aGri-culture Advance Data Analytics Lab

Food Networks – the global

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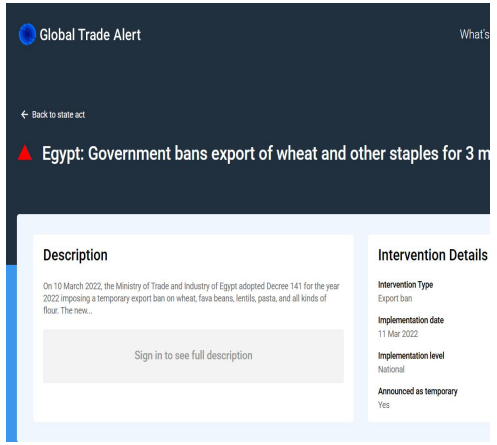
Cascading Failure in Food Networks

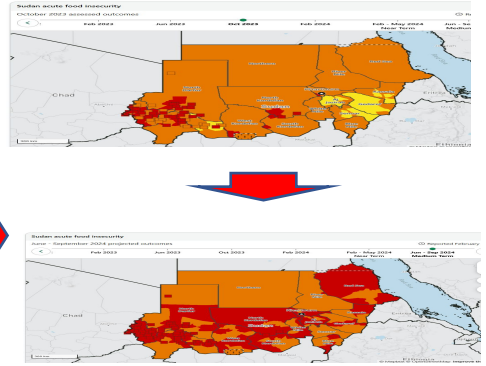
1. Russia Invades Ukraine

2. The price of soft wheat used in bread jumped from $271 per ton to nearly $389 per ton.

3. Egypt: Government bans export of wheat and other staples for 3 months



4. Sudan's worsening food security emergency leads to a risk of Famine in some areas. Worst in many years

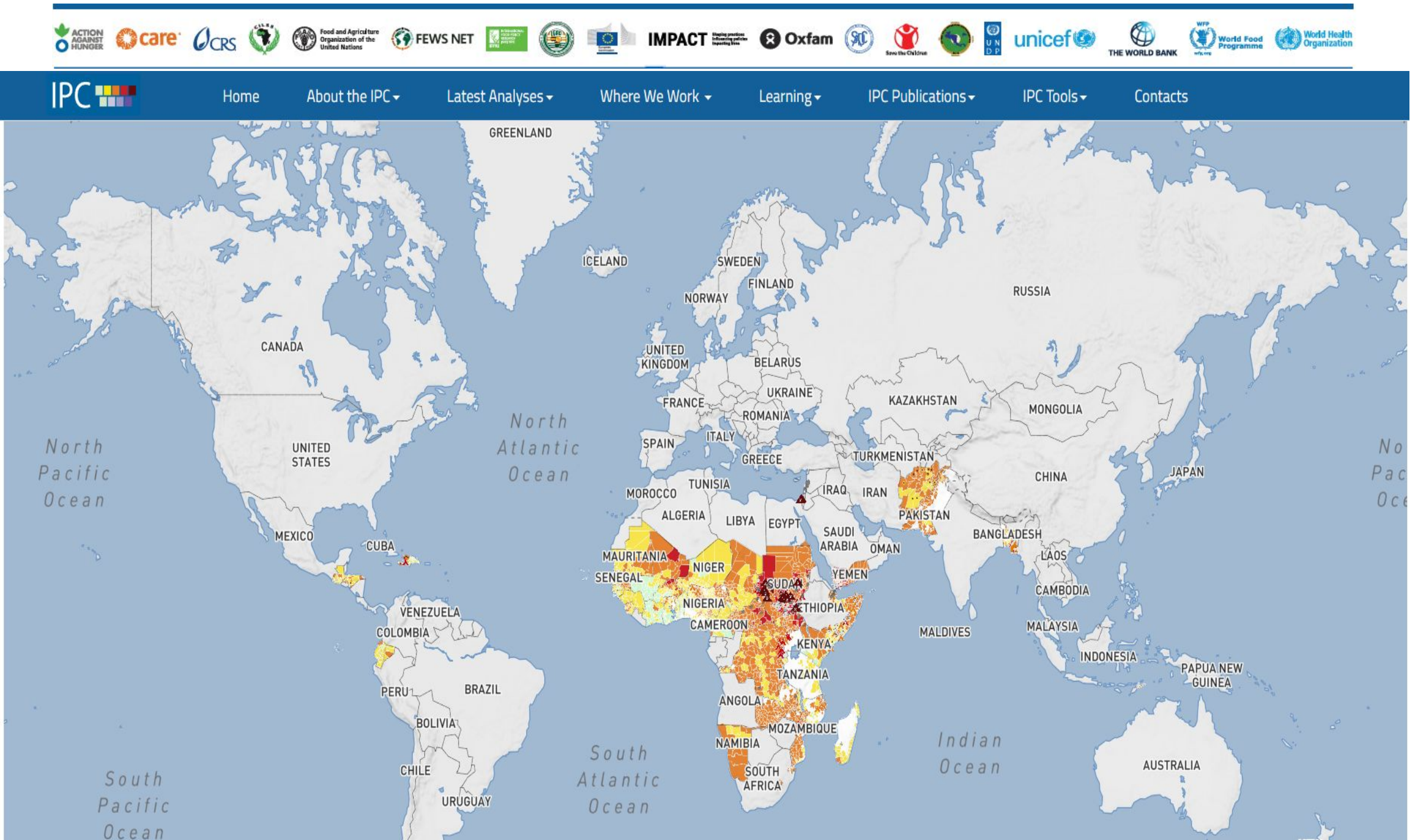


Feb 2022

Mar 2 2022

Mar 10-June 10 2022

May 2024



Motivation

Methods

Results

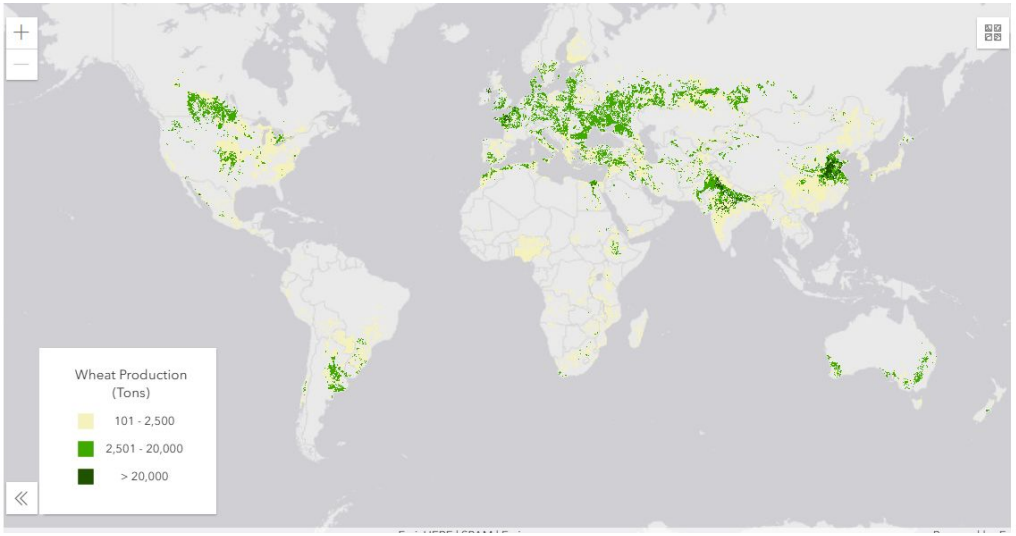
Discussion

Conclusion

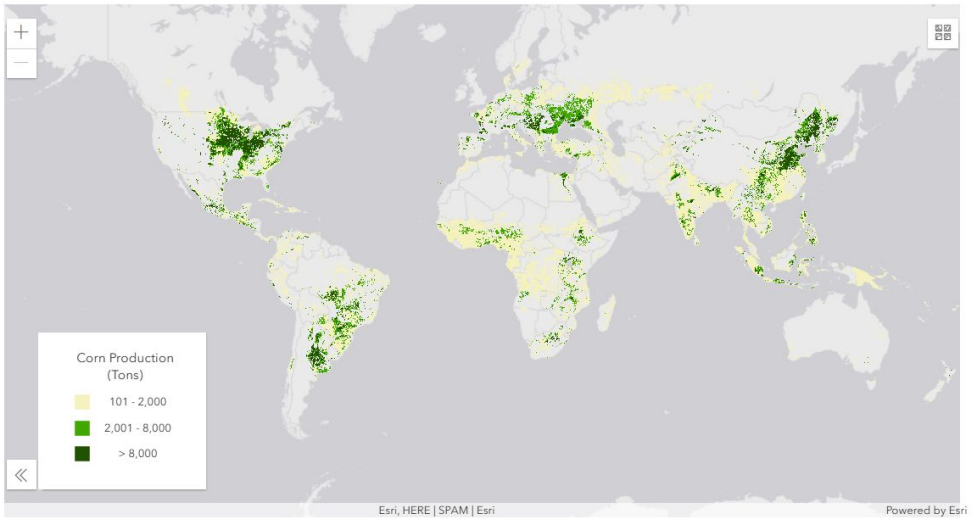
Food crisis = lack of calories.

Distribution of wheat, maize and rice grown in the world

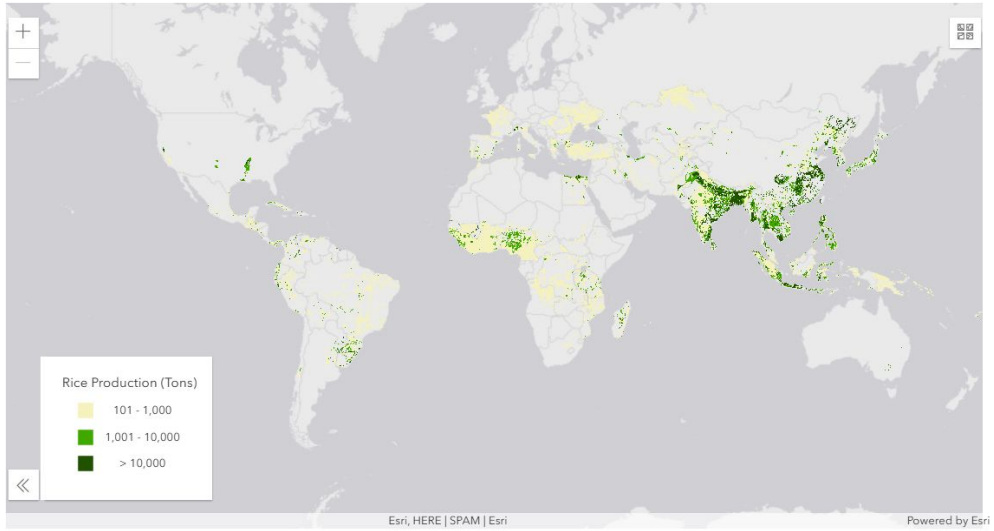
Wheat growth



Corn growth



Rice growth



Source: https://ipad.fas.usda.gov/cropexplorer/cropview/commodityView.aspx?cropid=0440000

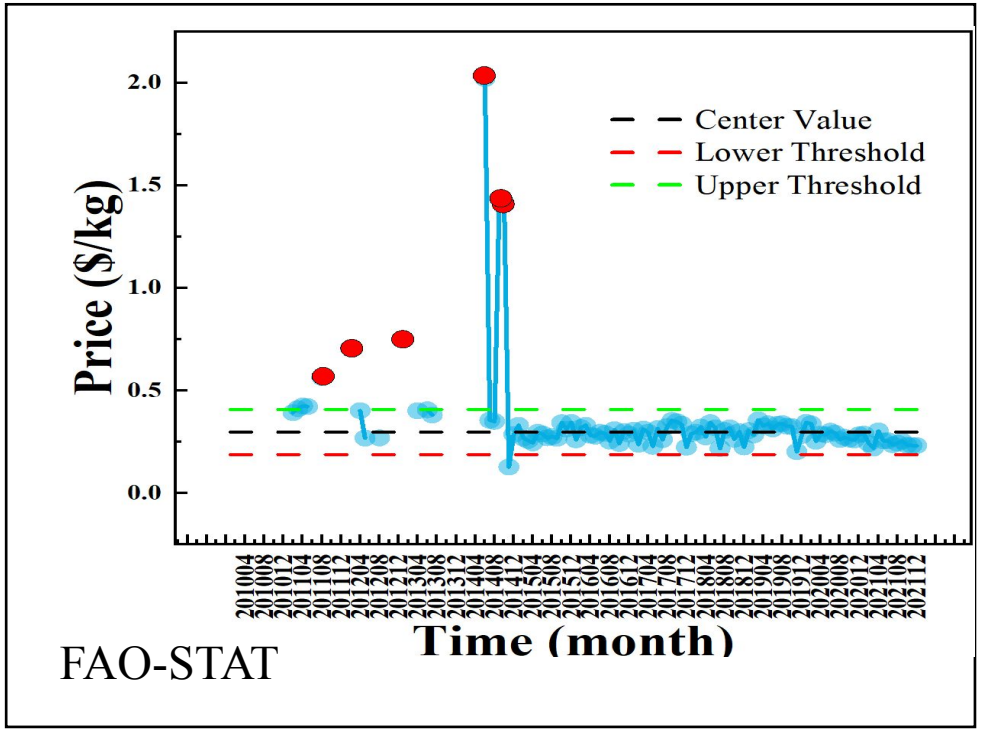
METHODS

Food Network Calories - Main Human Energy Source

DATA

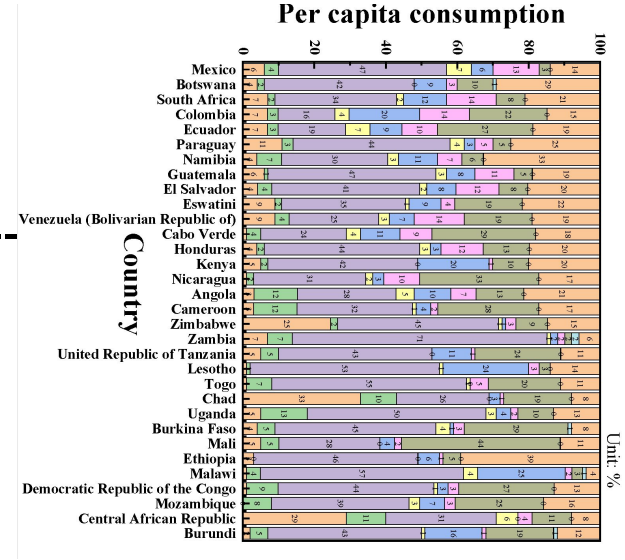
- Global food flow - rice, wheat, maize (shipping)
- Time: 2010-2021
- Countries consumption (habits and culture)
- What people eat!

- Data Cleaning and pre-processing

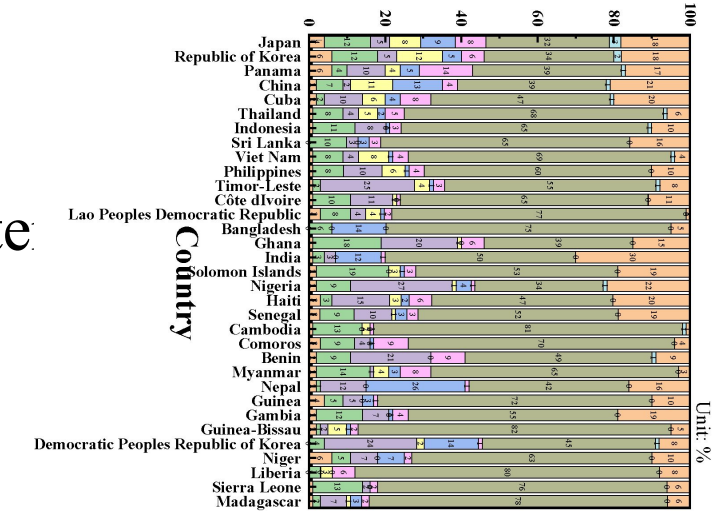


GROUPING GLOBAL COUNTRIES BY MAIN SOURCE OF CALORIES

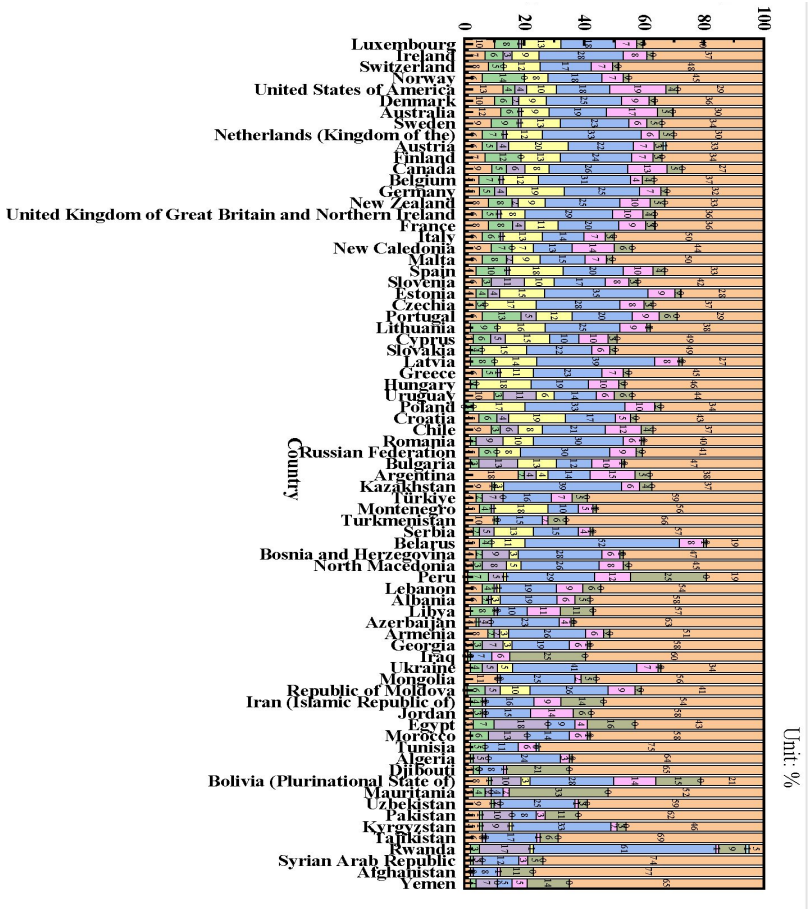
Cluster--ze

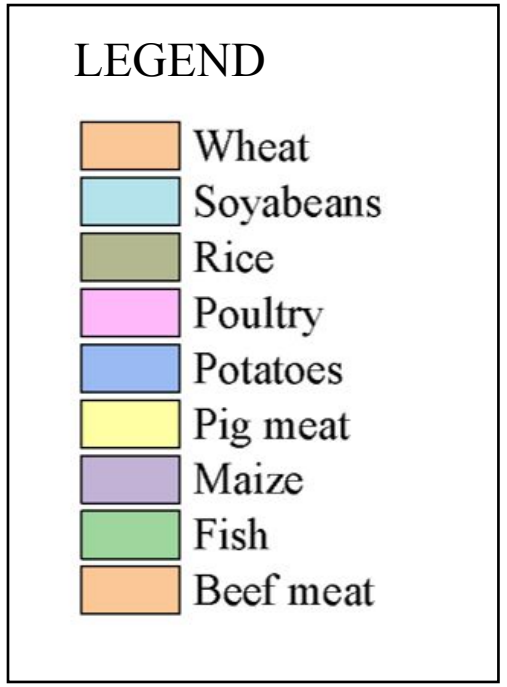


Cluste e

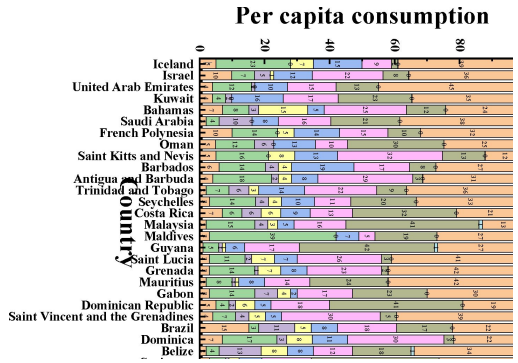


Cluster--Wheat

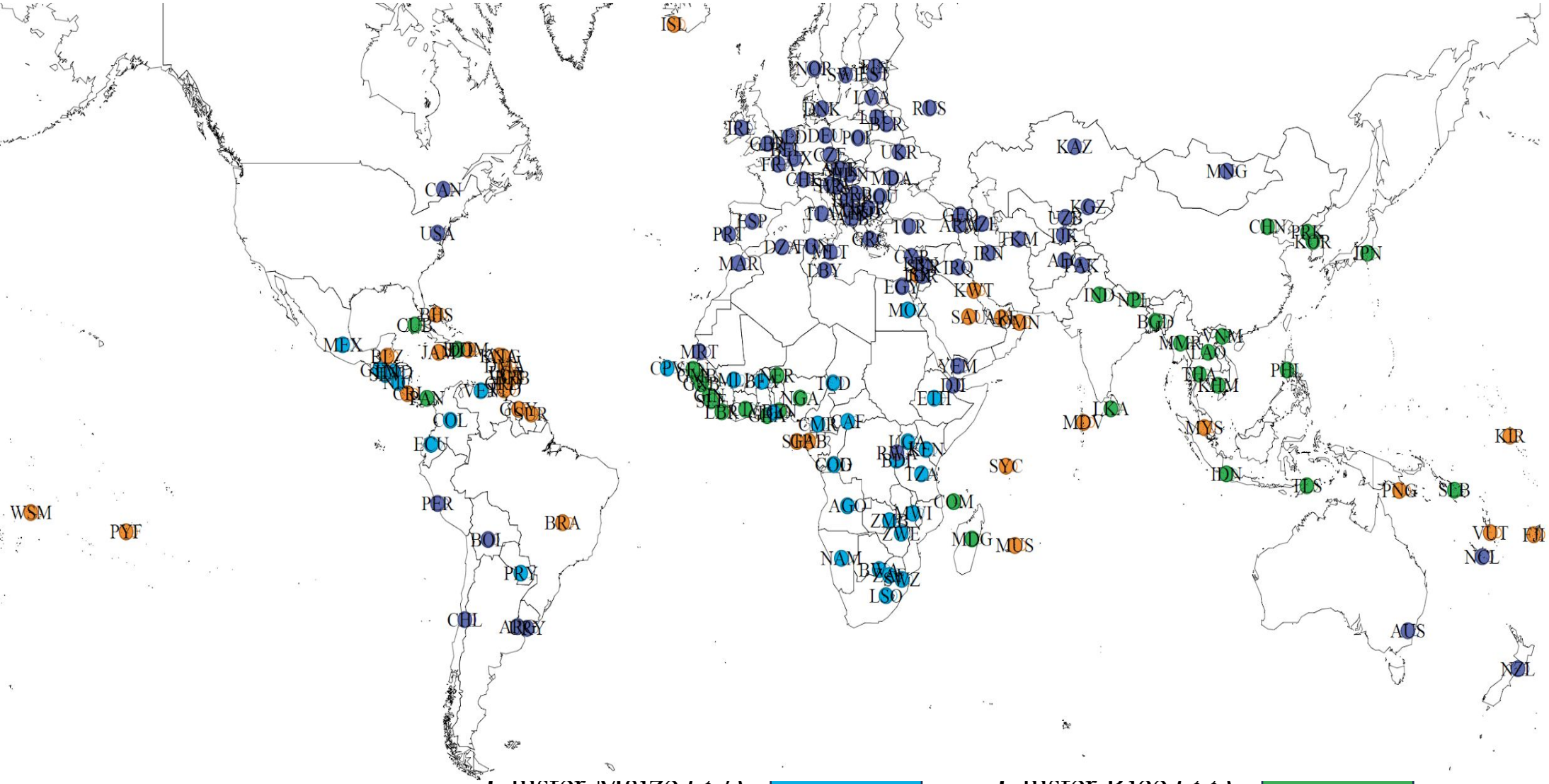




Cluster--other



Distribution of clusters on the map---- K-means (Maize, Whet, Rice Other)



Cluster Maize (32)

Cluster Wheat (75)

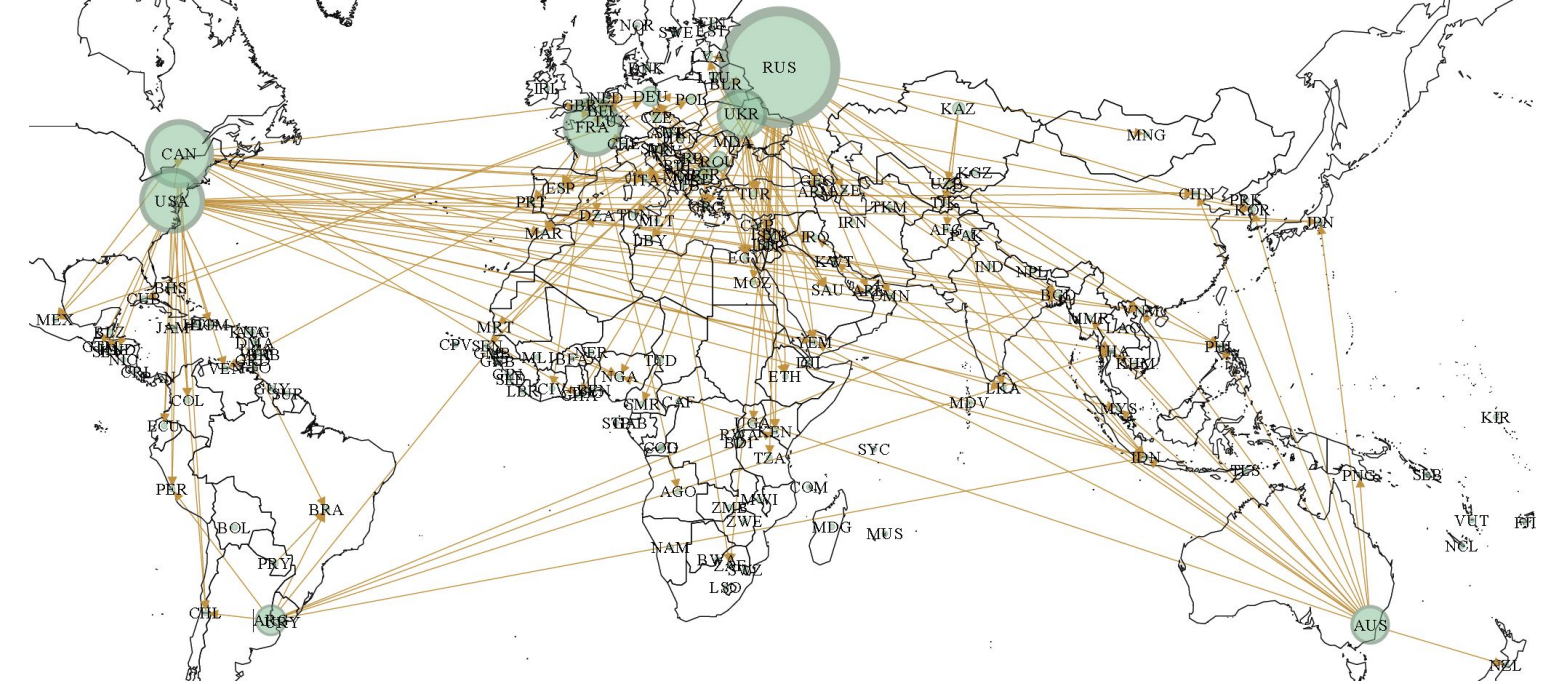
Cluster Rice (33)

Cluster other (35)

Export network 2018

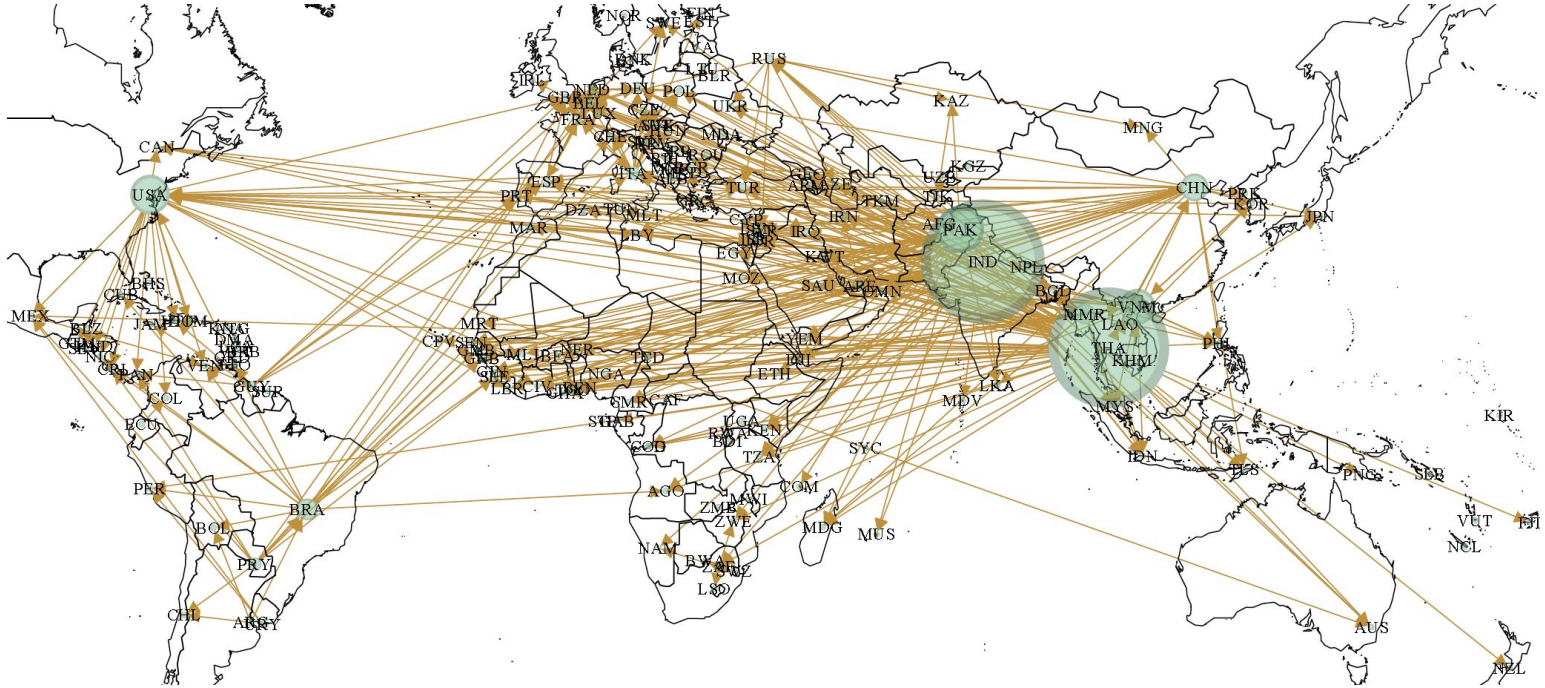
wheat

>2.21E+08 (Top 20%)

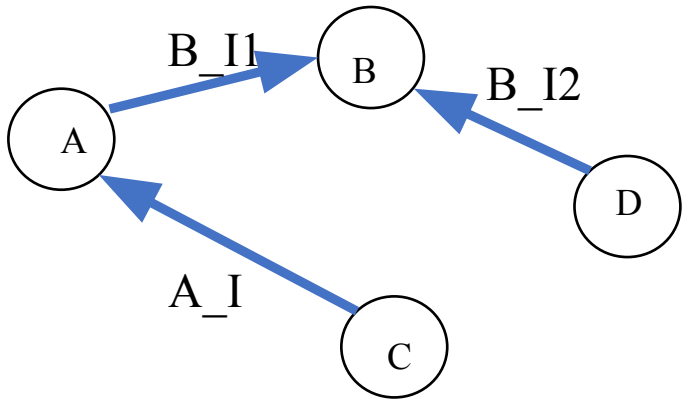


rice

>8.14E+06 (Top 20%)



Sensitive as Weights in Network



Set:

A_**P**: **Production** of Country A

B_P: Production of Country B

A_**I**: **Import** from Country C

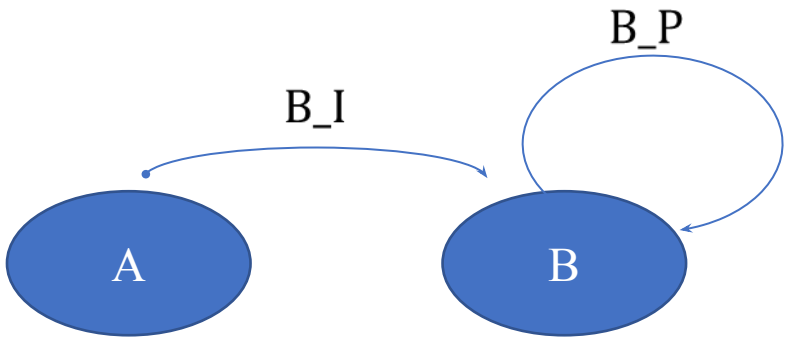
B_I1: Import from Country A

B_I2: Import from Country D

Sensitivity Weight C→A: $\frac{A\_I}{A\_P+A\_I}$

Sensitivity Weight A→B: $\frac{B\_I1}{B\_P+B\_I1+B\_I2}$

Sensitivity Weight D→B: $\frac{B\_I2}{B\_P+B\_I1+B\_I2}$

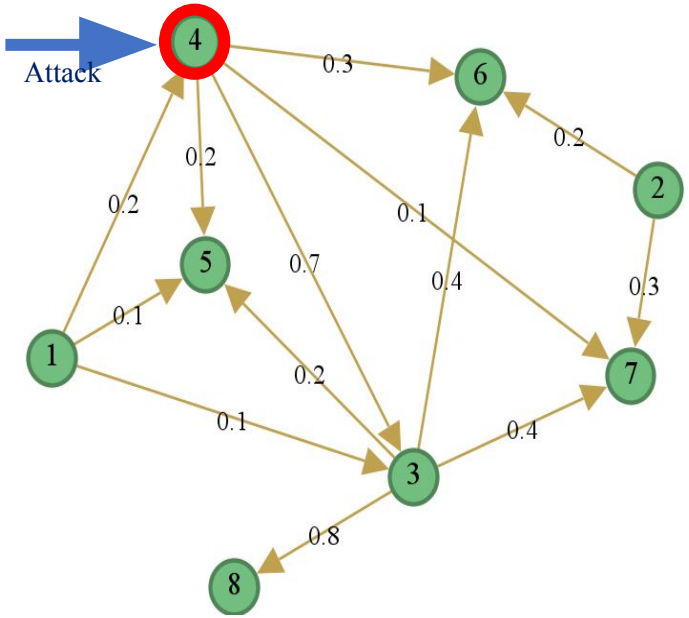


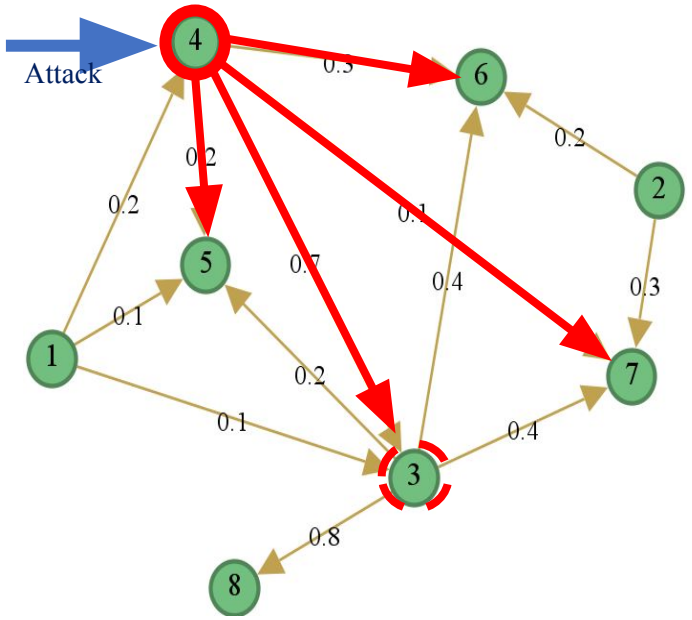
Sensitivity Weight of X1 to X2 $= \frac{\text{Import from X1 to X2}}{ALL\ IMPORTS+SELF\_PRODUCTION}$

All weights are then normalized.

CASCADING FAILURE PROCESSES

SIMPLE (1 step) CASCADING FAILURE





Here, weight 4->3 =0.7.
In a THRESHOLD = 0.6
Only node (3) will fail

Step 1: Randomly select 1 nodes to fail, eg: nodes 4

Step 2: Find all out links of these nodes: red lines

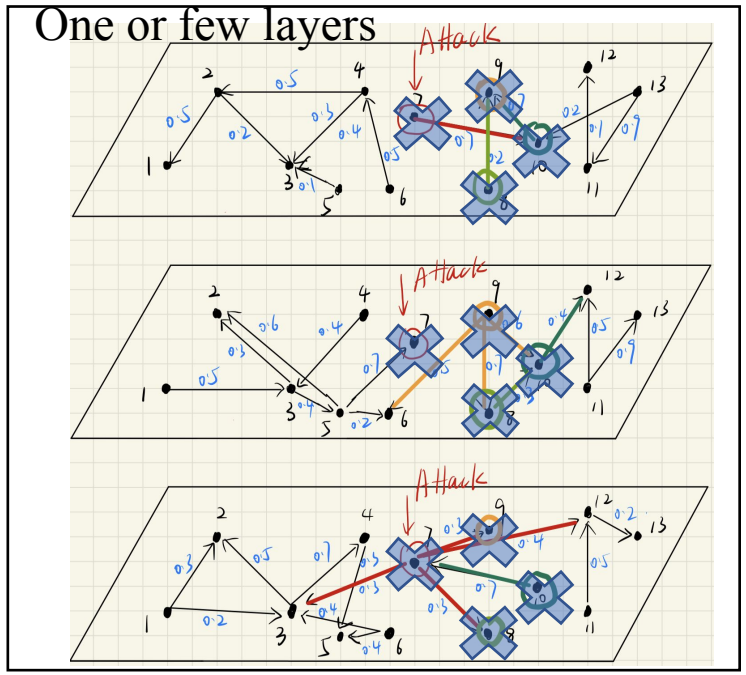
Step 3: Remove the affected countries with Weight>0.6, i.e. nodes 3; and keep nodes 5, 7, 6

Step 4: Calculate the number of affected countries: 2

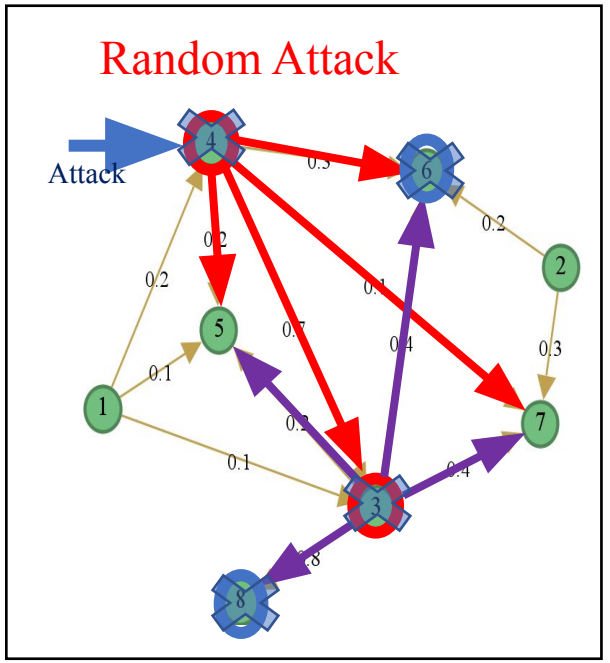
CASCADING FAILURE, 1 or FEW LAYERS

Assumption - if a country (A) gets into SERIOUS food CRISIS, it will stop exporting its own food and only take care of itself. Then the crisis cascades to other countries.

Cascading failure in multilayer network



Cascading failure in single-layer network



Target Attack

Attacks in **descending** order of exports, the others are similar to random attack

8 Types of Failures

Cascade (few steps)	One Step Failure	
Disease in one crop that spreads globally or in a .main producer	Example: Heatwave damages wheat fields in .Egypt Severity depends on Source .importance ,Crop diseases	One Layer
War in Ukraine and Russia, No wheat nor .Maize, long term	**War (**Ukraine and Russia), No wheat nor Maize, short !term	Multi-Layer

Random Attack
Intentional (targeted) attack

Targeted attack = very malicious attack intended to destroy a supplier`s food production capacity.
It can also be (near targeted) a result of a higher likelihood of crop disease where growing much of these crops

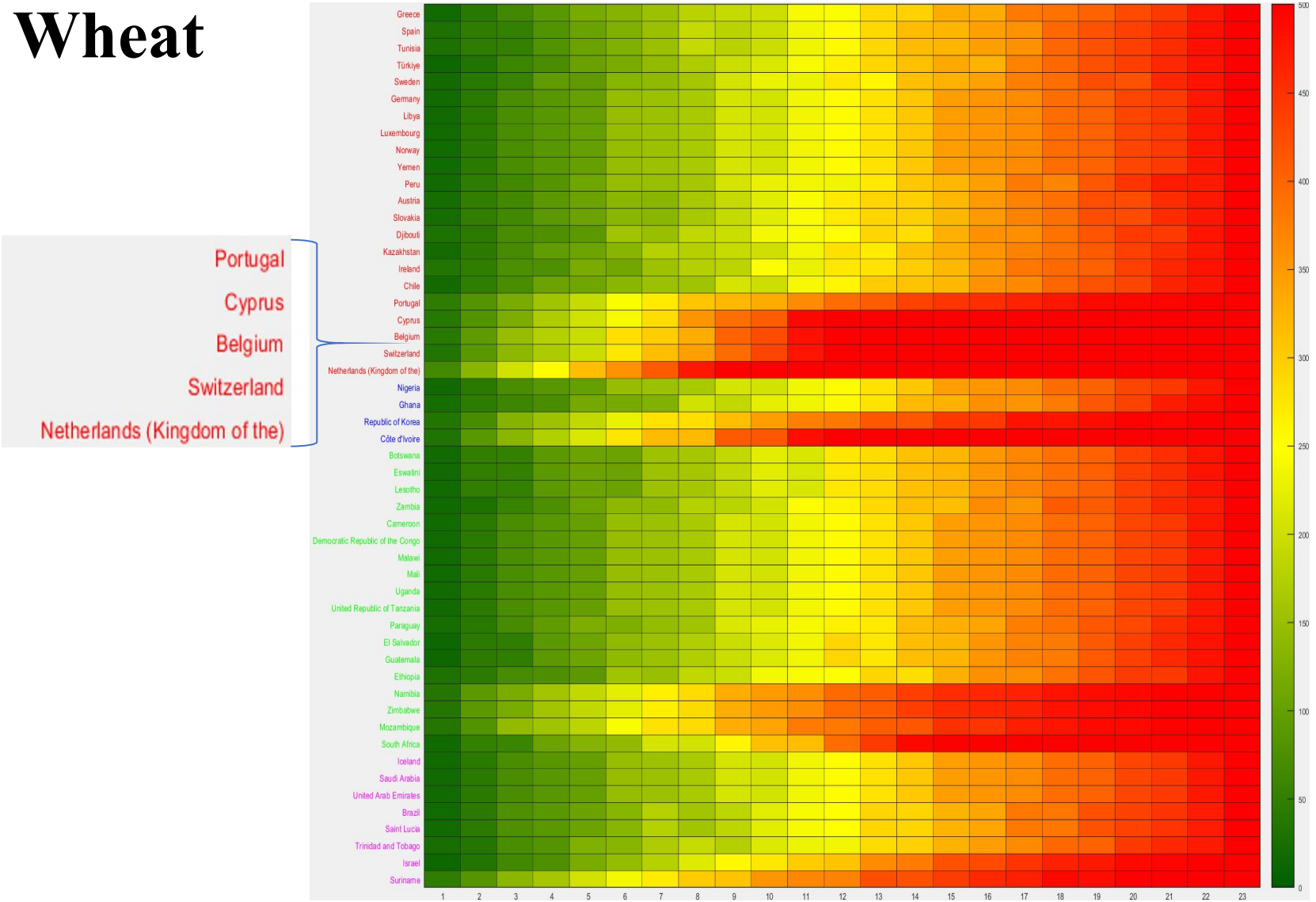
2013

Simulating the process of one step of failure in a single-layer network

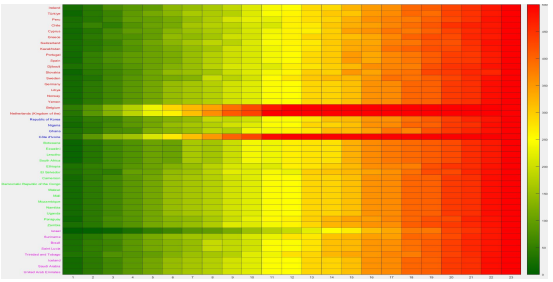
wheat rice maize other

Threshold=0.1

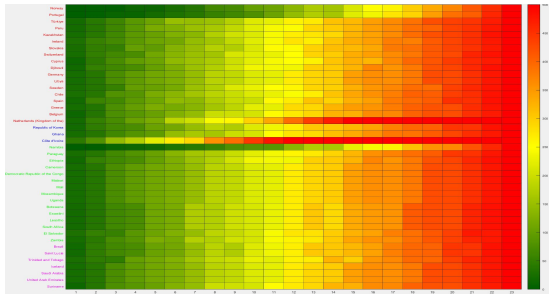
Wheat



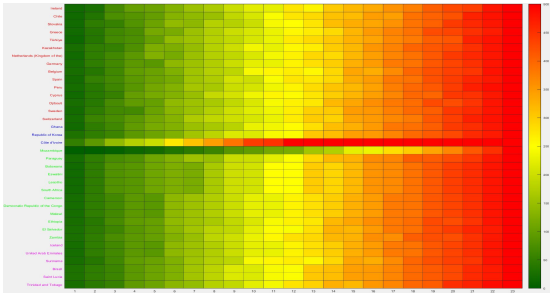
Threshold=0.3



Threshold=0.5



Threshold=0.7



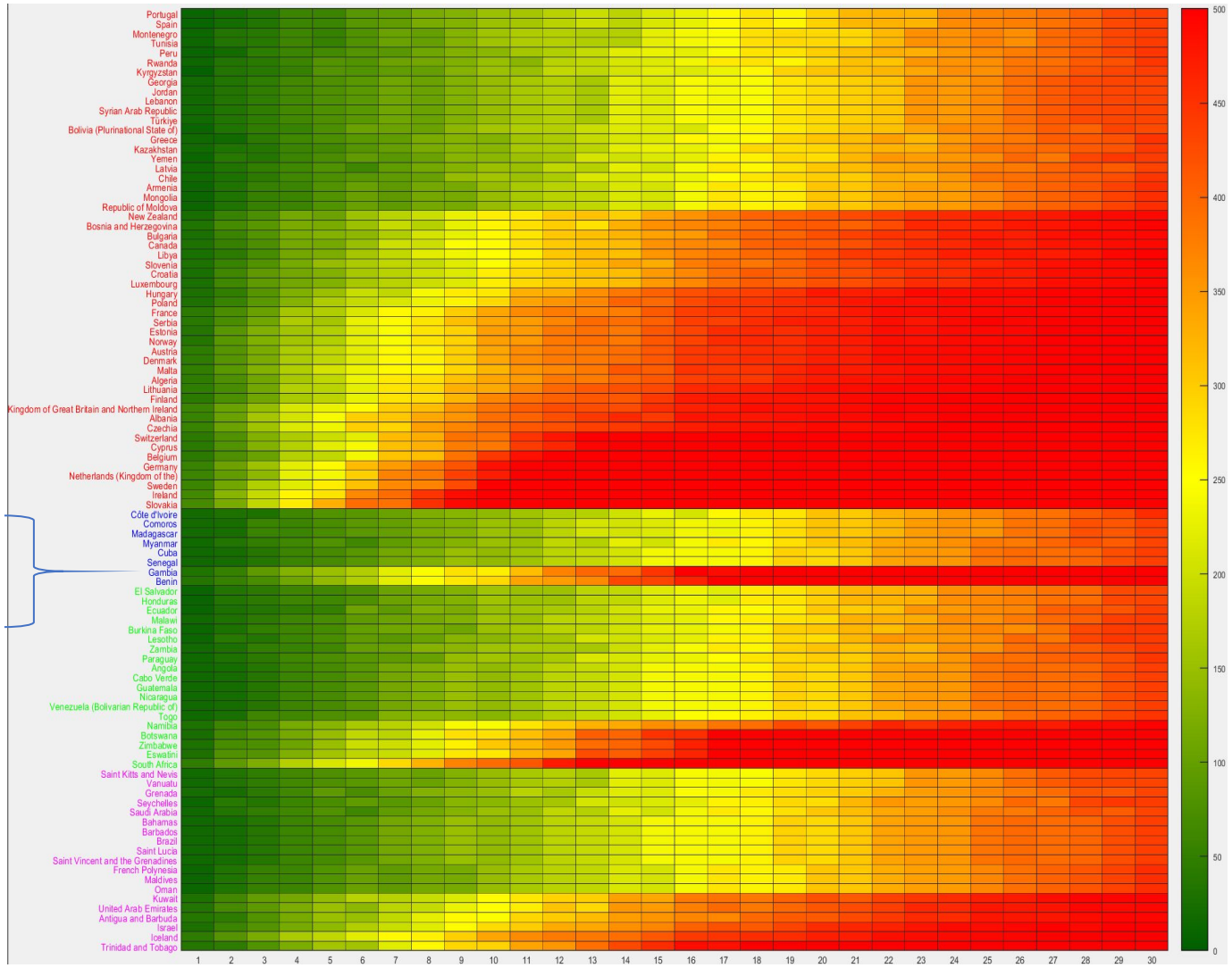
2013

Simulating the process of one step of failure in a single-layer network

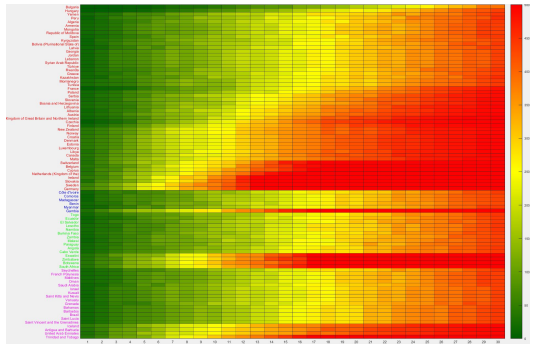
wheat rice maize other

Threshold=0.1

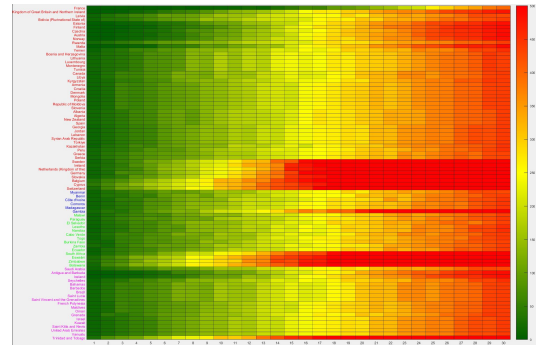
Rice



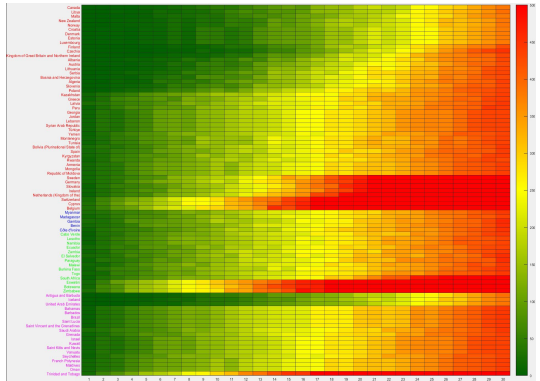
Threshold=0.3



Threshold=0.5



Threshold=0.7



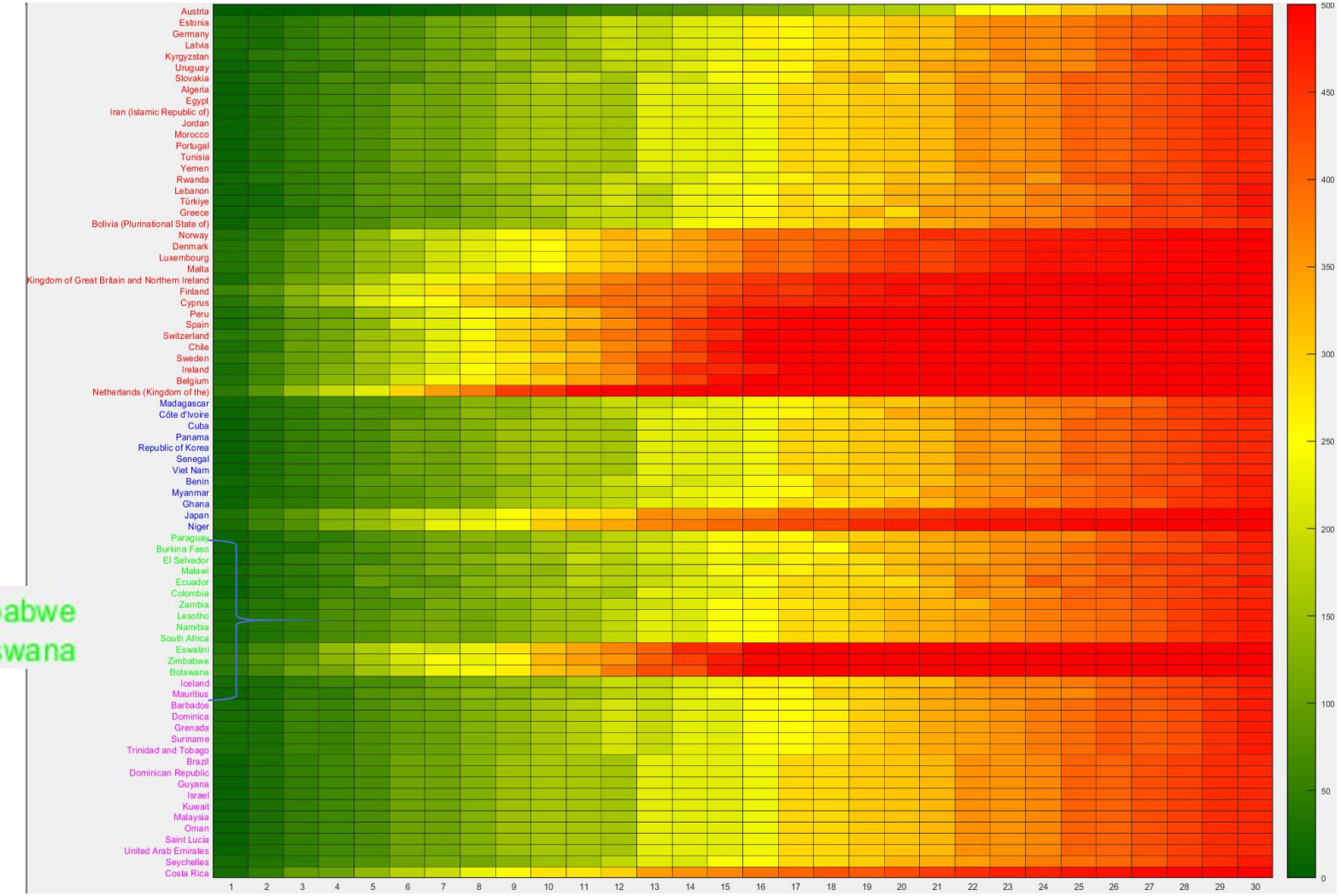
2013

Simulating the process of one step of failure in a single-layer network

wheat rice maize other

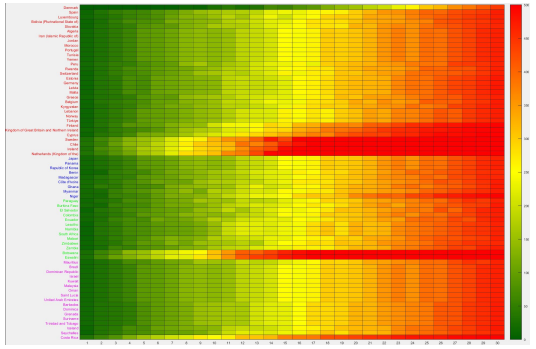
Threshold=0.1

Maize

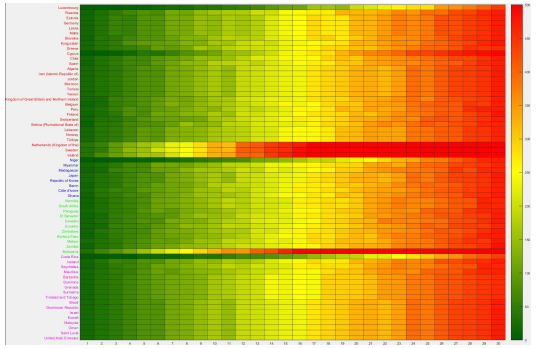


Zimbabwe
Botswana

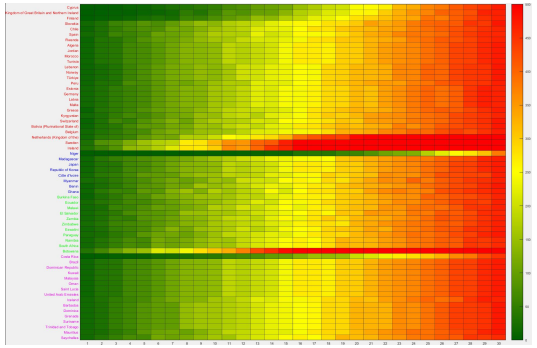
Threshold=0.3



Threshold=0.5

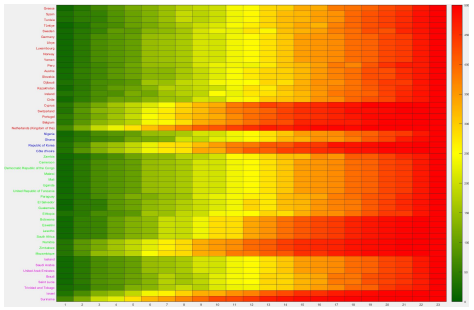
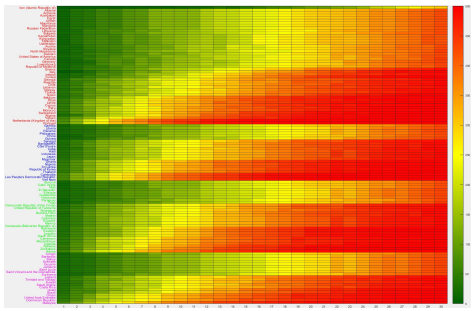
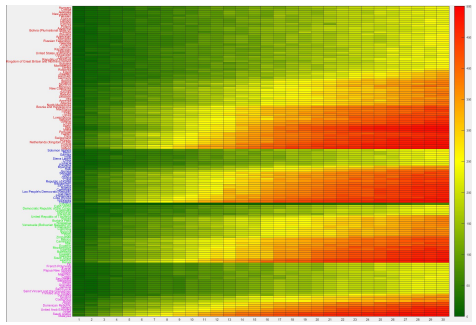
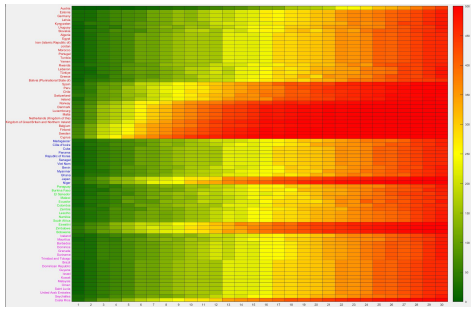
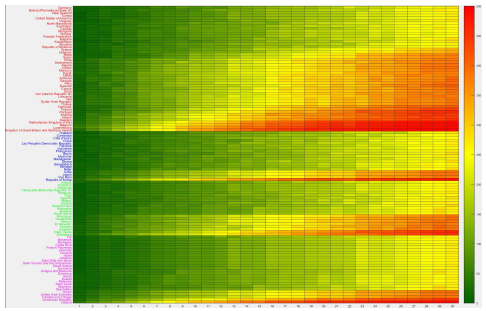
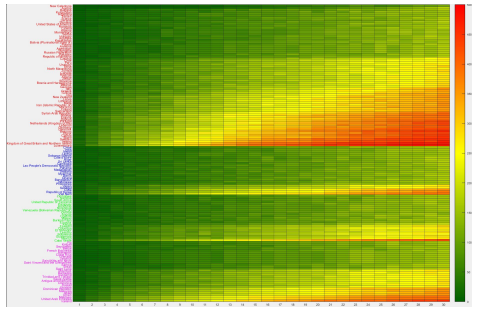
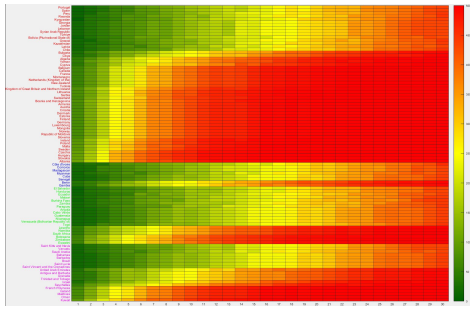
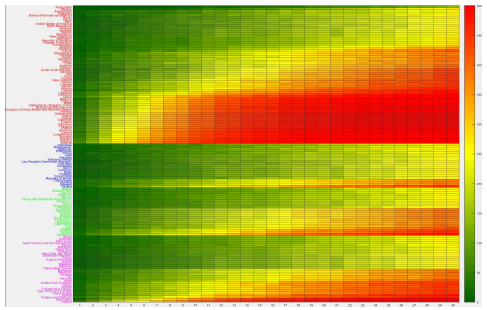
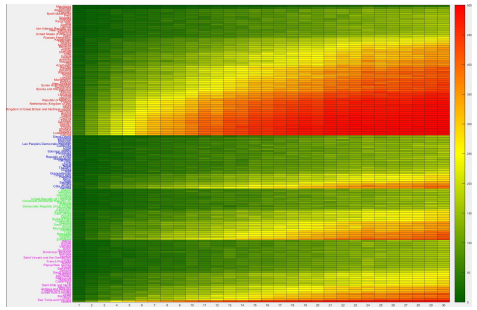


Threshold=0.7



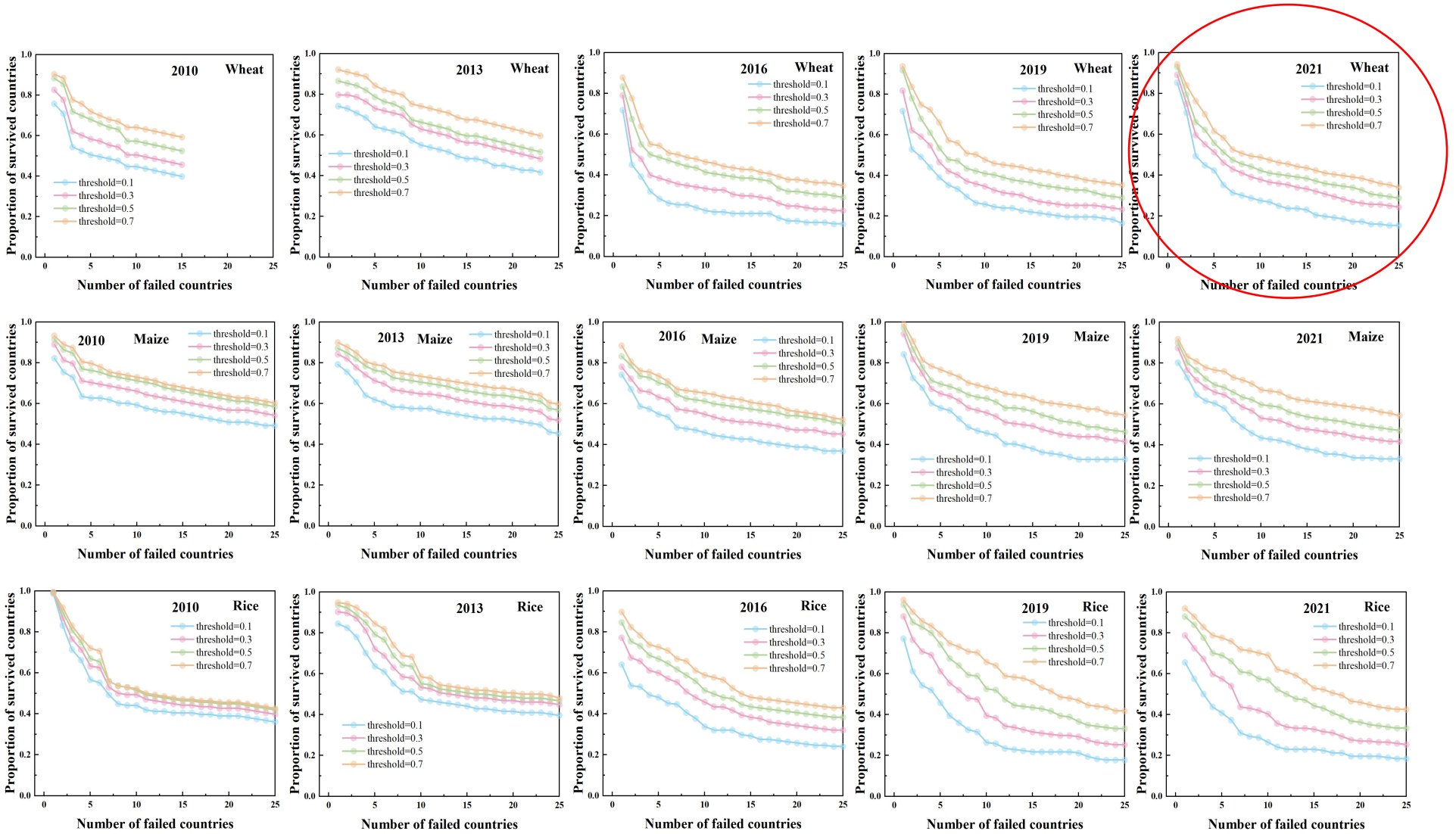
Stability over time

Threshold=0.1

	2013	2016	2021
wheat			
maize			
rice			

CONCLUSION: FOOD RESILIANCE GROWS OVER TIME

Target Attack only one step of failure in single-layer network



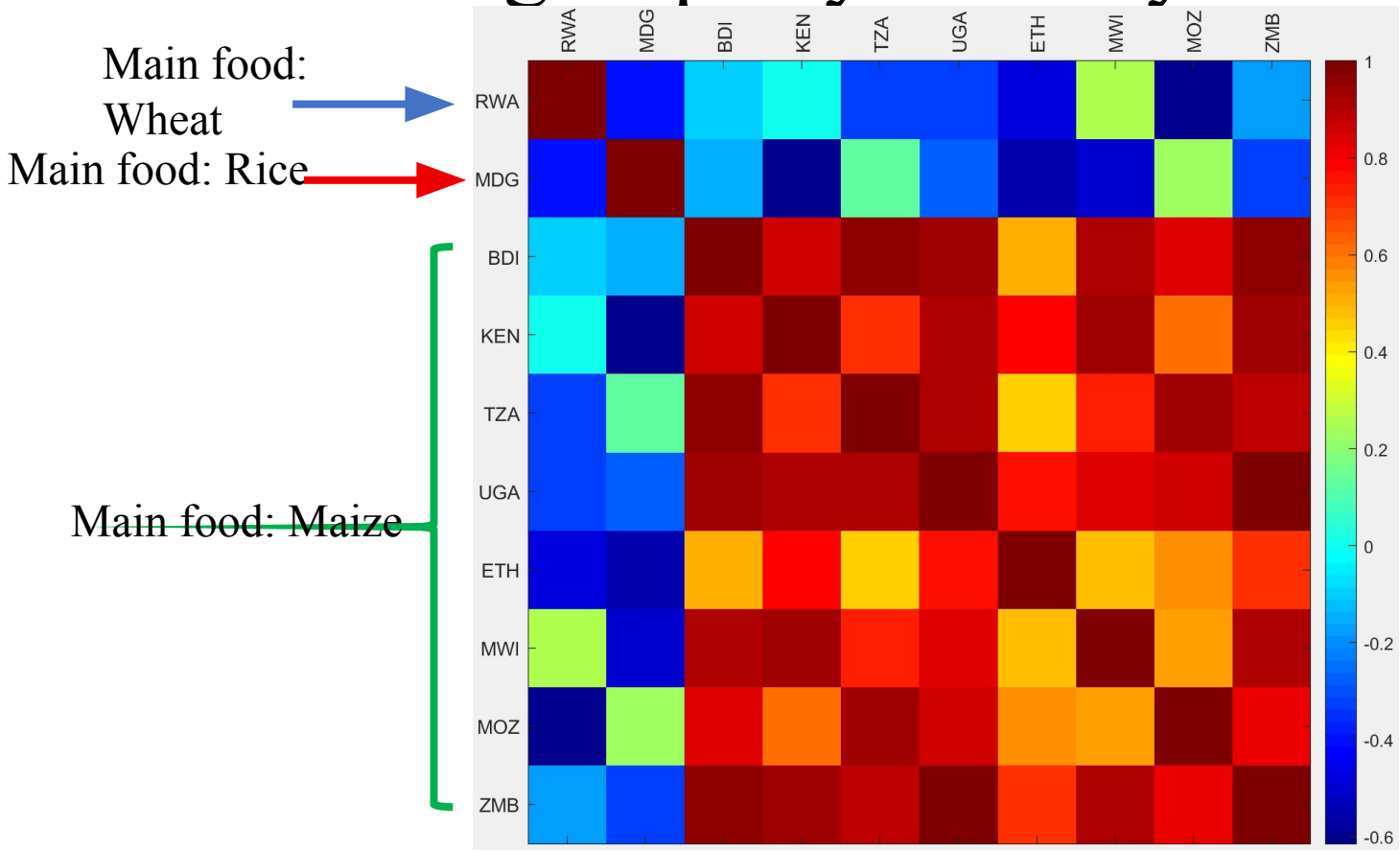
The strong slope represent a more centralized (sensitive to bad events) system.
Maize NETWORK is better and is less centralized than wheat and rice.

FOCUS OF EAST AFRICAN COUNTRIES

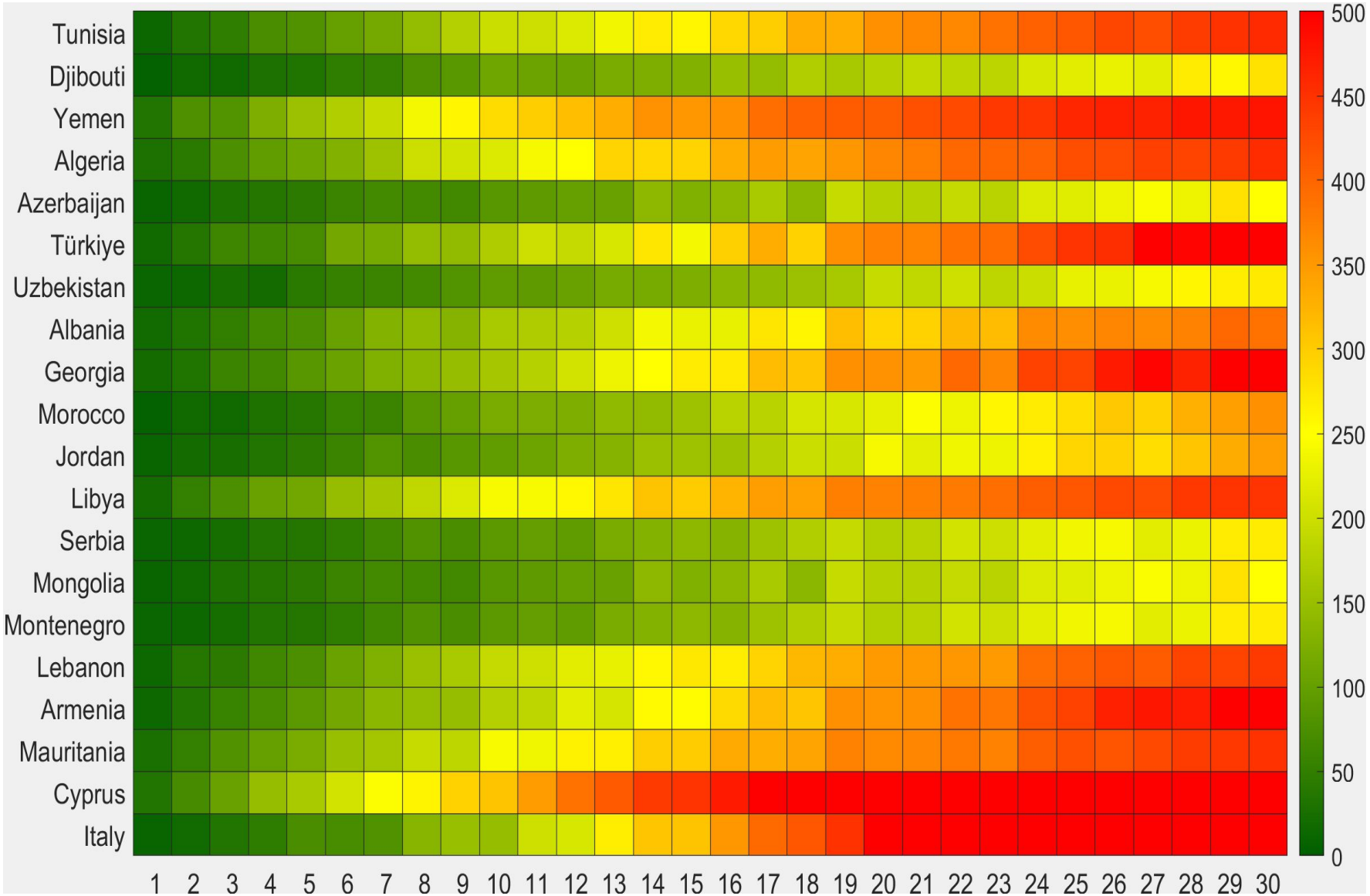
East Africa

Burundi
Kenya
Rwanda
United Republic of Tanzania
Uganda
Ethiopia
Malawi
Mozambique
Zambia
Madagascar

Countries groups by food styles



Top 20 Most Insecure WHEAT Countries



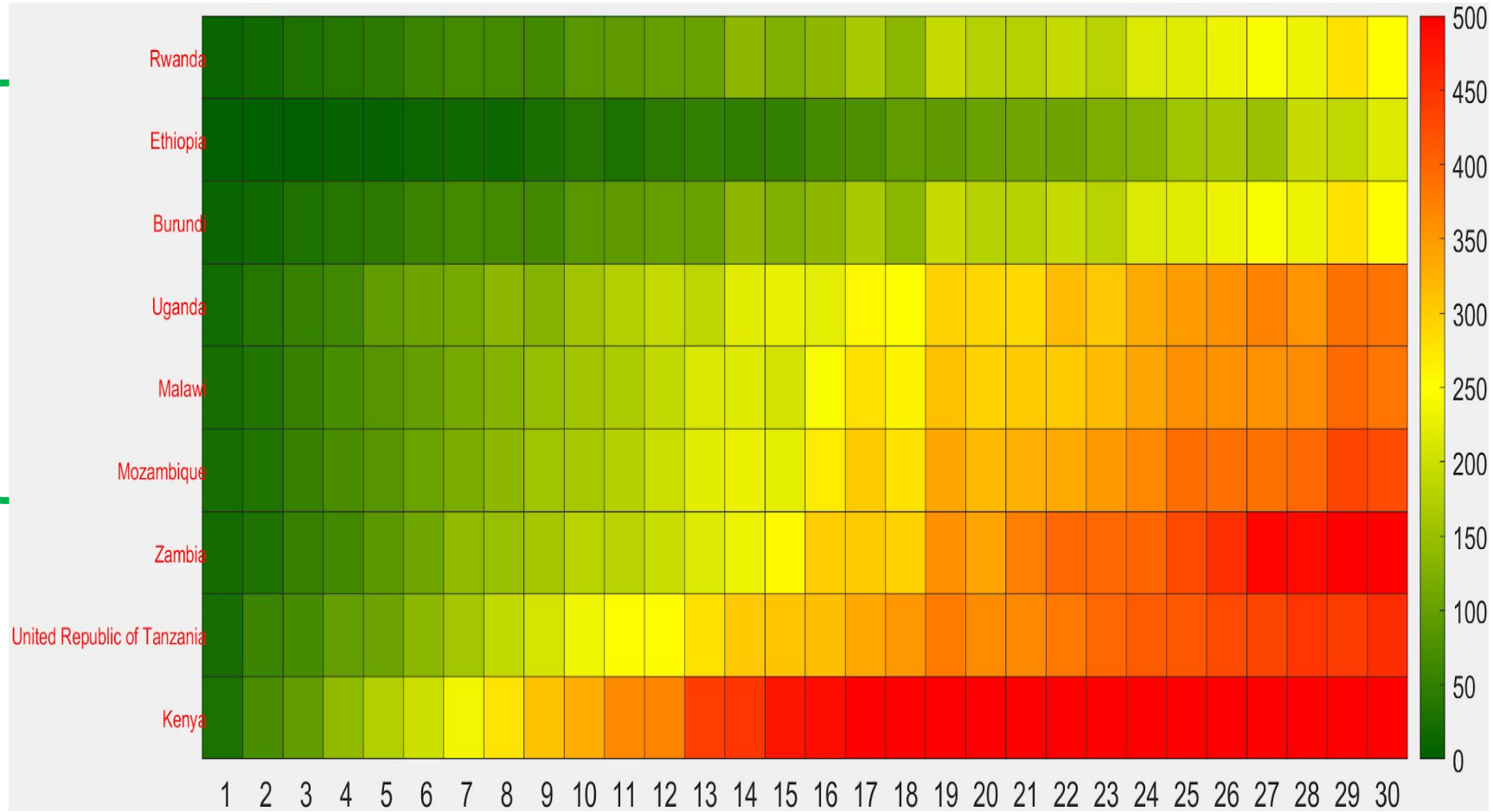
2021

East African countries

One step of failure in a single-layer network

Threshold=0.1

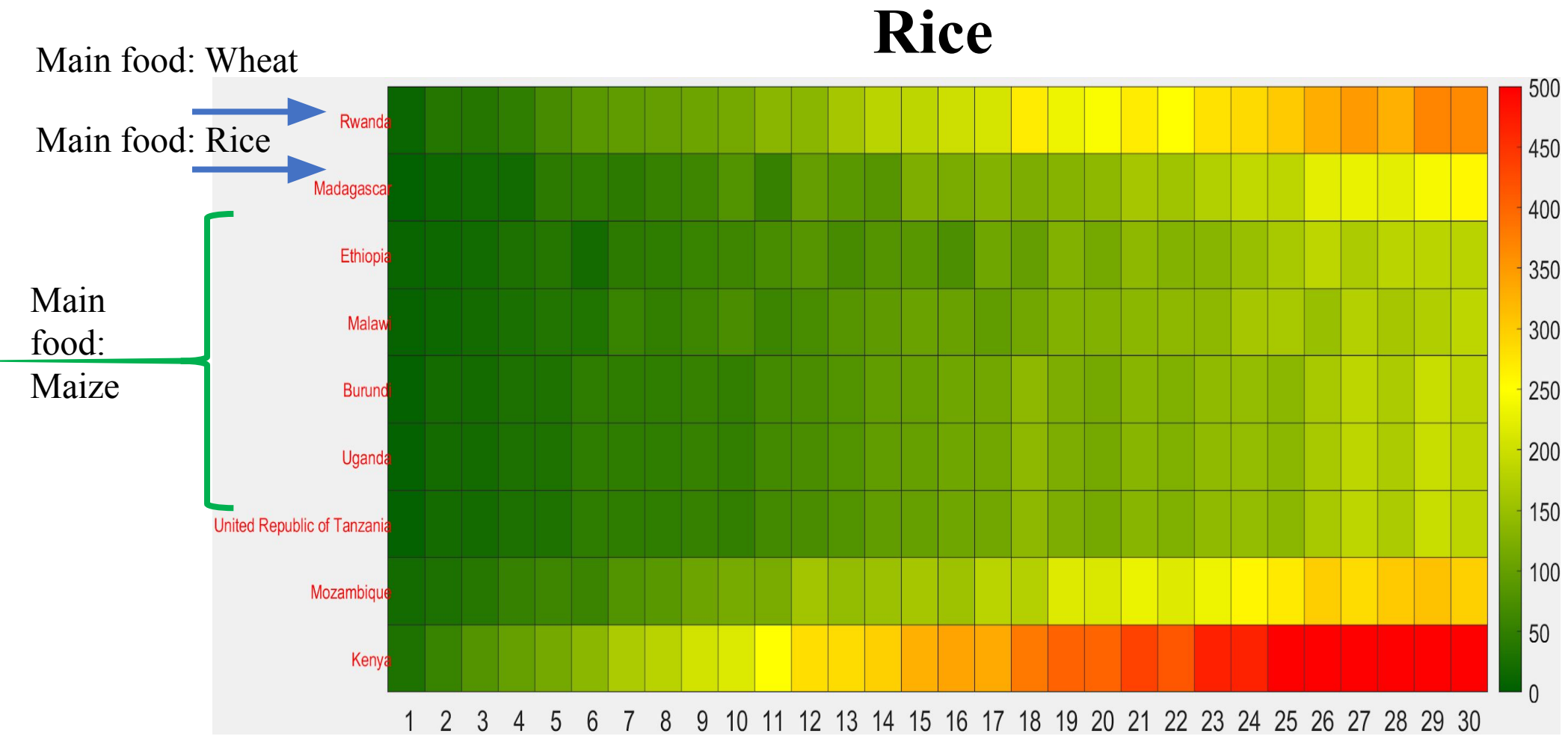
Main food: Maize



2021

The process of only one step of failure in a single-layer network

Threshold=0.1

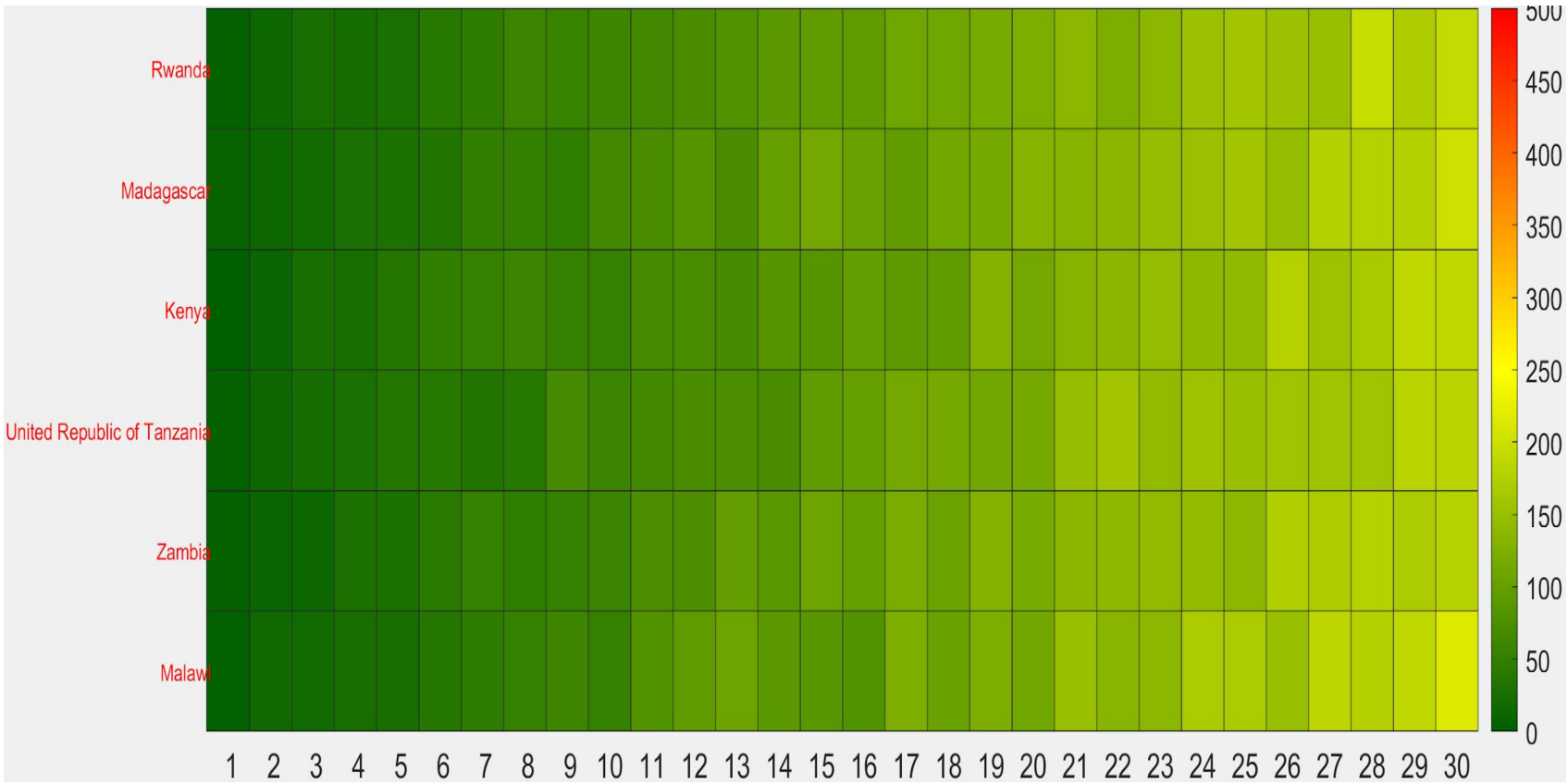


2021

The process of only one step of failure in a single-layer network

Threshold=0.1

Main food: Maize



First conclusion

- East Africa countries based on Corn (Maize) are rather resilient to shocks
- Rice and Wheat based countries are more sensitive to food shocks

Maize East Africa Import & Self-production

Country	Self-production %	Main import 1 %	Main import 2 %	Main import 3 %	Main import 4 %	Main import 5 %
Burundi	95.218	2.199 (Zambia)	1.149 (Tanzania)	0.840 (Rwanda)	0.594 (Uganda)	
Ethiopia	99.992	0.004 (Argentina)	0.004 (United Arab Emirates)			
Kenya	94.816	1.517 (Tanzania)	1.359 (Uganda)	1.197 (South Africa)	0.763 (Zambia)	0.346 (Malawi)
Malawi	99.366	0.600 (Zambia)	0.034 (South Africa)			
Mozambique	92.670	6.759 (South Africa)	0.340 (Zambia)	0.200 (Malawi)	0.024 (Zimbabwe)	0.007 (Eswatini)
Uganda	99.675	0.281 (Tanzania)	0.027 (Kenya)	0.009 (South Africa)	0.008 (Rwanda)	
Tanzania	99.583	0.211 (Zambia)	0.137 (South Africa)	0.054 (Uganda)	0.008 (Kenya)	0.003 (Malawi)
Zambia	99.912	0.071 (South Africa)	0.009 (Malawi)	0.008 (Zimbabwe)		

Conclusion

While East African countries have created a good blend of self-supply based on maize, and are less dependent on other countries, for their maize, ….

BUT…this food supply network structure <u>can</u> creates a risk in the <u>disease space</u>, since they all share a similar climate, crop genetics and regional proximity.

Kenya, Tanzania and **Zambia** are mostly sensitive to **wheat** shocks.

Kenya, **Rwanda**, **Mozambique** to **rice** shocks

As to maize, other methods should be applied to increase its genetic varicance.

Recommendations

1. Create a **blend** of s**elf-supply** with a **diverse international food network commodities grain CONTRACTS** as backup!
2. **Food Network Diversity (FND) helps survive food shocks (Like in biodiversity).**
3. Currently, Maize is self produce or in nearby countries.
4. Maybe long term grain contracts exist but we do not know!
5. Diversification of crops sources, (1) Regions countries diversity, (2) Cultivars crop diversity, (3) Political diversity., (4) Local genetic diversity of maize cultivars
6. Keeping local food consumption habits diverse always keep local alternatives, to switch in case of food crisis
7. Develop the local breeds of corn - less sensitive compare to imported breeds
8. FURTHER STUDIES REQUIRED TO FIND OPTIMAL BLEND OF SELF-PRODUCTION + CONTRACTS

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Quiyu Li

Dr. Fan Wang

Dr. Alon Sela

THANK YOU!
Asante sana kwa kusikiliza

Seeking for collaborations!

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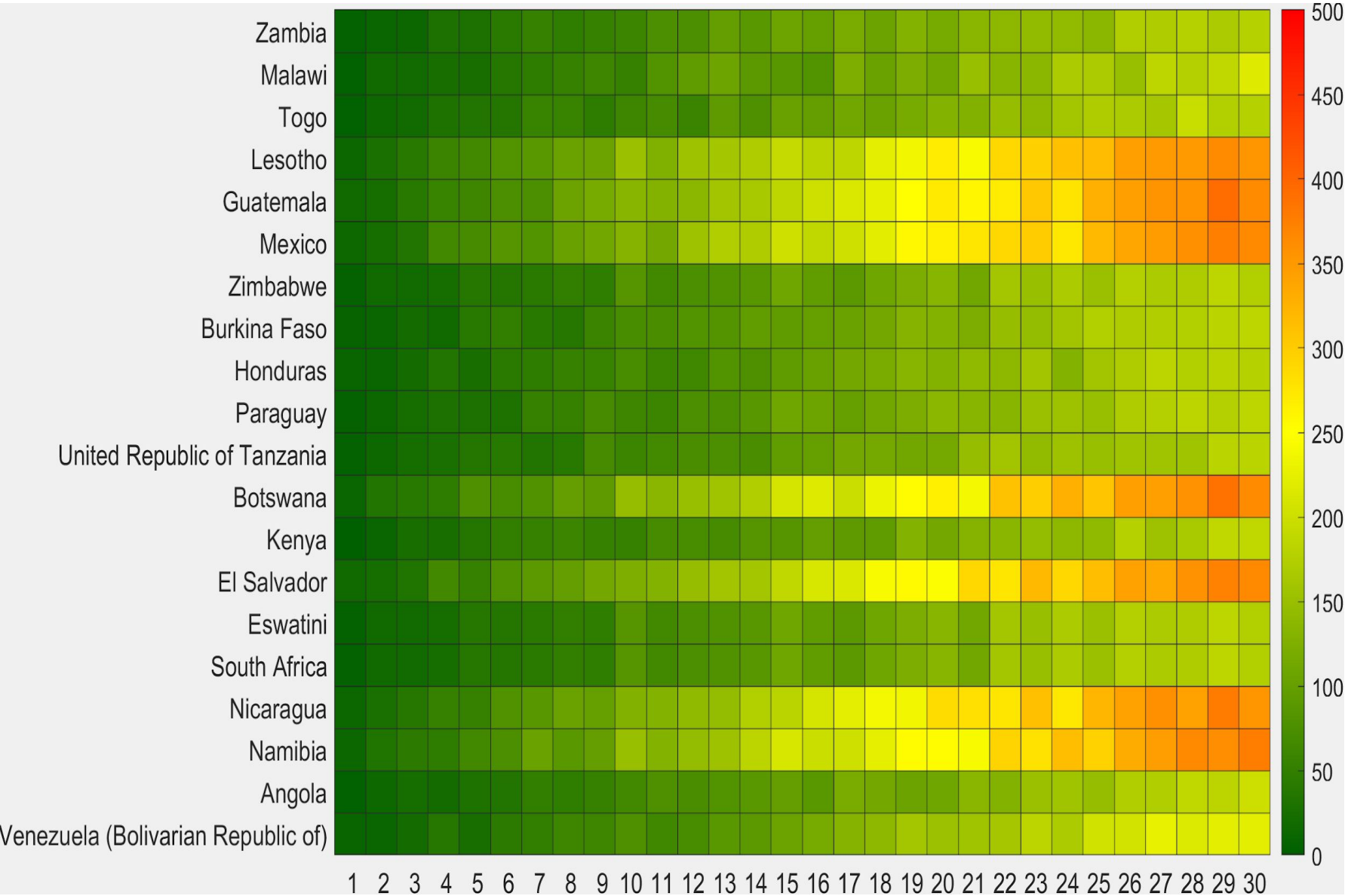
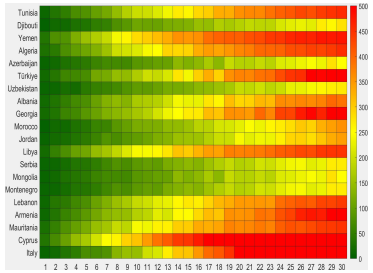
AL3M
Agri Local LLM

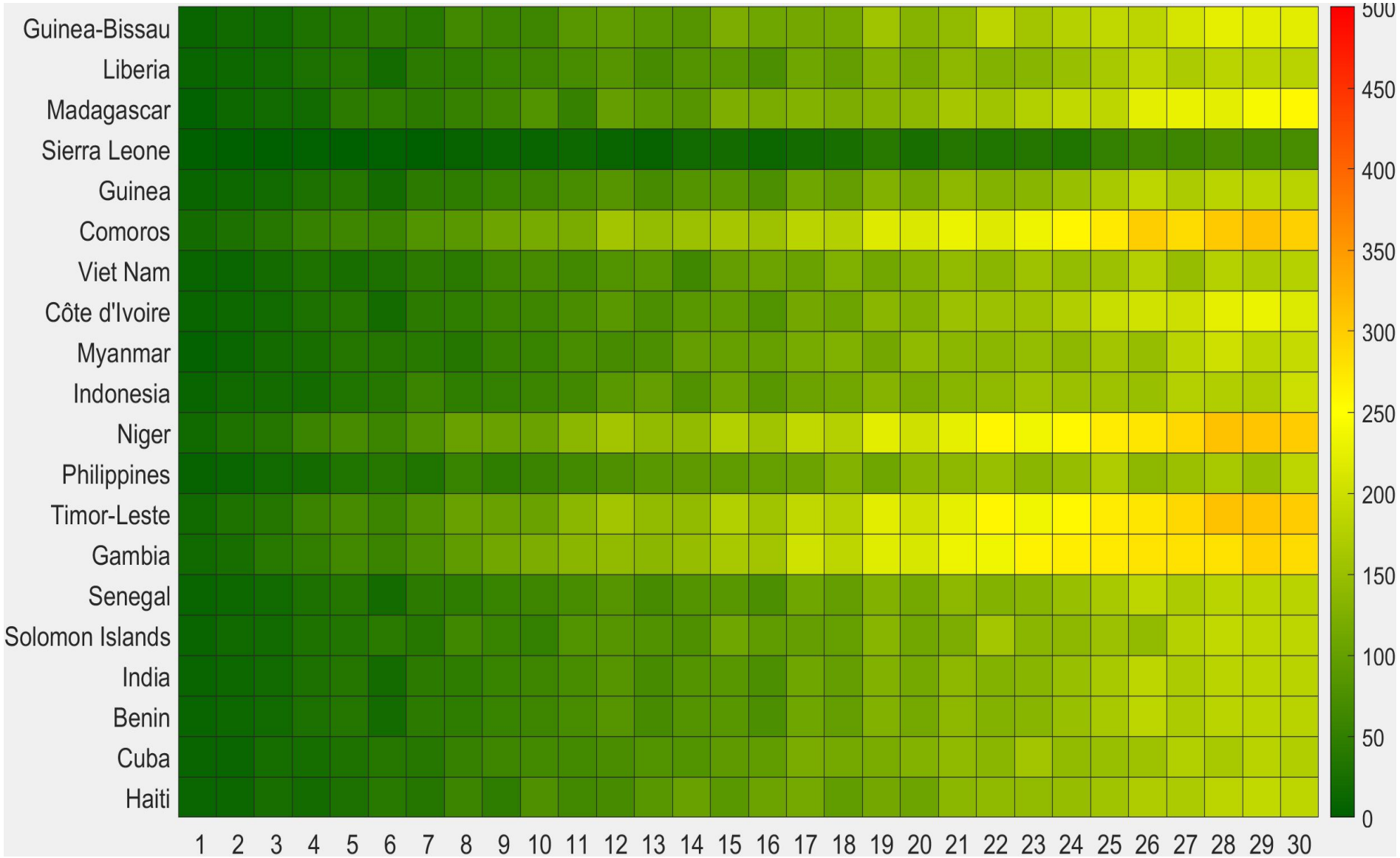
Top 20 Most Insecure MAIZE Countries



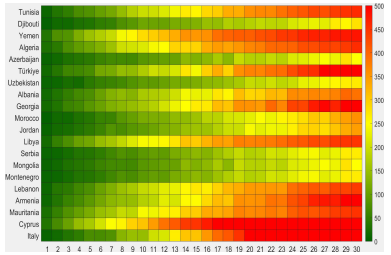
Maize network is more stable than Wheat network



Top 20 Most Insecure RICE Countries



Rice network is more stable than Wheat and Maize networks



2021

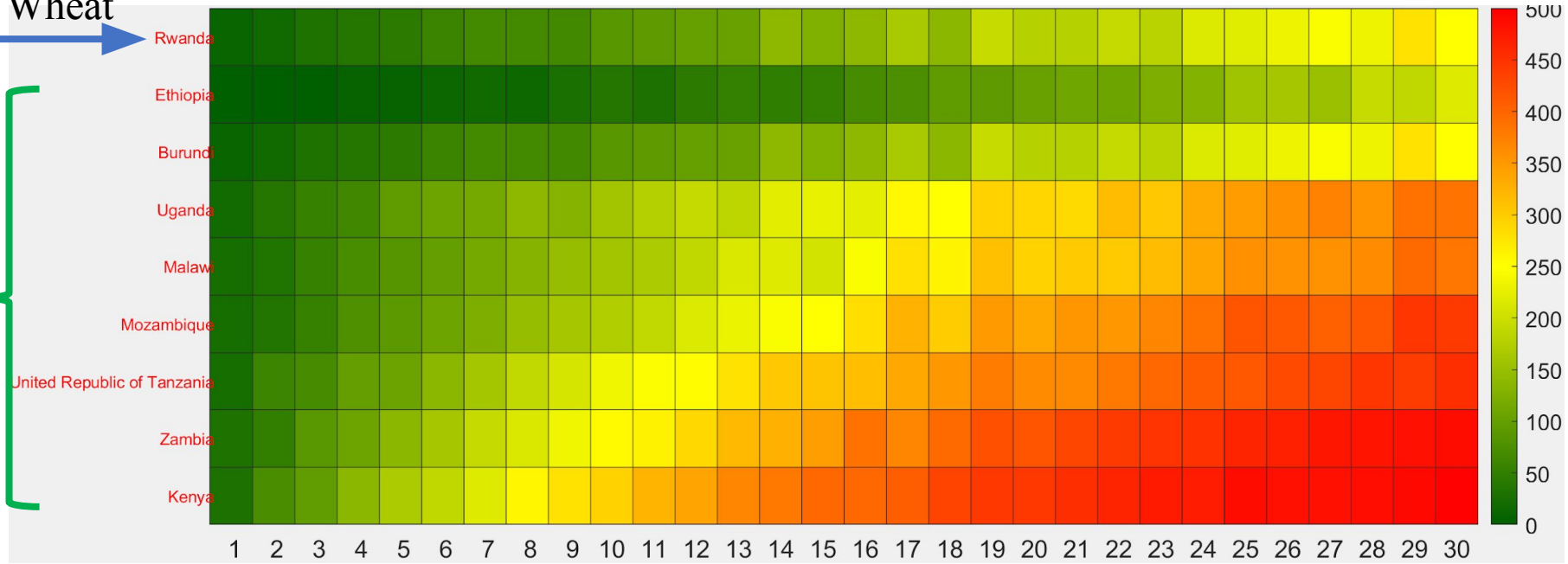
Cascading failure processes in single-layer network

wheat

Threshold=0.1

Threshold=0.3

Main food: Wheat



Main food: Maize

Threshold=0.5

Threshold=0.7

Conclusion – the Wheat network is unsecure compared to the maize network

2021

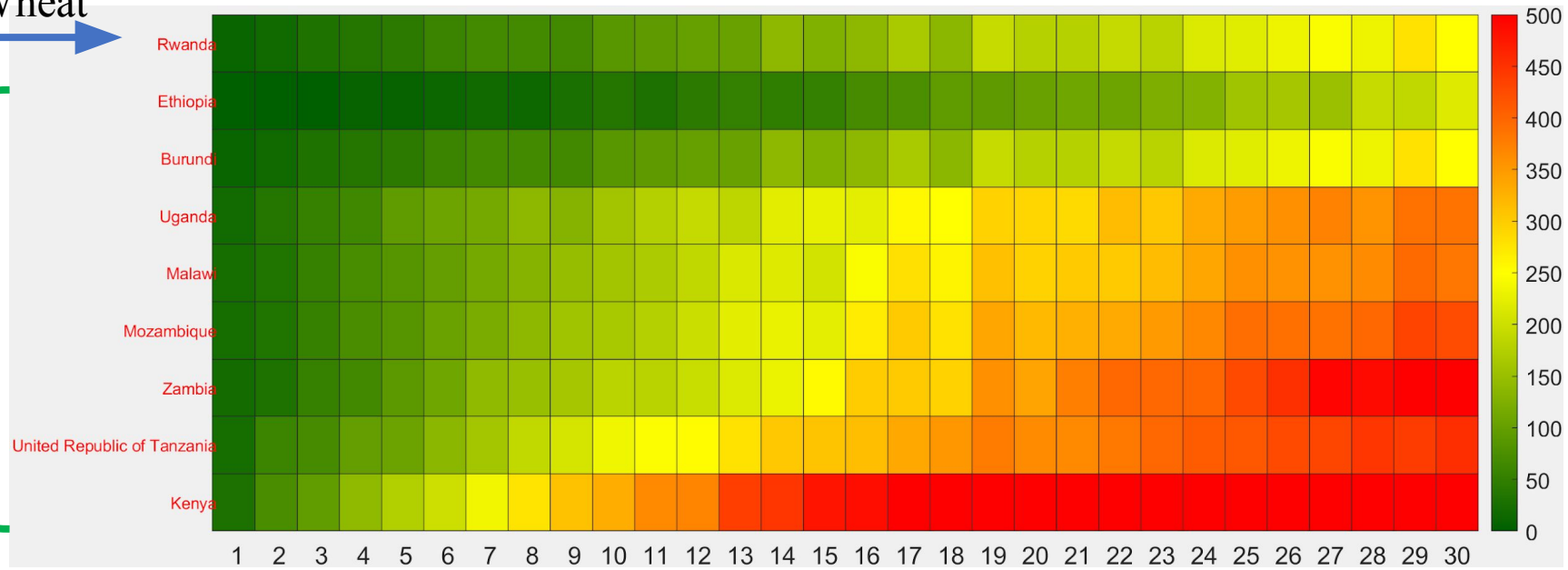
The process of only one step of failure in a single-layer network

wheat

Threshold=0.1

Threshold=0.3

Main food: Wheat



Main food: Maize

Threshold=0.5

Threshold=0.7

2021

The process of only one step of failure in a single-layer network

Maize

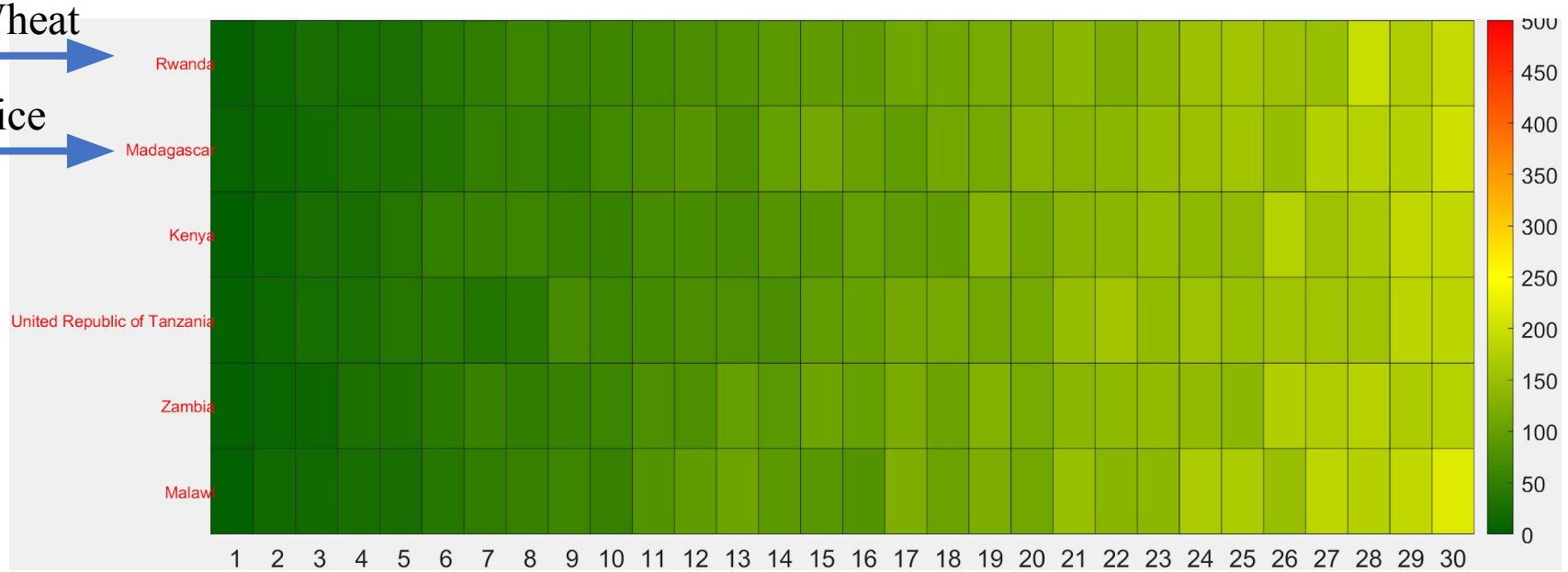
Threshold=0.1

Threshold=0.3

Main food: Wheat

Main food: Rice

Main food: Maize



Threshold=0.5

Threshold=0.7

2021

The process of only one step of failure in a single-layer network

Rice

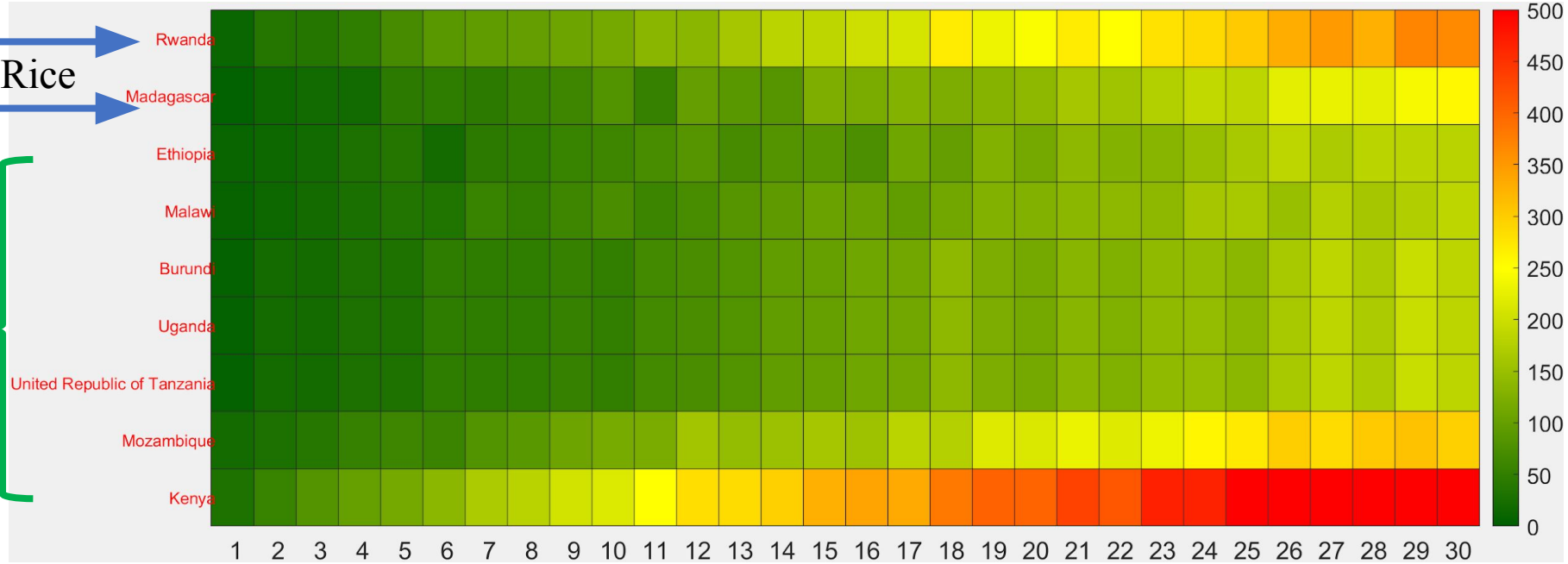
Threshold=0.1

Threshold=0.3

Main food: Wheat

Main food: Rice

Main food: Maize



Threshold=0.5

Threshold=0.7

2021

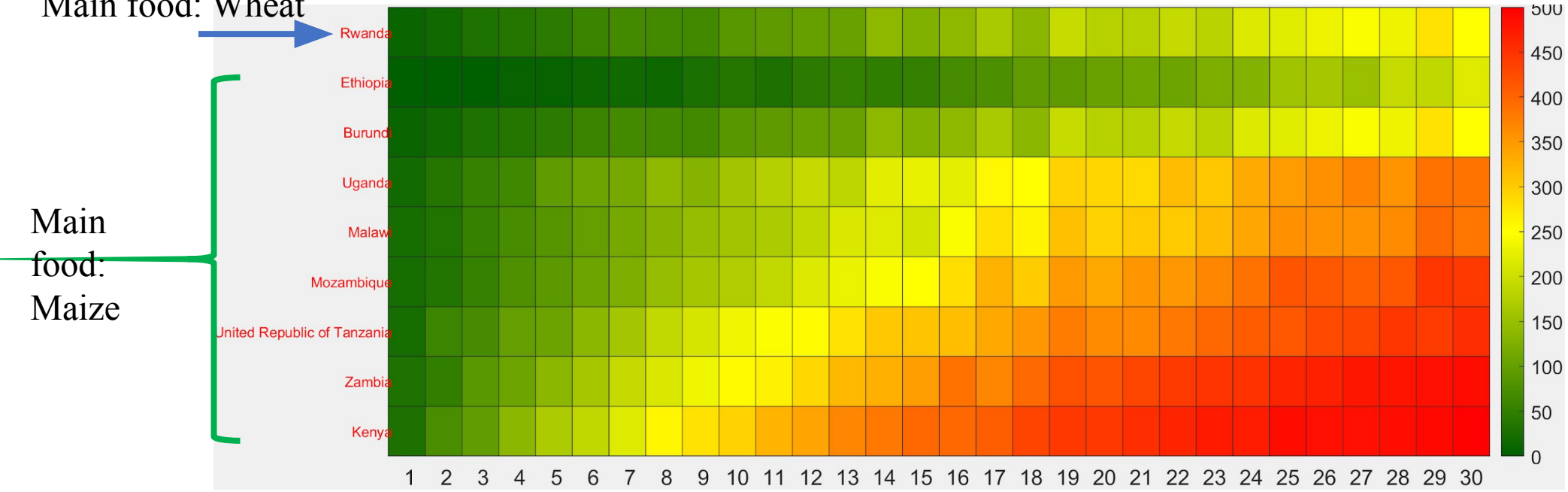
Cascading failure processes in single-layer network

wheat

Threshold=0.1

Threshold=0.3

Main food: Wheat



Main food: Maize

Threshold=0.5

Threshold=0.7

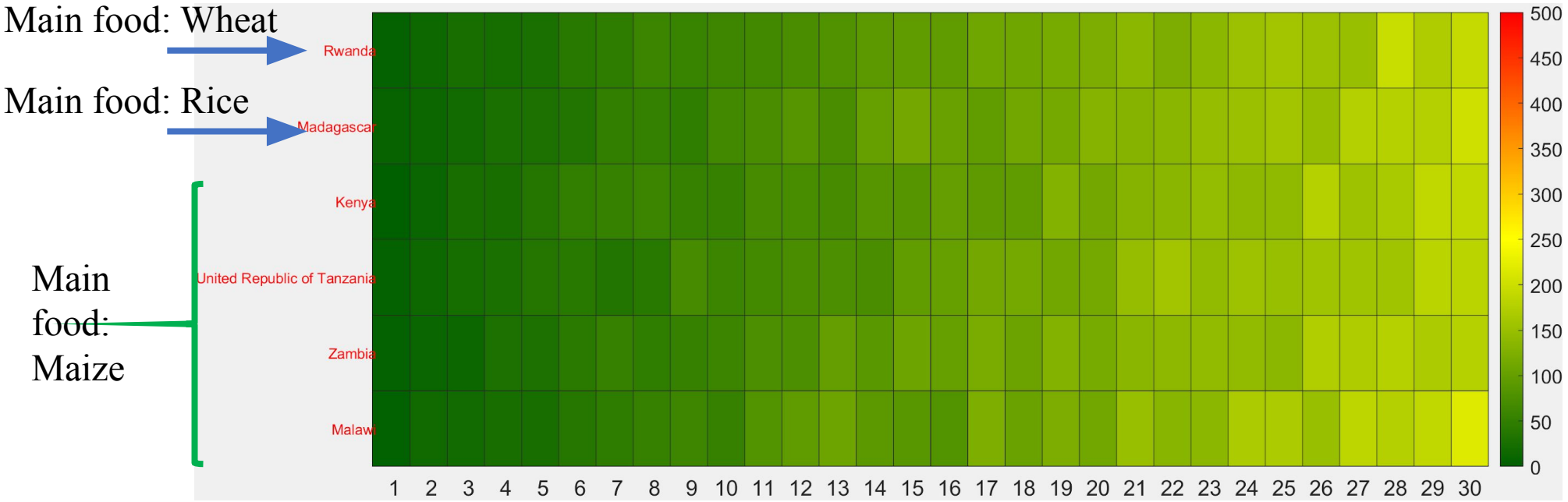
2021

Cascading failure processes in single-layer network

Maize

Threshold=0.1

Threshold=0.3



Threshold=0.5

Threshold=0.7

2021

Cascading failure processes in single-layer network

Rice

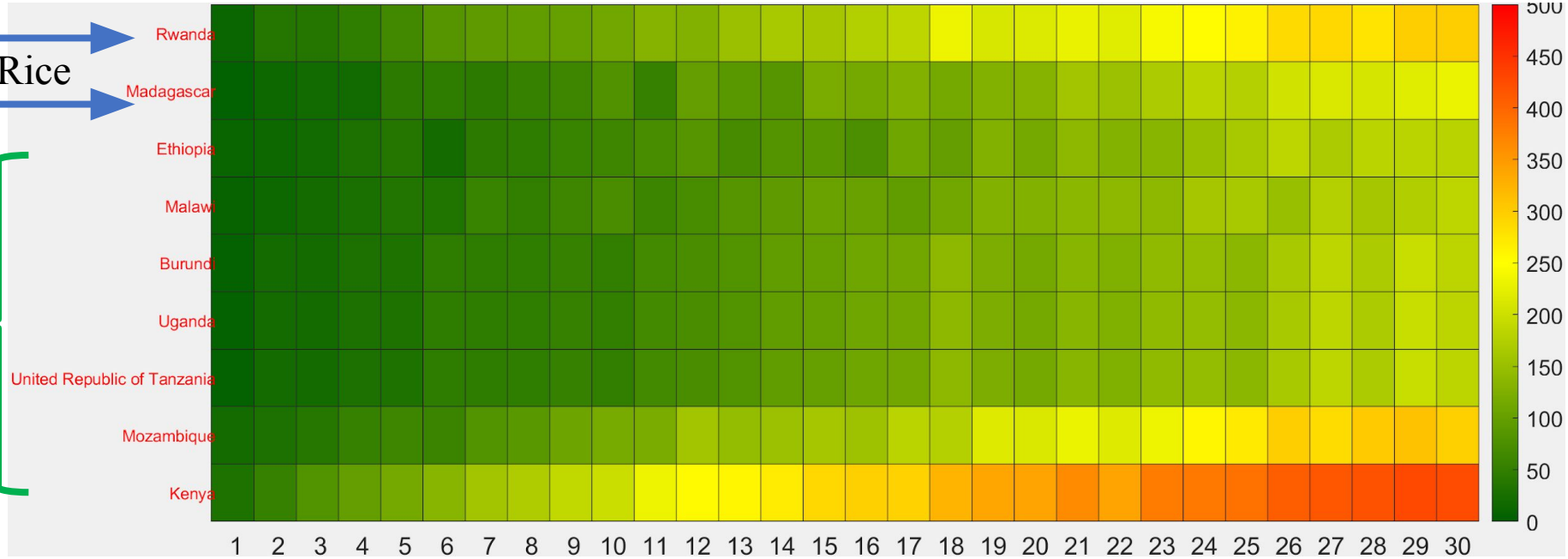
Threshold=0.1

Threshold=0.3

Main food: Wheat

Main food: Rice

Main food: Maize



Threshold=0.5

Threshold=0.7

Pre-processing

Number of country/region of globe: **175**

Filter abnormal data

Step:

1. Calculate the median of X, i.e., monthly data of wheat/rice export/import from/to country i to/from country j.
2. For each data point, calculate the absolute deviation from the median.

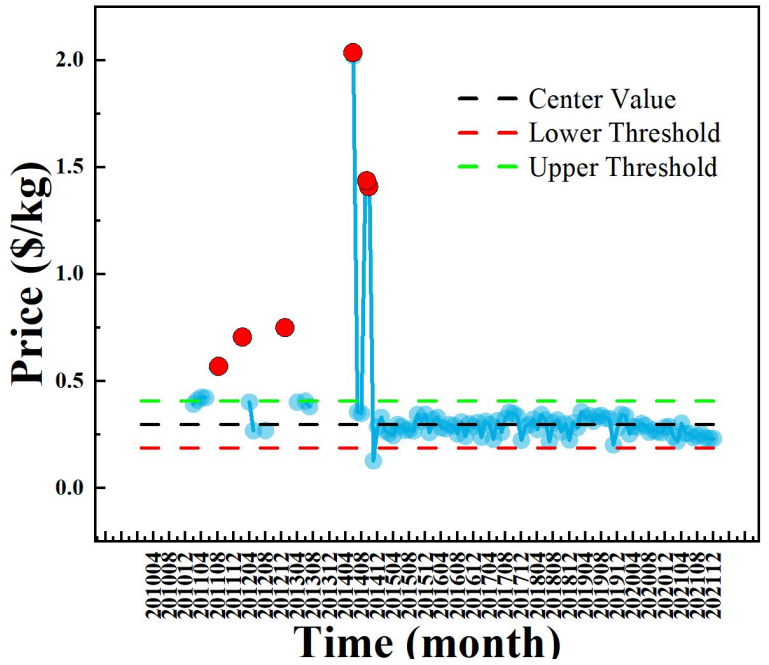
$$Deviation = |x_i - Median(X)|$$

3. Calculate the median absolute deviation

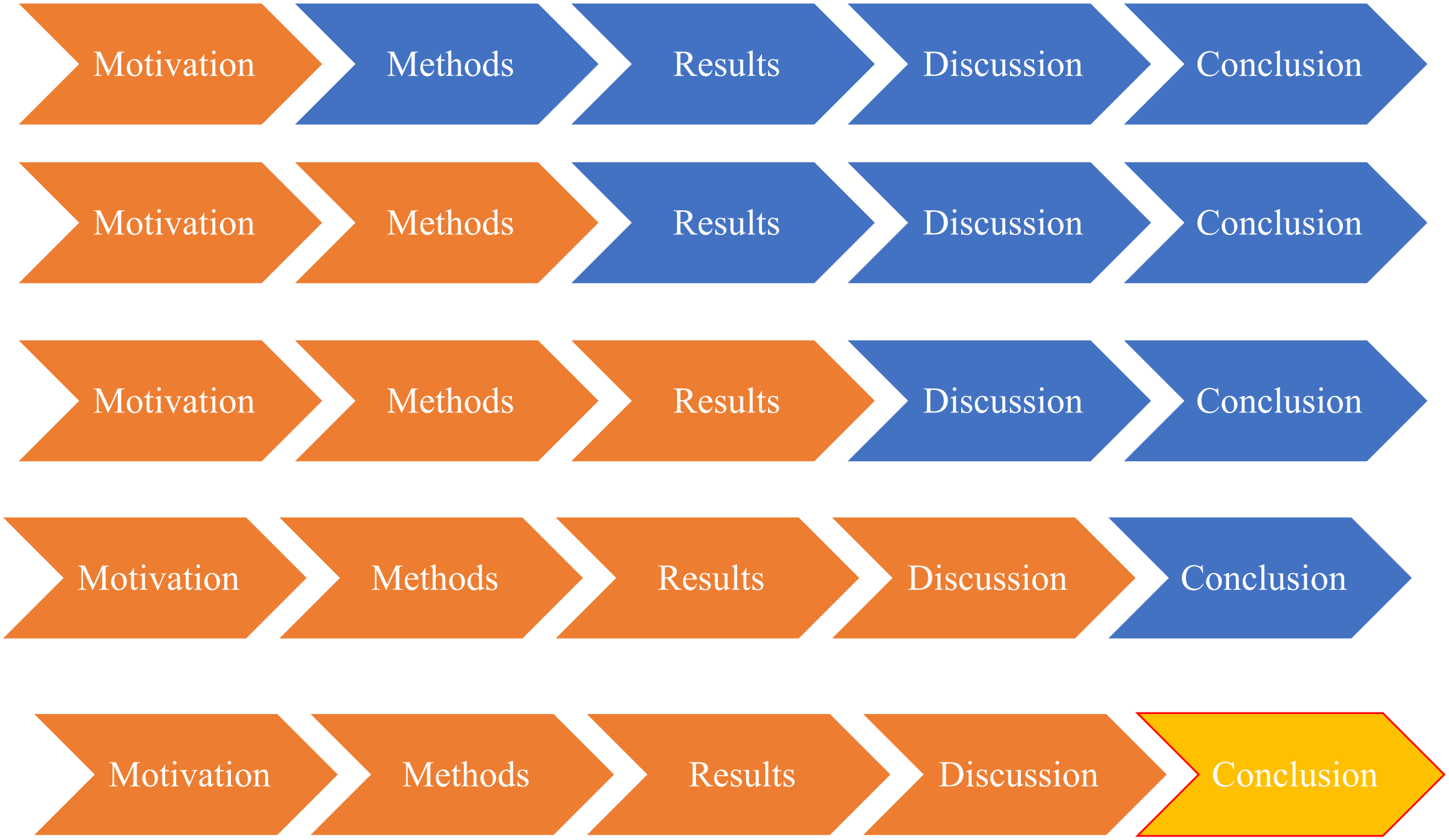
$$MAD = Median(Deviation)$$

4. According to the MAD algorithm, values outside a certain range are considered abnormal data:

x_i is an abnormal data if $|x_i - \text{Median}(X)| > 3 \times \text{MAD}$



MAD is more robust to extreme abnormal data than other methods (less sensitive to abnormal data)


Motivation
Methods
Results
Discussion
Conclusion
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Methods
Results
Discussion
Conclusion
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Results
Discussion
Conclusion
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Results
Discussion
Conclusion
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Countries groups by food styles

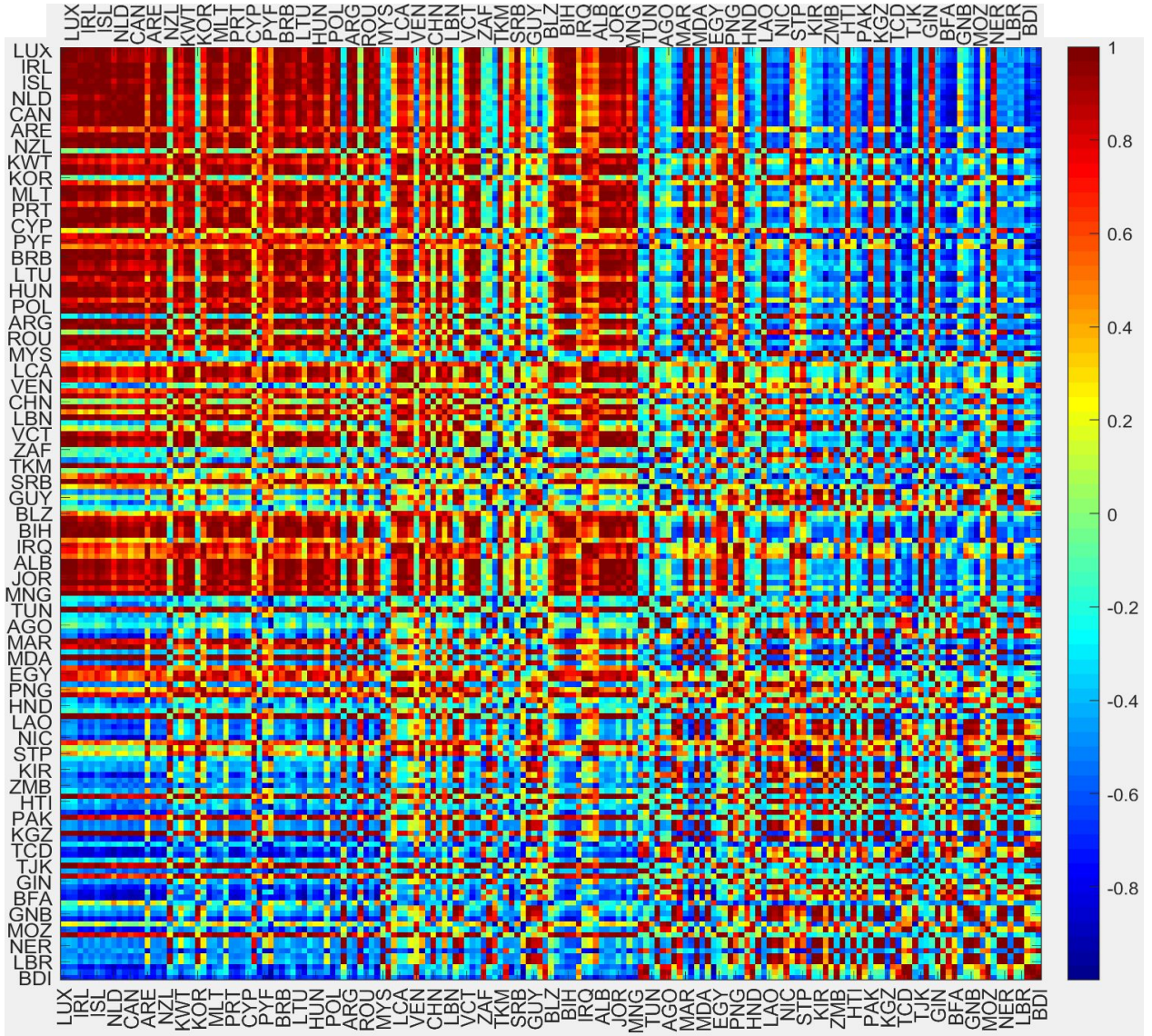
Similarity of the composition of main foods between countries

Proportion of consumption of wheat, rice, maize, potatoes

Country	Wheat(%)	Rice(%)	Maize(%)	Potato(%)
C_1	P_W_1	P_R_1	P_M_1	P_P_1
C_2	P_W_2	P_R_2	P_M_2	P_P_2
C_3	P_W_3	P_R_3	P_M_3	P_P_3

$$X_{C_1,C_2}(\tau) = \frac{\mathrm{cov}(C_1, C_2)}{\sigma C_1 \cdot \sigma C_2}$$

Richest country



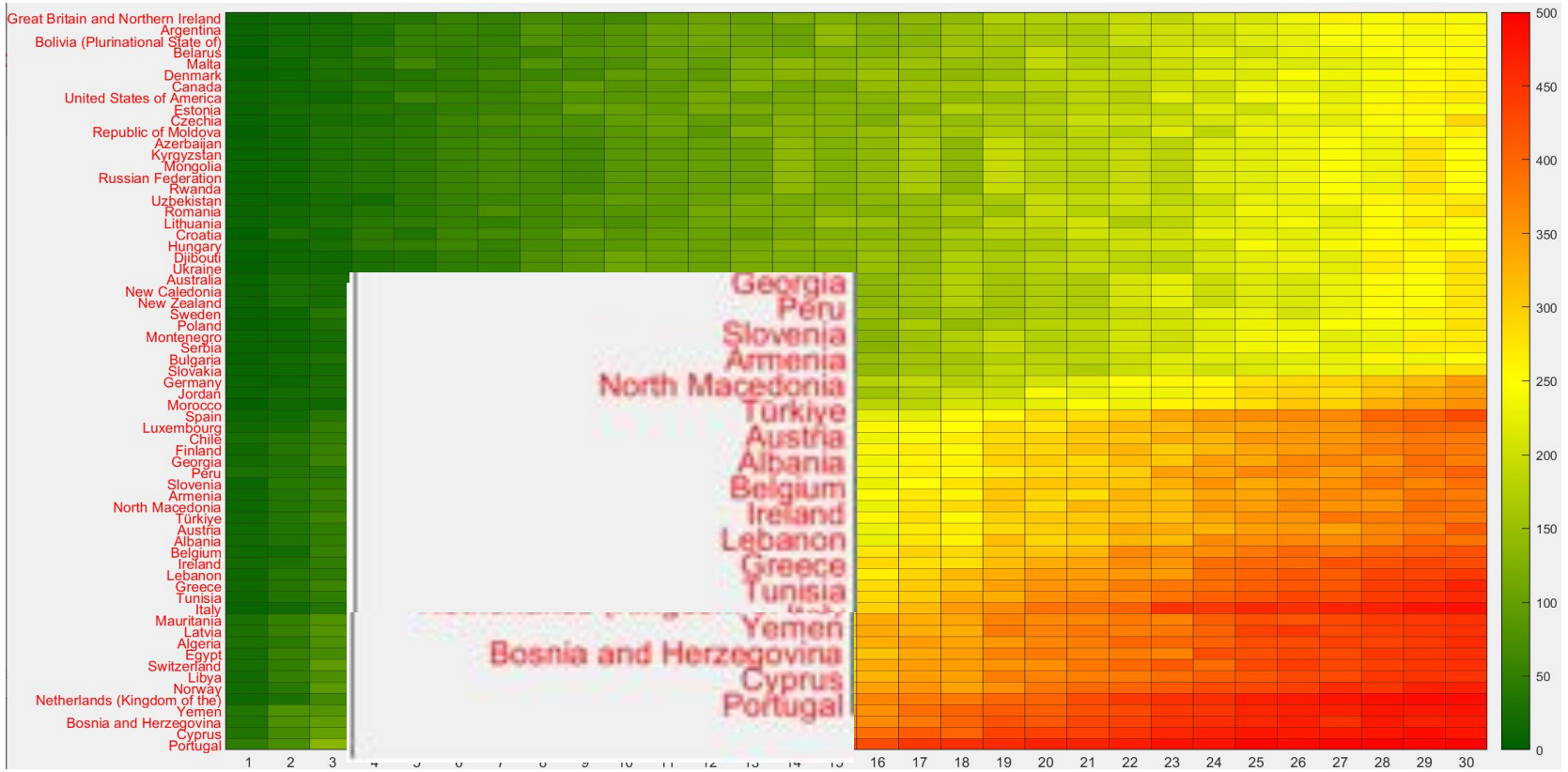
Poorest country

One step failure in a single-layer network

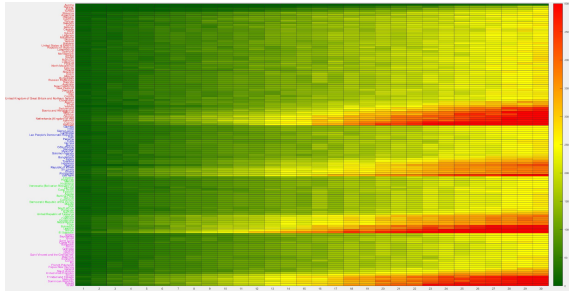
wheat rice maize other

wheat

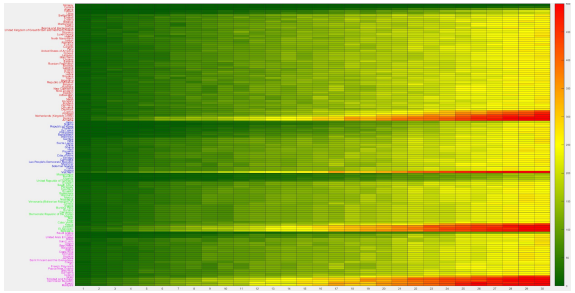
Threshold=0.1



Threshold=0.3



Threshold=0.5



Threshold=0.7