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Detecting the exposure of the Italian regional food systems to climate shocks

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Abstract

This work provides a configuration of interregional-international value chains activated by Italian domestic food consumption and shows how some countries and regions produce most of the agricultural goods necessary to supply final demand. Second, it provides a conceptual framework to assess the vulnerability of the Italian food regional systems, based on food products criticality. Finally, a spatial- and product-based disaggregation of agricultural production in Italian regions which well captures the exposure of the Italian food system to the flood that hit Emilia-Romagna in May 2023 will be presented.

JEL codes: Q12, Q18, Q54, R15
Keywords: regional food systems, climate shocks, input output analysis, food value chains

1. INTRODUCTION[1]

In a time in which climate shocks are expected to dramatically affect agriculture and food production also in comparison with competing shocks (e.g., FAO, 2023; Devot et al., 2023; FAO, 2021; Naumann et al., 2021), it is becoming day-by-day more relevant to evaluate the vulnerability of food systems. In this respect, in assessing the potential impact of climate shocks on the food supply, the interregional input-output framework represents a powerful tool of analysis (see, e.g., Avelino and Hewings, 2019; Koks and Thissen, 2016; Okuyama, 2007), given the configuration of the current production systems in interregional (e.g., Capello et al., 2023; Van Oort and Thissen, 2021; Bentivogli et al., 2019) and international value chains (e.g., Baldwin, 2016; World Bank, 2019). Indeed, since climate related shocks are often circumscribed in space (e.g., Siano et al., 2020), as well as their impacts on economic activities (e.g., Faggian and Modica, 2020), the identification of regional economic specializations and inter-sector interrelations stemming from specific regions constitutes a prerequisite when assessing potential propagation mechanisms.
At the same time, to fully control for the spatial granularity of climate shocks, economic specializations need also to be finely distributed in space (see, e.g., Inoue and Todo, 2019). Moreover, the heterogeneous impact of climate related disasters on the overall provision of food (see, e.g., Mairech et al., 2021; Burke and Emerick, 2016; Merloni et al., 2018) can be captured only if the products entering the food value chains are disaggregated at an adequate level. In this regard, input-output data at regional (and very often at national) level usually foresees aggregated both agricultural and food processing industry and products, leaving the evaluation of potential damages on the production network relatively blurred.

[1] We are extremely thankful to Geoffrey J. D. Hewings, Marco Modica and Claudia Ghisetti for their insightful comments. We also would like to thank the participants to the EU-REAL workshop held in Florence in June 2024, the participants to the "AISRe/IAERE Session: Local and environmental impacts of climate change" at the AISRE conference held in Naples in September 2024, and the participants to the 14th Geoffrey J. D. Hewings Regional Economics Workshop held in Wien in October 2024.

This research aims to better understand how the Italian regional food systems (henceforth RFSs) – implicitly, food security in the context of Italian regions – are vulnerable to the overall consequences of climate change. In this respect, the contribution of the work is threefold. First, using an interregional input-output table, we assess how the Italian food system is spatially organized, in terms of concentration of different production stages of the food value chain, regarding agricultural and food processing steps. Moreover, we evaluate to what extent it depends upon both direct and indirect imports by integrating the interregional input-output data with an inter-country IO table.
Second, we provide a conceptual framework to assess the degree of "criticality" of each food product from a value chain perspective. Being aware that some food products are more critical than others, their "criticality" is evaluated based on: i) their economic and nutritional importance, ii) the cost-opportunity for substitution, iii) the risk associated with the disruption of the value chains due to climate shocks.
Third, once the product-based nature of RFSs vulnerability has been assessed, we finally start developing a disaggregated accounting system in which regional agricultural production is highly, and properly, disaggregated by products and sectors. This conceptual framework is then used to give a first assessment of the exposure of the RFSs to the 2023 flood in Emilia-Romagna, with a focus on the production of fruits, which has been dramatically hit by that flood, causing a significant economic loss not only at the local level but also reducing fruit supply at the national level. We also provide data with regional spatial information about agricultural cultivations and administrative information about the affected areas. Finally, to evaluate to what extent the lack of fruits due to the disruption of the local supply chain has been filled by imports, we use (quasi) real-time information about regional exports and national imports.
The paper is organized as follows. Section 2 nests the issue of measuring the vulnerability of Italian regional food systems within a value chain framework based on interregional-international input-output tables. Given the limits of this preliminary assessment, Section 3 provides a conceptual framework to evaluate the level of criticality of the food products. Section 4 implements such a framework and disaggregates agricultural production in several products and industries. Moreover, it distributes cultivations in space and shows how such a framework can be used to give a preliminary assessment of the impact of the flood that hit Emilia-Romagna in May 2023 on food production.

2. NESTING THE VULNERABILITY OF ITALIAN REGIONAL FOOD SYSTEMS WITHIN A VALUE CHAIN APPROACH BASED ON INTERREGIONAL-INTERNATIONAL INPUT-OUTPUT TABLES

We first insert the Italian food system within a value chain framework based upon an interregional-international input-output table to emphasize the potential sources of vulnerability when it comes to RFSs. Although regional and local resilience to disasters provoked by climate and non climate related shocks has been increasingly addressed by the literature (e.g., Marin et al., 2021; Faggian and Modica, 2020), the approach through value chains represents an advancement since it consistently allows to connect in a systemic way the locations of food consumption and those of food production.
Moreover, via the intermediate inputs linkages connecting sectors and regions, it recognizes that production is spatially (in terms of regions and countries) and technologically (in terms of sectors and products) dispersed (see also Turchetti and Ferraresi,2024; Ferraresi et al., 2023a, 2023b) and explicitly models the connections among nodes of the supply chains.[2]
Indeed, a value chain approach allows to go beyond the analysis of isolated economic sectors by considering that different, but interconnected, sectoral production activities carried out in different locations must jointly be activated to satisfy the needs/demand expressed by a community of consumers spread region-wide. Isolating the role of each node in each supply chain is crucial in assessing the vulnerability of the RFSs, since it is a first, preliminary, step to identify potential sources of stress stemming from the impact of specific events hitting production somewhere in the world economy (see, e.g., Chepeliev, 2022). In this Section, therefore, we give a first, rough, picture of the configuration of the value chain activated by household food demand in Italy. Both at an international and at an interregional level.

[2] Apart from input-output literature, evidence about the connections among existing nodes in the production chains is well recognized by other approaches to the assessment of the regional vulnerability to natural disasters (see, e.g., Antonioli et al., 2022; Cainelli et al., 2019).

Before proceeding with the results, we provide both an intuitive and a formal definition of what is meant here for food value chain. A definition that is consistent with that of the vertically integrated sector (Pasinetti, 1973). Intuitively, we define a food value chain as the bundle of production steps activated in any part of the world to satisfy the final demand for food arising in a specific area, either a region or a country. In this framework, the food consumption basket is mostly directly "served" by firms belonging either to the agricultural sector or to the food processing industry. At the same time, their production processes will require raw materials as well as intermediate goods and services provided by other firms and plants, which do not necessarily belong to the same industry/region. This gives rise to a second production step. The process may be further extended, as firms engaged in the second step also demand intermediate inputs and may activate additional production stages. The value chain associated with food demand is therefore defined by the set of firms (and sectors) involved in all the production processes originating from it.

More formally, in the context of an interregional input-output table (see Appendix A) like the one used in this context (i.e., IRPET interregional input-output table: IRIOT), let $Fd_{z,s}$ be an *(MxN)x1* final food demand shock vector[3] expressed by region *s* (net of foreign import), and *A* the (*MxN)x(MxN)* matrix of input coefficients obtained by dividing the intermediate input demand of each sector (*i*) in every region (*j*) by its total output.[4] In terms of production, a food value chain can be defined as Taylor series approximation as:

$$\begin{aligned} Fd_{z,s} + AFd_{z,s} + A(A)Fd_{z,s} \ldots + A(A^{n-1})Fd_{z,s} \\ = (I-A)^{-1}Fd_{z,s} = Y_{z,s} \end{aligned} \quad [1]$$

with $n \to \infty$ defining the iteration step. The left-hand side of the equation reports the chain of production steps activated by the food final demand shock as a power series approximation. First, the shock itself, which is accommodated by a particular industry, or set of industries; then the first round of demand for intermediate inputs required to accommodate the final demand shock; subsequently, the production of intermediate inputs needed to produce the intermediates demanded in the previous round; and so on.

From equation [1] we can then get sectoral/regional value added activated by the final demand shock as:

$$V_{z,s} = \hat{V} \cdot (I-A)^{-1} \cdot Fd_{z,s} \quad [2]$$

with $\hat{V}$ being a diagonal matrix containing along its main diagonal the value added coefficients. Within an interregional framework, in which international exports have to be considered as exogeneous, and foreign import are recursive endogenous, the foreign value added content within the value chain identified in [2] can be roughly approximated by the difference between the sum of the initial shock ($i \cdot Fd_{z,s}$)[5] and that of the total value added domestically activated ($i \cdot V_{z,s}$).[6] However, to provide a better and more robust assessment of the foreign value added, the most proper way is to fully endogenize the rest of the world by inserting the interregional framework in an inter-country I-O structure. More precisely, we aggregate the IRPET IRIOT to fit the full Italian economy and use it to compute the shock to be applied to the inter-country input output (ICIO) table provided by OECD. We then use the latter one to retrieve the sector/country value added contributions in terms of intermediate input supply to serve the Italian households' final demand for food.

Going back to the interregional production value chain framework defined by eq. [1], pre-multiplying $Y_{z,s}$ by the matrix of input coefficients A, we can reconstruct the intermediate input interregional trade network that serves the final demand for food associated to the shock $Fd_{z,s}$. Such matrix can be analyzed using standard network analysis techniques. For instance, the degree of a node is given by:

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[3] The number of rows (*MxN)* in an inter-regional framework is equal to the number of regions (M) times the number of sectors (N).

[4] In a interregional framework letting *T* be the matrix representing the flows of intermediate inputs demanded by sector *j-nth* in region *r-nth* to sector *i-nth* in region *s-nth* (t_{ij}^{rs})and *Y* a diagonalization of the output of each sector in every region, the matrix *A* is obtained by post-multiplying *T* by the inverse of *Y*, i.e., $A = TY^{-1}$.

[5] With *i* being a row vector of ones. Notice that this sum only refers to foreign value added indirectly activated. In order to retrieve total foreign value added serving internal food demand, international imports of final goods have to be added.

[6] Given the exogeneity of the international export and recursivity of foreign import, the foreign value added estimated here will be upwardly biased. Indeed, we cannot track the contribution of Italian regions to the production of the intermediate inputs imported by Italian regions to serve the final demand for food.

$$s_i = C_D^w(i) = \sum_j^N w_{ij} \quad [3]$$

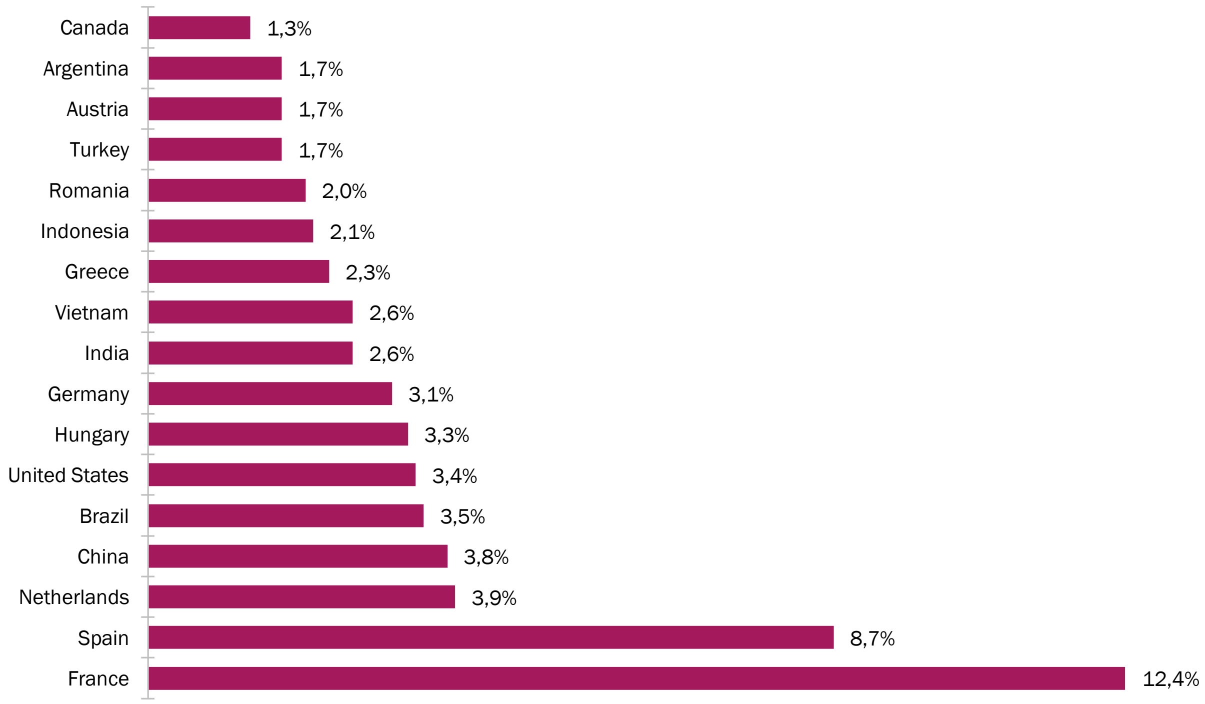
where w is the weighted contiguity matrix; w_{ij} is greater than 1 if i is connected to j, and its value is given by the trade flow. Being it directed, we can analyze the network both in terms of out-degree and in terms of in-degree.[7]

As to the shock examined in this work, we consider the food value chain activated by internal households' final demand for food in Italy. Moreover, we concentrate only on the production side of food, and not on commercial and transportation services connecting the final producers to the consumers.

In terms of results, 80% of final food products demanded by households in Italy is provided by Italian firms, while the remaining 20% is directly imported from abroad. However, the contribution of foreign countries in the provision of intermediate inputs accounts for 26% of the value added. Considering both the final goods directly imported from abroad and the intermediate inputs demanded from Italian firms serving the demand for food, for every Euro spent in food by Italian households,[8] 40 cents remunerate factors located abroad.

Considering the supply of intermediate inputs of foreign countries to the Italian firms in charge of production of the final food products, in Figure 1 and 2 we report the contributions of different countries as shares in the world total value added contribution of the agricultural sector (Figure 1) and of all aggregated sectors (Figure 2). As to the agricultural sector, France and Spain contribute for more than 20% of foreign value added.[9] Considering all the sectors in the world economy, instead, Germany represents the most important supplier.

Figure 1.
COUNTRY SHARES IN TERMS OF AGRICULTURAL VALUE ADDED CONTRIBUTION TO THE VALUE CHAIN (2018)



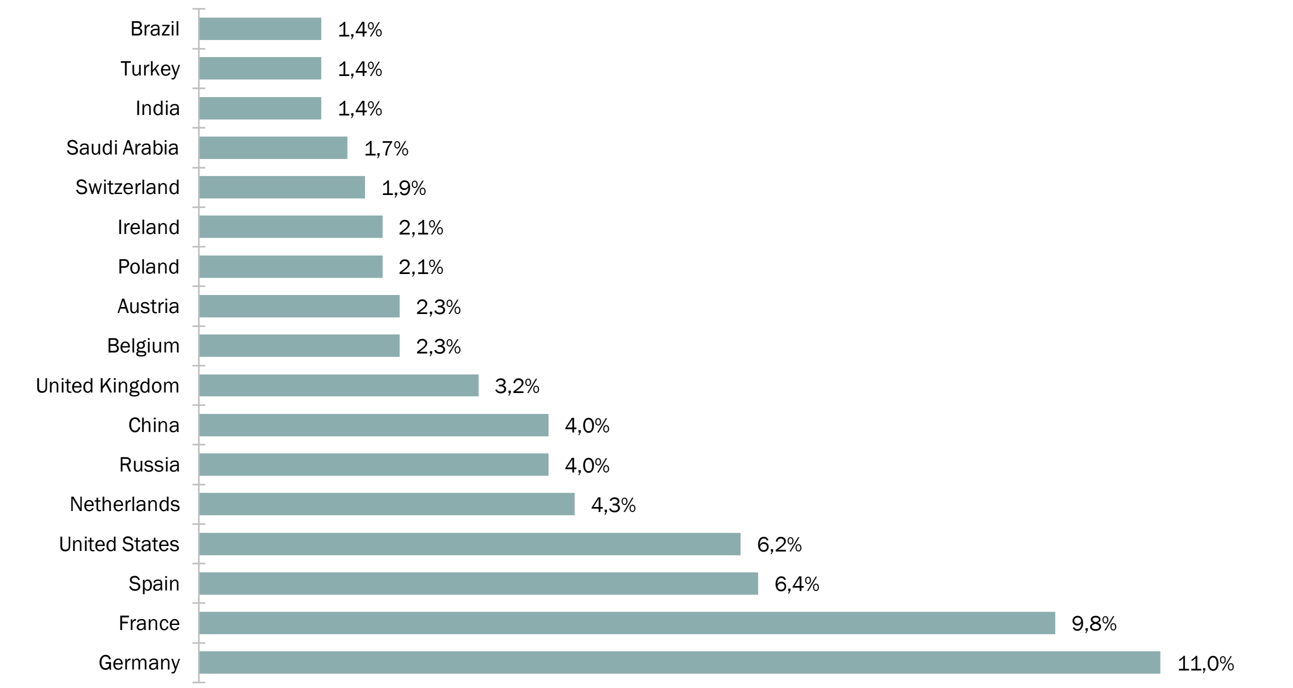
Source: Elaborations on IRPET IRIOT, OECD ICIO

[7] The out-degree refers to the vertices departing from a given node in the network, while the in-degree refers to the vertices entering a given node.

[8] Excluding net taxes on consumers and commercial and transport margins related to the provision of the final products.

[9] A drawback of OECD ICIO table is given by the fact that a substantial economic contribution to the world economy stems from a residual area (Rest of the world) which is mostly composed by African countries. In terms of agricultural value added contribution to the Italian demand for food, rest of the world accounts for 23% of value added.

Figure 2.
COUNTRY SHARES IN TERMS OF TOTAL VALUE ADDED CONTRIBUTION TO THE VALUE CHAIN (2018)



Source: Elaborations on IRPET IRIOT, OECD ICIO

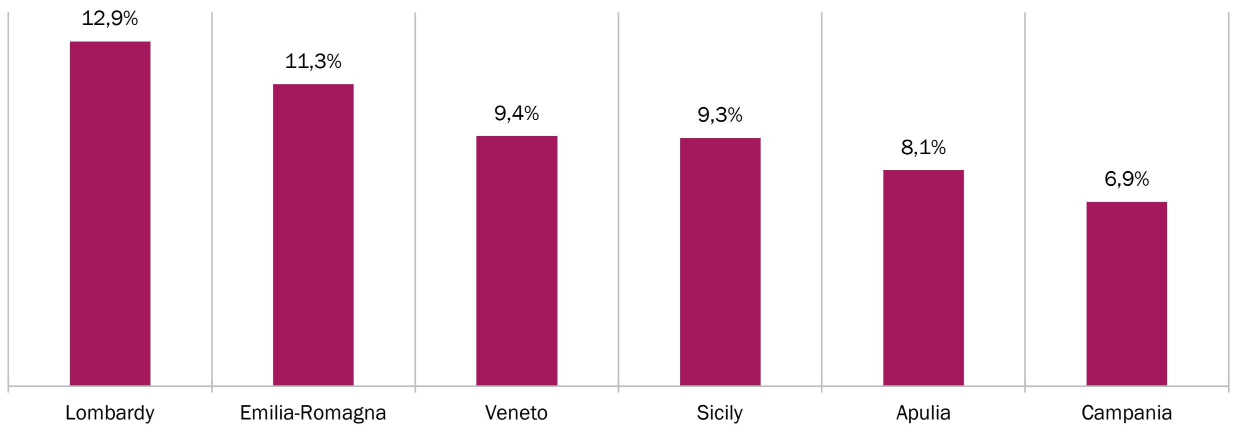
When it comes to measuring the vulnerability of the regional food systems to climate shocks in a value chain approach, aggregating sectors at the country level is not satisfactory since production and climate related events are usually heterogeneously distributed in space. For instance, as to Italy, Figure 3 depicts the interregional production network of intermediate input flows generated by the Italian household demand for food in terms of out-degree (left) and in-degree (right). In this respect, it is quite evident that production is highly concentrated into a few regions, namely Veneto, Emilia-Romagna (especially in terms of in-degree) and Lombardy (especially in terms of out-degree).

Figure 3.
THE INTERREGIONAL PRODUCTION NETWORK OF INTERMEDIATE INPUT FLOWS GENERATED BY THE ITALIAN HOUSEHOLD DEMAND FOR FOOD. OUT-DEGREE (LEFT), IN-DEGREE (RIGHT) (2018)

Source: Elaborations on IRPET IRIOT

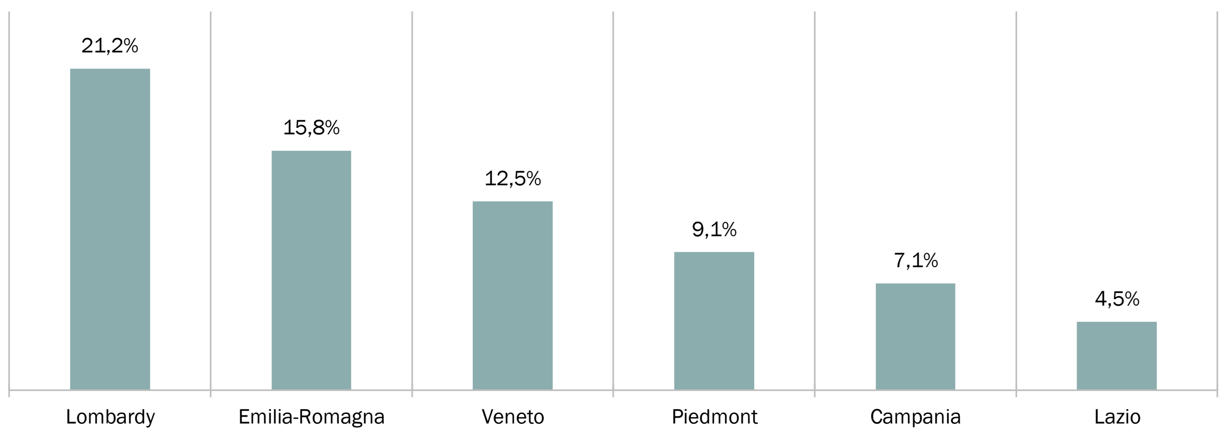
In terms of regional value added contributions to the food value chain, Figure 4 and 5 report the regional shares as to the national value added contribution of agriculture (Figure 4) and food processing industry (Figure 5). Although agricultural production is more fragmented than food processing, about 40% of the agricultural value added generated by the demand for food stems from 4 regions in the North (Lombardy, Emilia-Romagna, Veneto and Piedmont). Lombardy, Emilia-Romagna and Veneto represent also the three most important regions in terms of value added generated by the food industry.

Figure 4.
REGIONAL SHARES IN TERMS OF VALUE ADDED CONTRIBUTIONS IN AGRICULTURAL SECTORS (2018)



Source: Elaborations on IRPET IRIOT

Figure 5.
REGIONAL SHARES IN TERMS OF VALUE ADDED CONTRIBUTIONS IN THE FOOD PROCESSING INDUSTRY (2018)



Source: Elaborations on IRPET IRIOT

In synthesis, whereas the interregional-international value chain serving Italian demand for food is highly spatially fragmented – with several countries and regions engaged in producing both the final goods and the intermediates needed to produce them – some countries and regions have emerged as crucial in the provision of food to Italian households.
Such primary results provide a general picture of the potential exposure of Italian regional food systems to the impact of shocks hitting the world economy. However, to grasp the granularity of climate shocks, economic specializations need to be finely distributed in space. Moreover, the industry-based configuration of the value chain given in the present Section does not tell us anything about the goods, final and intermediate, which are traded along it, and their level of "criticality". Finally, the heterogenous impact of climate related disasters on the overall provision of food can be captured only if products of the food value chains are disaggregated at an adequate level, as their resilience to different kinds of events might highly differ.

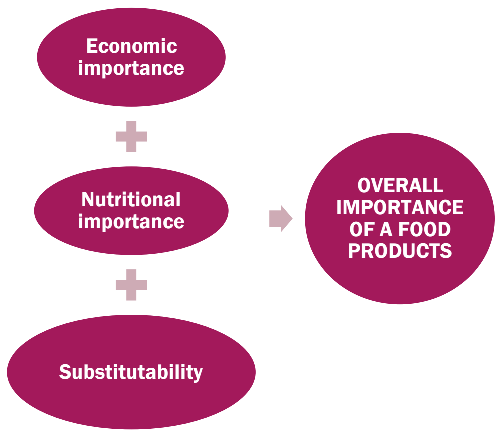
3. EVALUATING THE "CRITICALITY" OF A FOOD PRODUCT

As already mentioned, not all food products can be considered as equally critical. The reduced supply of some of them may negatively affect the overall vulnerability of the food systems, while some others can be replaced with no excessive economic and environmental costs.

To evaluate the "criticality" of food products, we refer to the most recent versions of the methodology developed by the European Commission to provide a list of critical raw materials for the European industry (EC, 2023). The concept of "criticality" is based on the idea that both the relevance of some products and the conditions of supply may increase the vulnerability of the economic system. It reflects the current situation and not the capacity of a member state or a region to adequately respond to these critical situations (Nuss and Chuta, 2018; Blengini et al. 2017). This approach, with some adjustments and simplifications, can be advantageously used to assess the criticality of food products and, therefore, evaluate the vulnerability of the RFSs.

The assessment of critical products is based on two main dimensions: a) economic importance (EI) and b) supply risk (SR). The EI indicates how much the materials is fundamental for industry, grounded on the distribution of products among the end-users (shares of net demand) and the gross value added generated by its use. In the case of food systems, the overall importance (OI) can also be assessed in terms of nutritional intakes of products and their relevance for human health. A cross-component of the OI is *substitutability on the demand side*, which can be evaluated as the cost-opportunity of substitution (both economically and environmentally), the nutritional balance of substitution and the level of acceptance by the consumers (Figure 6).

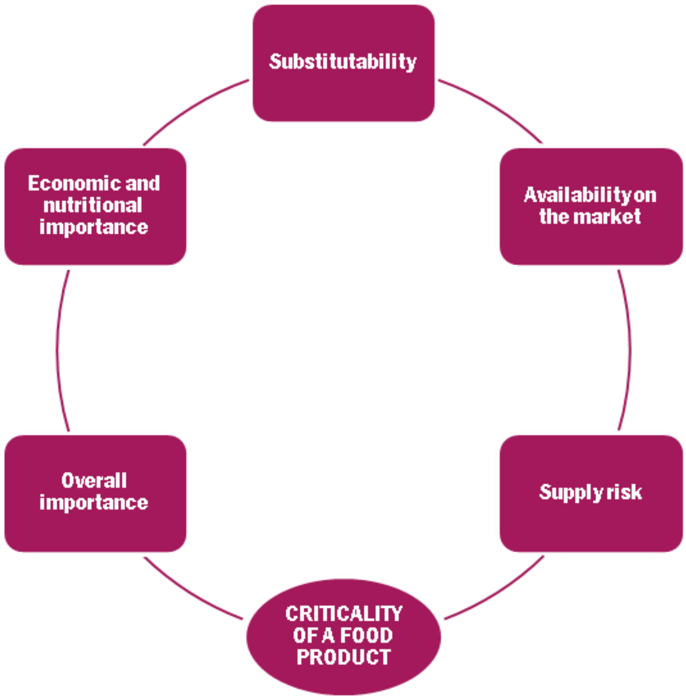
Figure 6.
ASSESSMENT OF THE OVERALL IMPORTANCE OF A FOOD PRODUCT



Source: Authors' own elaboration

The SR accounts for the risk associated with any possible disruptions in the supply chain that may trouble the capacity of the food system to meet the dietary needs of consumers. In our case, we mainly consider the disruptions caused by the extreme events associated to climates change, which are likely to reduce the global supply of agricultural products and their availability on the markets, with possible consequences on either the adequate provision of food and nutrients or prices. Moreover, the higher the concentration of production into few producers, the higher the risk of disruption of the supply chains. The SR is based on two dimensions: a) adequate amount of available food on the markets, both domestic and foreign (import dependency); b) *substitutability on the supply side*, which reflects the suitability of the available alternatives on the markets (Figure 7).

Figure 7.
ASSESSMENT OF THE "CRITICALITY" OF A FOOD PRODUCT



Source: Authors' own elaboration

Substitutability is, therefore, a component that enters both dimensions of criticality. In this respect, it must be considered that, intrinsically, agricultural products are more homogenous if compared to industrial products and, from a theoretical perspective, their margins of differentiation have always been considered very low. However, over time the so-called "fictitious differentiation" – i.e., based on some additive characteristics determined by marketing, including advertising, branding, labeling, and any other element that can confer specificity to the product – has increased, because of the ever-increasing focus on the territories of origin, quality, health, safety, and production methods characterized by environmental or social sustainability (Saccomandi, 1999).
Even though some food may be available on the markets as a substitute, it does not entail that its characteristics technically fit the demand of the food industry or they are accepted by the consumers; moreover, other effects have to be evaluated, i.e. effects on prices and the environmental impact.

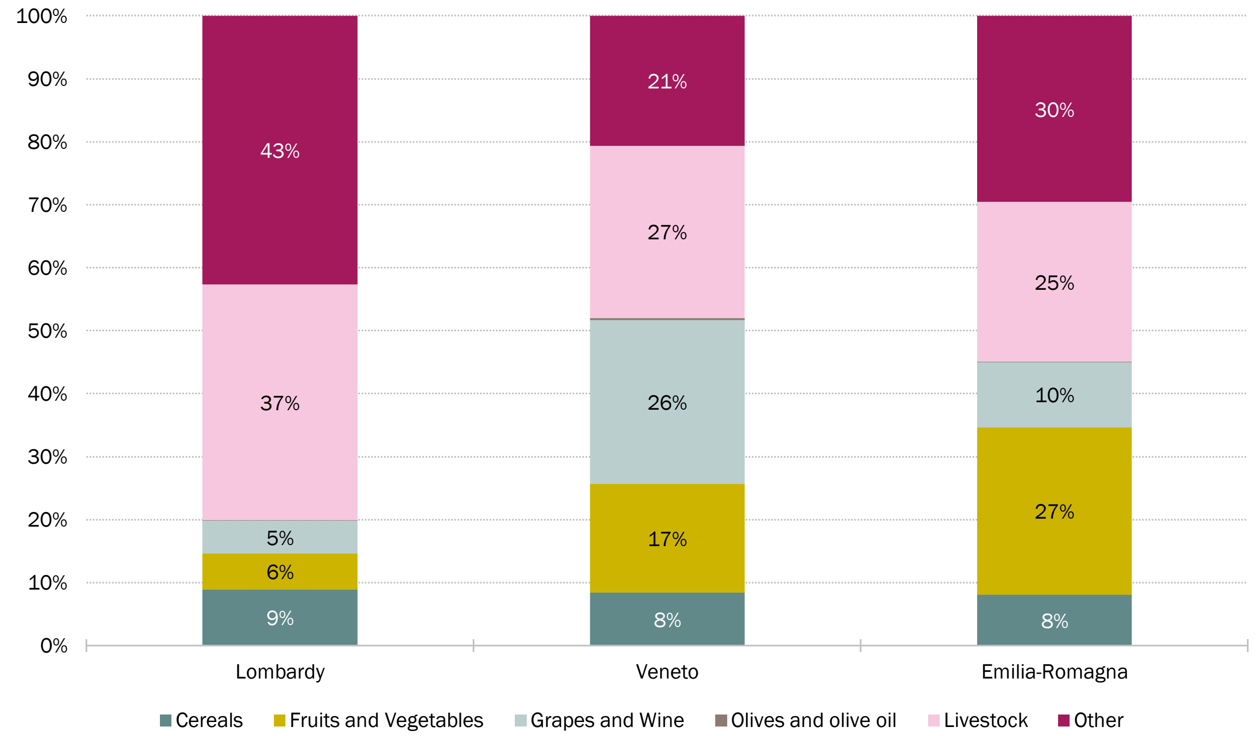
4. BEYOND SECTORS AND REGIONS: REGIONAL FOOD RELATED PRODUCTS AUGMENTED WITH SPATIAL DATA ON CULTIVATIONS

Given the product-level of the conceptual framework illustrated in the previous Section, we can integrate the assessment of criticality within the input-output framework. In this section, we do present a disaggregation of Italian regional agricultural production in terms of industries and products. Moreover, we augment regional accounts with spatial data about cultivations to obtain a one-to-one mapping from the (potential) territorial disaggregation of climate related shocks and the exposure of RFSs to them. Once illustrated some of the main features of this newly constructed database, we do use it to assess the exposure of regional food systems to the flood which hit Emilia-Romagna in late May 2023 (hence, 2023 flood). Finally, we corroborate our results with evidence stemming from (quasi) real-time international trade data both at the regional (NUTS3 level) and at the national level.
Entering the details of the work, by using different data source (see Appendix A), we disaggregate agricultural sectors and products at the regional level. More precisely, we use Istat agricultural regional

accounts and Farm Accountancy Data Network (FADN)[10] accounts to regionally disaggregate agriculture in 8 sectors and up to 31 agricultural goods.

Our analysis focuses on the impact of the 2023 flood on the production of fruits, namely peaches, pears and apples, serving the Italian RFSs. There are two reasons as justification to this choice. Firstly, if we consider the agriculture specializations in terms of products, Emilia-Romagna does emerge as one of the main suppliers of fruits and vegetables, accounting for about one third of national production (Figure 8). According to this picture, the economic relevance of this production for RFSs, with strong linkages with food industry and serving both the domestic and the foreign markets, is self-evident.

Figure 8.
COMPOSITION OF AGRICULTURAL PRODUCTION IN LOMBARDY, VENETO AND EMILIA-ROMAGNA (%; 2018)



Source: Elaborations on Istat, Eurostat data

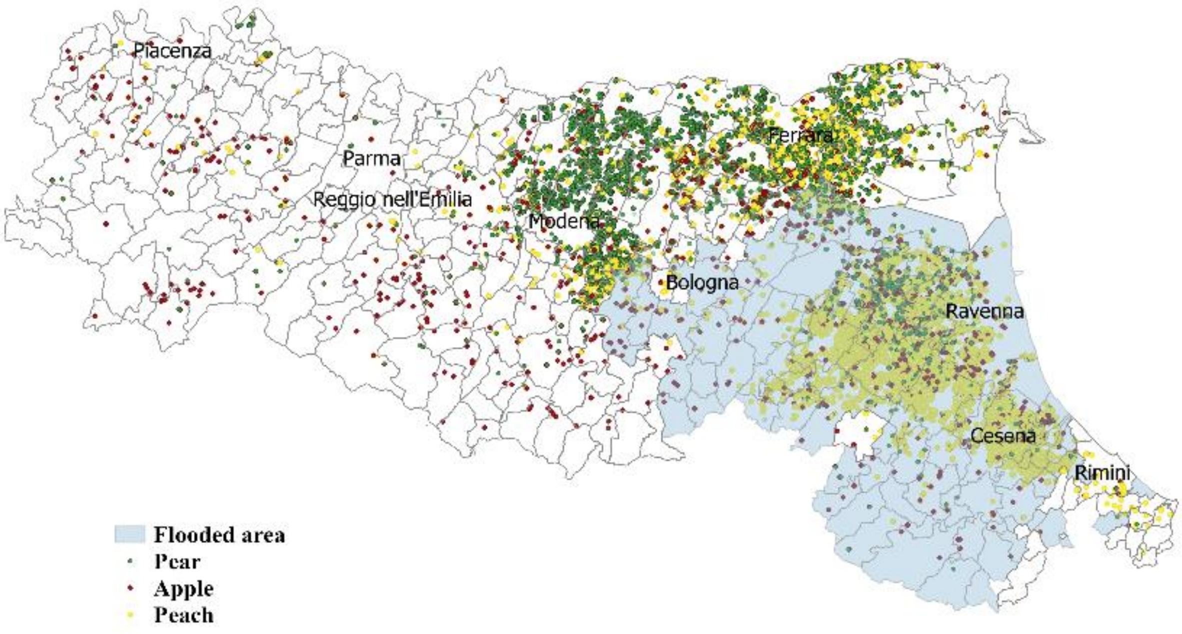
Moreover, the daily consumption of fruits and vegetables is recommended by the Italian food-based dietary guidelines, because of the low calories' intakes and the provision of fibers, vitamins and minerals (CREA, 2018). From a nutritional perspective we can consider fruits as critical products.

Secondly, the areas specialized in the cultivation of fruits have been largely hit by the 2023 flood. Using the Piani Colturali Grafici of Emilia Romagna,[11] we overlap the map of the hit municipalities according to the regional government with that of their main specializations in terms of cultivations. The most hit provinces are Forlì-Cesena, Ravenna and Bologna. In terms of cultivations, such areas are specialized in the production of pome fruits and stone fruits. In particular: pears, apples and peaches (Figure 9). Since the flood hit the region during the harvesting season of peaches, thus putting at risk almost the whole yearly production, we cannot exclude that some damages to capital goods (i.e., the trees) as well as land might have troubled the production for several years.

[10] The FADN is a European information system based on the production of economic and financial statistics collected annually through interviews to a representative sample of agricultural holdings classified according to size, type of production and region.

[11] The Piani Colturali Grafici are the crop plans presented periodically by farmers who intend to demand economic support within the common agricultural policy (CAP) framework. They are geo-referenced and allow the identification and localization of the single parcels of the farms and their main uses. Results based on Asia Agricoltura are not dissimilar from the one obtained here. However, Piani Colturali Grafici have to be preferred since they are based upon the localization of the cultivations and not upon the one of the firm headquarters. This latter operation has been implemented thus far for Emilia-Romagna and Tuscany.

Figure 9.
THE SPATIAL DISTRIBUTION OF CULTIVATIONS OF PEARS, APPLES AND PEACHES IN EMILIA-ROMAGNA AND THE MUNICIPALITIES MAINLY HIT BY THE 2023 FLOOD



Source: Elaborations on Piani Colturali Grafici Emilia-Romagna, Istat, Eurostat

The shares of yearly production exposed to the flood are 93.4% of peaches, 42.8% of apples and 21.4% of pears. As to the national production at risk for 2023, the hit zones produce 13.9% of pears, 13.5% of peaches and 3.0% of apples.
If such results capture the amount of production exposed to the flood, they don't tell anything about the impact of the fall of production on the national consumption. In this respect, data about production and consumption are still not available, but international trade flows at the national and at the subnational (NUTS3) level are released with very short lags. In this respect, at the time of writing we can already observe:

1) *if there has been a substantial and significant fall of international exports of agricultural goods in the third quarter of 2023 in the provinces which have been severely hit by the flood.*

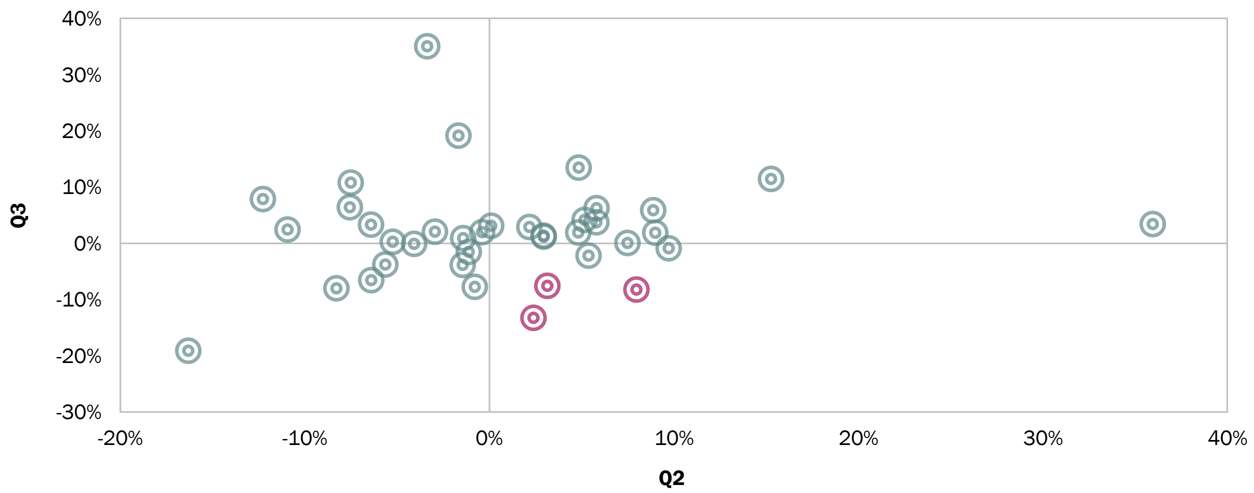
We deal with the first issues by employing Istat Coeweb data at the provincial and product (CPA 3 digit) level. This are at disposal on a quarterly basis since 2011Q1. We aggregate exports of 3-digits CPA agricultural products distinguishing between hit vs. non-hit provinces and estimate the following econometric model:[12]

$$y_{i,t} = \alpha + \beta Flood_t + \gamma Hit_i + \eta(Flood_t \cdot Hit_i) + \epsilon_{i,t} \quad [4]$$

where $y_{i,t}$ is given by the yearly rate of change of exports at quarterly frequency; $Flood$ is a dummy variable being 1 in 2023Q3 and 0 in all other quarters; Hit is a dummy variable being 1 in case the region has been affected by the flood and 0 otherwise. The coefficient of interest is η. We considered as hit provinces Forlì-Cesena, Ravenna and Bologna.[13]
We concentrate upon perennial crops, which are the ones mainly hit by the flood. In this respect, Figure 10 reports the yearly rates of change in Q3 vis-à-vis Q2 of exports of the product of interest of the main exporters among Italian provinces (at quarterly basis), among which the three hit regions stand (in red). As it can be seen all of them are characterized by significant falls in Q3, especially in comparison with other Italian provinces.

[12] We also estimate an alternative model in which NUTS 3 regions are held disaggregated. In such case, we did discard from the sample all the provinces with negligible exports. We end up with 38 provinces with which we estimate the very same model. Results are robust and coefficients stable and statistically significant.
[13] We exclude Rimini from hit regions since it was marginally hit by the flood (see Figure 9) and its contribution to total regional exports of perennial crops rather marginal.

Figure 10.
RATES OF GROWTH OF EXPORTS OF PERENNIAL CROPS OF THE MAIN NUTS3 REGIONS IN ITALY. YEARLY RATES OF CHANGE AT QUARTERLY BASIS. Q2 2023 VS. Q3 2023



Source: Elaborations on Istat Coeweb data

The results from the econometric model, reported in Table 1, confirm such visual evidence. Independently from the time span considered, the coefficient capturing the impact of the flood is always statistically and economically significant. Indeed, the flood has caused a drop of 15/16% of international exports in the hit regions in 2023Q3.[14]

Table 1.
THE IMPACT OF THE 2023 FLOOD IN EMILIA-ROMAGNA

Model	η	SE	t-test	p-value	Adj. R2	Obs.
2011Q1-2023Q3	-0,14	0,067	-2,15	0,034	0,10	94
2021Q1-2023Q3	-0,16	0,063	-2,55	0,021	0,34	22
2022Q1-2023Q3	-0,16	0,039	-4,07	0,002	0,62	14

Source: Elaborations on Istat Coeweb data

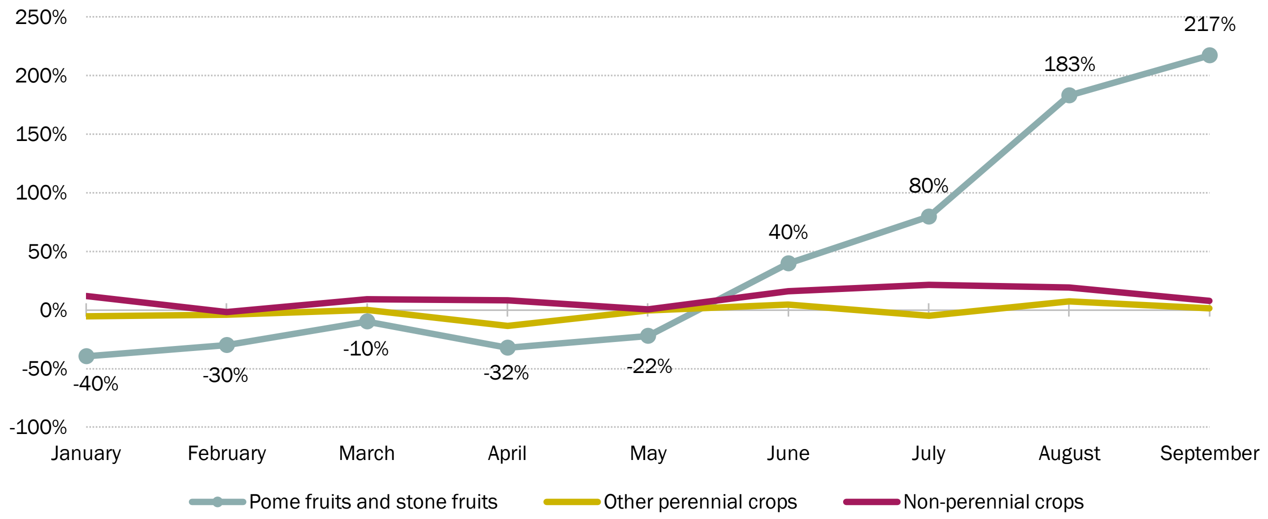
2) *If there has been an increase in international imports of Italy of the agricultural goods whose production was more exposed to the flood (i.e., pome fruits and stone fruits).*[15]

Whereas the fall of regional exports is an important symptom of a decrease in production, they might not really capture the extent of the fall of the latter one. Indeed, for the kinds of products which were more exposed to the flood, foreign markets might represent a relatively small share with respect to domestic destinations. That is why we shift our focus to the dynamics of Italian international imports of pome fruits and stone fruits (CPA code 01240) in the aftermath of the 2023 flood. In this respect, Figure 11 reports it in terms of yearly percentage changes in imported tons on a monthly basis. As it can be seen from the graph, international imports dramatically rose since June 2023 (+40%), to peak at +217% in last period of observation (i.e., September). Such a dynamics is significantly different from the ones characterizing other perennial crops and non-perennial crops.

[14] This corresponds to a 60% fall on an annual basis.

[15] As to international imports, data at the national scale has to be preferred. First, imports at the regional scale, especially of goods destined to final consumption, are largely biased by the uneven distribution of firms in charge of logistic services. Second, they are at disposal in quantities and on a monthly basis.

Figure 11.
ITALIAN IMPORTS OF POME FRUITS AND STONE FRUITS IN 2023. TONS (YEARLY % CHANGES)



Source: Elaborations on Istat Coeweb data

The impressive increase in imports of both pome and stone fruits in the aftermath of the 2023 flood is clear evidence that the products were available on international markets and they were adequate substitutes for both food industry and final consumers. However, about substitutability we cannot evaluate: 1) if there were any differences in terms of safety of the products (i.e. chemical residuals) and the overall impact on health and environment (i.e. emissions, use of inputs); 2) the impact on prices. In the third quarter, on average, the consumer prices of fruits in Italy increased by 10% if compared to the same quarter of 2022. However, to detach the net effect generated by the 2023 flood from the effect of inflation/other factors more in-depth analysis is needed.

Table 2.
SUMMARY TABLE OF THE CRITICALITY OF FRUITS PRODUCTION OF EMILIA ROMAGNA

Criticality	**Overall importance**	**Supply risk**
Economic importance	+++	
Nutritional importance	+++	
Availability on the market		+++
Substitutability on the demand-side (cost-opportunity)	+-	
Substitutability on the supply-side (suitability)		+-

Source: Authors' own elaboration

5. IN LIEU OF A CONCLUSION

Whereas climate change is expected to dramatically affect agriculture and food production in the very next years, there is a lack of toolkits in economic research to correctly track the paths from the places affected by climate shocks to those in which food is consumed. In this respect, value chains approaches based on interregional input-output tables represent an appealing solution as they are able to connect the places of consumption to those where production takes place. However, both the geographic lenses and the level of sector/product disaggregation of such models leave often unsatisfied.

The present work contributes to the existing research in many respects. First, it provides a configuration of interregional-international value chains activated by Italian internal food consumption and show how fragmented it appears. Moreover, it shows how some countries and regions are in charge of producing most of the agricultural goods necessary to finalize production. Second, it provides a conceptual framework to assess the vulnerability of a RFS, starting from the assessment of criticality of a food product and encompassing all the final as well as the intermediate goods necessary to produce it or

providing it via imports. Finally, a primary version of this framework of spatial- and product-based disaggregation of agricultural production in Italian regions has been applied to the case of the flood occurred in Emilia Romagna in May 2023, in order to capture the exposure of Italian food system to the reduced supply of fruits.
In our intention, future research will expand the conceptual framework presented in this study over several dimensions. First, disaggregation of industries and sectors involved in serving the consumers final demand for food, as well as the food consumption basket, will be considered in the implementation of a comprehensive food satellite account for Italian regions. Second, the spatial module now implemented for Emilia-Romagna and Tuscany will be extended to all the regions for which spatial data are available. Moreover, apart from cultivations, the final spatial archive will include plants linked to livestock and to the food processing industry. Third, firm level data will be considered so as to include the potentially heterogeneous impact of climate shocks on firms balance sheets. Fourth, international trade data and a multi-country Supply and Use based model will complete the international module of the value chain configuration. Finally, a climate related module about the impact of climate shocks on food production will be envisaged.

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7. APPENDIX

A. Data

In order to implement the analysis performed in Section 2 we use the IRPET interregional input-output table graphically represented in Figure A1 (see Paniccià and Rosignoli, 2018 and Bentivogli et al., 2019 for the methodology). The interregional input output table (IRIOT) contains information for 43 sectors and 20 Italian administrative regions (plus extra-regio). Each row of the matrix indicates the destination of the production generated by a sector *j* located in a region s distinguishing, in terms of intermediate uses, the region and the sector demanding such inputs; in terms of final uses, the region and the specific final demand component. Moreover, the last two columns identify changes in inventories and foreign exports.

Reading the IRIOT by column provides information about production requirements in terms of intermediate inputs and productive factors services of each single sector/region. Evidently, in IRIOT, the origin of the intermediate inputs is distinguished by sector and geographical area of origin (apart from foreign imports). The total of each single column of the intermediate part of IRIOT is the sectoral total output as the sum of demand for intermediate inputs, value added at basic prices and net indirect taxes.

The accounting structure of the table can be summarized by the following identity, for each *j*-th sector and *r*-th region:

$$\sum_{s=1}^{N}\sum_{i=1}^{M} x_{ij}^{sr} + va_j^r + tax_j^r + imports_j^r \equiv \sum_{s=1}^{N}\sum_{i=1}^{M} x_{ji}^{rs} + \sum_{s=1}^{N}\sum_{z=1}^{Z} Fd_{s,z}^{rs} + inv_j^s + exports_j^s \qquad [A1]$$

Where: *N* = number of regions; *M* = number of sectors; *Z* = number of final demand components; *x* = intermediate goods and services; *va* = value added at basic prices; *Fd* = final demand; *tax* = indirect taxes; *imports* = intermediate input imports; *inv* = changes in inventories of final products; *exports* = international exports.

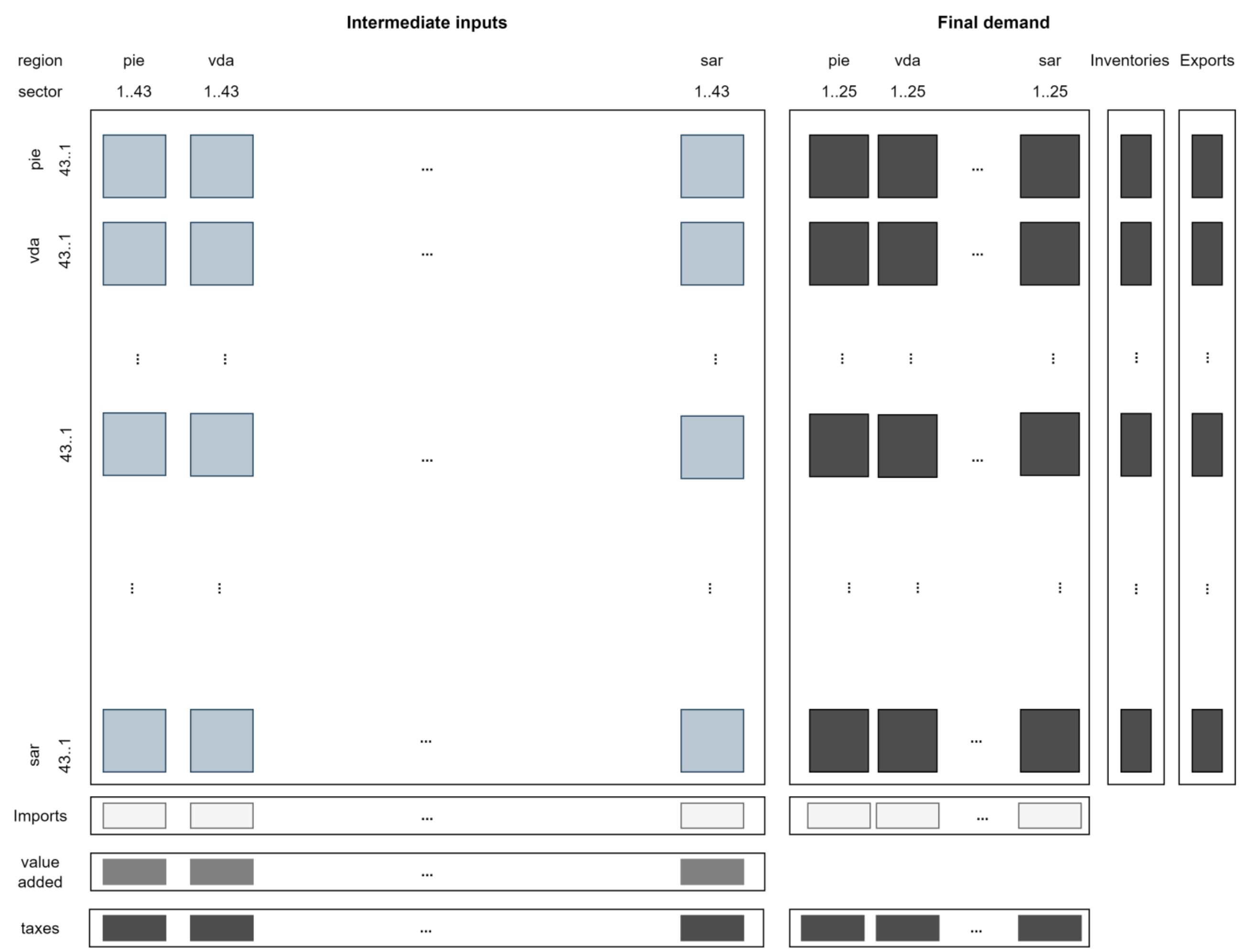
Final demand components at the regional level in the IRIOT foresee household consumption divided into 12 COICOP expenditure functions;[16] public administration consumption divided into 10 expenditure functions;[17] fixed capital formation; non-profits institutions serving households; valuables.

The reference year for the analysis is 2018.

[16] The 12 (2-digits) COICOP household expenditure functions include: 1) food and non-alcoholic beverages; 2) alcoholic beverages, tobacco and narcotics; 3) clothing and footwear; 4) housing, water, electricity, gas and other fuels; 5) furnishings, household equipment and routine household maintenance; 6) health; 7) transport; 8) communication; 9) recreation and culture; 10) education; 11) restaurants and hotels; 12) miscellaneous goods and services.

[17] The 10 Public Administration expenditure functions include: 1) general public services; 2) defence; 3) public order and safety; 4) economic affairs; 5) environmental protection; 6) housing and community amenities; 7) health; 8) recreation, culture and religion; 9) education; 10) social protection.

Figure A1.
A GRAPHICAL REPRESENTATION OF THE IRPET INTERREGIONAL INPUT OUTPUT TABLE (IRIOT). 2018



Further data used in Section 2 includes the OECD inter-country input-output (ICIO) table, whose main characteristics can be found here.
In order to carry out the analysis reported in Section 4, several sources of openly available data were used. Table A1 provides summary information about all the data sources used in the present work.

Table A1.
DATA SOURCES

Database	**Website**
IRPET IRIOT	
OECD ICIO	https://www.oecd.org/industry/ind/inter-country-input-output-tables.htm
Farm accountancy data network (FADN)	https://agriculture.ec.europa.eu/data-and-analysis/farm-structures-and-economics/fadn_en
Conti della branca agricoltura, silvicoltura e pesca	http://dati.istat.it/
Piano Colturale Grafico Emilia-Romagna	https://agreagestione.regione.emilia-romagna.it/agrea-file/
Flood May 2023 hit zones	Decreto legge 61/2023 - Interventi urgenti per fronteggiare l'emergenza provocata dagli eventi alluvionali verificatisi a partire dal 1° maggio 2023
Coeweb international trade data	https://www.coeweb.istat.it/