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Tactical Network Planning for Food Aid Distribution in Kenya

M.-È. Rancourt, J.-F. Cordeau, G. Laporte and B. Watkins, *Computers & Operations Research*, 56: 68-83, 2015

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Outline

- Context: humanitarian logistics
- The network design problem
  - Field work and data collection
  - Mathematical formulation
- Results
- Conclusions and future research directions

Humanitarian logistics

The process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of meeting the end beneficiaries' requirements

A. Thomas and M. Mizushima (2011)

Humanitarian logistics
Disaster response versus development projects

Disaster response

- The Federal Emergency Management Agency (FEMA) defines a disaster as:

  « an event that causes 100 deaths or 100 human injuries or damage worth 1 million dollars »

Development projects

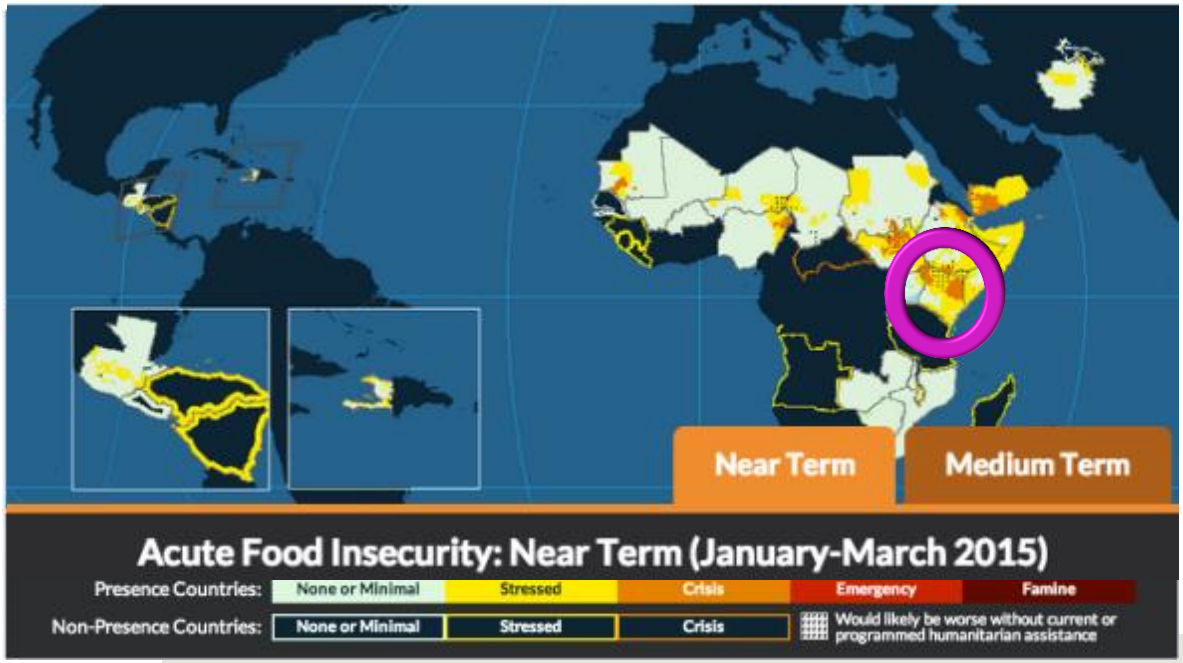
- Also involve human suffering and economic damage, but **covering longer time-spans**
- Their cause can usually not be traced back to a specific catastrophic event

East Africa struggles with…

- Extreme poverty and rapid population growth
- Wars and population migrations
- Diseases (malaria, HIV/AIDS, …)
- Gender issues and lack of education
- Governance challenges
- Fragile food production systems
- Recurrent droughts and floods
- Food insecurity

Food insecurity

- Hunger and malnutrition are the greatest risks to global health (World Food Programme, UN)
- Eradicating extreme poverty and hunger is the first goal of the eight UN Millennium Development Goals
- Sub-Saharan Africa is the only region in the world suffering from persistent chronic food insecurity



Acute food insecurity as of today

FEWS NET
FAMINE EARLY WARNING SYSTEMS NETWORK

UNITED STATES AGENCY INTERNATIONAL DEVELOPMENT
USAID

Source: FEWS NET

Food aid as an instrument to reduce food insecurity

Food aid

- Providing food and related assistance to tackle hunger, either in emergency situations, or to help with deeper, longer term hunger alleviation and achieve food security
- **This project focuses on in-kind food donations to beneficiaries**

Kenya

- Between 1988 and 2011
  - 182,000 MT per year on average (FAO)
- Number of beneficiaries
  - 14.3 million people in 2013-2014
- Main causes
  - Poverty
  - Seasonal droughts
  - Refugee camps (about 480,000 refugees in Dadaab and Kakuma)

Objective of this project

- **Objective:** Improve the design of the food aid distribution network taking into account the welfare of multiple stakeholders
- **Scope:** Determination of final delivery points, last-mile of food aid distribution
- **Methodology:** Mathematical programming
  - Problem class: Facility location and coverage problems
- **Geographical coverage:** Garissa district, Kenya

Collaboration

- The World Food Programme (WFP) of the United Nations
  - The largest humanitarian agency, aims to fight against hunger in the world
  - Know-how in the areas of food security analyses, nutrition, **food procurement and logistics (transportation and warehousing)**
- Kenya Red Cross
  - Run different projects (services): famine, education, blood, first aid, disaster and emergency

Scientific contributions

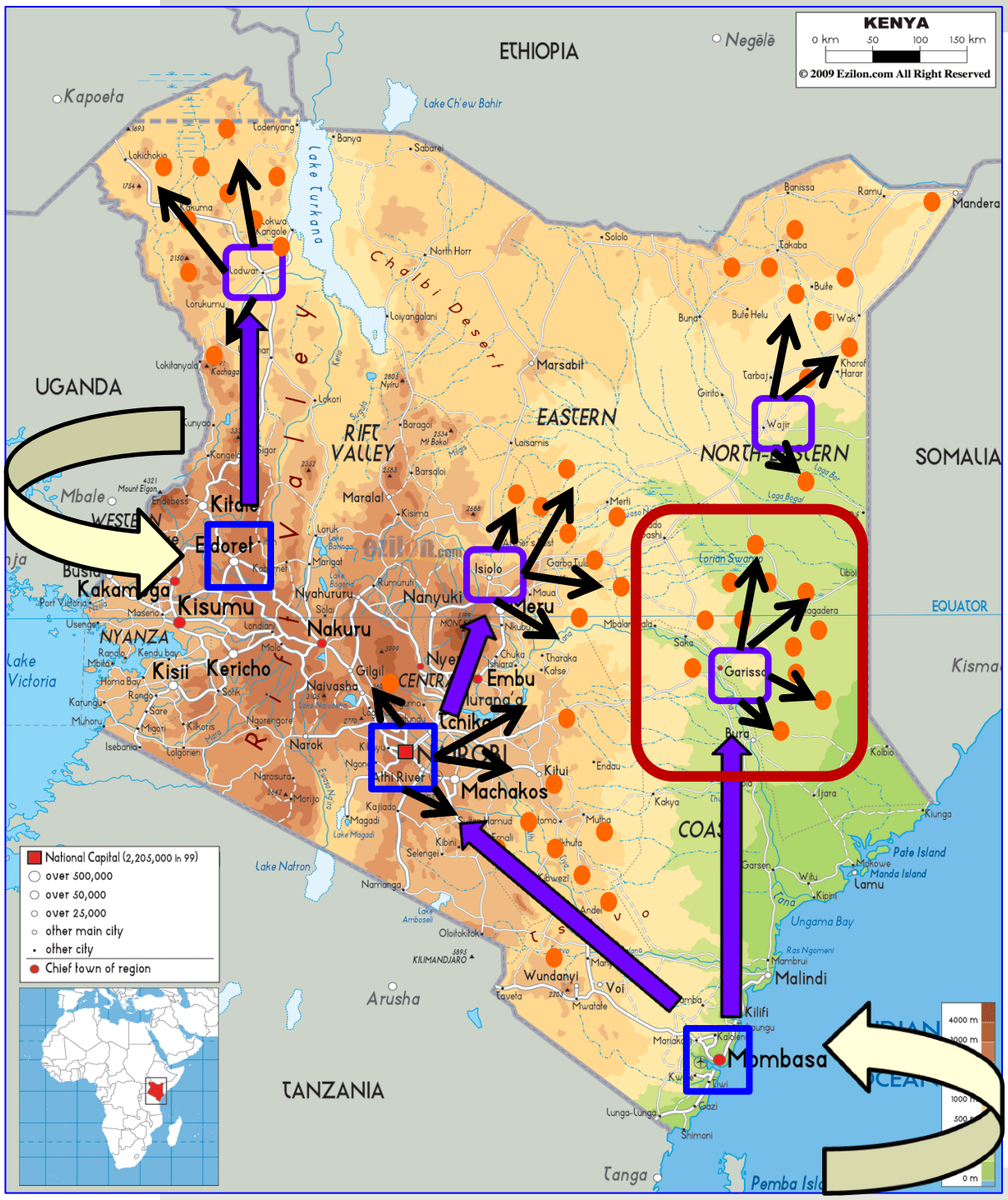
- The main challenge of the project lies more in modeling the problem, carrying out data collection and processing, and performing analyses than on algorithmic development
- Describe the logistics processes of food aid distribution and estimate stakeholders' costs
- First paper to apply optimization tools using real data in the context of last-mile food aid distribution in Africa and computing stakeholders' tradeoff costs

Steps

1. Understand the food distribution process
2. Determine the network parameters
   - Demand
   - Potential FDP locations
   - Distances
3. Estimate the stakeholder cost functions
   - Beneficiaries
   - World Food Programme (WFP)
   - Kenya Red Cross
4. Formulate and solve the mathematical models
5. Estimate tradeoffs

Step 1: Understanding the food distribution process

- Field work
  - Interviews
  - Facility visits
  - Food distribution observation
- Food distribution process



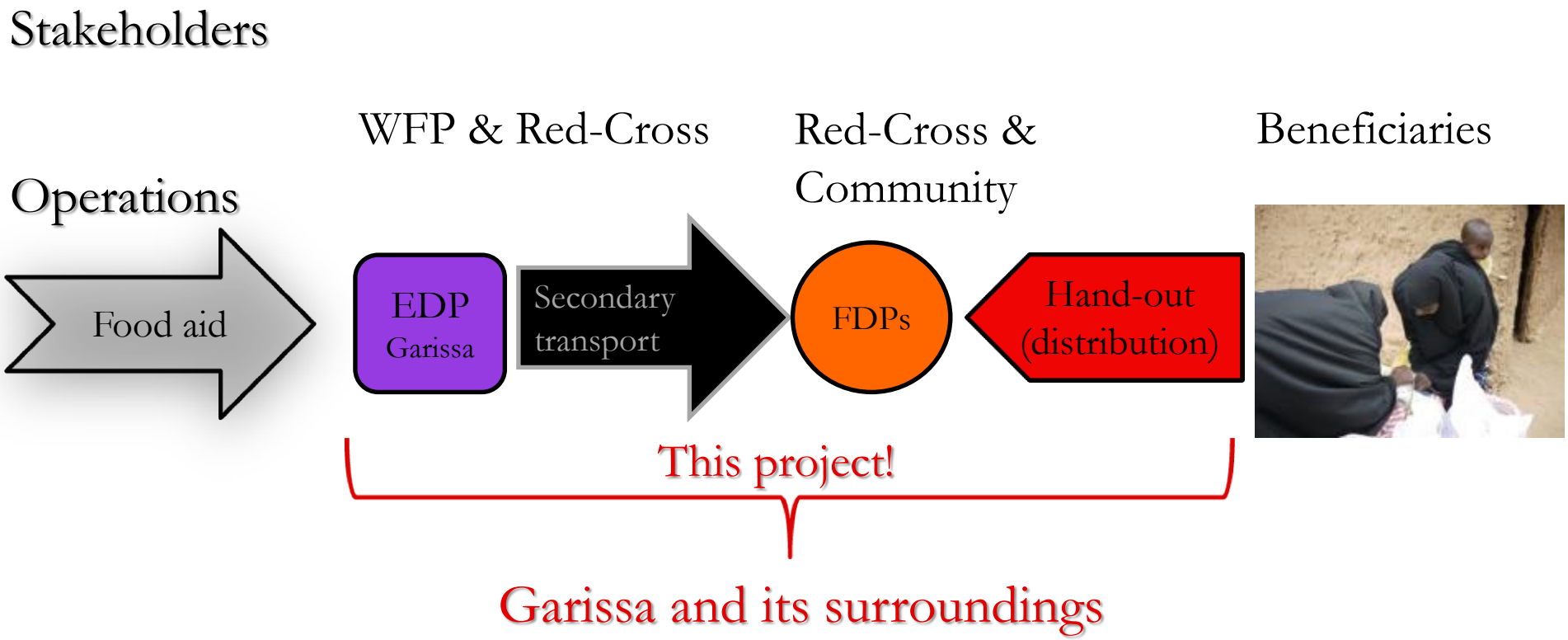
Legend:

- Hub
- EDP
- FDP
- Food entries (international transport)
- Primary transport
- Secondary transport

Extended Delivery Point (EDP)

Final Delivery Point (FDP)

Food aid regional supply chain
Operations and stakeholders



Why Garissa and its surroundings?

- One of the most vulnerable regions in Kenya
  - 35% of the region's population received food aid in the last 12 years (62% during the most difficult period)
  - High poverty rate
  - Arid land with low rainfall
  - Pastoralism is the dominant livelihood system
- Food aid is constant
  - Fixed distribution system which justifies the need for an optimized network

Activities/Responsibilities at the EDP and a FDPs

Activities/Responsibilities at a FDP

- "Community Relief Committee"
  - Elected by the community
  - Trained by Red Cross
  - Targeting, record keeping, arrange food distribution, provide storage and ensure security
- Red Cross
  - Ensure that food assistance reaches beneficiaries
  - Assist the community

Activities/Responsibilities at a FDP

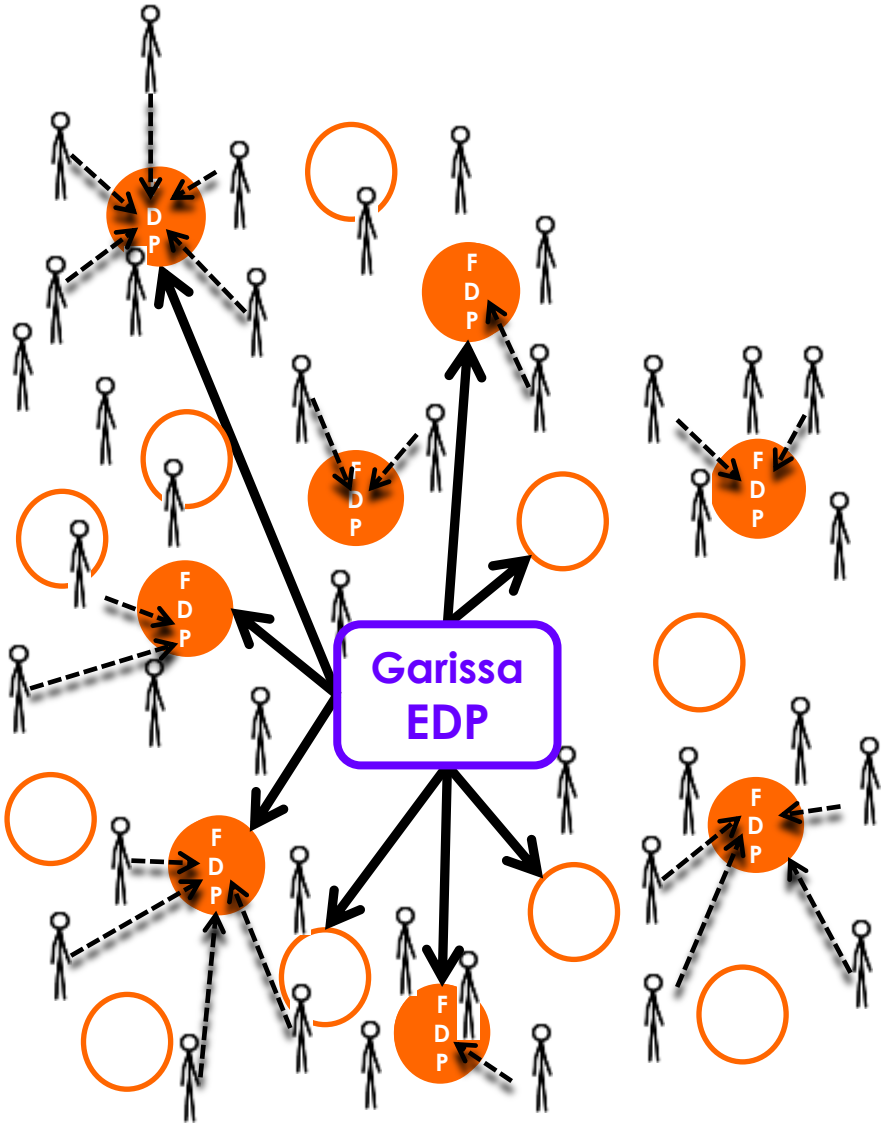
Activities/Responsibilities at a FDP

- Shipment management
  - Counting
  - Signing waybill
  - Losses/damaged bags

Activities at a FDP

- Distribution
  - "Scooping"
  - Hand-out (distribution)
  - Donkey transportation service

Tactical "FDP" location problem



Nodes:

Population points ($\mathcal{V}_1$)

Potential FDP locations ($\mathcal{V}_2$)

Costs:

Transportation costs (WFP)

Location and hand-out costs (Kenya Red Cross)

Access costs (beneficiary opportunity costs)

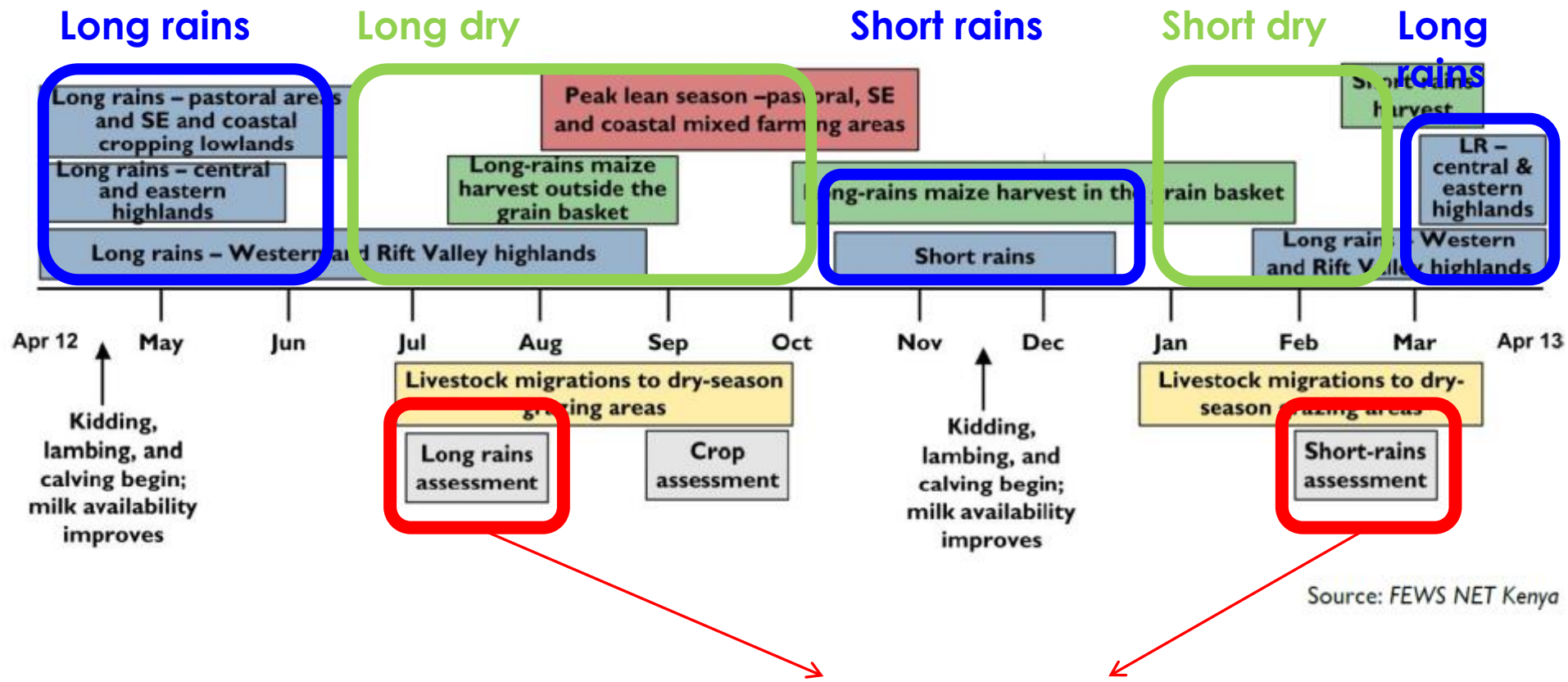
Step 2: Determine the physical network structure

1. Demand
   - Population needs
   - Population locations
2. Potential FDP locations
3. Transportation network (distances)
   - Distance from each population point to closest road
   - Distance from Garissa EDP to each potential FDP locations
   - Distance from each population points to each potential FDP locations

Question 1 – Demand

- **Where are the beneficiaries?**
  - Geographic Information Systems (GIS) and gridded population data
- **How much food are they entitled to?**
  - 2012 Short Rain Need Assessment

Need assessment in Kenya



Source: *FEWS NET Kenya*

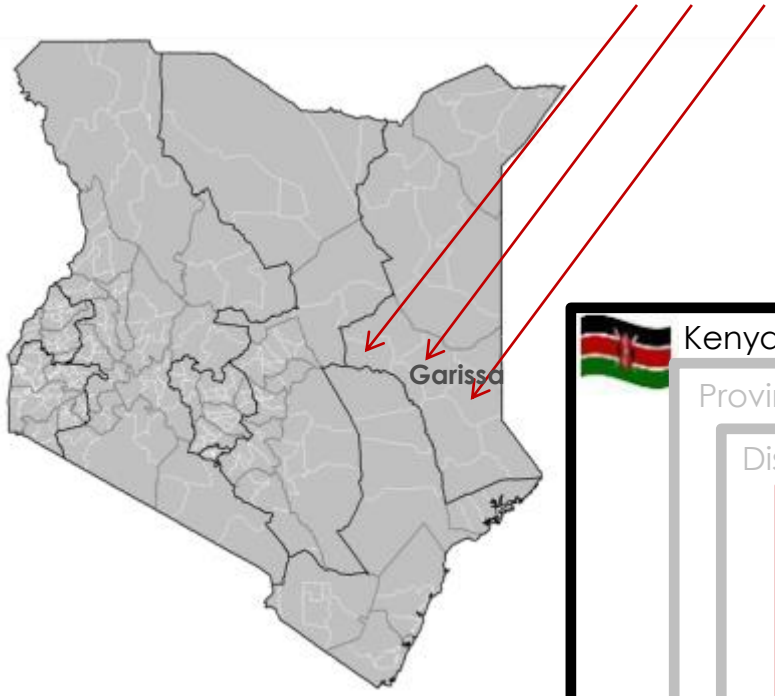
Need assessment: Determination of the <u>demand</u> for the following 6 months.

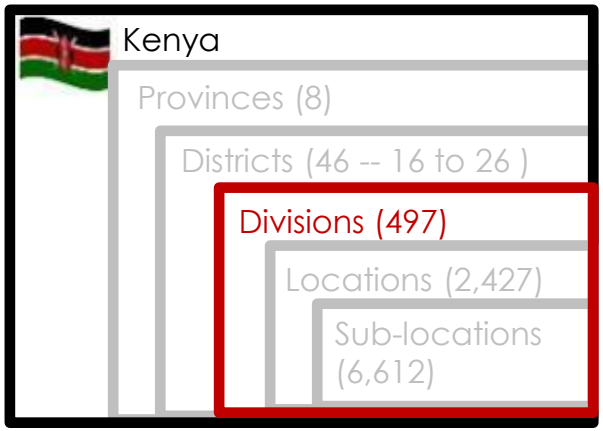
Need assessment in Kenya

- For each division of Kenya, two parameters are determined (effective for a period of 6 months):
  - Number of beneficiaries
  - Ration entitlement

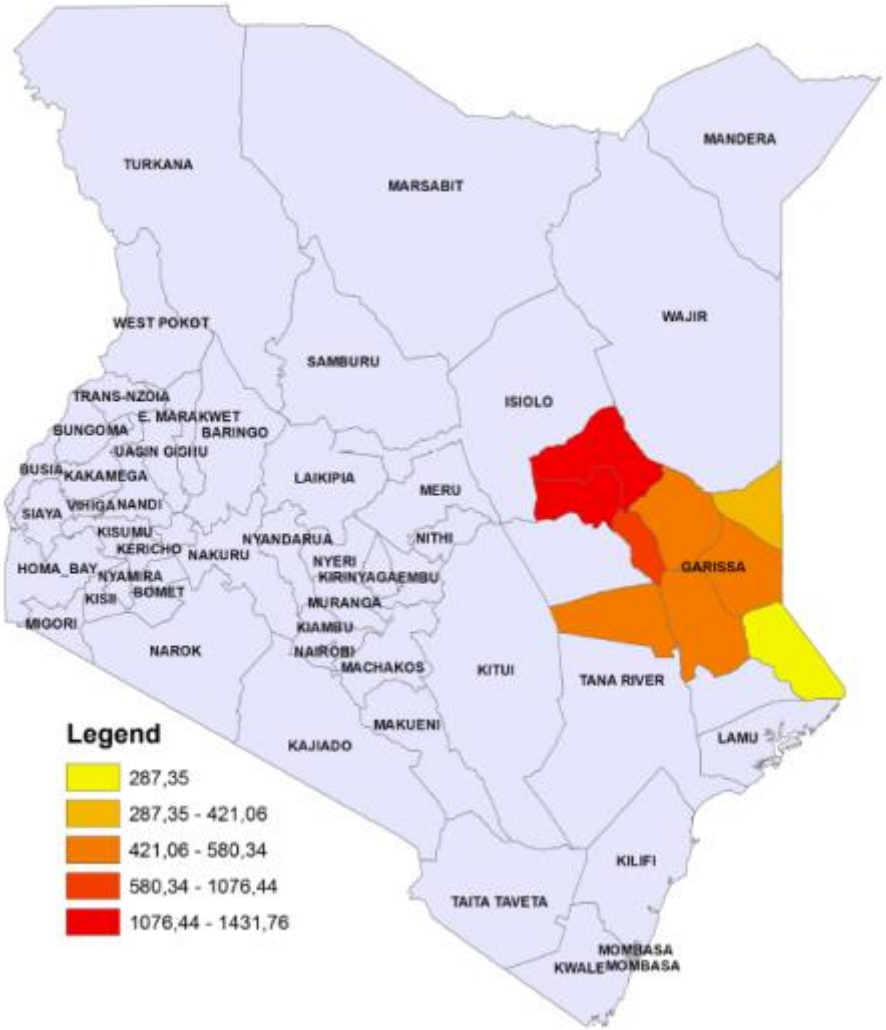
(# beneficiaries, ration entitlement)

400g of cereal flour/rice/bulgur
60g of pulses
25 g of oil (vit. A fortified)
50 g of fortified blended foods (Corn Soya Blend)
15g of sugar
15g of iodized salt





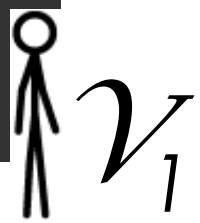
2012 Short Rain Assessment for Garissa and its surroundings

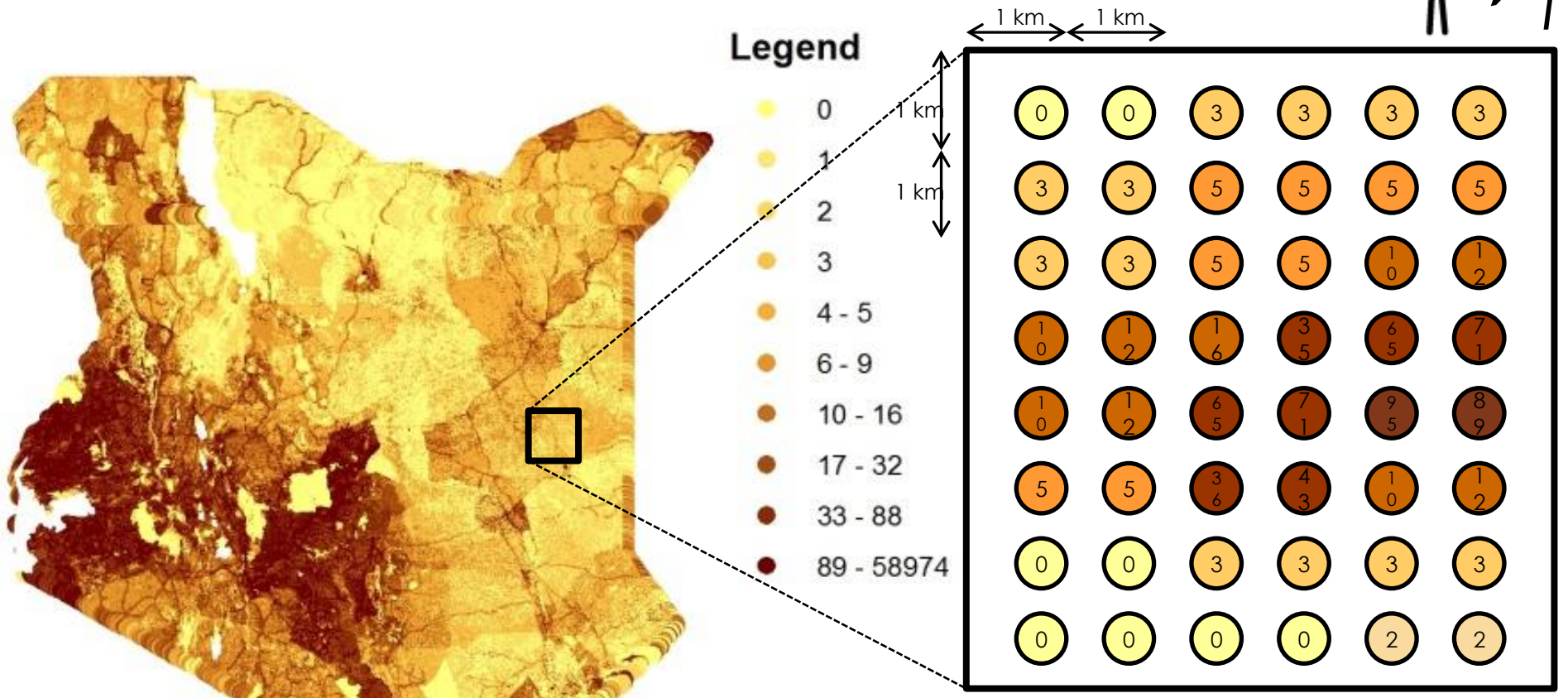


Food aid requirement (tonnes/month)

Set of population points – V_1

Source: GIS gridded population data





Needs q_i at population point *i* :

$$q_i = \frac{p_i}{P} B \times ration$$

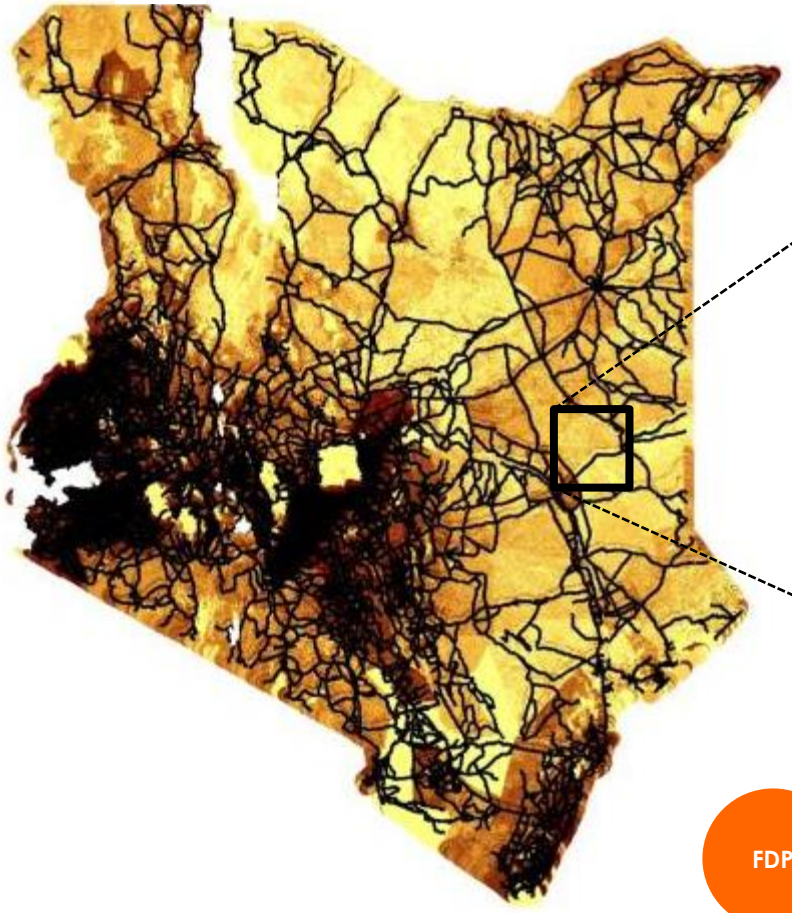
With p_i the population at *i*, *B* the number of beneficiaries, *P* the total population and *ration* the entitled amount of food aid per beneficiary at smallest division level

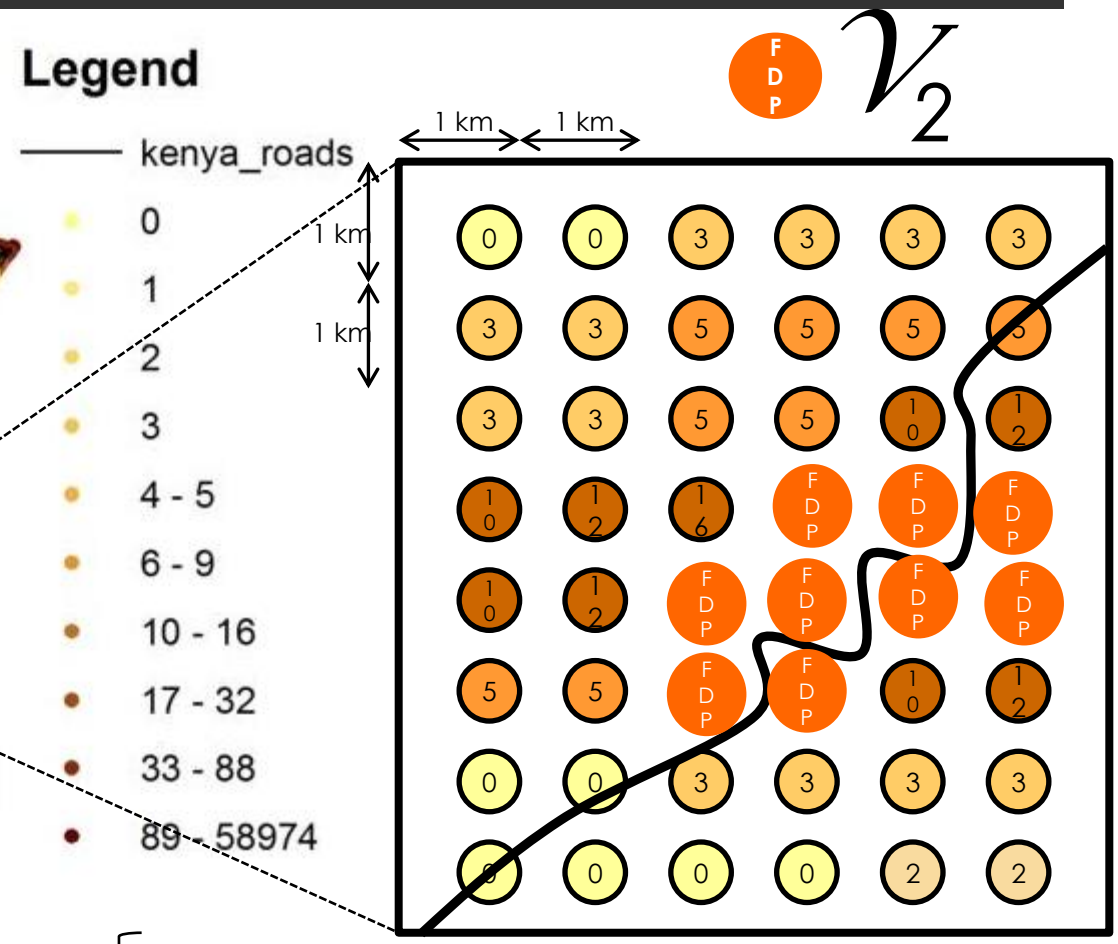
Question 2 – Potential FDP locations

- **Where are the potential FDP locations?**
  - Geographic Information Systems (GIS)
    - Road network
    - Population data

Set of potential FDP locations – V_2

Sources: GIS gridded population data and road vectors





FDP

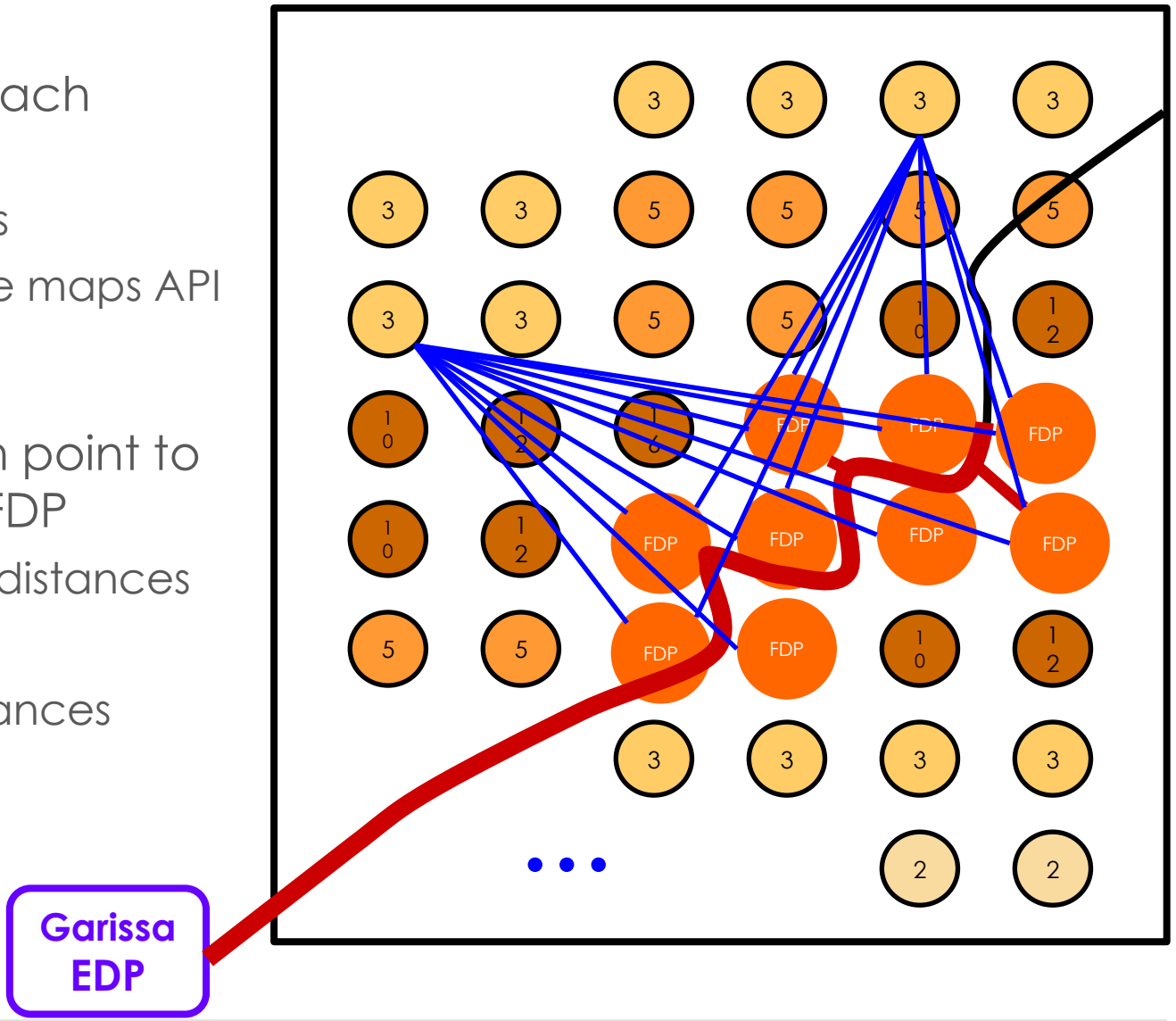
- Close to a road (≤ 200 m)
- Population center (≥ 20 people)

Question 3 – Transportation distances

- **What are the network transportation distances?**
  - Geographic Information Systems (GIS)
    - Road network
    - Population data
  - Algorithms

Distances within the network

- Garissa EDP to each potential FDP
  - Road distances
  - Source: Google maps API
  - 1460 distances
- Each population point to each potential FDP
  - Geographical distances
  - Source: GIS
  - 35,701,380 distances



Network description

Description	Parameter	Mean	Std dev.	Median	Min.	Max.
Population nodes ($\|V_1\| = 24,453$)	V_1					
Number of people	p_i	17.36	221.15	5	3	13,793
Six-month food need per beneficiary (t)	q_i	0.02438	0.02442	0.01136	0.0396	0.11534
Geographical distance to closest route (km)	$d_i^{r^*}$	11.03	9.34	8.49	0	50.34
Geographical distance to closest potential DC (km)	$d_{ij^*}^{g}$	11.85	10.91	8.71	0	54.48
Potential DC nodes ($\|V_2\| = 1,460$)	V_2					
Road distance to MW (km)	d_{0j}^{r}	106.32	71.41	107.16	0.05	268.93

Step 3: Estimate the stakeholder costs

- Stakeholders that bear costs
  - Beneficiary opportunity costs (access costs)
  - WFP (transportation costs)
  - Kenya Red Cross (location and hand-out costs)
- Data sources
  - Beneficiary questionnaires
  - Contracts between the WFP and the Kenya Red Cross

Beneficiary opportunity costs

- Value of walking time:

0.25 h/km · 2 · *distance to FDP* (km) · 22,25 KSh/h

Walking time (pace: 4 km/h)

Minimum wage rate for unskilled labor

- Value of food transport service (donkey):

20 KSh + 2.5 KSh/km · *distance to FDP* (km)

Statistics based on a monitoring report for WFP

- **Beneficiary opportunity costs:**

11,4 KSh/km · *distance to FDP* (d_{ij}) + 20 KSh

α_{ij}

Transportation costs (WFP)

- The Red Cross contracts and coordinates with local transporters, but WFP fixes secondary transportation rates and pays for the services:

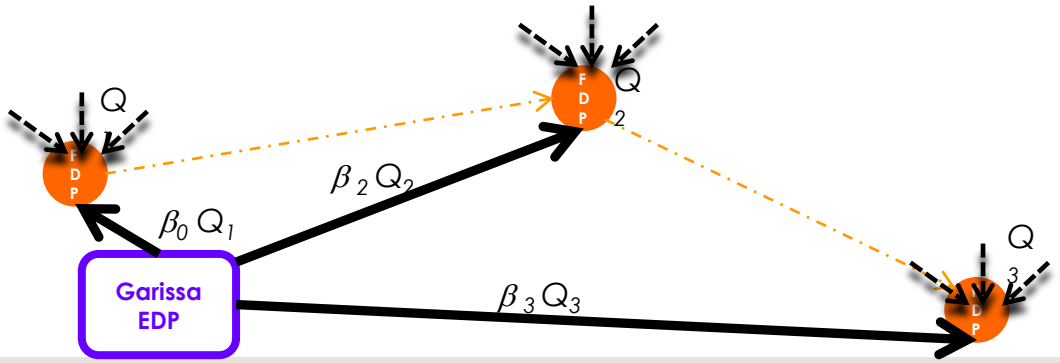
$$\beta_j = \begin{cases} c_0 & \text{if } d^r_{0j} \in [0, \bar{d}_0] \\ c_1\, d^r_{0j} & \text{if } d^r_{0j} \in (\bar{d}_0, \bar{d}_1] \\ c_2\, d^r_{0j} & \text{if } d^r_{0j} > \bar{d}_1. \end{cases}$$

c_0: constant price per tonne

c_1, c_2: constant price per km-tonne

- Transportation costs to serve the FDPs depend on the distance and the quantity of food delivered

$$Q_j = \sum_{i \in V_1} q_i\, x_{ij}$$



Location and hand-out costs (Kenya Red Cross)

- **Fixed costs**: Relief comity training and registration validation
  - Two workdays for the Red Cross facilitator
- **Variable costs**: Monthly food distribution monitoring
  - Two workdays per month for the Red Cross staff (announcement, dispatch and distribution)
- **Total estimated costs:** $\underbrace{\gamma \text{ KSh}}_{\gamma_j}$

Step 4: Mathematical formulation of the problem

- Define the decision variables
- Determine the objective function
- Formulate the constraints

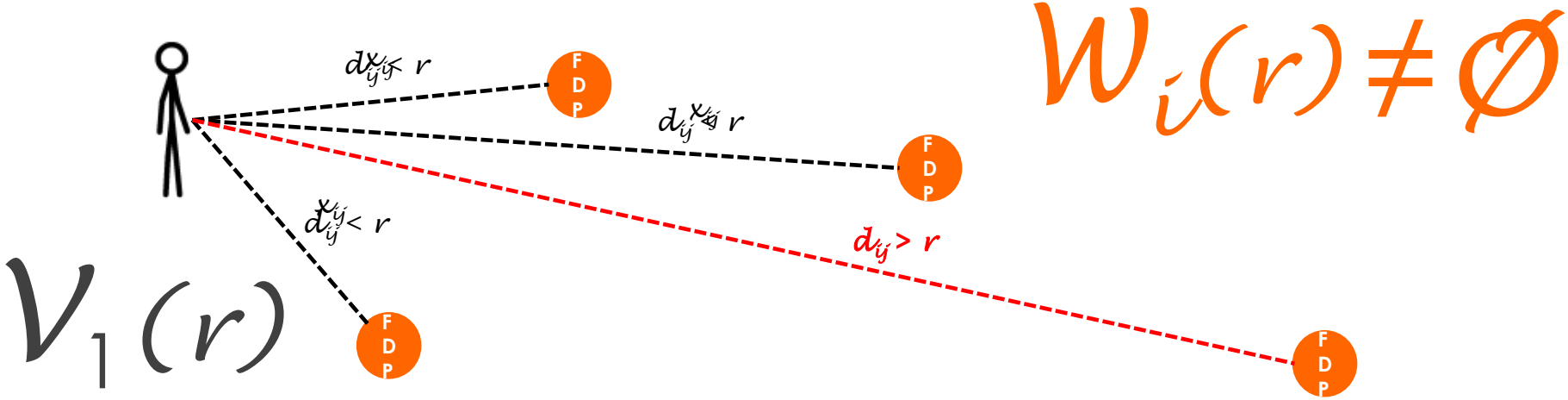
Decision variables and coverage radius

- Decision variables

  y_j: is equal to 1 if FDP j is selected, 0 otherwise $(j \in V_2)$

  x_{ij}: proportion of the needs of population i served by FDP j
  $\left(i \in V_1(r) \text{ and } (j \in W_i(r)\right)$

- Radius of coverage r and $W_i(r)$



Mathematical formulation – Cost Model

$$\text{minimize} \underbrace{\sum_{i \in V_1(r)} \sum_{j \in W_i(r)} \alpha_{ij}\, x_{ij}}_{\text{Beneficiaries opportunity costs}} + \underbrace{\sum_{i \in V_1(r)} \sum_{j \in W_i(r)} \beta_j\, q_i\, x_{ij}}_{\text{Transportation costs (WFP)}} + \underbrace{\sum_{j \in V_2} \gamma_j\, y_j}_{\text{Location and hand-out costs (Kenya Red Cross)}}$$

subject to

$$\sum_{j \in W_i(r)} x_{ij} = 1 \qquad i \in V_1(r) \qquad \text{Demand}$$

$$x_{ij} \leq y_j \qquad i \in V_1(r),\ \ j \in W_i(r) \qquad \text{Open FDPs}$$

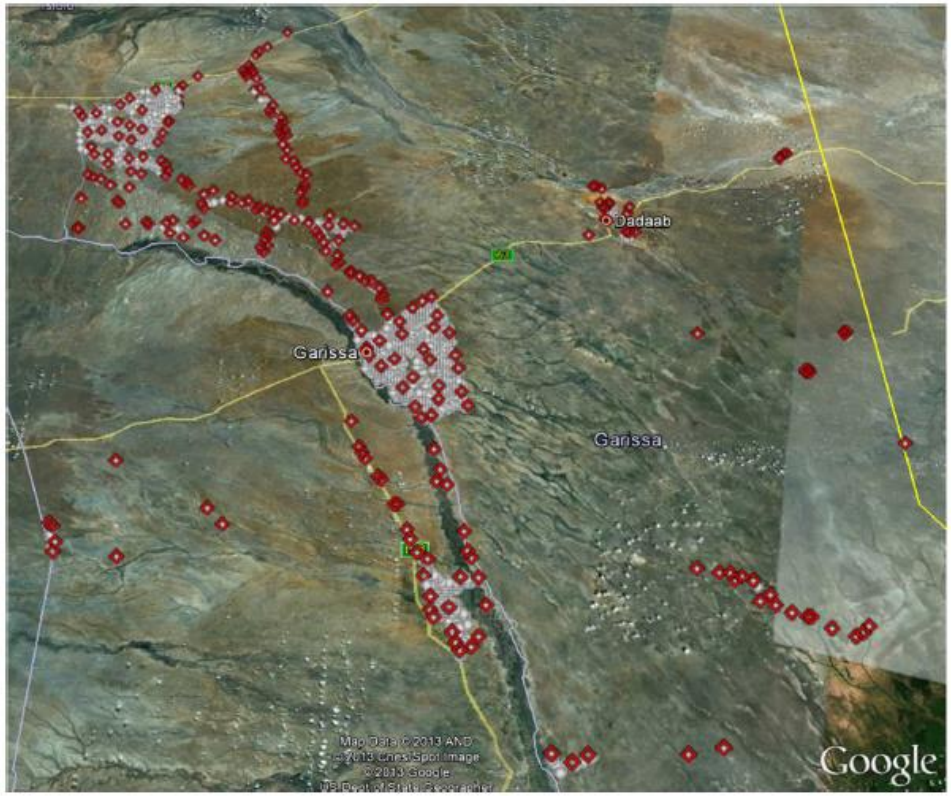
$$x_{ij} \geq 0 \qquad i \in V_1(r),\ \ j \in W_i(r) \qquad \text{Non negativity}$$

$$y_j \in \{0, 1\} \qquad j \in V_2 \qquad \text{Binary}$$

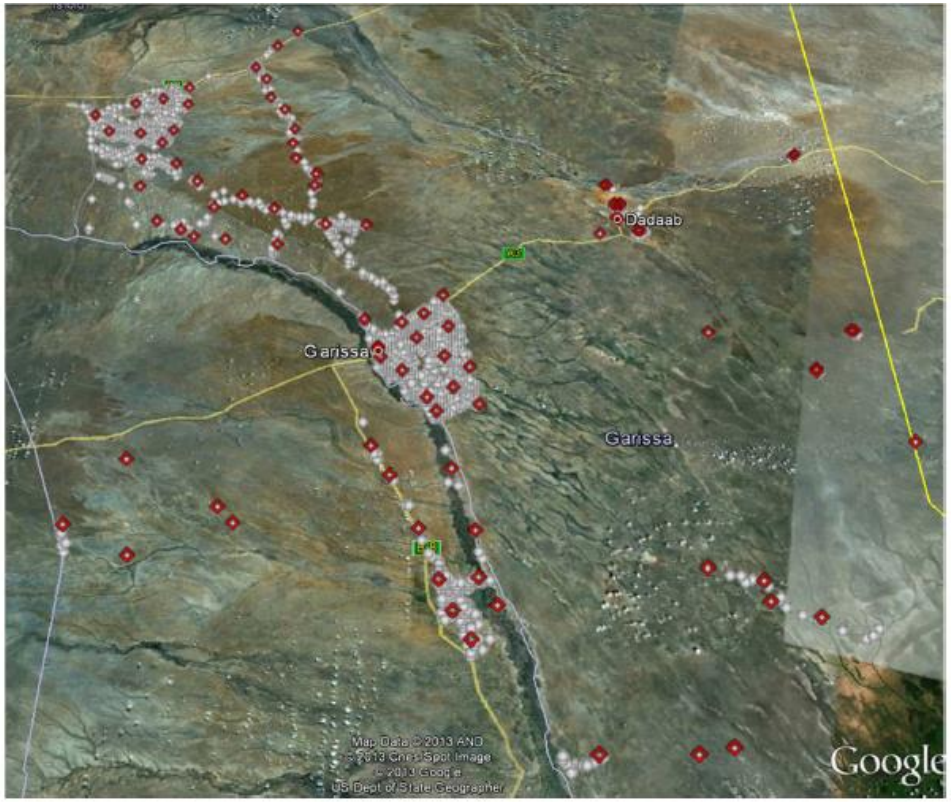
Step 5: Computational results

- Solve the problem using the CPLEX 12.5 library in a C++ program
  - Optimality gap: 0.1%
- Comparative analyses
  - Impact of the response system structure on the stakeholder welfare costs
  - Compare results of the cost model with classic covering models

Solution illustrations



(a) Solution with $r = 5$ km.



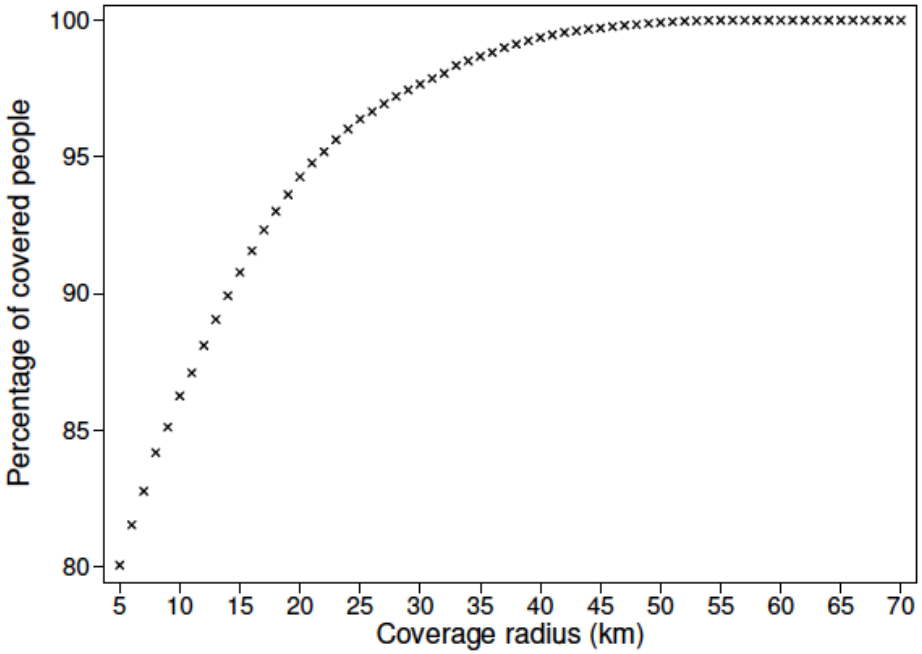
(b) Solution with $r = 55$ km.

Solution characteristics

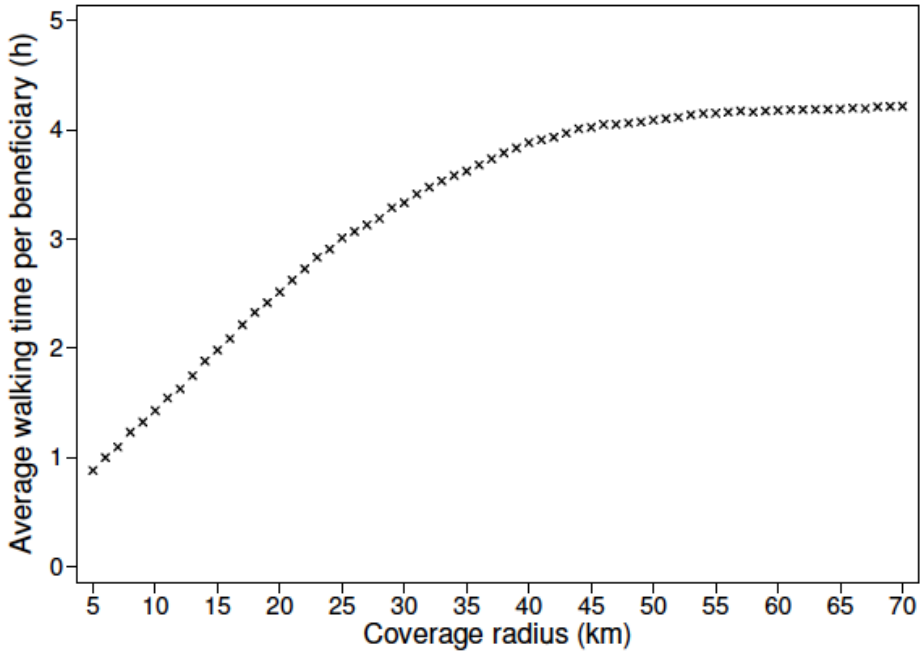
Solution	Costs				DCs	Covered people	Uncovered people		CPLEX
r (km)	Total (KSh)	Beneficiary (KSh)	Supply (KSh)	Hand-out (KSh)	#	Average walk time (h)	Proportion (%)	Average walk time (h)	CPU time (s)
5	39,564,680	2,659,196	31,299,708	5,605,776	264	0.88	19.94	8.33	4,312.3
10	38,260,488	3,921,704.3	31,005,046	3,333,738	157	1.43	13.75	10.37	80.9
12	38,099,196	4,401,085	30,852,754	2,845,356	134	1.63	11.90	11.11	338.36
17	38,314,480	5,842,935	30,241,976	2,229,570	105	2.21	7.67	13.18	203.41
25	38,863,984	7,853,155	29,248,408	1,762,422	83	3.01	3.62	16.50	173.75
55	39,449,296	10,767,909	27,322,410	1,358,976	64	4.15	0	0	1,228.85

Covered people as a function of the coverage radius

% of the population covered as a function of *r*

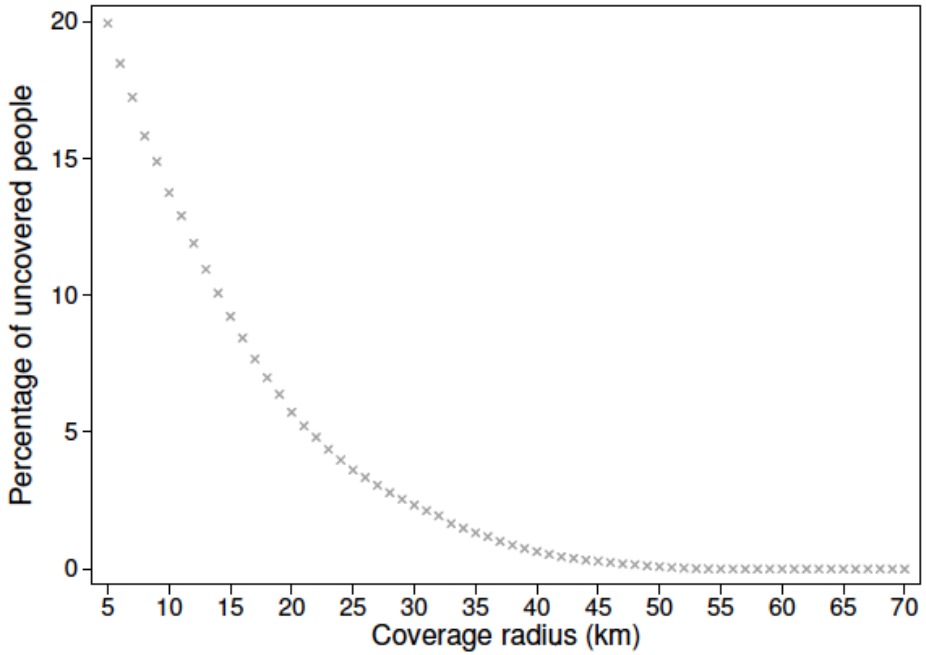


Average walking time per beneficiary as a function of *r*

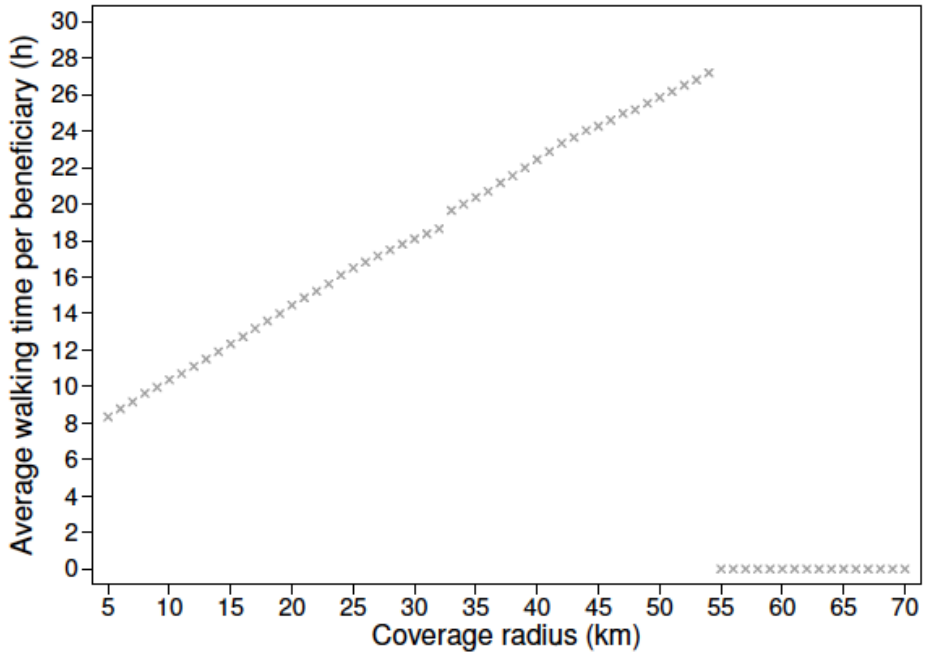


Uncovered people as a function of the coverage radius

% of the population uncovered as a function of *r*

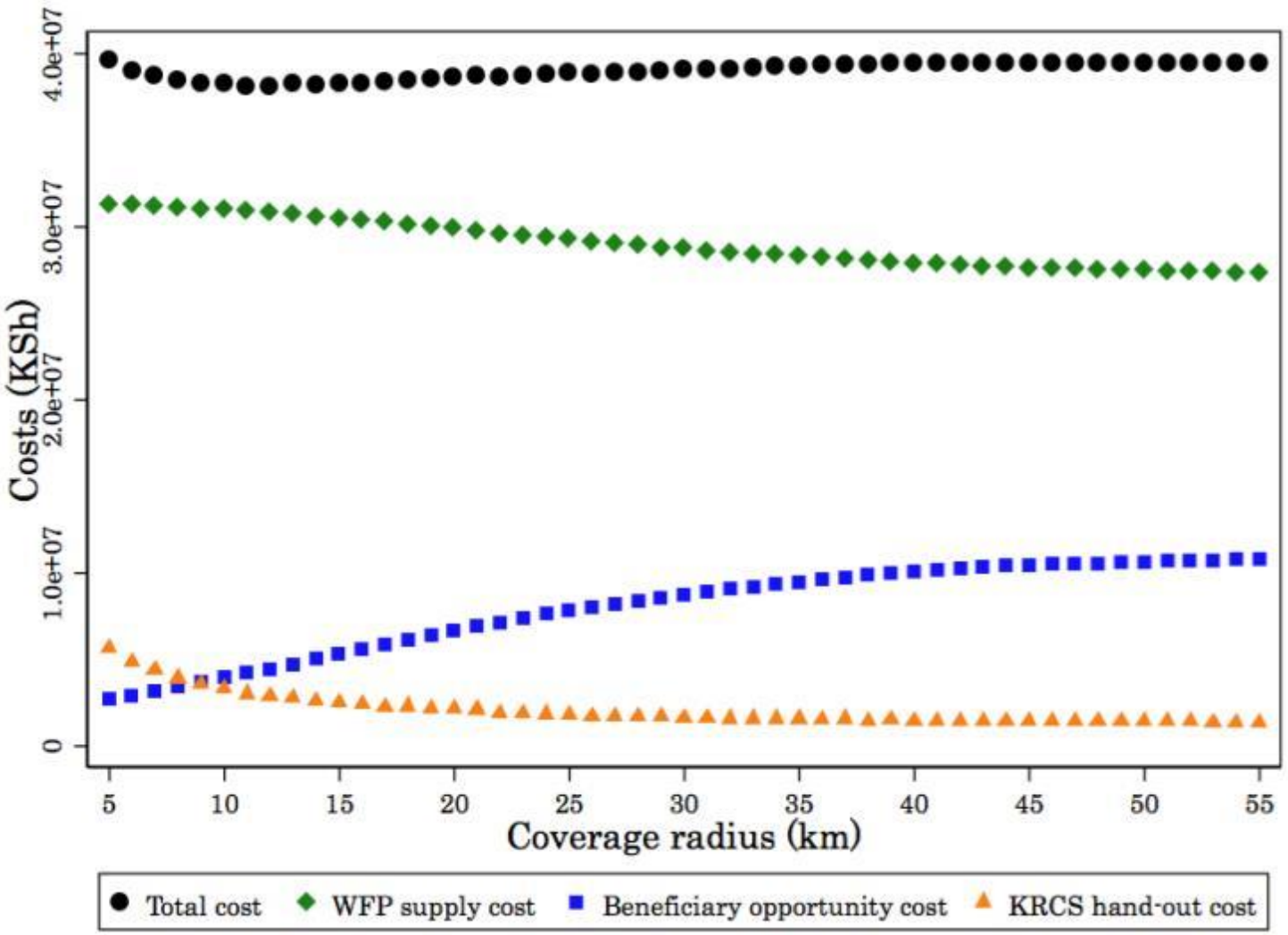


Average walking time per beneficiary as a function of *r*



Assuming they register to the closest open FDP

Stakeholder costs



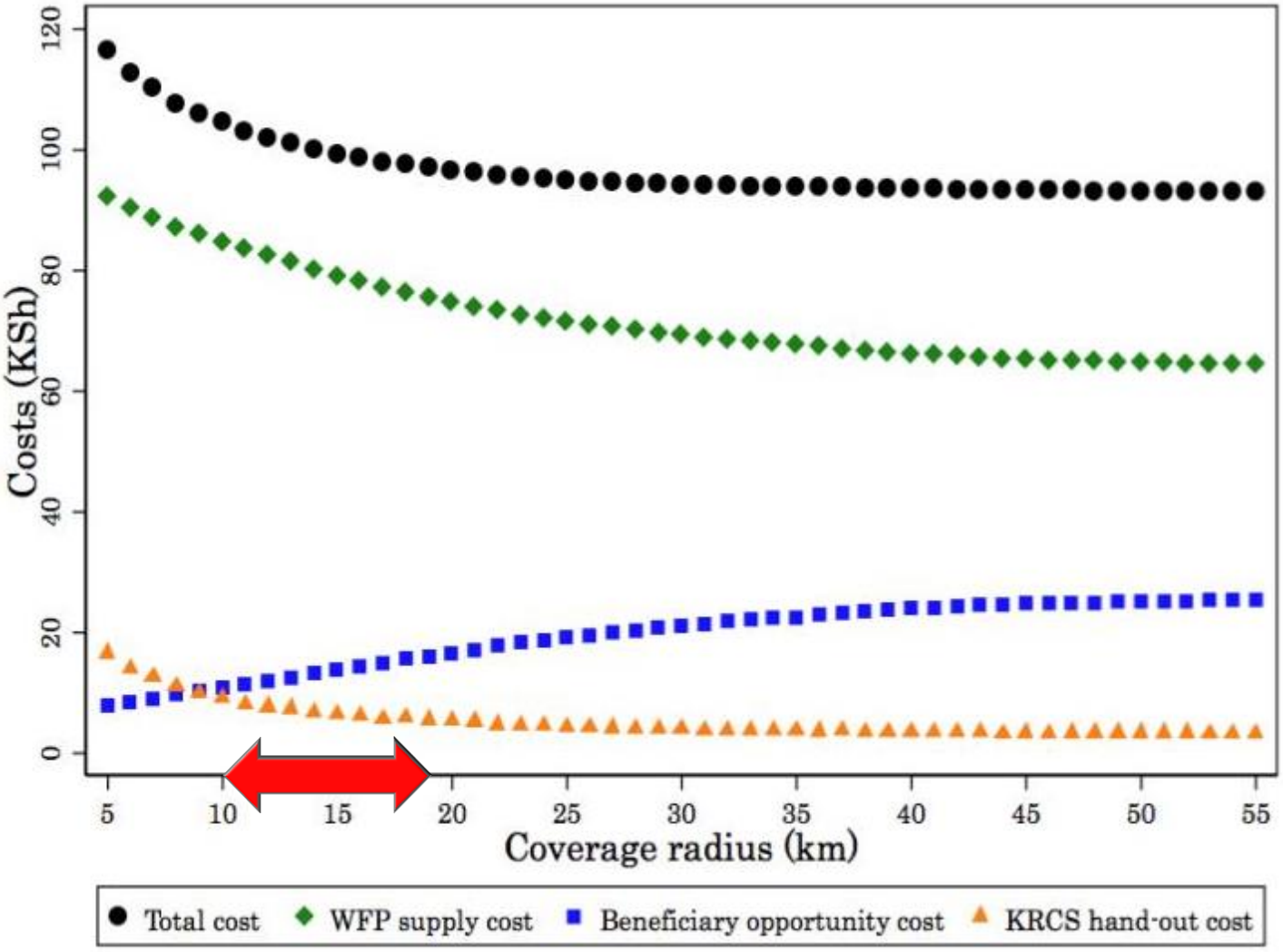
Total welfare cost

WFP
73% of the total cost on average

Beneficiaries
22% of the total cost on average

Red Cross
5% of the total cost on average

Stakeholder costs per beneficiary



Fair and cost-efficient solutions obtained with:

$r = 10, 11, \ldots, 17.$

Fair?

Complying with The Sphere Project Standards (2014), i.e. 90% of the beneficiaries should be covered within a one-day return walk .

Here, about 92% of the people are covered with an average walking time of 2 hours.

Tradeoff between beneficiary and transportation costs

Minimizing beneficiary opportunity costs

- Average % of decrease in average walking time per beneficiary
  - 37%
- **Average % of increase in transportation costs**
  - **14%**

Minimizing supply transportation costs (WFP)

- Average % of decrease in transportation costs
  - 15%
- **Average % of increase in beneficiary average walking time**
  - **188%**

A small increase in WFP costs can yield a large reduction in beneficiary opportunity costs

Coverage Model

- Maximize covered need with *156* FDPs

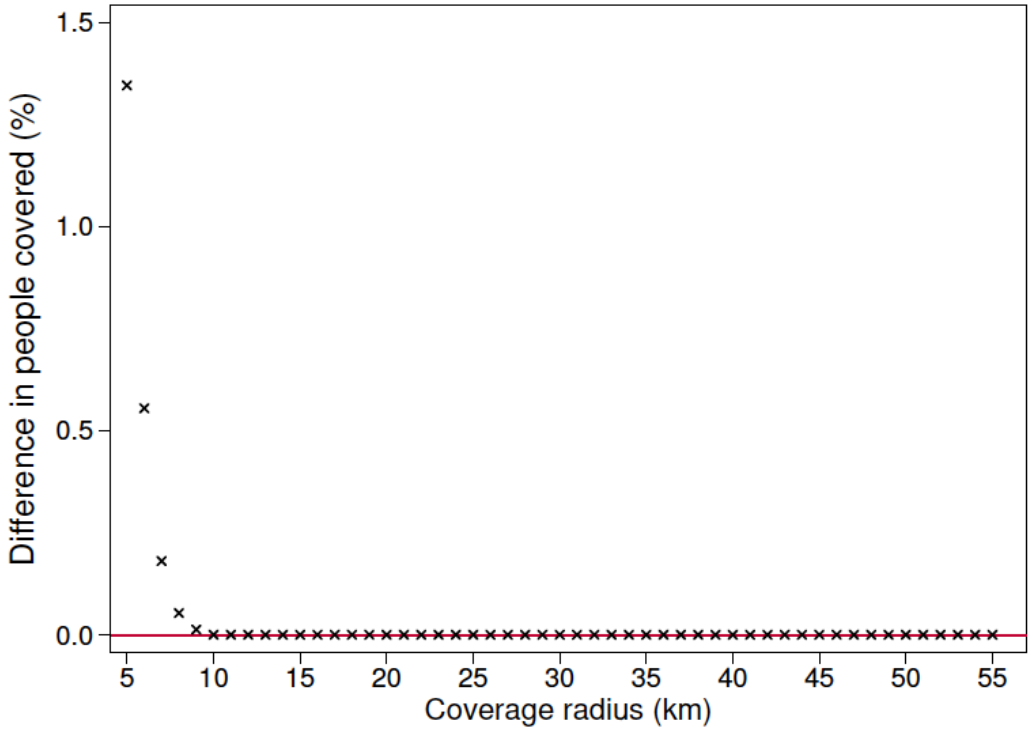
$$\text{maximize} \quad \sum_{i \in V_1(r)} q_i \, z_i$$

subject to

$$\begin{aligned}
z_i &\leq \sum_{j \in W_i(r)} y_j && i \in V_1(r) \\
\sum_{j \in V_2} y_j &= \bar{w} && \\
0 \leq z_i &\leq 1 && i \in V_1(r) \\
y_j &\in \{0, 1\} && j \in V_2.
\end{aligned}$$

Comparative analysis – Coverage

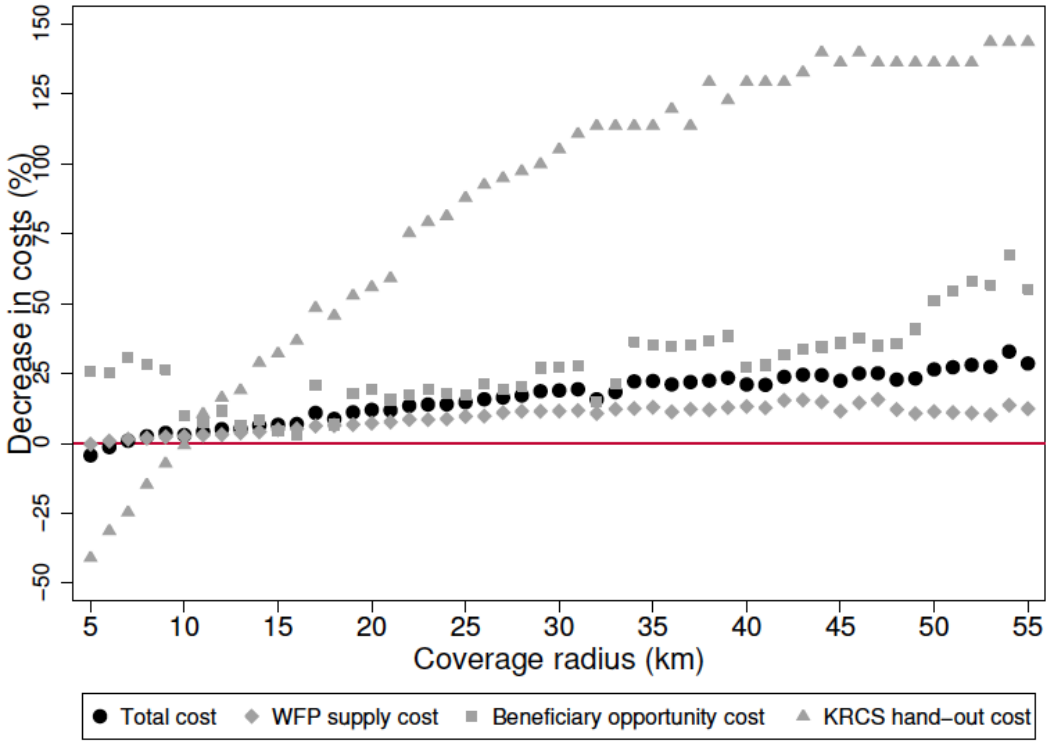
- Comparison of the % of covered people obtained with the cost model and the coverage model with 156 FDPs



Less covered people when $r \leq 10$

Comparative analysis – Stakeholder costs

- Comparison of the stakeholder costs obtained with the cost model and the coverage model with 156 FDPs



Larger beneficiary and WFP costs for all *r*, but similar cost when *r* = 10 km

Conclusions

- Defined a framework to optimize food aid distribution networks (FDP locations)
- Highlighted the importance of valuing the beneficiaries' time
- Found transportation costs to be the largest costs
- Found that, taking beneficiary opportunity costs into account, a relatively low value of *r* minimizes **total** costs

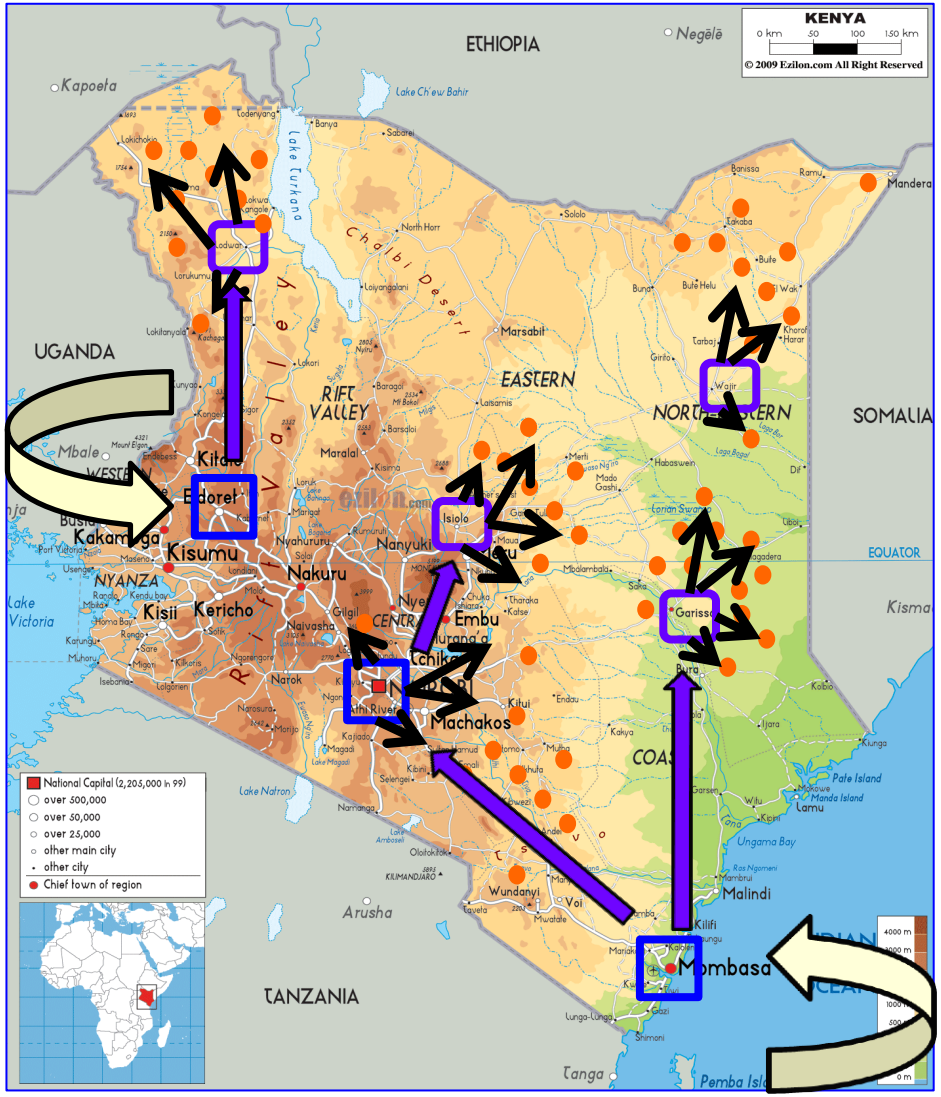
Next steps:

- How to design food aid supply chains that will lead to a more sustainable response and favour long-term economic growth?

Emerging aid systems
Sustainable food security and resilient supply chains

- **« Cash and Vouchers »**
  - Cash transfers provide money to people who are struggling to provide food to their families
  - Vouchers can be redeemed for food items or « spent » in selected shops
- **« Local purchase »**
  - WFP purchases locally in developing countries in its criteria of price, quality and quantity can be met
- **« Purchase for Progress »**
  - Test new procurement approaches best suited for small producers
  - Support farmers to get better yields, reduce losses, improve the quality of their crops and connect them to markets

Future research



- Dynamic and stochastic problem at the national level
- Procurement:
  - International
  - Local
- Two type of commodities
  - Food
  - Cash & vouchers
- Effect on local markets and food production
- Stakeholders
  - WFP and Kenya Red Cross
  - Beneficiaries
  - Local producers and traders
  - Non beneficiaries

Discussion

Questions and discussion…