $S_i(x)$ in turn depends on the relation between production (yield or productivity per head) and processing needed to obtain the *i* primary product, i.e. processing or slaughtering yield, fodder units produced by the *f* fodder crop consumed by animals and converted into animal products. On these bases, the model is adopted to assess the capabilities of the regional agricultural system in meeting food demand, in different conditions of either the supply or the demand structure. The implemented model aims at minimizing the sum of the differences that each staple food shows between its own quantitative levels of production and consumption, according to a multi-objective formulation:

Minimize $\sum_i w_i \left|D_i - S_i\ (x)\right| \sum_i w_i \left|D_i - S_i\ (x)\right|$ (5)

Subject to $Ax \leq c$ (6)

and $x \geq 0$ (7)

where x is the vector of the decisional variables, c the vector of coefficients used in the function, A the (known) matrix of coefficients and the w the importance given to each primary product i to meet the respective food demand, set equal to 1 for all the staple foods.

Constraints summarized in (6) are explained as follows:

- land constraints, to ensure that all the available agricultural area, but no more than this, is cultivated

$$\sum_i x_i + \sum_f x_f = \sum_i land_i + \sum_f land_f \tag{8}$$

with $land_i$ and $land_f$ the current land extents of the i primary product and the f fodder crop respectively.

In addition, the maintenance of areas intended for permanent crops is imposed:

$$x_i = land_i \text{ if } i = \text{“}\textit{winegrapes}\text{” or “}\textit{olive for oil}\text{”} \tag{9}$$
$$x_f = land_f \text{ if } f = \text{“}\textit{permanent grassland}\text{”} \tag{10}$$

- fodder units balance, which ensures that animals bred consume all the fodder units provided by the f forages

$$\sum_f fu_f * x_f - \sum_a dfu_a * x_a = 0 \quad (11)$$

with *fu* the fodder units per hectare (FU/ha) of the *f* fodder crop and *dfu* the amount of fodder units consumed by the *a* animal.

- balance for animal productions:

$$x_a - ly_p * x_p = 0 \quad (12)$$

where *ly* is the number of animals needed for a unit of the *p* final animal product.

Set scenarios and specific constraints

In order to assess how the regional system may adapt to structural changes optimizing the compliance with food demand, specific scenarios related to these modifications have been identified. A recalibration of the imposed general constraints has been carried out, to have returned the most efficient allocation of local agricultural resources (agricultural area and animal heads) under different production pattern and dietary habits. Accordingly, the scenarios are as follows:

- *Scenario 0 ("Baseline scenario")*: current agricultural productions are returned, describing the features of the regional agricultural system, in terms of both cultivated crops and livestock heads.
- *Scenario 1 ("Minimum gap").* It focuses on minimizing the quantitative gap between demand and supply, returning the how plant and animal resources should be managed in order to satisfy as much as possible the demand of each staple food. The specific constrain affecting this simulation ensures sufficient quantities of crop and animal productions to meet the respective food demand:

$$S_i(x)= D_i \quad (13)$$
$$S_p(x)= D_p \quad (14)$$

- *Scenario 2 ("100% fodder").* The strong presence of livestock breeding in the region requires a large amount of fodder, which is currently locally supplied for only 30%. Thus, this scenario aims at assessing the consequences that producing locally all the fodder need could have on the capacity of agricultural production in complying with food demand. For this reason the inputs related to fodder needs vary according to this, *ceteris paribus* the conditions and constraints set in the previous scenario.
- *Scenario 3 ("Vegetarian").* The hypothesis of converting the agricultural system towards practices that satisfy a vegetarian diet is made: this allows returning the

most cost-effective solution able to replace meat proteins with those provided by legumes, milk and eggs:

$$\sum_i (cal_i * x_i) + \sum_p (cal_p * x_p) = DC \quad (15)$$

where cal_i and cal_p are respectively the calories provided by the amounts of the i primary product of plant origin and the p product of animal origin, and DC the caloric intake from diet.

- *Scenario 4 ("Vegan")* finally represents an even more rigorous condition, with all the proteins of animal origin are replaced with those by pulses only:

$$\sum_i (cal_i * x_i) = DC \quad (16)$$

Results and discussion

The baseline scenario describes the features of the agricultural system in the region, revealing that it is mainly based on cereals (especially rice) and fodder cultivation, this latter to feed the high number of animal bred for both dairy and meat productions (Table 3). This result in a scarce compliance with the other minor food crops, finally leading to an overall inadequate compliance with the dietary pattern as a whole.

In fact, the minimization of the distance between demand and supply, modelled in the first scenario ("Minimum gap"), suggests that increased land extents intended for crops are requires, except for those which productions already exceed demanded amounts, i.e. rice. With regard to fodder crops, a redistribution of agricultural areas amongst fodder maize and temporary grasslands is encouraged. This also impacts, with more pronounced modifications, on the possibility to sustain animal breeding: an increase in the number of dairy cows and layers, and even stronger of broilers is particularly evident, along with a marked decrease in fattening pigs, traditionally the most spread animal breeding in the area. Such a scenario has then repercussions on the total production value: the variation in livestock heads causes in fact a diminution in the economic dimension of about 200 Million Euro.

Under the hypothesis of a complete self-sufficiency in fodder crops (scenario 2), agricultural land devoted to food crops encounters the same redistribution observed in the previous condition; the cultivation of temporary grasslands is however not encouraged at all, in favour of permanent meadows and especially grain maize for feed. Such a productive pattern can sustain all animal breeding, except beef cattle; at the same time, similarly to the previous scenario, a strong decrease in the number of fattening pigs is observed. Though the profitability of fodder maize, the reduced number of animals leads to a further decrease in the total production value, in comparison with both the *baseline* (-24%) and *scenario 1* (-19%). It is certainly not a coincidence that the economic value of production in these latter scenarios are lower than the reference condition. The current productive pattern,

Table 3. Results of simulated scenarios.

Agricultural land use and animal breeding	Agricultural area (ha)				
	Scenario 0 (baseline)	Scenario 1 (minimum gap)	Scenario 2 (100% fodder)	Scenario 3 (Vegetarian)	Scenario 4 (Vegan)
Total available land	*458,518*	*458,518*	*458,518*	*458,518*	*458,518*
Orchards	1,596	40,053	40,053	40,053	40,053
Wheat	44,446	122,661	122,661	122,661	13,096
Barley	2,294	5,708	5,708	5,708	
Oats	77	478	478	478	
Maize	2,153	155	155	155	155
Rice	140,190	10,297	10,297	10,297	10,297
Vegetables (open field)	3,668	13,658	13,685	13,658	13,658
Vegetables (protected)	865	3,221	3,221	3,221	3,221
Pulses	1,042	9,134	9,134	90,122	250,223
Potatoes	380	5,201	5,201	5,201	5,201
Olive yards	425	425	425	425	425
Oil plants	3,341	4,633	4,633	4,633	
Vineyards	15,024	15,024	15,024	15,024	15,024
Sugar beet	6,895	9,432	9,432	9,432	9,432
Fodder maize	109,362	67,443	130,706	49,718	
Temporary grassland	39,030	63,264			
Permanent grassland	87,732	87,732	87,732	87,732	87,732
	Agricultural area (ha)				
	Scenario 0 (baseline)	Scenario 1 (minimum gap)	Scenario 2 (100% fodder)	Scenario 3 (Vegetarian)	Scenario 4 (Vegan)
Beef cattle	786,060	602,646			
Fattening pigs	2,279,849	241,930	201,510		
Broilers	1,322,993	13,248,520	4,319,331		
Layers	2,756,754	3,154,211	3,154,211	up to 22,959,140	
Production value (Mio. EUR)	3,015	2,813	2,289	3,362	2,081

in fact, emerges as the result of the laborious process of adaptation to the global economic environment, in order to take advantage of the competitive factors the regional agricultural system is equipped with. This has then led to the particular specialization of agriculture, which modification necessarily implies a reduction of the generated value.

Scenarios 3 and 4 concern a profound change in the demand, expressed by the modification in consumers' dietary habits. In the former case, where compliance with a vegetarian diet is needed, results of the model generally indicate the necessity for increased crop productions, except for rice and maize for both food and feed: amongst crops, the highest augmentation is related to pulses, which cultivation can rely on more than 90.000 ha. This ensures a fairly good overall correspondence with food demand. Concerning animal productions, a twofold augmentation in the number of dairy cows occurs, while layers are subjected to an increase of up to an order of magnitude: this leads to self-sufficiency for allowed animal products. Despite lower income provided by food crops than by feed or animal products, the total economic value generated is strongly affected by the large amounts of milk and eggs, resulting in more than 3.3 Million Euro (+12%).

With the "V*egan" scenario*, agricultural land intended for temporary forages are redistributed amongst other land uses. The cultivation of minor cereals – particularly barley and oats - and oil plants is in this case not favoured; as long as the strong reduction in rice cultivation, the most part of agricultural area for food is devoted to pulses (67%). In this condition the compliance with food demand ensure and optimal correspondence: on one hand food crop productions allow quantitative surpluses, except in the case of olives for oil and wine grapes, while on the other hand the system adapts itself to the demand, not returning any area devoted to feed crops and consequently not permitting animal breeding. This situation however leads to a reduction in the production value from agriculture: in comparison to the current capacities, it decreases from 3 to 2 billion Euro (-31%). Such kind of trend is shown also if compared with the economic results obtained in the *vegetarian scenario*, with the reduction of 38% mostly due to the absence of products of animal origin.

Finally, different production values are due to implications not immediately evident from their direct comparison. In fact, though the lower economic balances of scenarios 0, 1 and 2, it must be considered that the former production pattern includes a range of processed foods. This way, the processing itself can contribute in increasing the agricultural production value of the region by generating further value added: in these cases the economic balances returned by simulations can potentially increase due to this condition. Conversely, more limited amounts of foods to be processed, or even their total lack, as in the vegetarian and in the vegan productive system respectively, would scarcely generate further value, finally resulting in the actual potentialities of the system.

Conclusions

The adoption of linear programming has allowed to create a theoretical and methodological framework that can be applied to any other case study area or territorial aggregations. It must be pointed out that further analyses (Wascher et al.

2015) have been allowing the assessment of agro-food systems in different European metropolitan areas and the quanti-qualitative description of their productive and supplying capacities. In this sense, preliminary results demonstrate an incomplete fulfilment of dietary needs either in other urban contexts: two of them are similar to the case study area for agricultural area extent and policentricity of urban settlements – the Rotterdam metropolitan region -, and for population numerousness, i.e. Berlin-Brandenburg. Despite strong demographic and territorial differences they have in common the sustainment of the demand only for few food categories and not for the diet as a whole, finally revealing the specialization of the primary sector in the areas. These analyses describe the different compliance with food requirements and indicate a diversified agricultural production across considered regions: in the Dutch case most of agricultural productions are intended for milk and dairy products, fruits and vegetables and sugar beets satisfying their respective demand; produced amounts in Berlin are more diversified, encompassing cereals, oil plants, and meat, too, but with a level of food self-reliance similar to that of the Rotterdam area. Such an approach reflects the quantitative dimension of food demand and supply which constitutes the first step for the implementation of the proposed linear programming model; in fact, the interpretation of results indicates the possibility to run the model in these contexts, as well, where chances to reconnect demanded and supplied amounts can be deepened.

This kind of approach aims at assessing the potentialities of the agro-food system in a regional area in adequately responding to its internal food demand. In strongly urbanized contexts such performances are poor, due to exiguous availability of agricultural and the high food demand expressed by population. Such a scarce capacity is instead balanced by market dynamics as well as by national and international trade in food products, which however don't allow catching the actual potentialities of the agro-food system. In addition, the potentialities of the agricultural system depend on the regional features of the context under analysis, from agro-climate characteristics to land suitability and cultural aspects. These peculiarities must be taken into account whenever adopting a simulation model, in order to consider plausible scenarios for the case study area, as well as when conclusions are drawn: for a more comprehensive analysis of the system, results should however be discussed taking into account the effective and practical feasibility of suggested indications. In fact, as results have demonstrated under changes on dietary habits, interventions suggested represent a radical choice that certainly affects, far beyond economic results, the system as a whole, requiring profound structural modifications with strong consequences and repercussions on the agro-food sector. The deterministic nature of the model has led to assessing the potentialities of the system only, without providing insights on the consequences at a wider level the application of optimal allocation would have. Actually, this was not the focus of the paper, but such considerations should be contemplated for a better characterization of system potentialities and sustainability.

In this perspective and in general terms, the utilization of linear programming model has revealed to be a relatively simply approach to simulate modifications in the regional production-consumption relations. Moreover, the simulations have shown the role of the modeling itself in deepening the possibility to maintain agricultural areas close to the city, as a strategy for strengthening peri-urban agriculture and the metropolitan system as a whole. This could be strategic not only in economic terms, but also for the resilience of farms - which number has been suffering from a reduction (ISTAT 2010) – and according to a political perspective, as it may provide useful indications for food-related policies and regulations in both the agricultural, food, urban and landscape sector.

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