Systemic Risk in the Multilayer Network of Trade and Production of Food

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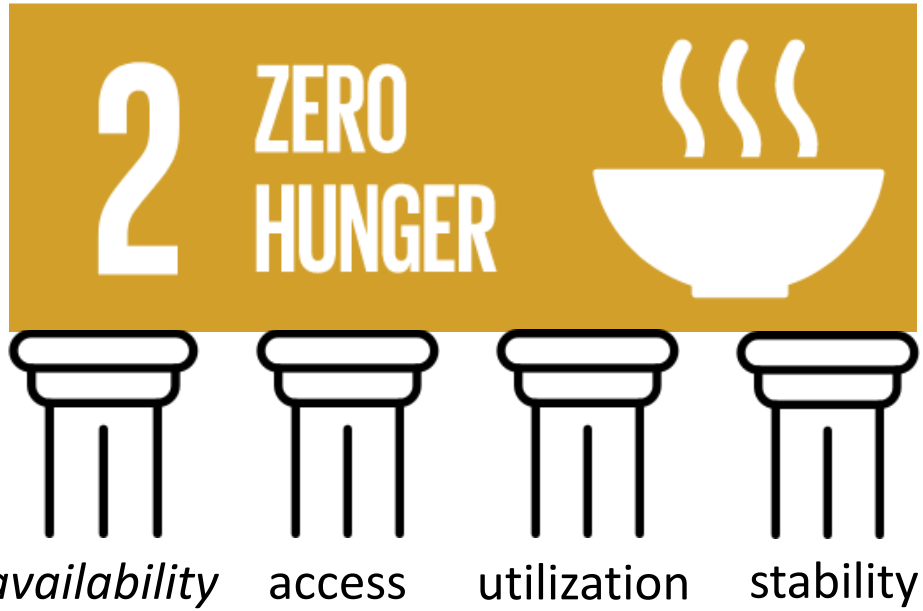
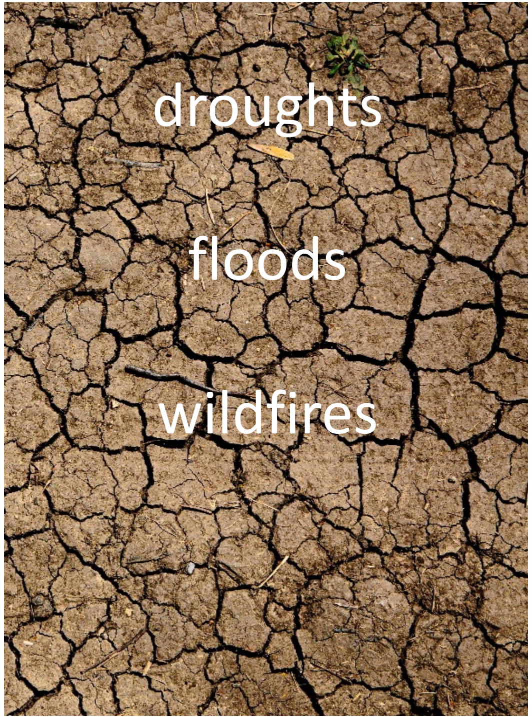
What is food security?



» **Food security** exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.«[1]

1 **World Food Summit *Rome*** *Declaration on World Food Security* (1996), URL: https://www.fao.org/3/w3613e/w3613e00.htm
Image: https://www.un.org/sustainabledevelopment/hunger/ (modified)
Icon made by PixelPerfect from www.freeicon.com

Threats to food security

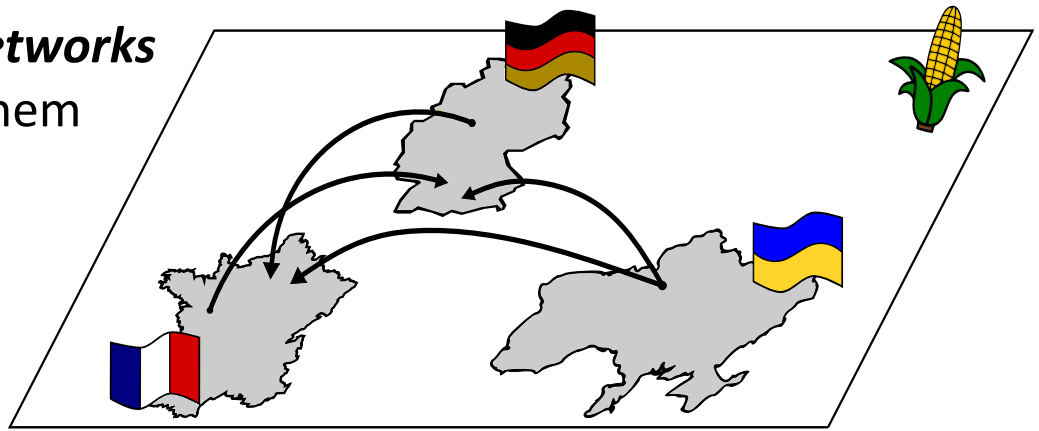


2 **Cottrell et al.** *Food production shocks across land and sea* , Nature Sustainability 2 (2019)
3 **De Raymond et al.** *Systemic risk and food security: Emerging trends and future avenues for research,* Global Food Security 29 (2021)
Image (left): www.preventionweb.net/news/fao-desert-locust-campaign-east-africa-upsurge-suppressed-kenya-free-desert-locust
Image (right): www.unsplash.com/photos/GKFsewk-hz0
Image(center): www.raconteur.net/wp-content/uploads/2022/05/GettyImages-1239801616.jpg

Trade influences the availability of food

Trade can enhance the availability and diversity of food, but it also creates new dependencies and risks[4].

The structure[5,6] of ***food trade networks*** and dynamical processes[7,8] on them shed light on these risks.

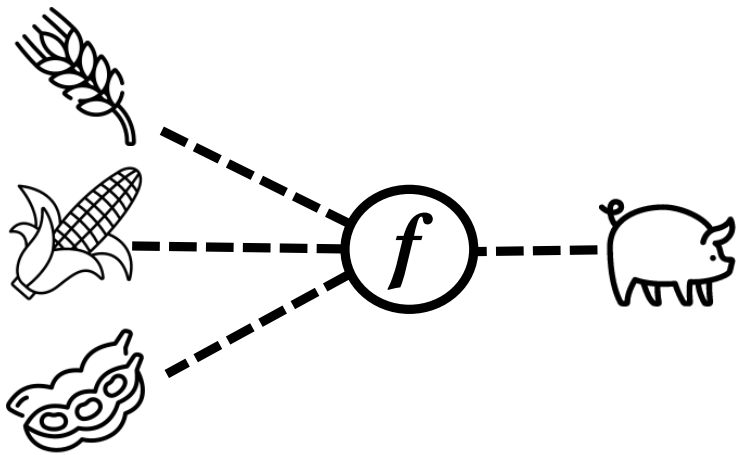


4 **Kummu et al. 2020** *Interplay of trade and food system resilience: Gains on supply diversity over time at the cost of trade independency;* Global Food Security 24
5 **Puma et al. 2015** *Assessing the evolving fragility of the global food system;* Env. Res. Lett. 10 2
6 **Dupas et al. 2019** *Time dynamics and invariant subnetwork structures in the world cereals trade network;* PLOS ONE 14 5
7 **Marchand et al. 2021** *Reserves and trade jointly determine exposure to food supply shocks;* Env. Res. Lett. 11 9
8 **Burkolz & Schweitzer 2019** *International crop trade networks: the impact of shocks and cascades;* Env. Res. Lett. 14 11

Products turn into other products

Production functions describe how products are converted into other products.
They can be reconstructed from supply and use tables.

Use	Pig farming	…
Wheat	4 Mt	
Maize	5 Mt	
Soy	2 Mt	
Pigs	0	
…	…	..



Supply	Pig farming	…
Wheat	0	
Maize	0	
Soy	0	
Pigs	60 M	
…	…	..

9 **Bruckner et al. 2019** *FABIO—The Construction of the Food and Agriculture Biomass Input–Output Model;* Environmental Science and Technology 53 19

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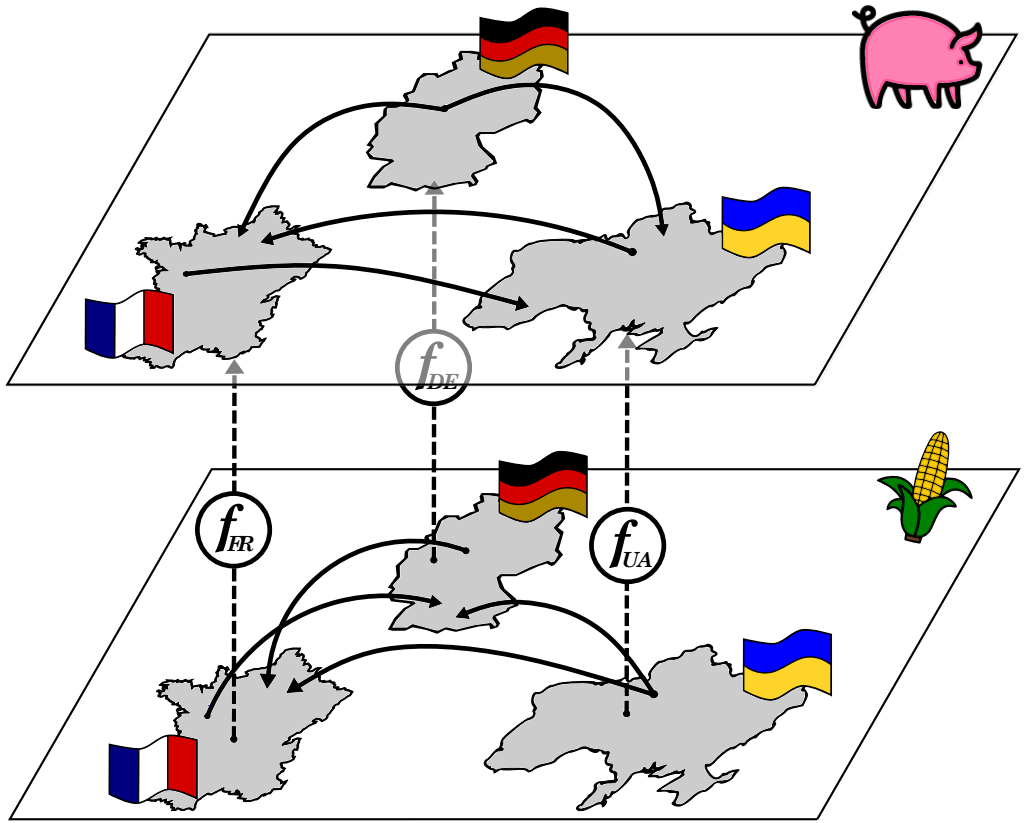
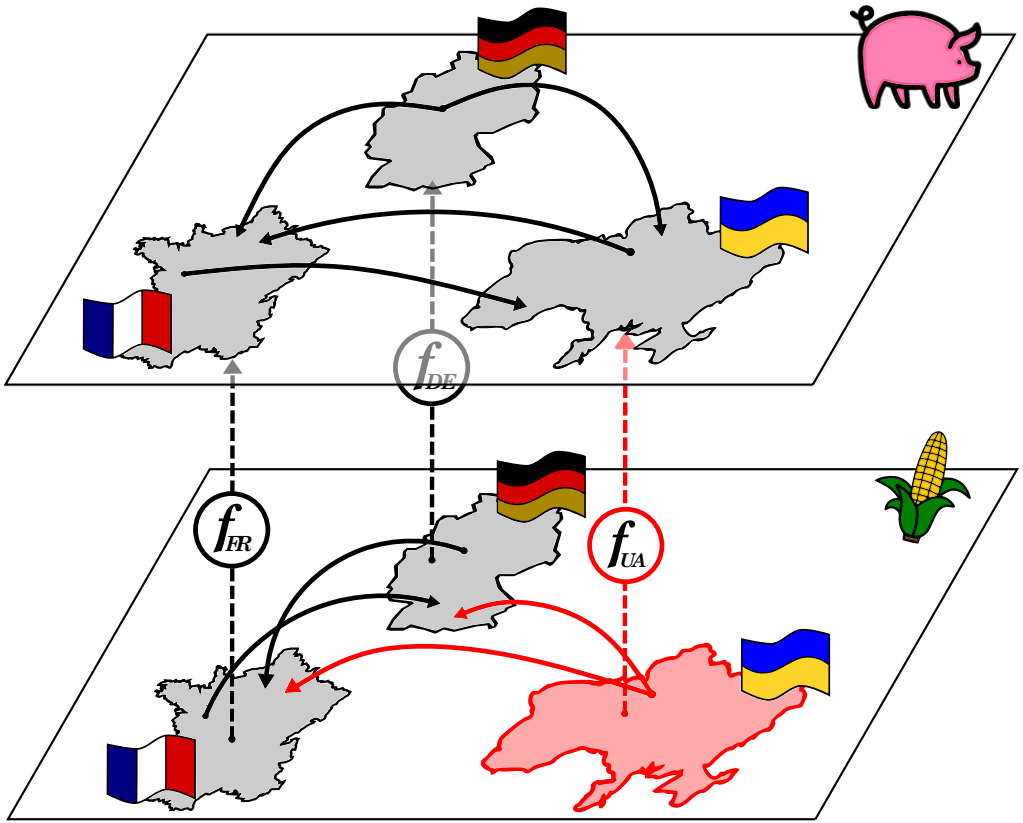
Combining trade and production



The combination of trade and production leads to **indirect dependencies** across layers.

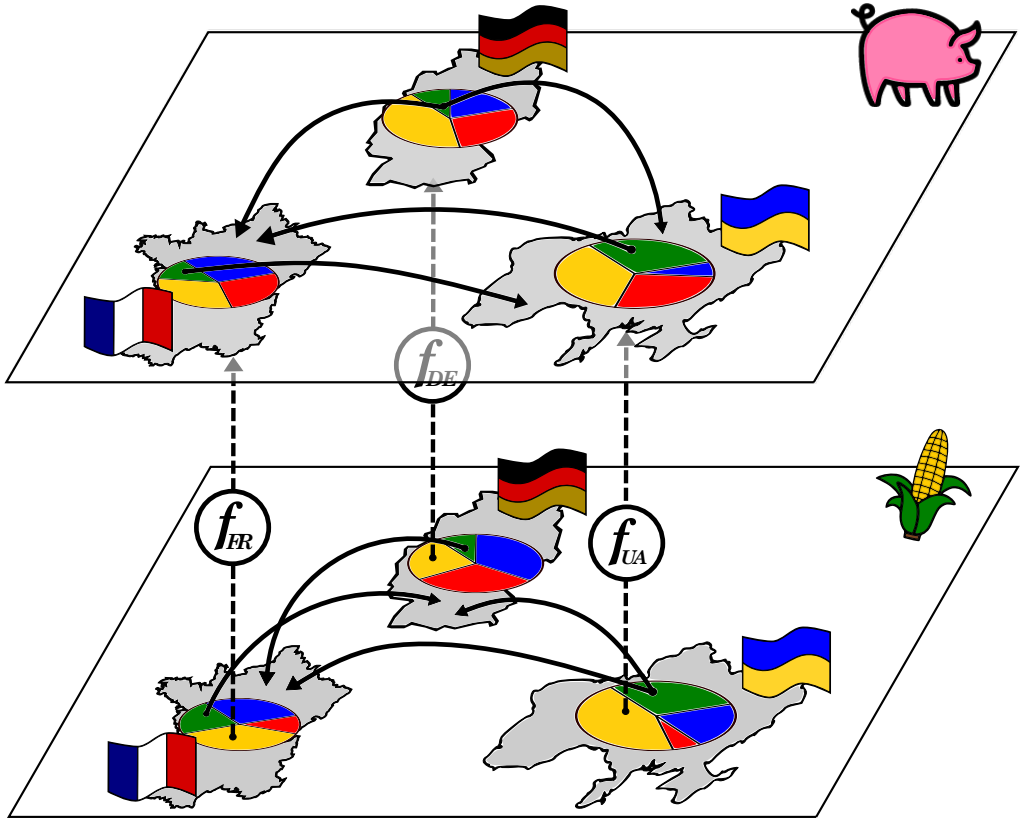
These dependencies strongly impact the availability of food products.

Shock propagation



The **propagation of shocks** on the international food production network is a tool to quantify dependencies.

A multilayer network model of the food system

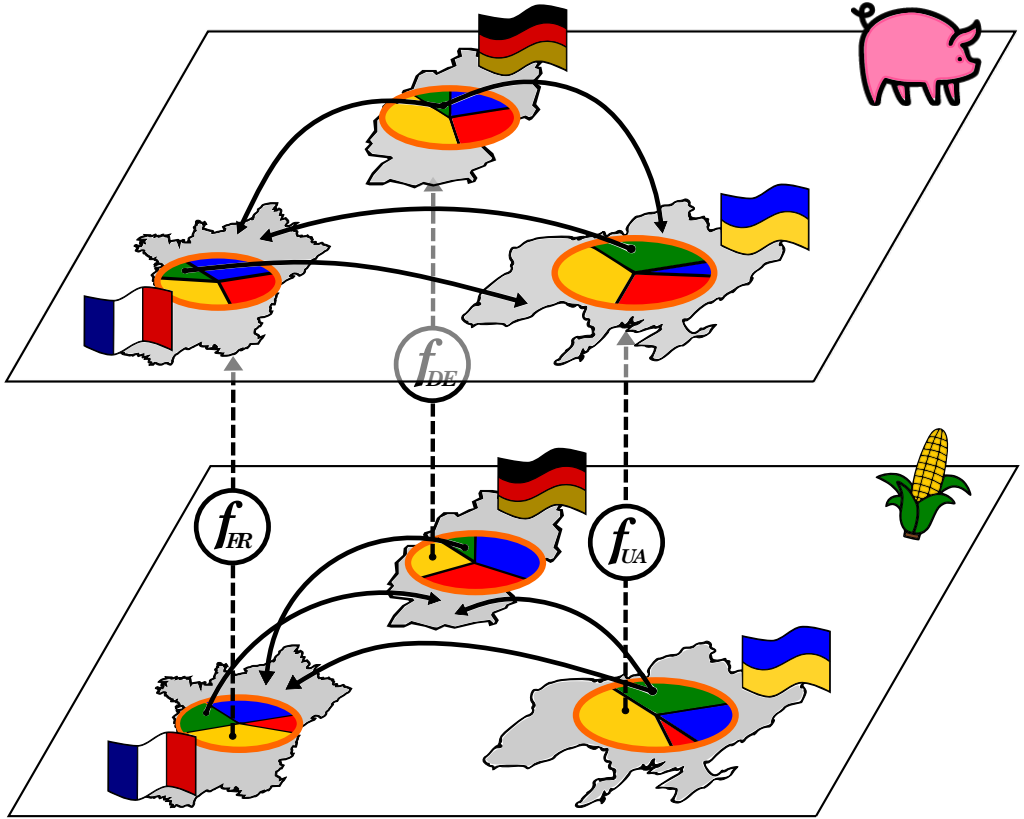


The **baseline scenario** consist of

1. Allocation
2. Production
3. Trade

Repeat

A multilayer network model of the food system

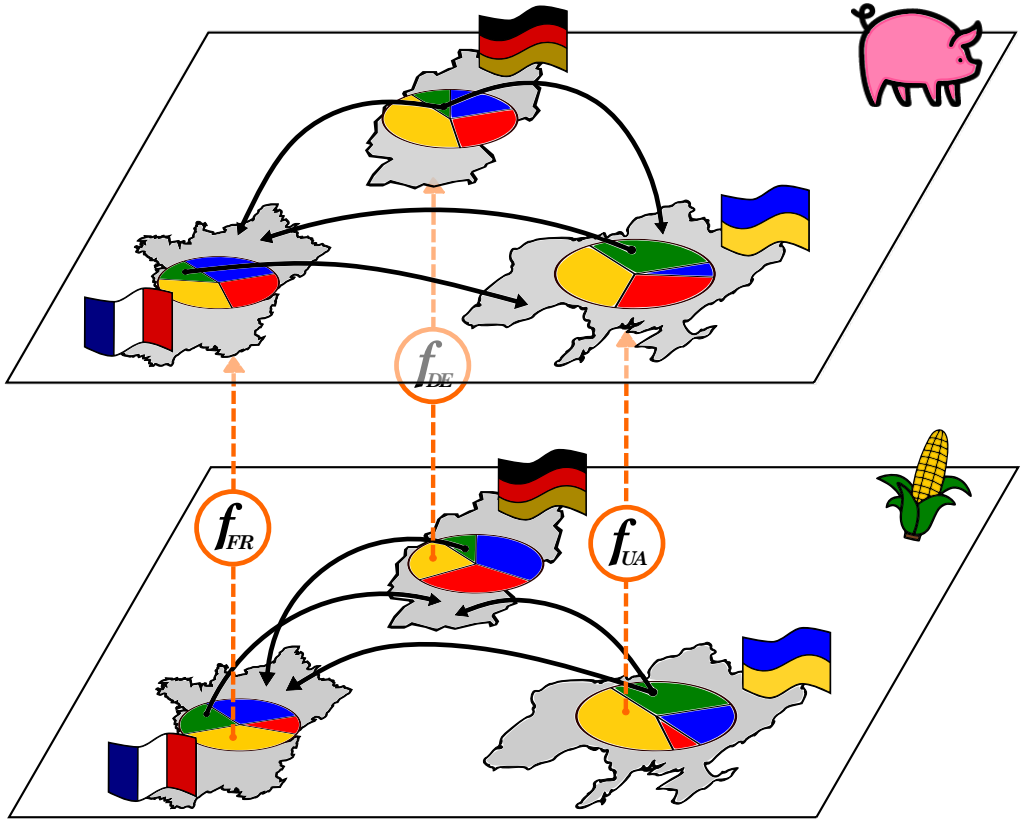


1. Allocation

Countries allocate fixed shares of the total amount of a product to different purposes

- Processing
- Export
- Food
- Other

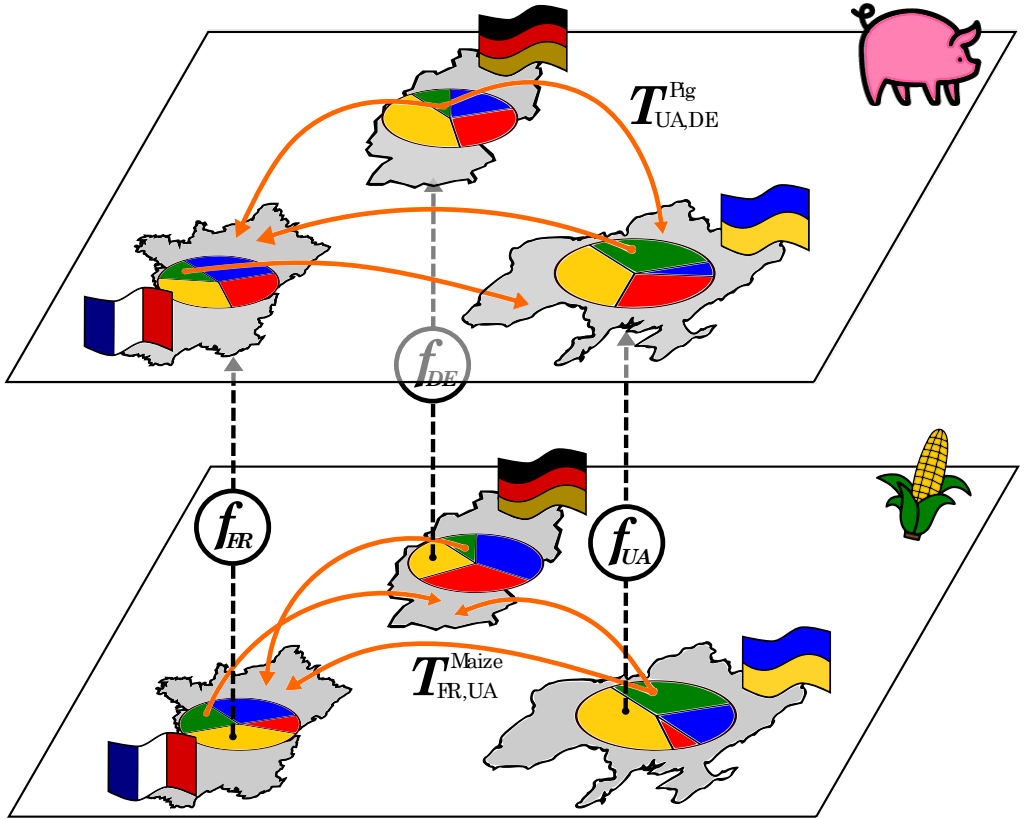
A multilayer network model of the food system



2. Production

Countries convert products into other products according to a production function.

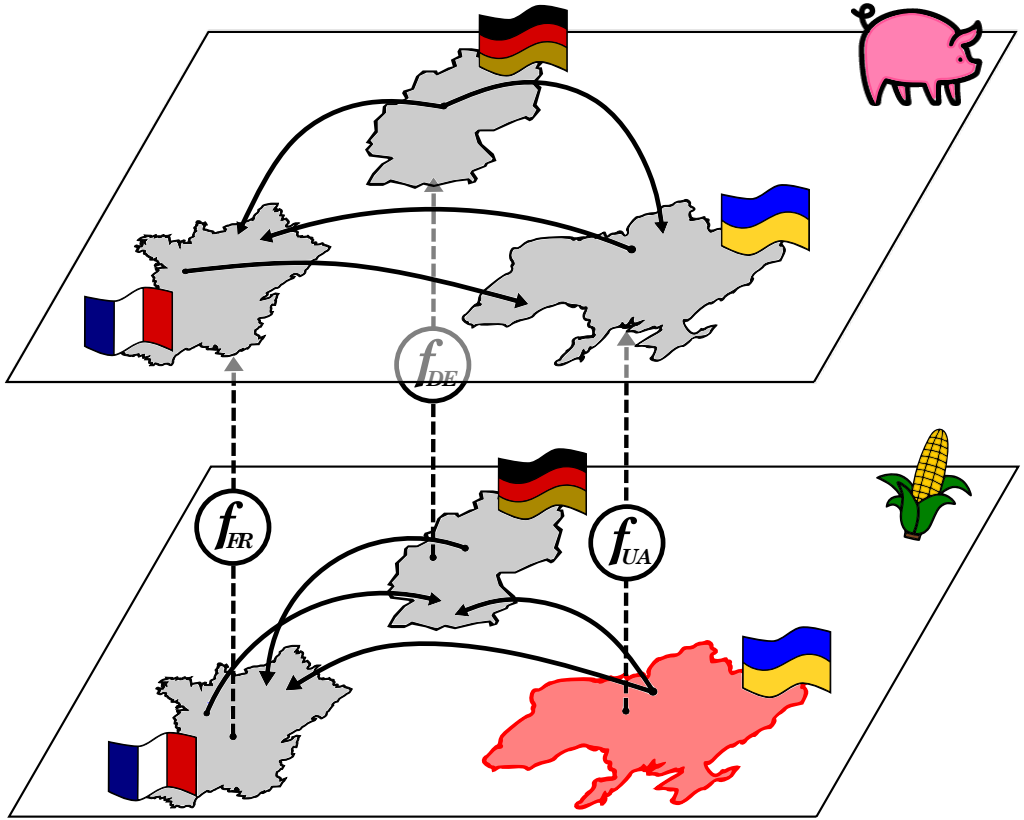
A multilayer network model of the food system



3. Trade

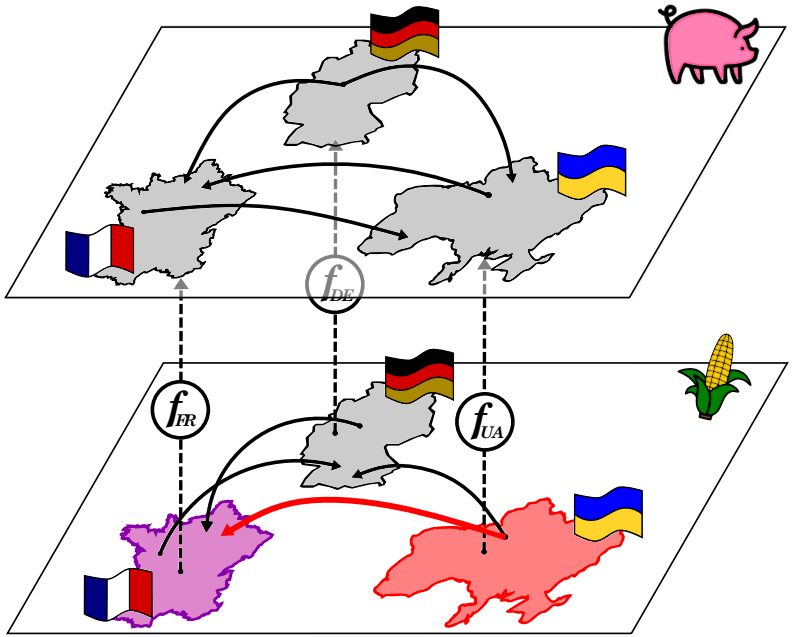
Countries import goods from other countries.

Shock propagation

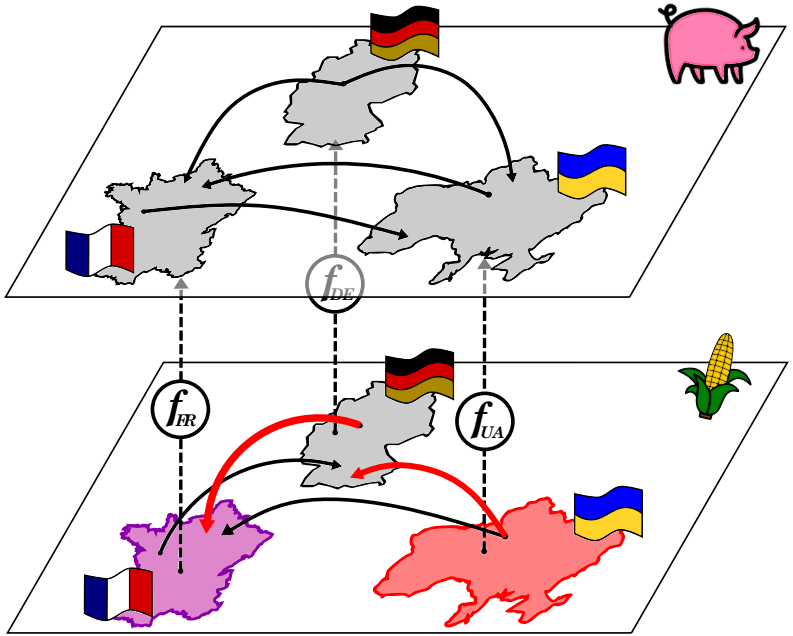


In the **shocked scenario**
100% of the produced goods in a specific country are lost, every time step.

Shocks spread along multiple channels

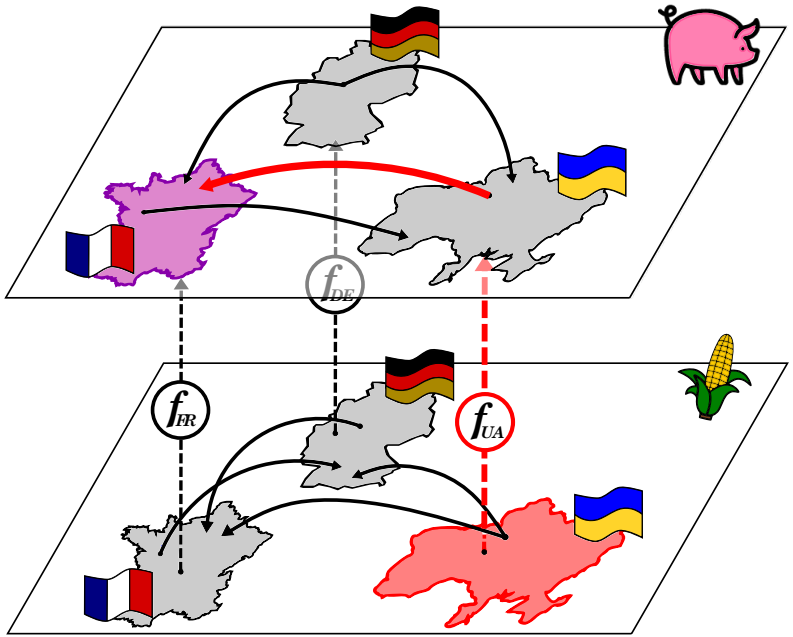


direct trade

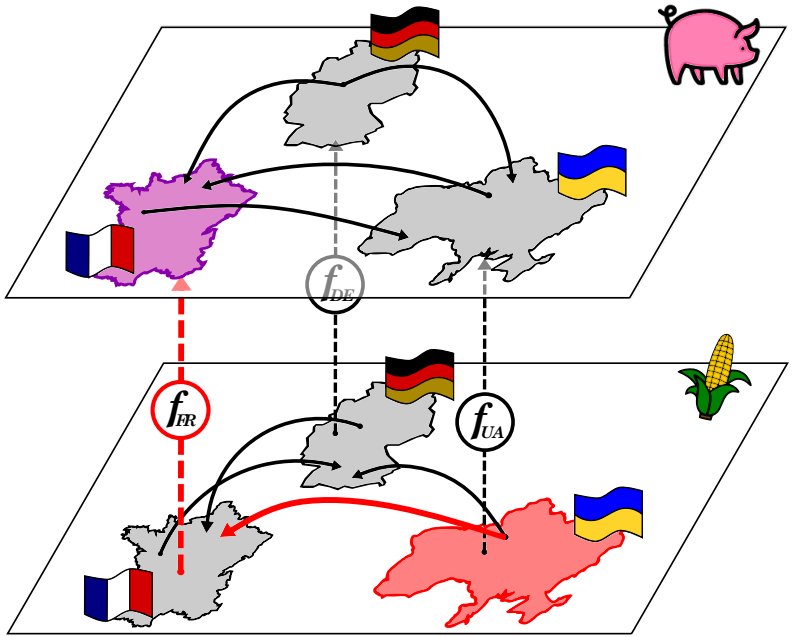


indirect trade

Shocks spread along multiple channels

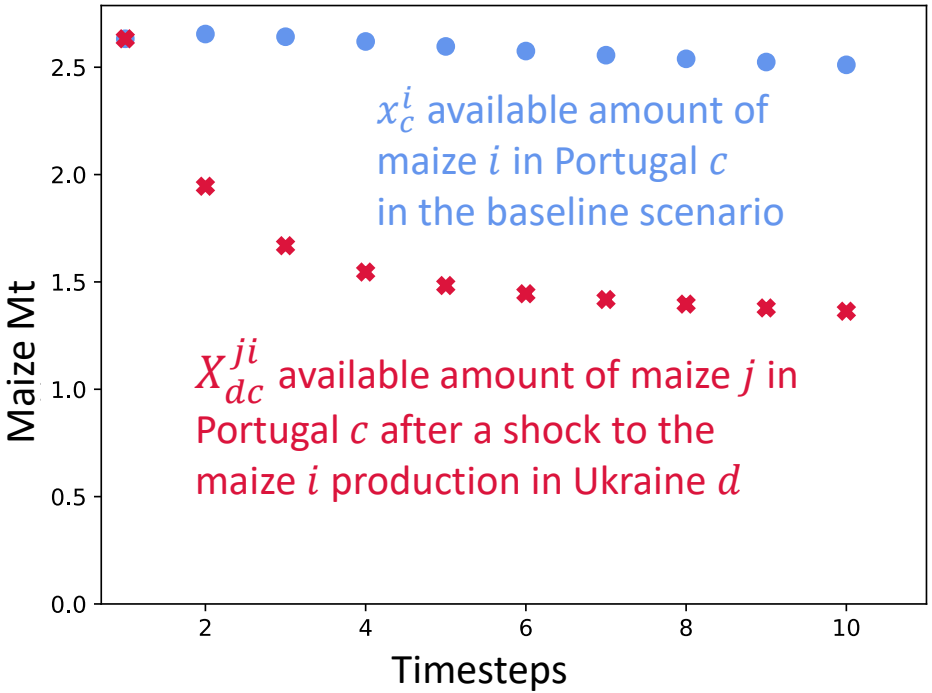


foreign production



domestic production

Relative loss as a measure of risk

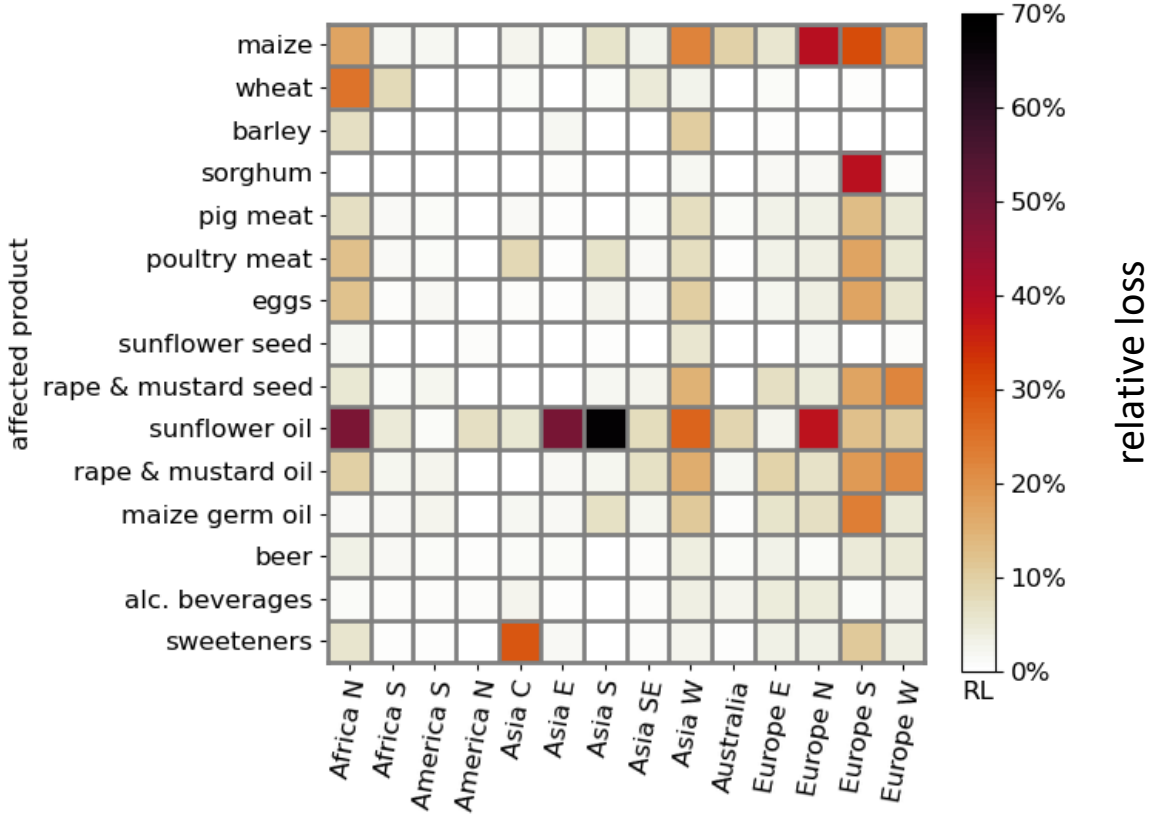


Availability of maize in Portugal in the baseline scenario and after a shock to maize production in Ukraine

The **relative loss** measures the reduction of available resources after a shock with respect to the baseline scenario.

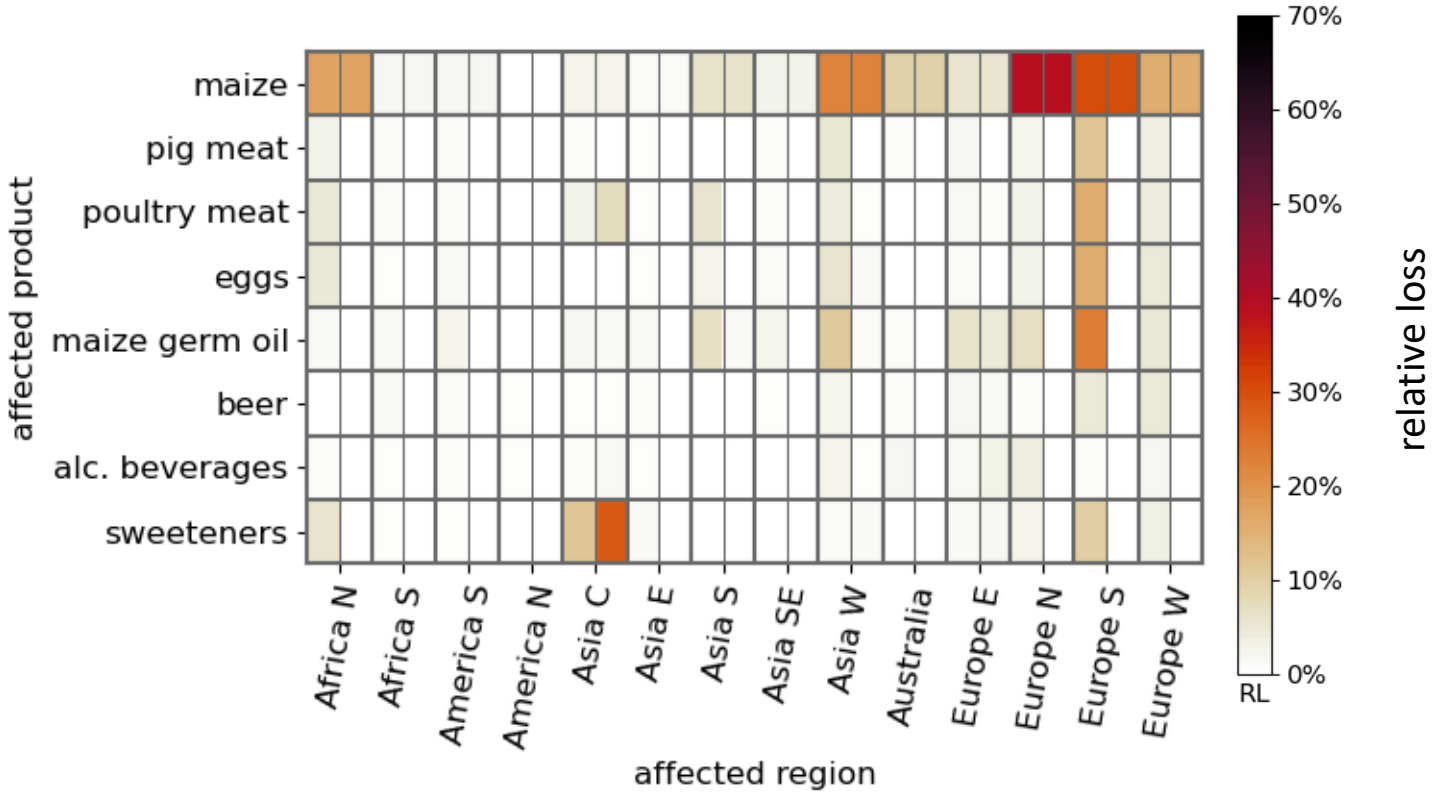
$$RL_{dc}^{ji}(t) = \frac{x_c^i(t) - X_{dc}^{ji}(t)}{x_c^i(t)}$$

Shock to the agricultural production of Ukraine

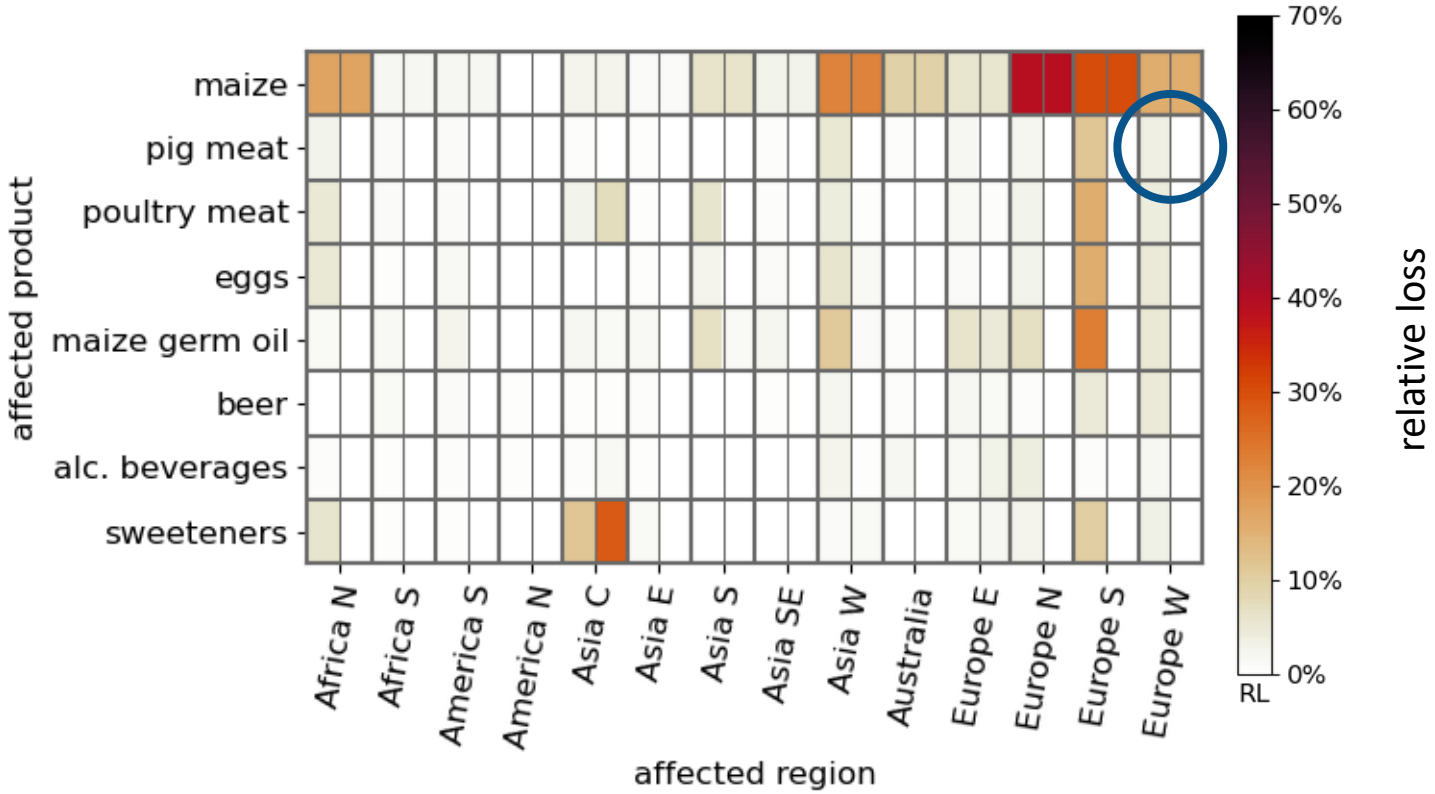


$$RL_{\mathrm{UA}\to\mathrm{c}}^{\mathrm{all}\to i}$$

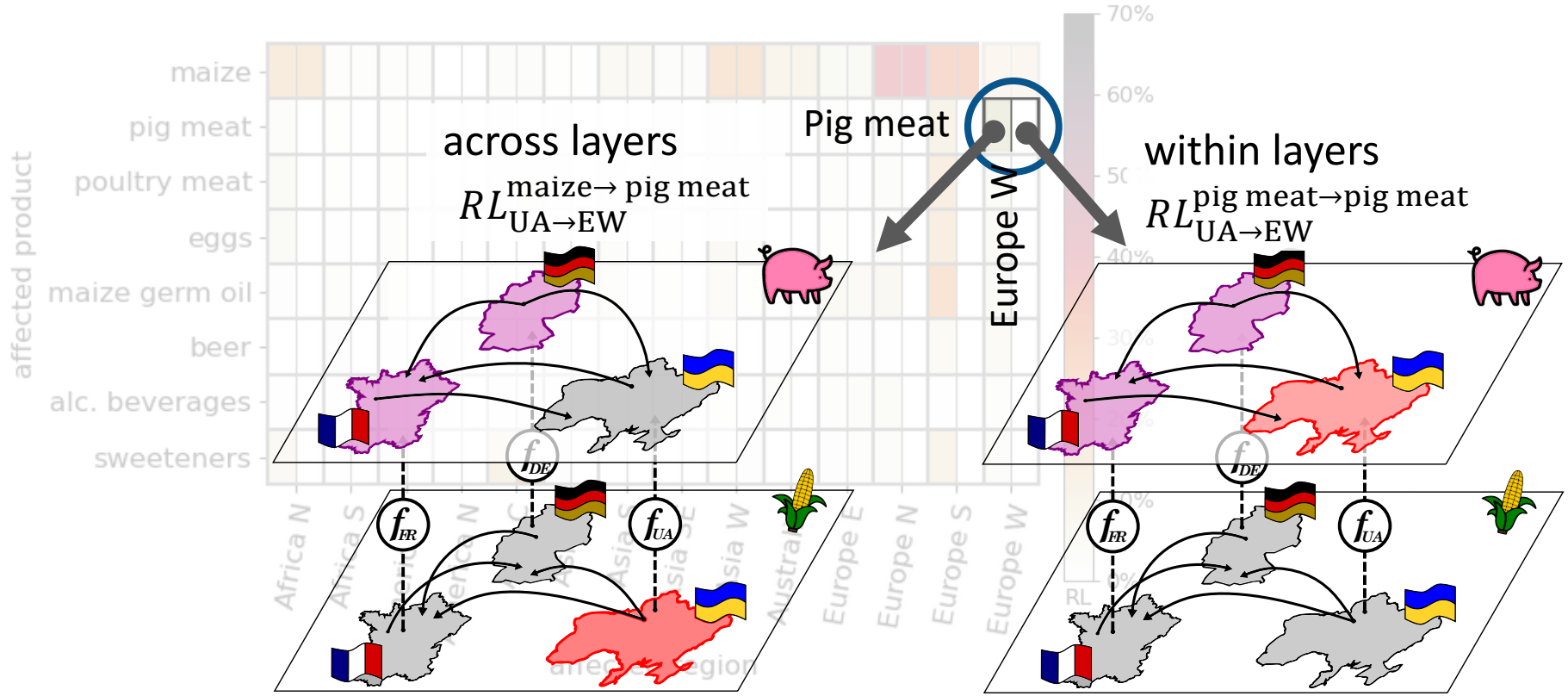
Indirect effects of a shock to maize production



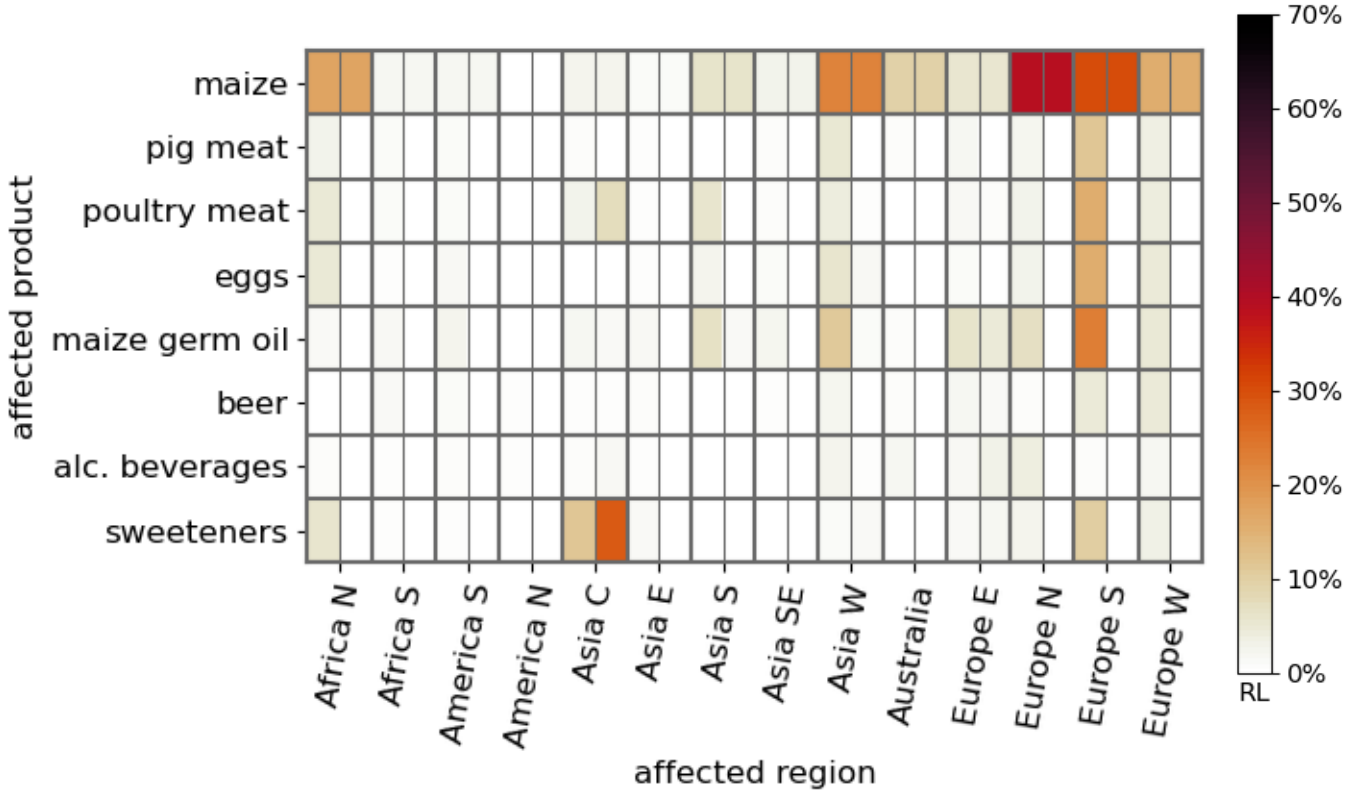
Indirect effects of a shock to maize production



Indirect effects of a shock to maize production

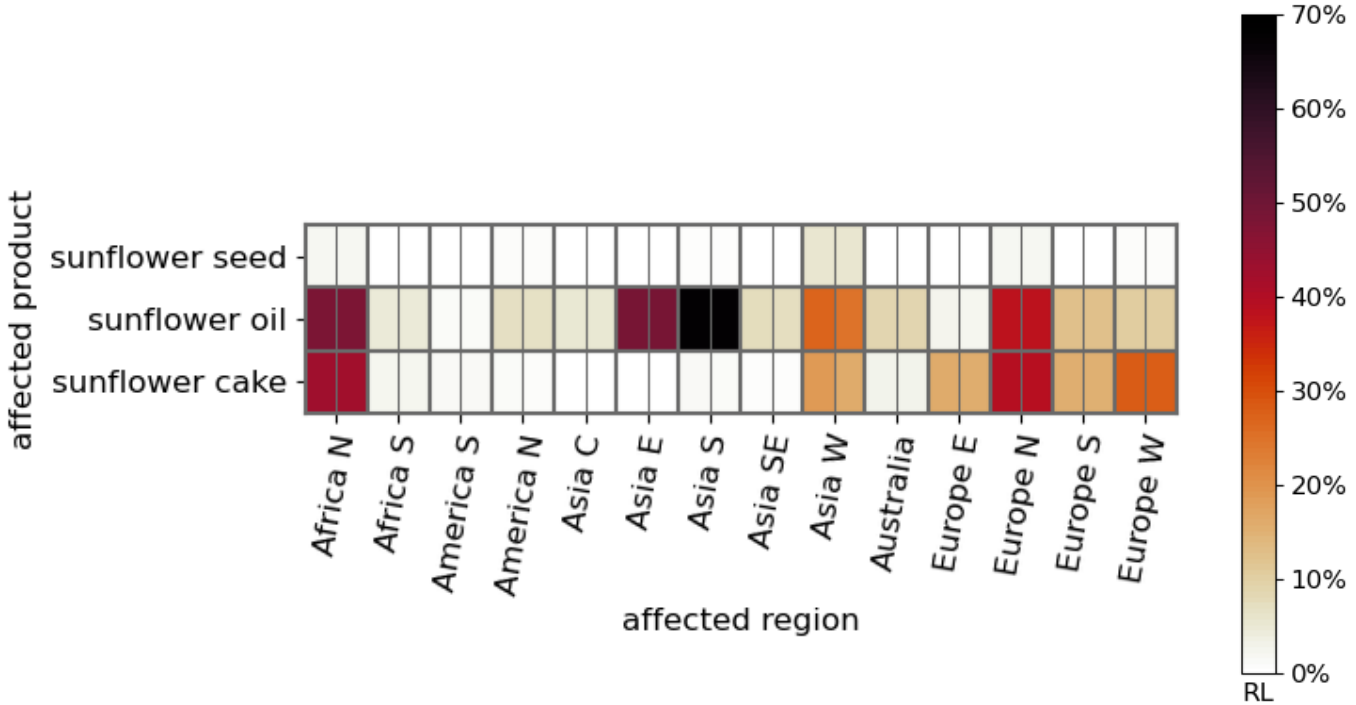


Indirect effects of a shock to maize production



$$RL^{\text{maize}\to i}_{\text{UA}\to c} \,\Big|\, RL^{i\to i}_{\text{UA}\to c}$$

Shocks to sunflower seed production



$$RL^{\text{seeds}\to i}_{\text{UA}\to c} \mid RL^{i\to i}_{\text{UA}\to c}$$

Limitations

- Substitution effects
  - Switching of suppliers
  - Substitution of products
- Prices are not included
- Resolution of data
  - Limited product resolution
  - Only country-level data

Further research

- Extension to non-agricultural inputs, e.g. fertilizers or machinery
- Implementation of other production functions
- Refinement of country properties
  - Stocks
  - Adaptive allocation

Conclusion

- Production processes are a key element to assess food security more realistically
- Indirect effects, across trade-layers, can lead to large losses
- Shock propagation on the multilayer-network of international food production is a versatile tool to asses food availability

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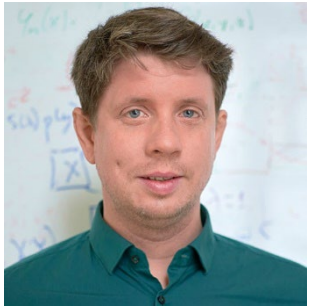

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Laber et al. *Shock propagation from the Russia–Ukraine conflict on international multilayer food production network determines global food availability*. Nature Food **4**, 508–517 (2023). https://doi.org/10.1038/s43016-023-00771-4 .