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analytics for a BETTER WORLD

University of Amsterdam

Analytics for a Better World

Dick den Hertog

University of Amsterdam
Amsterdam Business School

UN Sustainable Development Goals

Contents

- Two ABW cases

  1. Optimizing food supply chain
  2. Optimizing hospital locations

- ABW-Institute

Optimizing food supply chain WFP

Team that won the Franz Edelman Award 2021

Koen Peters	**World Food Programme**
Sérgio Silva	
Tim Sergio	
Luis Anjos	
Nina van Ettekoven	
Éric Combette	
Anna Melchiori	
Hein Fleuren	**Tilburg University**
Dick den Hertog	University of Amsterdam
Ozlem Ergun	Northeastern University

Introduction to WFP

Hunger Map 2020

CHRONIC HUNGER

If current trends continue, the number of hungry people will reach 840 million by 2030

<2,5% | <5% | 5-14,9% | 15-24,9% | 25-34,9% | >35% | DATA NOT AVAILABLE

Prevalence of undernourishment in the total population (percent) in 2017-19

International Boundary — Armistice or International Administrative Line — Other Line of Separation — Special boundary line

The fact is: there is enough food

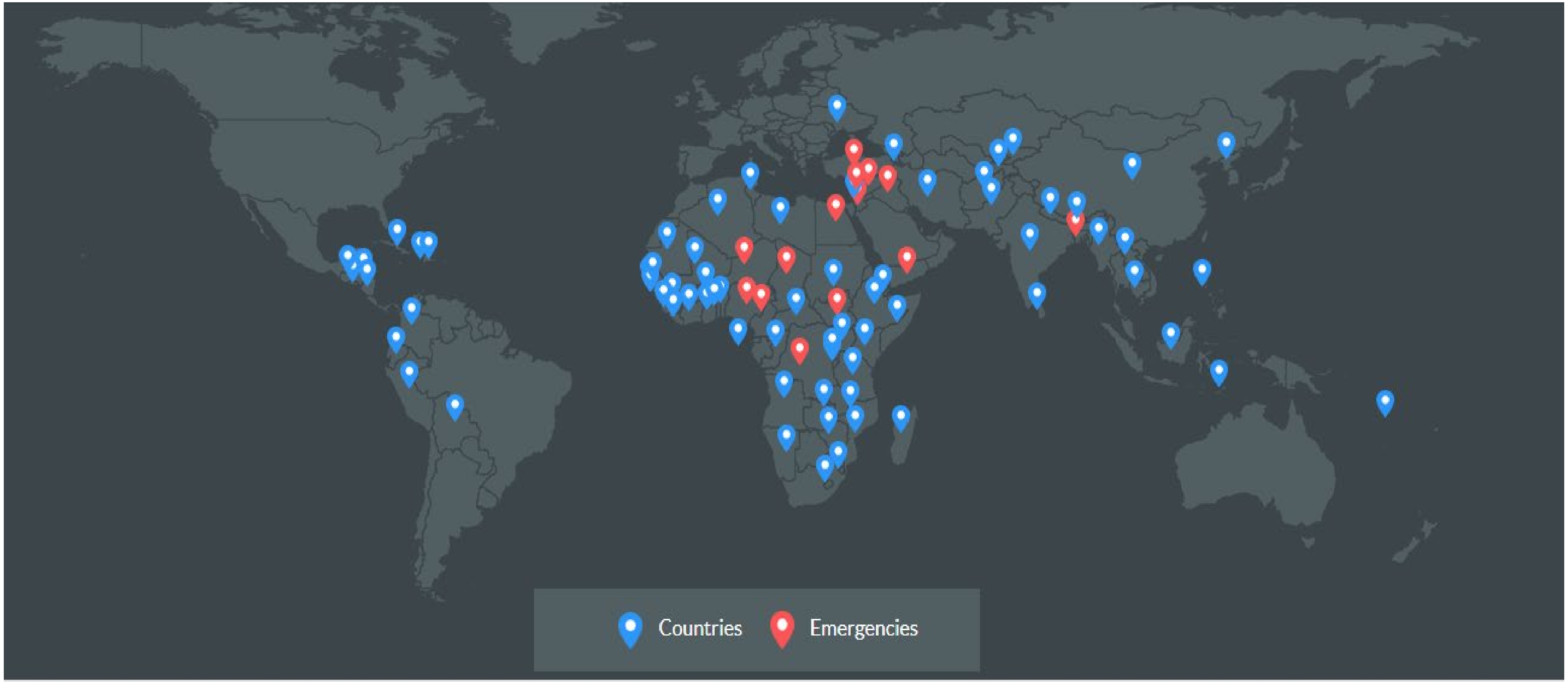
- We have a transportation issue

- The United Nations –

  World Food Programme
  is **supporting 80 Million**
  of the 821 Million beneficiaries

- They ship **4 million metric tons** each year!

WFP is active in about 75 countries

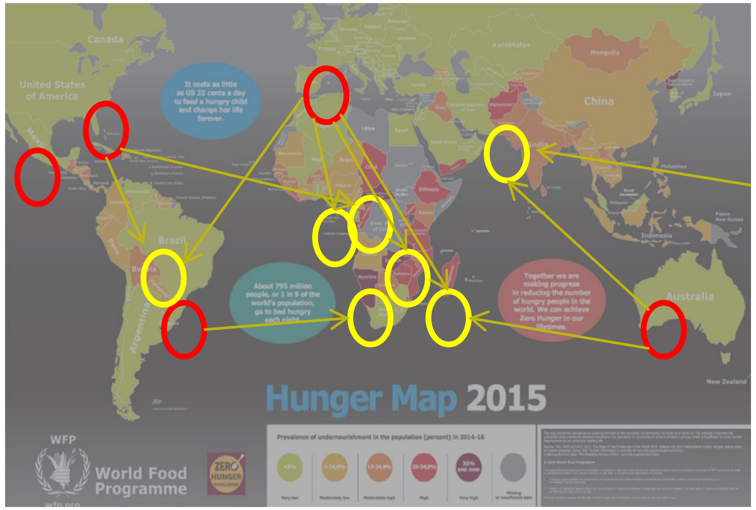


Optimization

Core element of success of model

Take also nutrients into account in the supply chain.

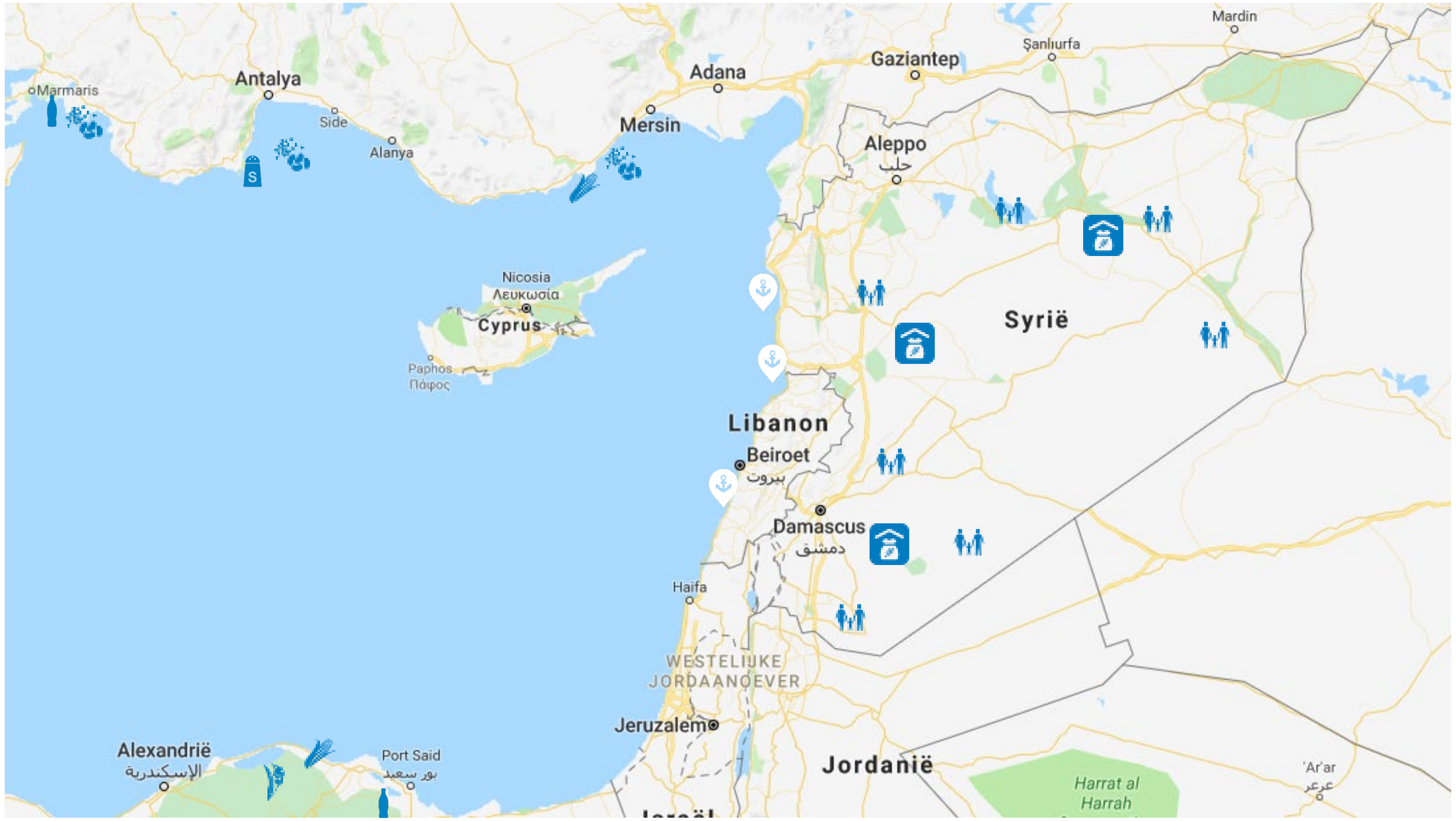
Multicommodity min cost flow + Diet model



Nutrition Facts

Serving size	1 potato (148g/5.2oz)
Amount per serving	
Calories	**110**
	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 0mg	0%
Total Carbohydrate 26g	9%
Dietary Fiber 2g	7%
Total Sugars 1g	
Includes 0g Added Sugars	0%
Protein 3g	
Vitamin D 0mcg	0%
Calcium 20mg	2%
Iron 1.1mg	6%
Potassium 620mg	15%
Vitamin C 27mg	30%
Vitamin B6 0.2mg	10%

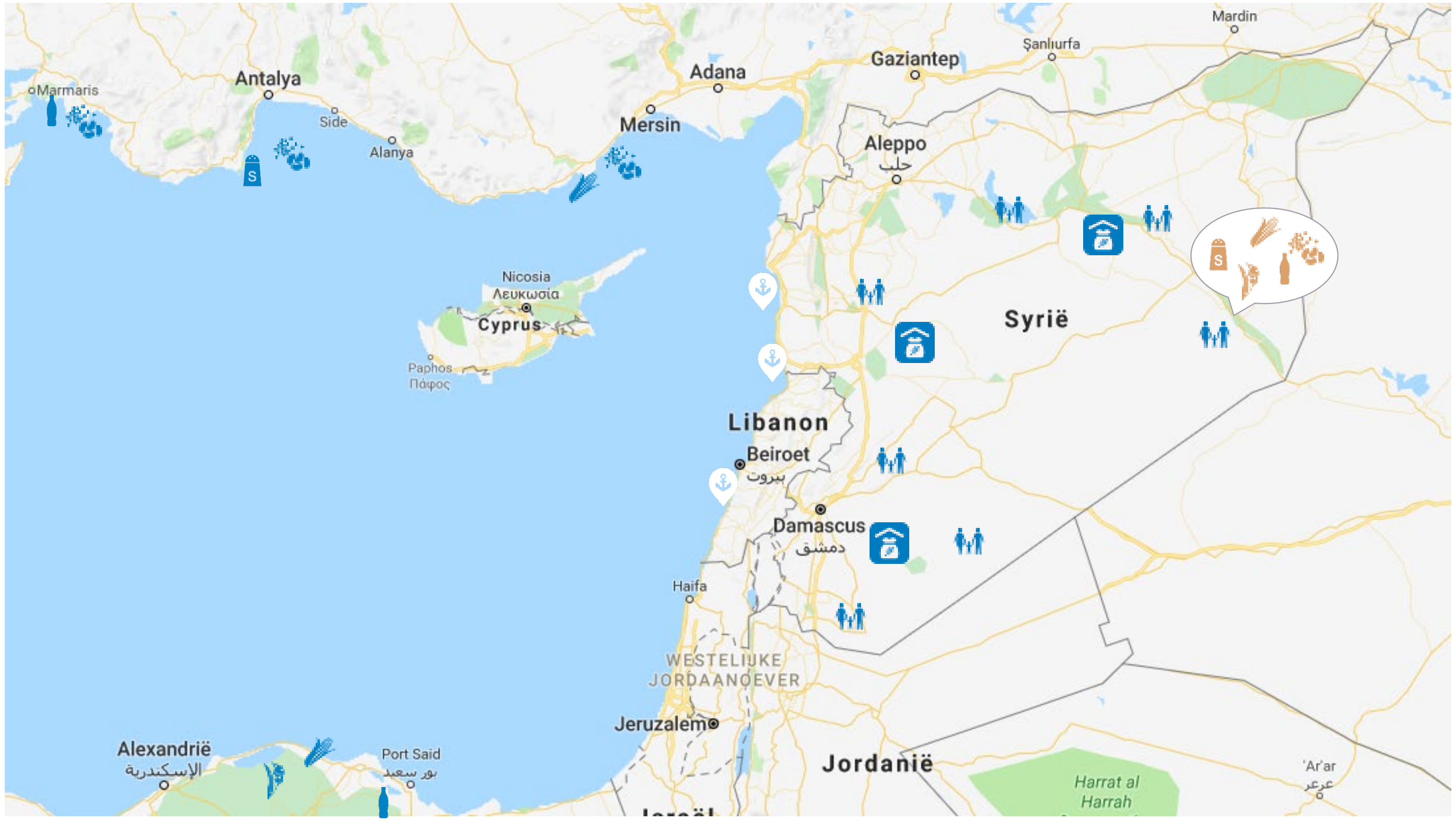
From source to delivery



Supplier   Harbor   Transshipment point   Delivery point

From source to delivery

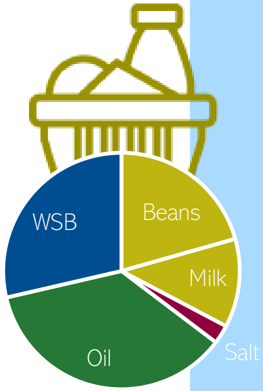
Food basket >

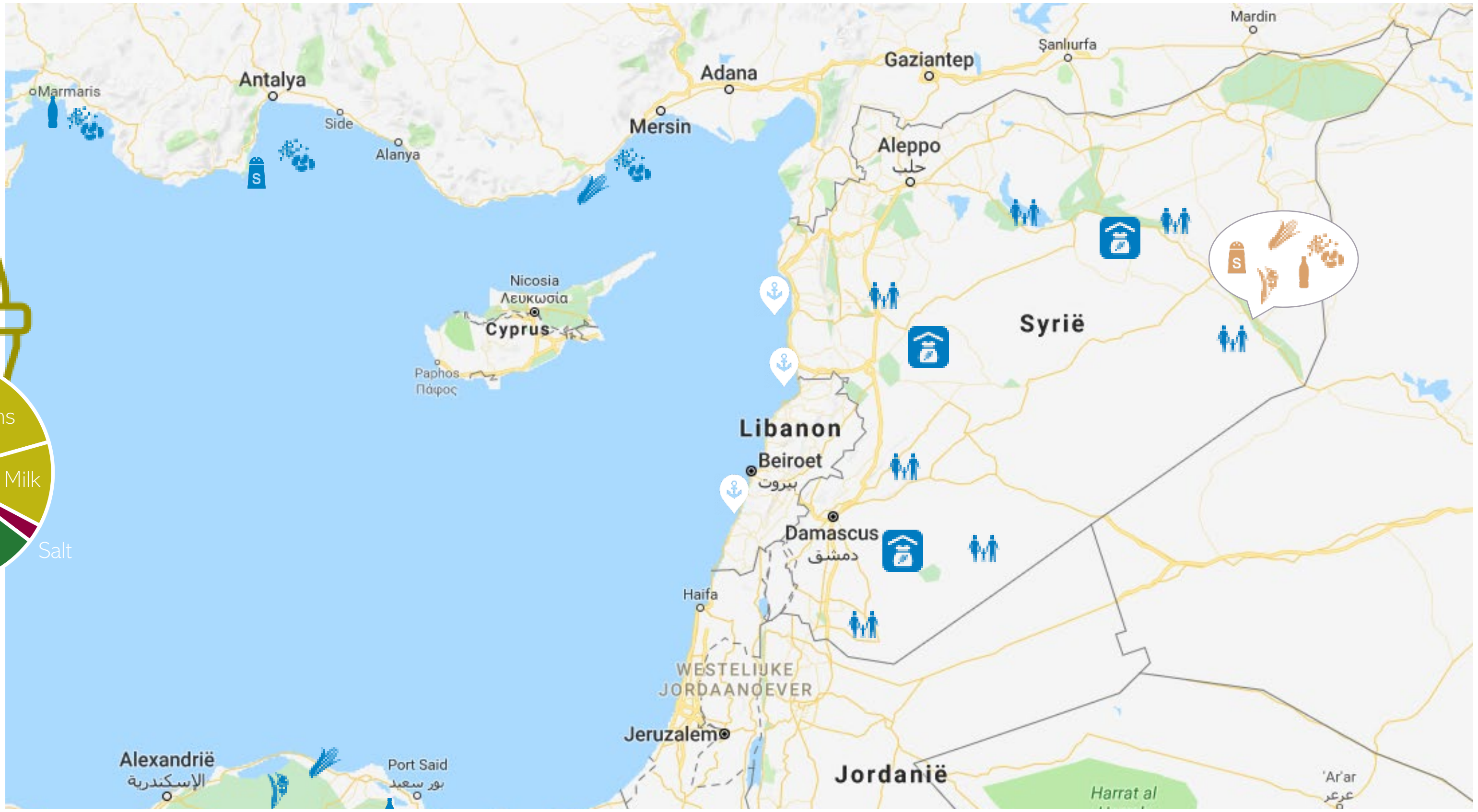


Based on the nutritional requirements of the beneficiaries

From source to delivery

Food basket >

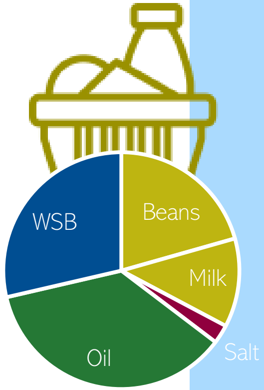


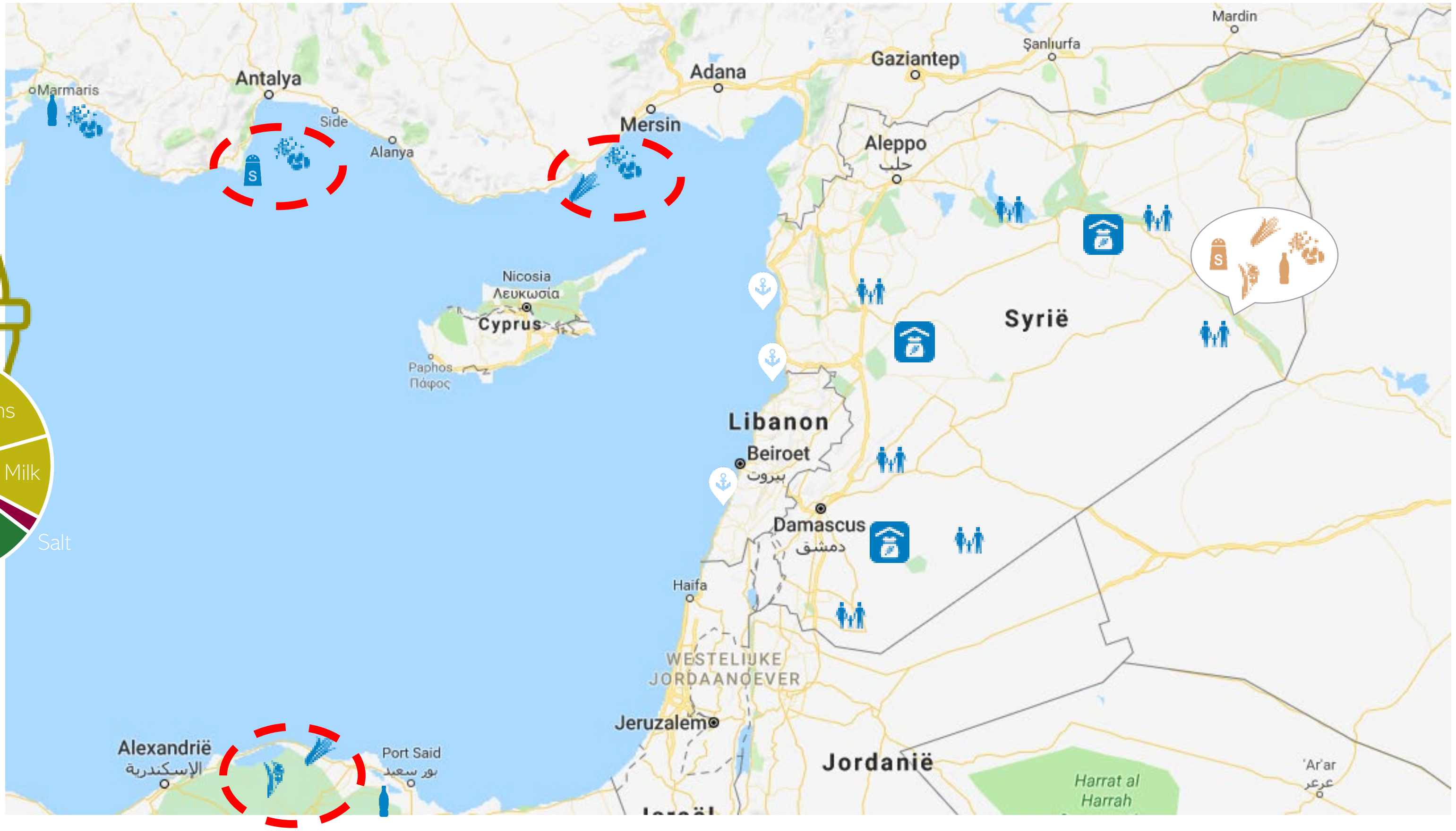


The model finds the most cost-effective food basket composition

From source to delivery

Food basket > Sourcing





Together with the most efficient sourcing plan

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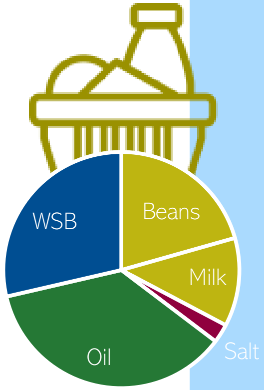
From source to delivery

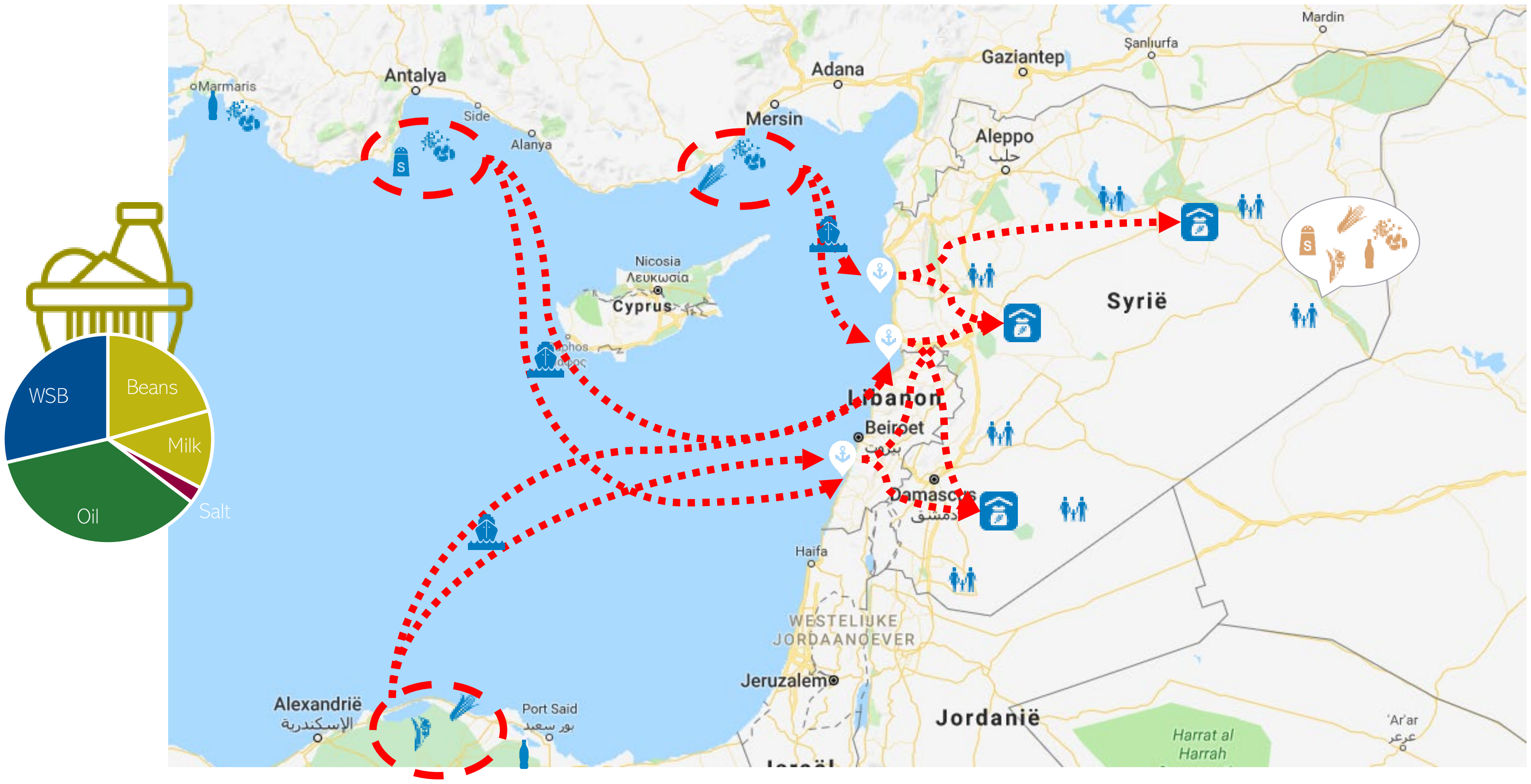
Food basket > Sourcing > Delivery



And delivery plan from the source

From source to delivery

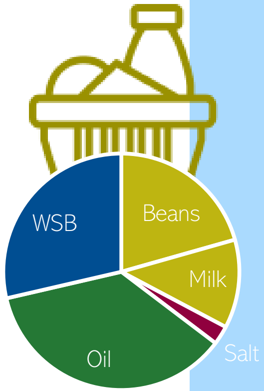
Food basket > Sourcing > Delivery

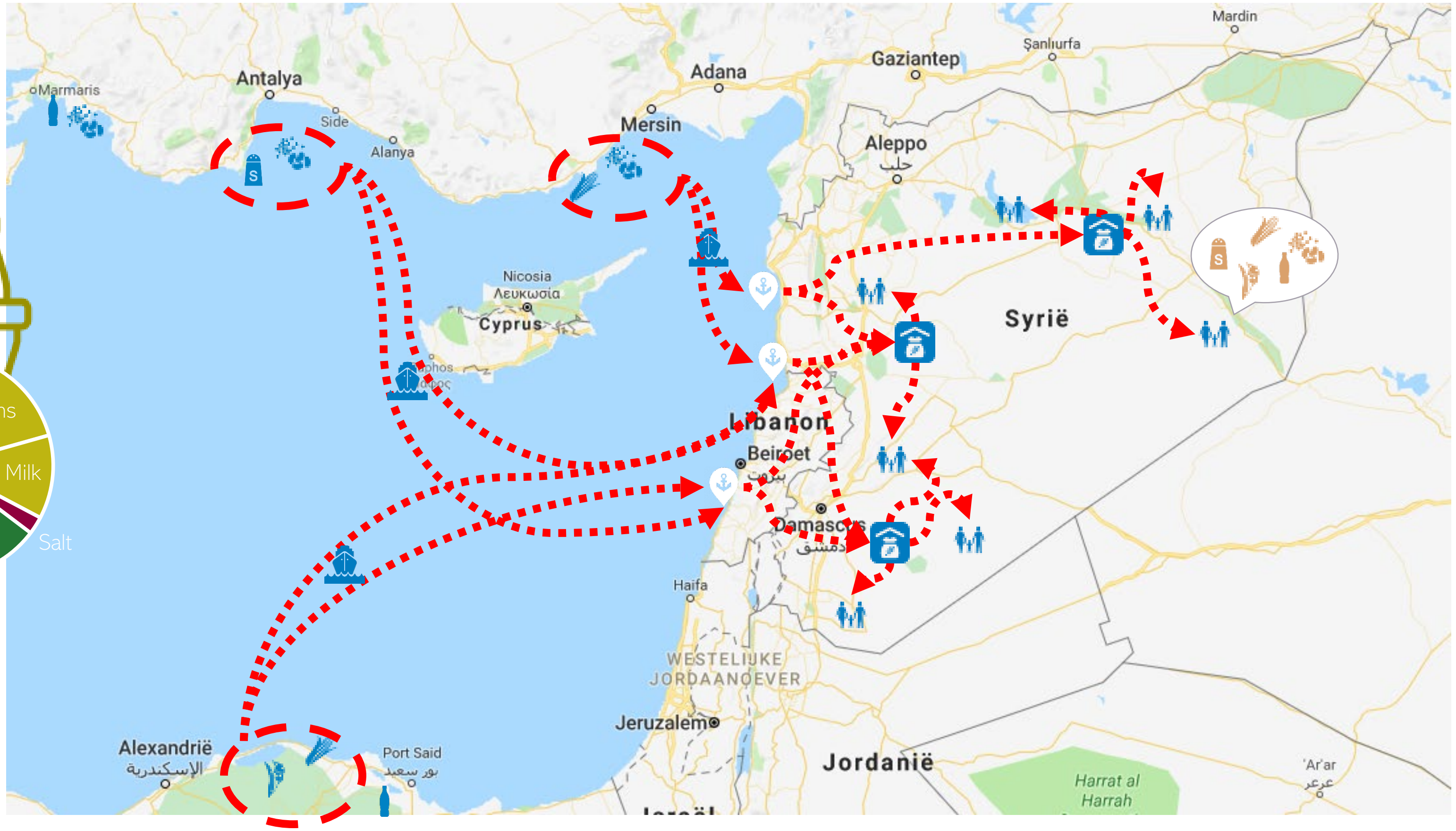


Via transshipment points

From source to delivery

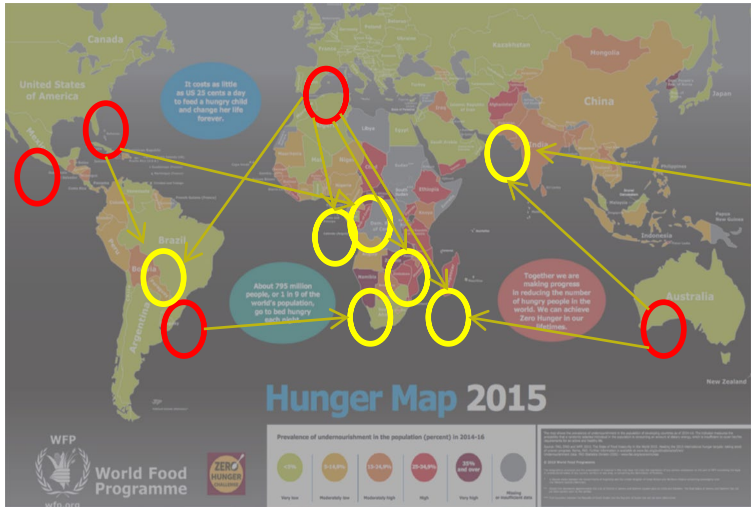
Food basket > Sourcing > Delivery





To the final delivery points

Optimization model



Multicommodity min cost flow

+

Diet model

Simplified optimisation model [1/2]

Sets

N = Set of Nodes $(i, j \in N)$
N_S = Set of Suppliers
N_P = Set of Ports
N_W = Set of Warehouses
N_B = Set of Beneficiary Camps
K = Set of Commodities $(k \in K)$

L = Set of Nutrients $(l \in L)$

Parameters
dem_i = Number of beneficiaries at node $i \in N_B$
hc_i = Costs $\left({}^{\$}/_{kg}\right)$ of handling at node $i \in N \backslash N_S$
pc_{ik} = Cost $\left({}^{\$}/_{kg}\right)$ of procuring commodity $k \in K$ from node $i \in N_S$
tc_{ijk} = Cost $\left({}^{\$}/_{kg}\right)$ of transporting commodity $k \in K$ from node $i \in N$ to node $j \in N$
$nutreq_l$ = Nutritional requirements of a beneficiary for nutrient $l \in L$
$nutval_{kl}$ = Nutritional value (per kg) of commodity $k \in K$ for nutrient $l \in L$

Variables
F_{ijk} = Amount (kg) of commodity $k \in K$ sent from node $i \in N$ to node $j \in N$
R_k = Ration size (kg) of commodity $k \in K$

Simplified optimisation model [2/2]

$$\min_{F} \sum_{i \in N_S, j, k} pc_{ik} * F_{ijk} + \sum_{i,j,k} tc_{ijk} * F_{ijk} + \sum_{i,j,k} hc_j * F_{ijk}$$

Such that:

1. Flow is preserved

$$\sum_{i} F_{ijk} = \sum_{i} F_{jik}, \qquad \forall j \in N_P \cup N_W, \forall k \in K$$

2. All beneficiaries receive a food basket

$$\sum_{i} F_{ijk} \geq dem_j * R_k , \qquad \forall j \in N_B, \forall k \in K$$

3. Nutritional requirements

$$\sum_{k} nutval_{kl} * R_k \geq nutreq_l , \qquad \forall l \in L$$

4. Flows and Rations are non-negative

$$R_k , F_{ijk} \geq 0, \qquad \forall i \in N, j \in N, k \in K$$

Extensions of the simplified model (1)

- Multiperiod
- Seasonal price windows / season basket
- Different beneficiary types
- Adults / children / pregnant women / …
- Ration differentiation by location
- Cash Based Transfers
- Cash / Commodity Vouchers / Value Vouchers
- Donor restrictions

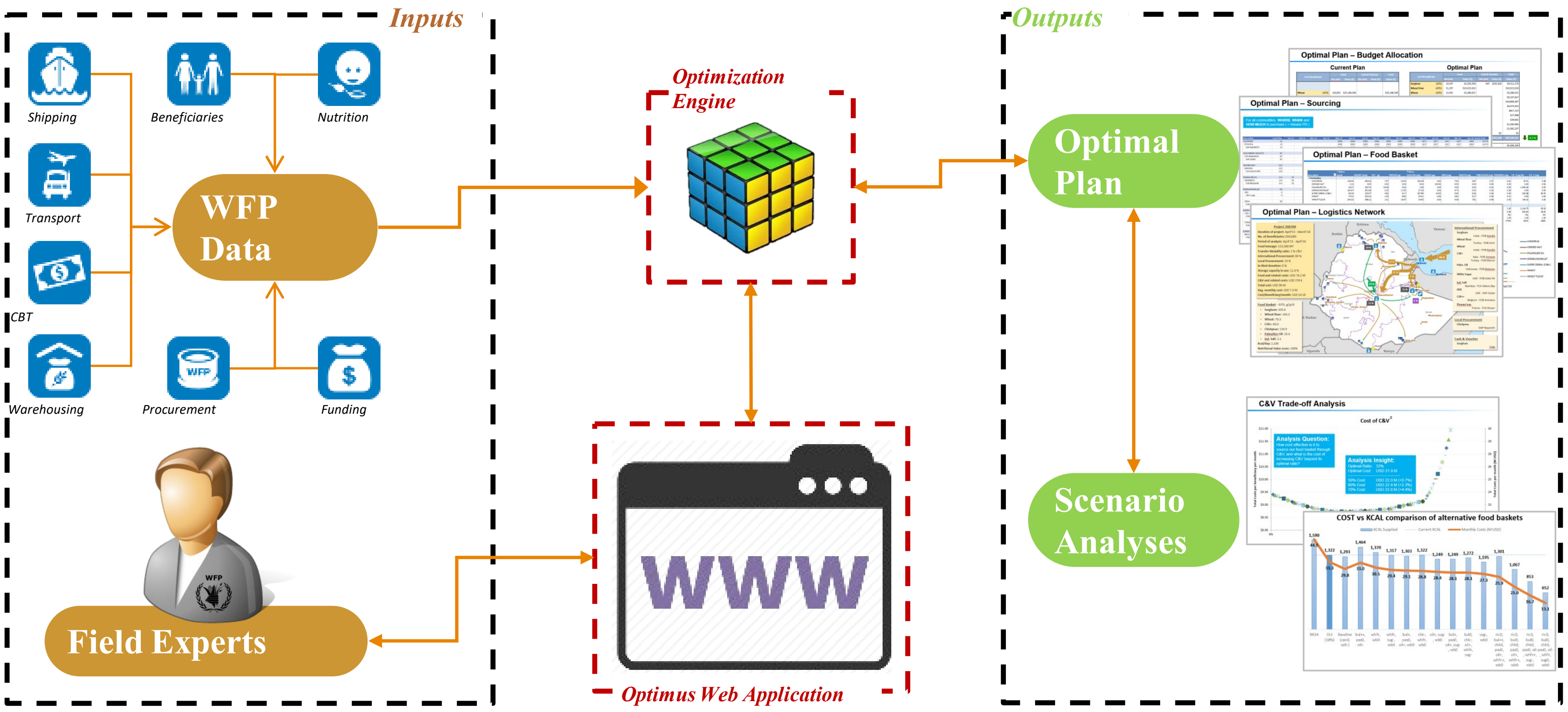
Extensions of the core model (2)

- Palatable restrictions

Food Group	Min rat (g/p/d)	Max rat (g/p/d)
Cereals & Grains	250	500
Pulses & Vegetables	30	130
Oils & Fats	15	40
Mixed & Blended Foods	0	60
Meat & Fish & Dairy	0	40

- International / Regional / Local
- Different and multiple objectives
- Dietary diversity score, development, agility (e.g. max lead time)

Software: Optimus



Can be accessed online, allows users to interact with data from a wide range of sources in order to optimize their operation.

Applications and Benefits

Application to Iraq - 2015

500,000 beneficiaries per month - 6.57 million USD per month

With the **new** food basket:

- Save **17%** of the total costs: **1.12 million USD per month**
- Or supply **85,000 more** beneficiaries

Application to Syria - 2016

We could show that there are food baskets possible of:
- 96.0% nutritional value at **74%** of the cost
- 97.5% nutritional value at 85% of the cost

The first option is chosen by WFP in Syria for 2016
and therefore, **with the same budget**,
we can feed **1 Million people more**
than the 4 Million in 2015!

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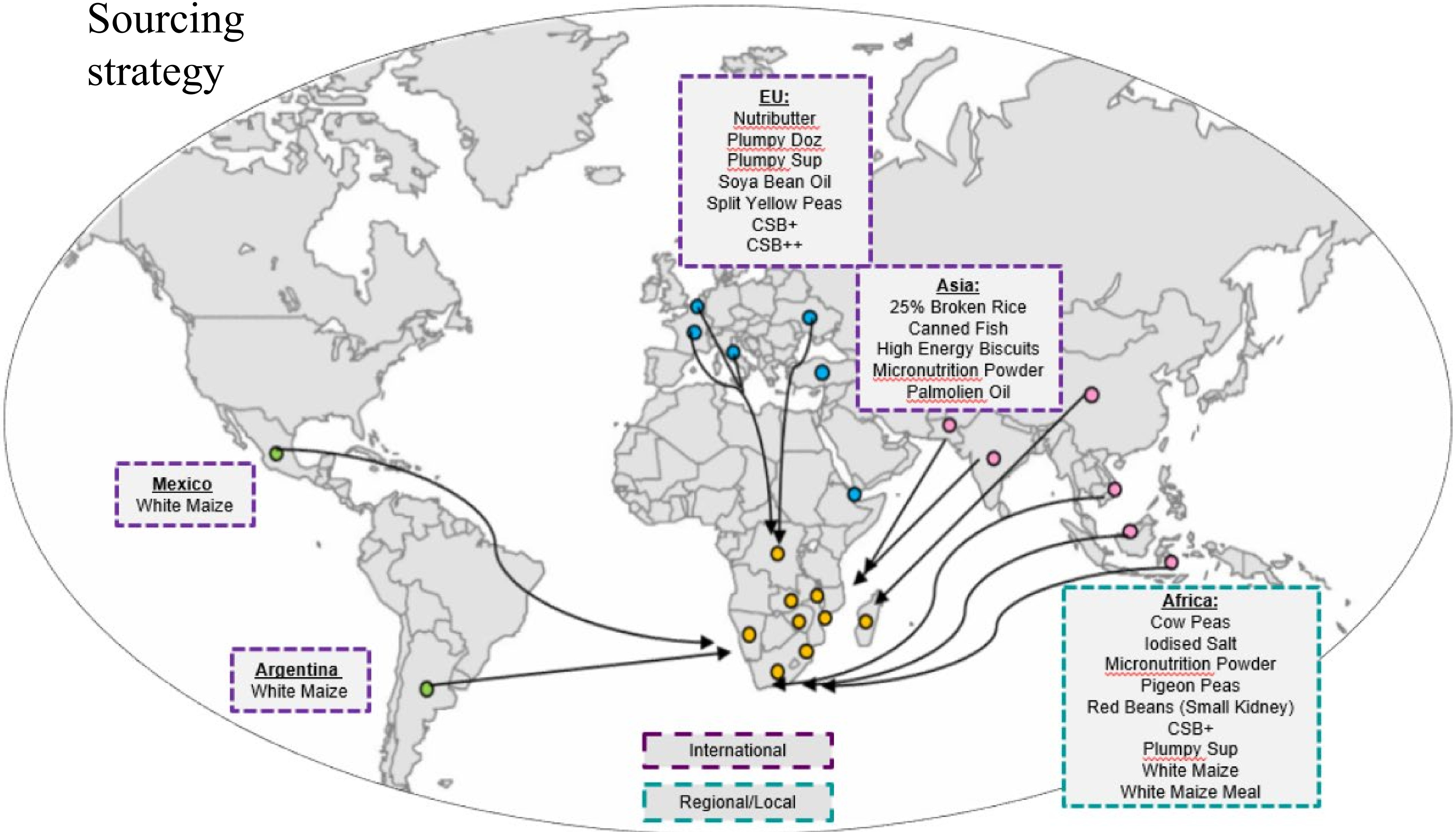
Application to El Nino crisis

Sourcing strategy



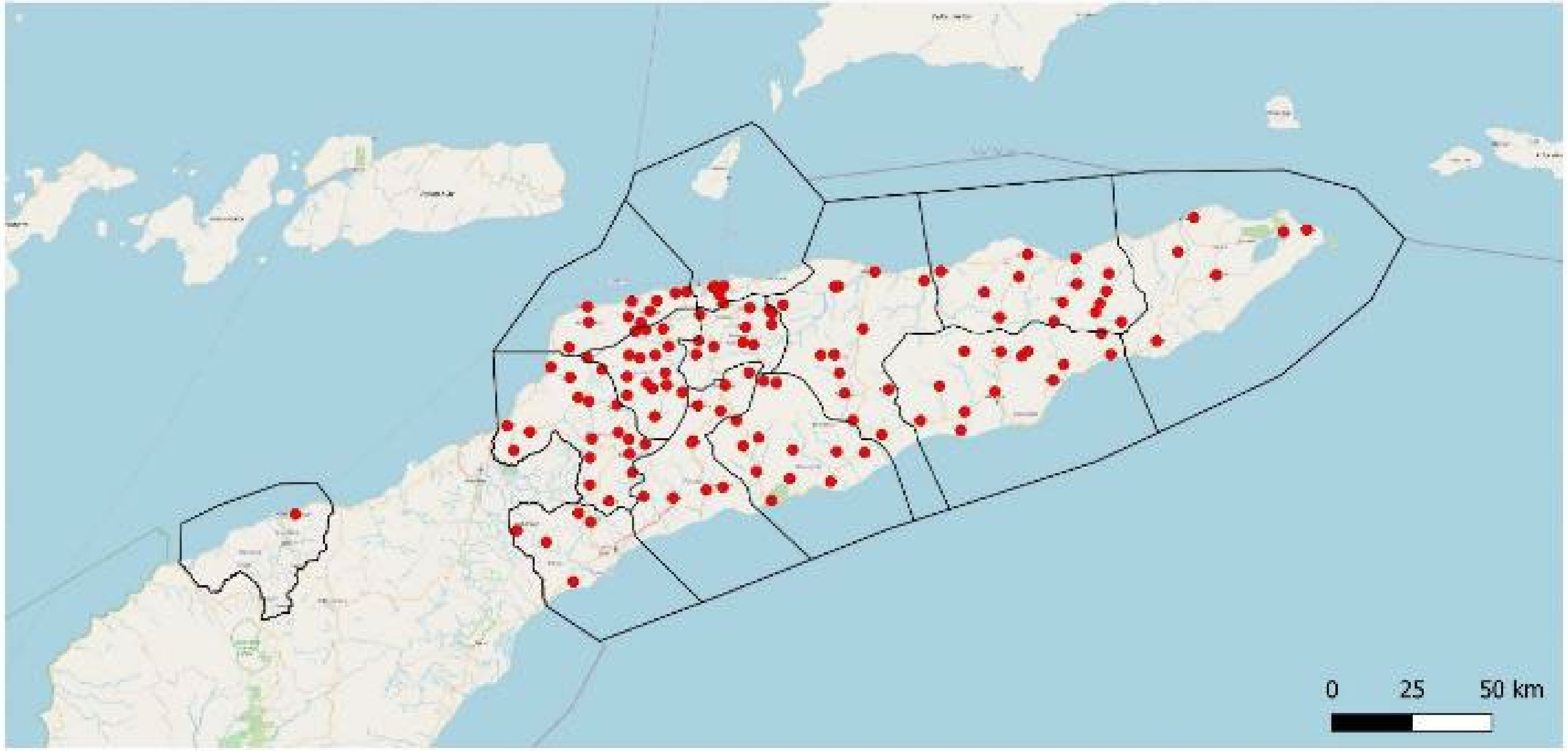
Hospital location optimization in Timor-Leste

WORLD BANK

3 GOOD HEALTH AND WELL-BEING

Timor-Leste

Find optimal locations of new hospitals



… maximize number of people that can reach a hospital within 5 kilometers travel distance.

Reachability of health care is important

There is a direct link between the distance patients must travel and the reduction of illness and suffering in a country.

If health facilities are located close to patients instead of far away, they tend to use them more.

The distance factor is especially significant in rural Third World settings

GPBP

HOME TIMOR LESTE VIETNAM

GEOSPATIAL PLANNING & BUDGETING PLATFORM

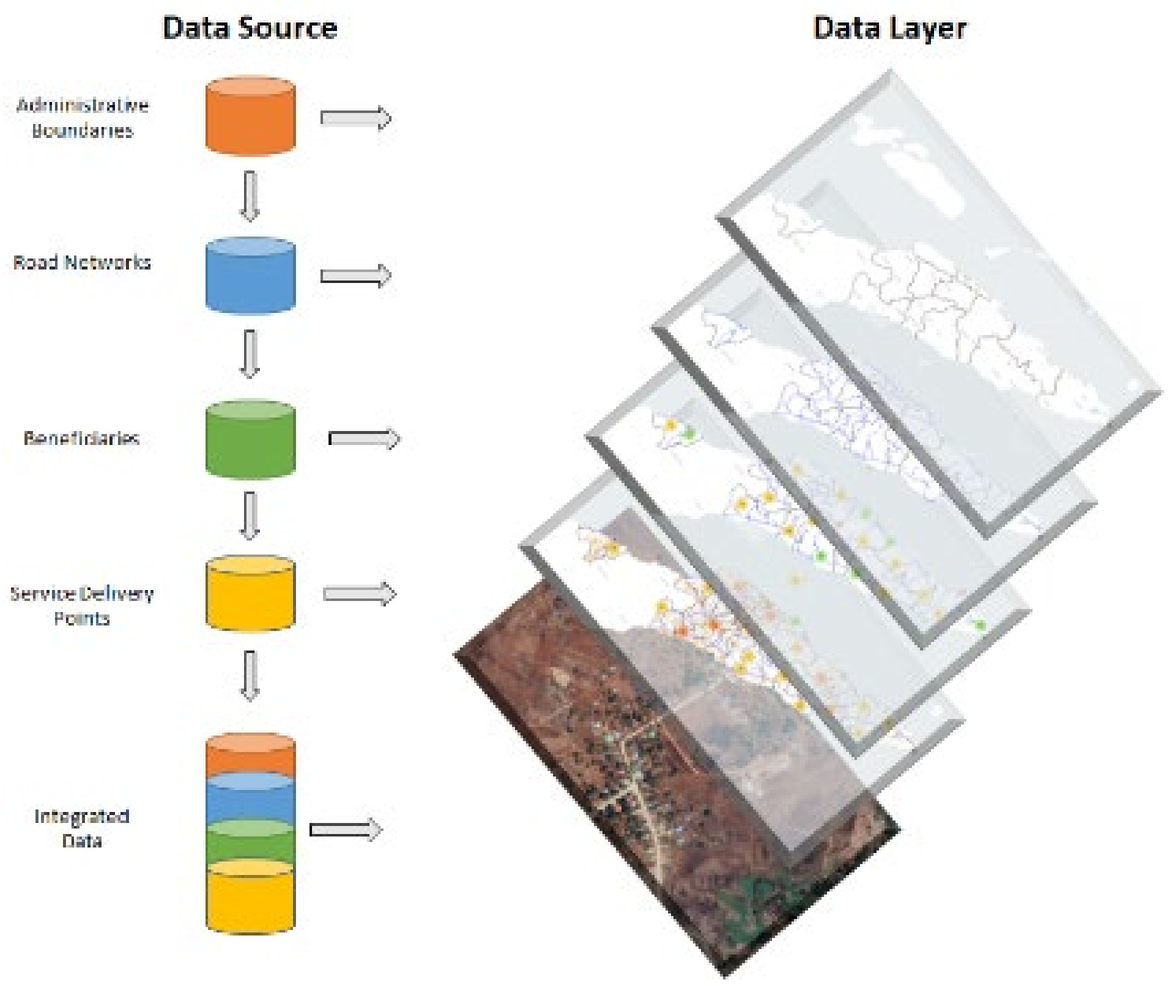
THIS INTERACTIVE SITE ALLOW USERS TO EXAMINE KEY SPATIAL LAYERS RELATED TO FACILITY LOCATION, ROAD NETWORK CONSOLIDATIONS, POPULATION DISTRIBUTION, ADMINISTRATIVE BOUNDARIES, RISK LAYERS (E.G., FLOODING), AND SATELLITE IMAGERY.

TIMOR-LESTE BASIC HEALTH CARE ACCESS

VIETNAM STROKE VICTIM HEALTH CARE ACCESS

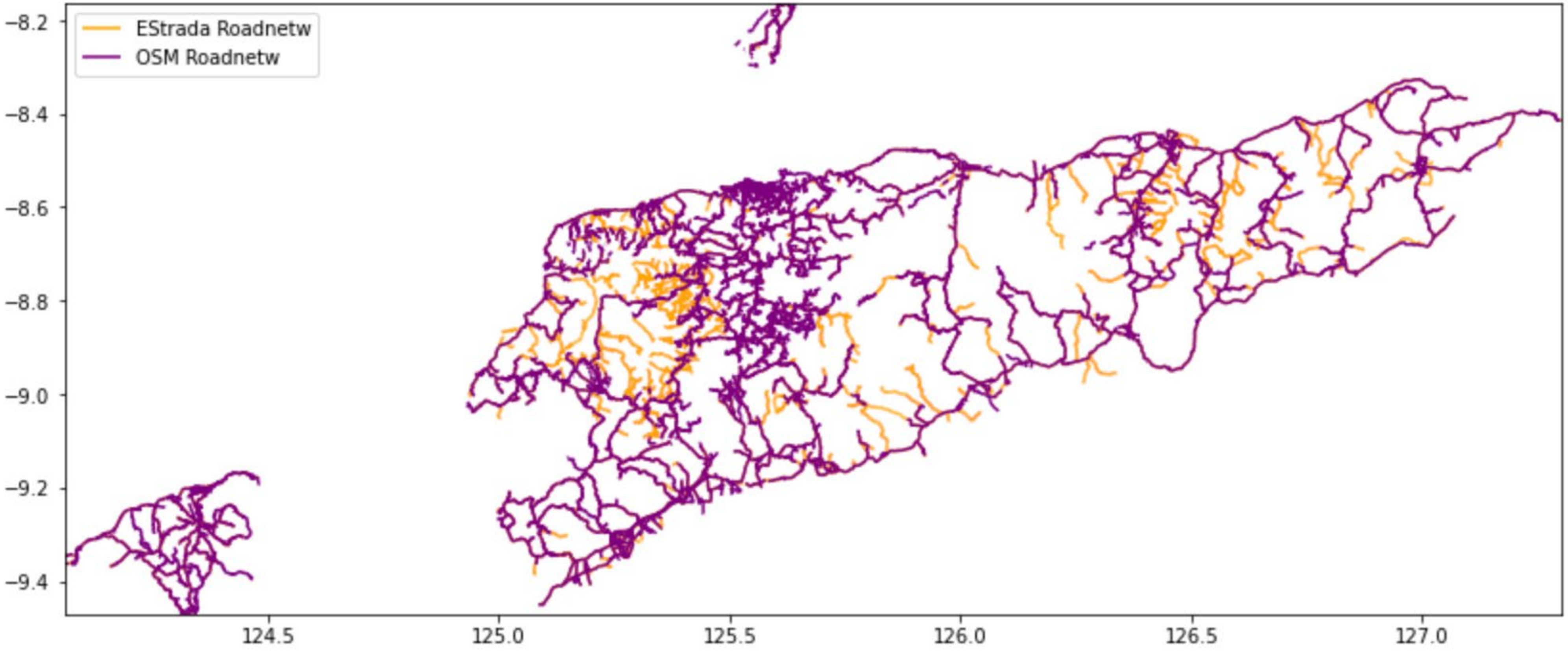
Necessary data layers

- Beneficiaries
- Currently located hospitals
- Potential hospital locations
- Road network



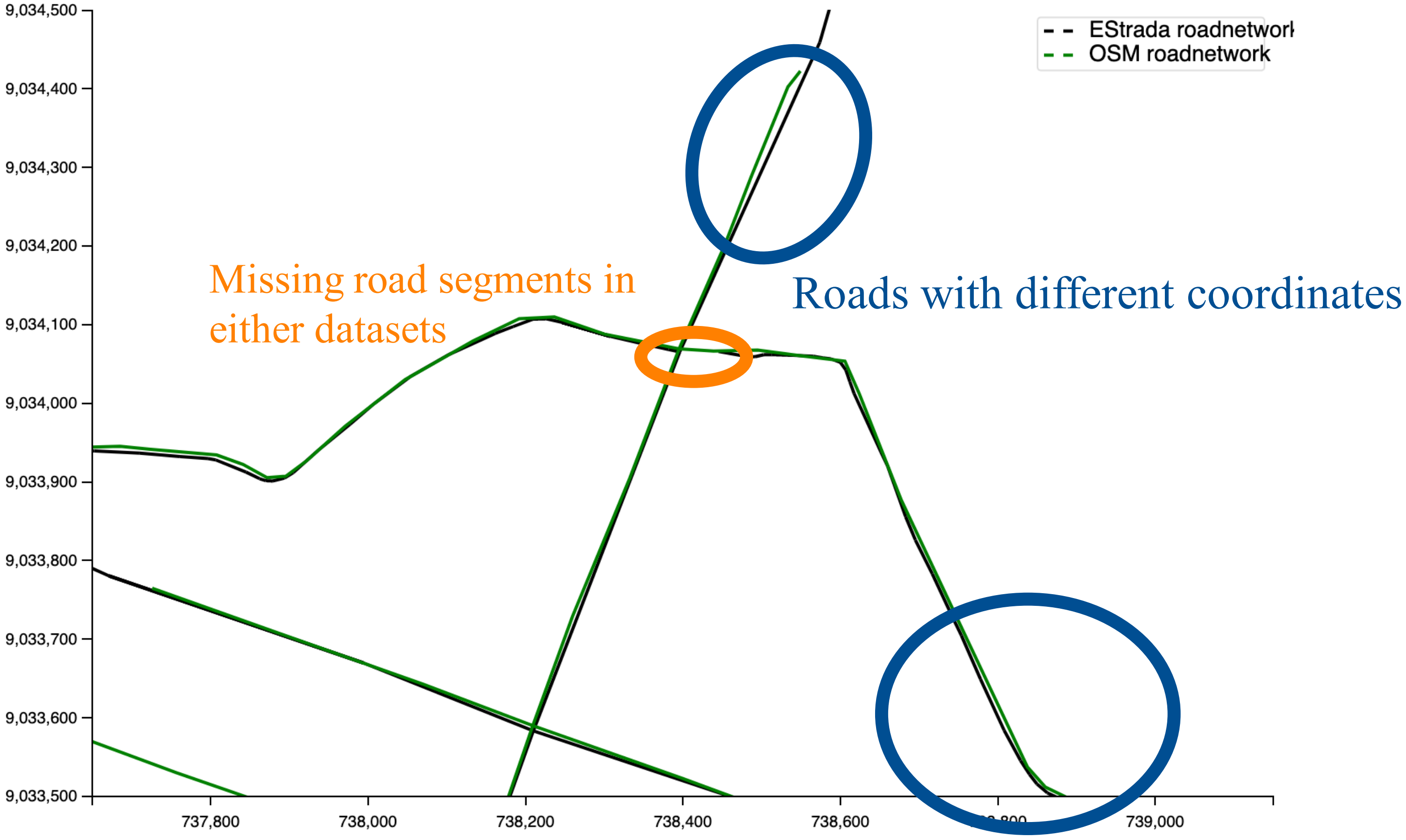
Merging road networks

Combining OSM and eStrada. This is very usefull.



Problem: they have overlap, but with different coordinates

- Resulting in roads being included twice in the dataset
- Roads don’t have the exact same coordinates, but refer to the same road



Optimization model

- Uncapacitated facility location model
- Mixed integer linear optimization model
- Large problem: 15,000 possible locations, 40,000 household locations
- Solver: Gurobi
- Time: < 1 minute

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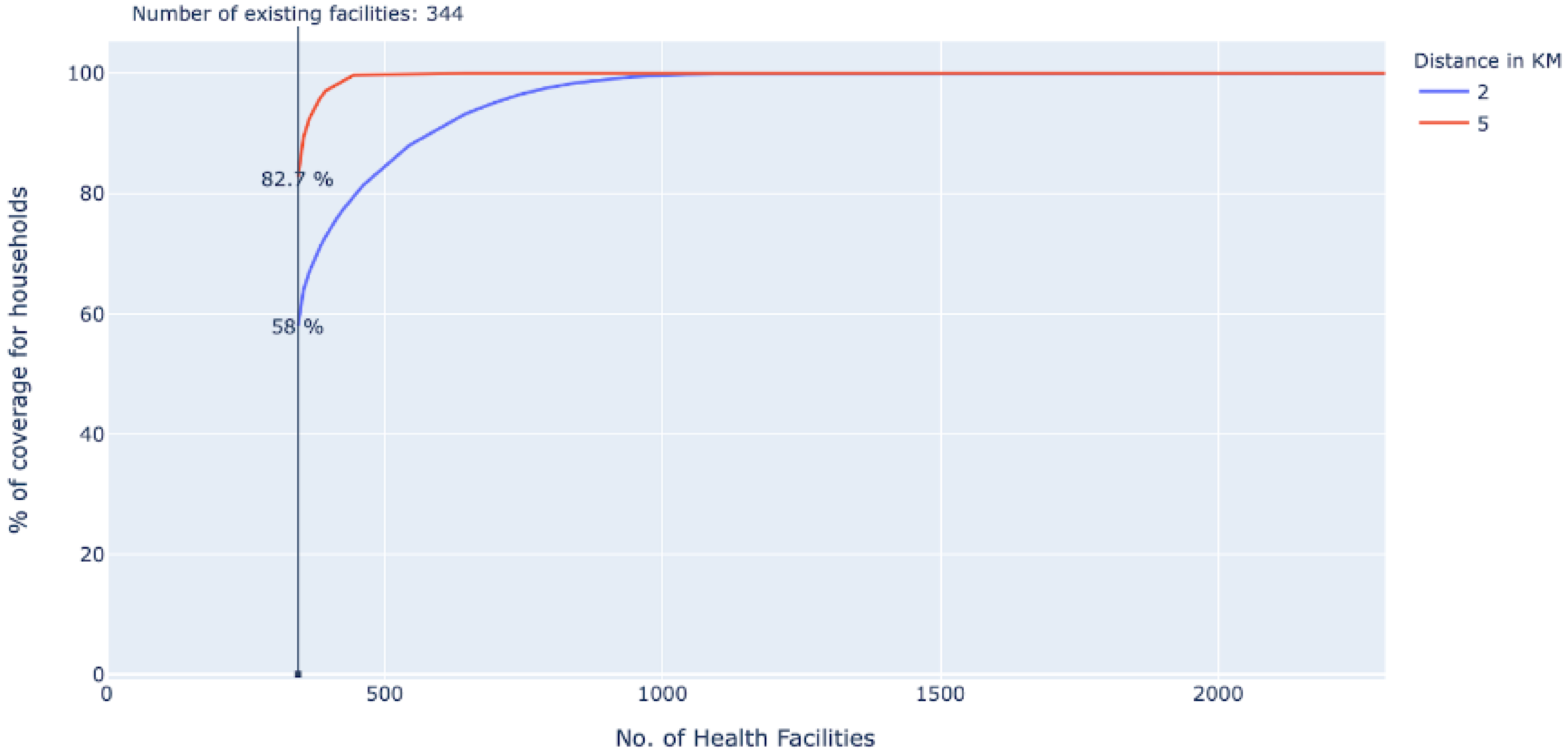
Results



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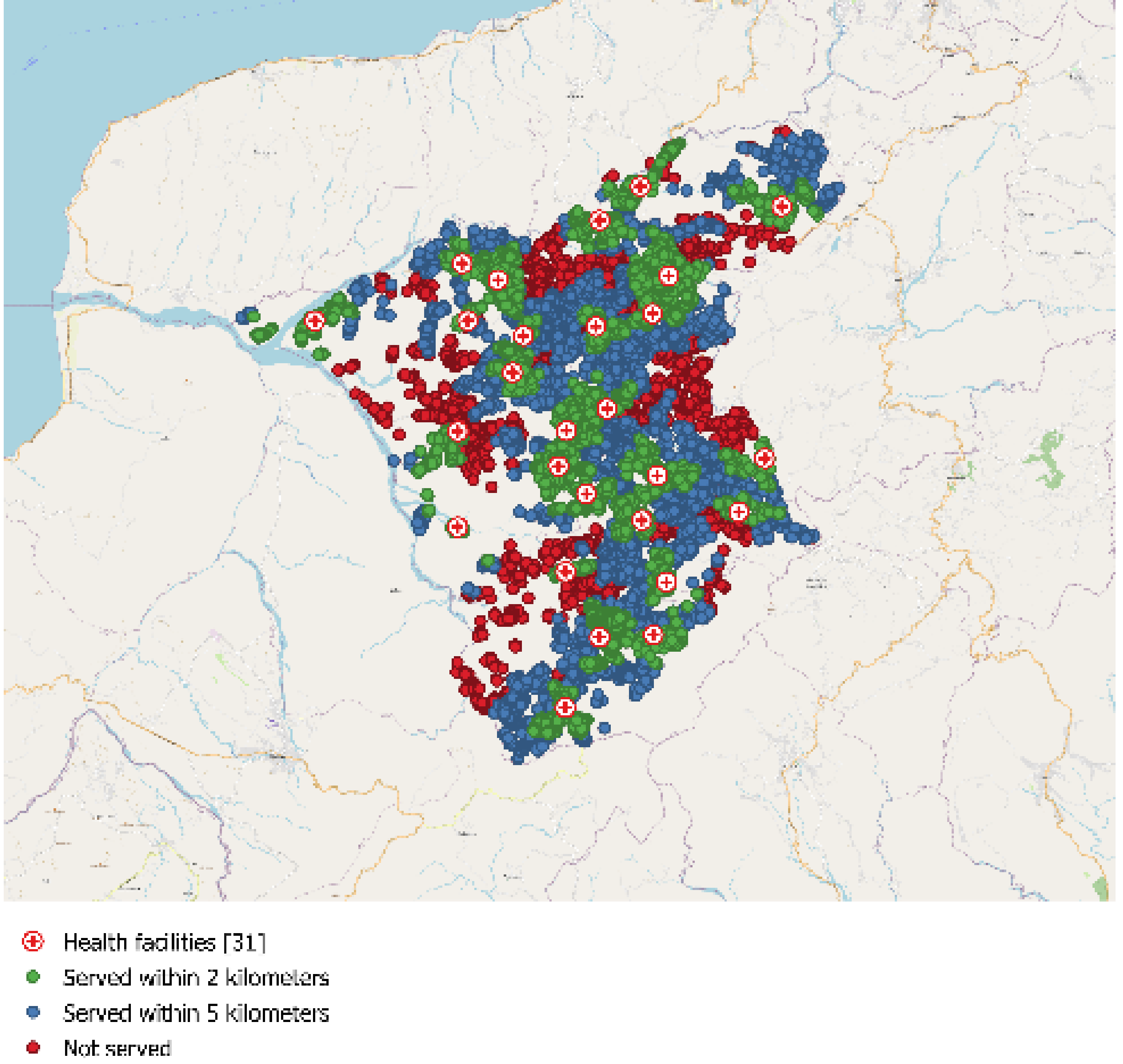
Ermera

Households

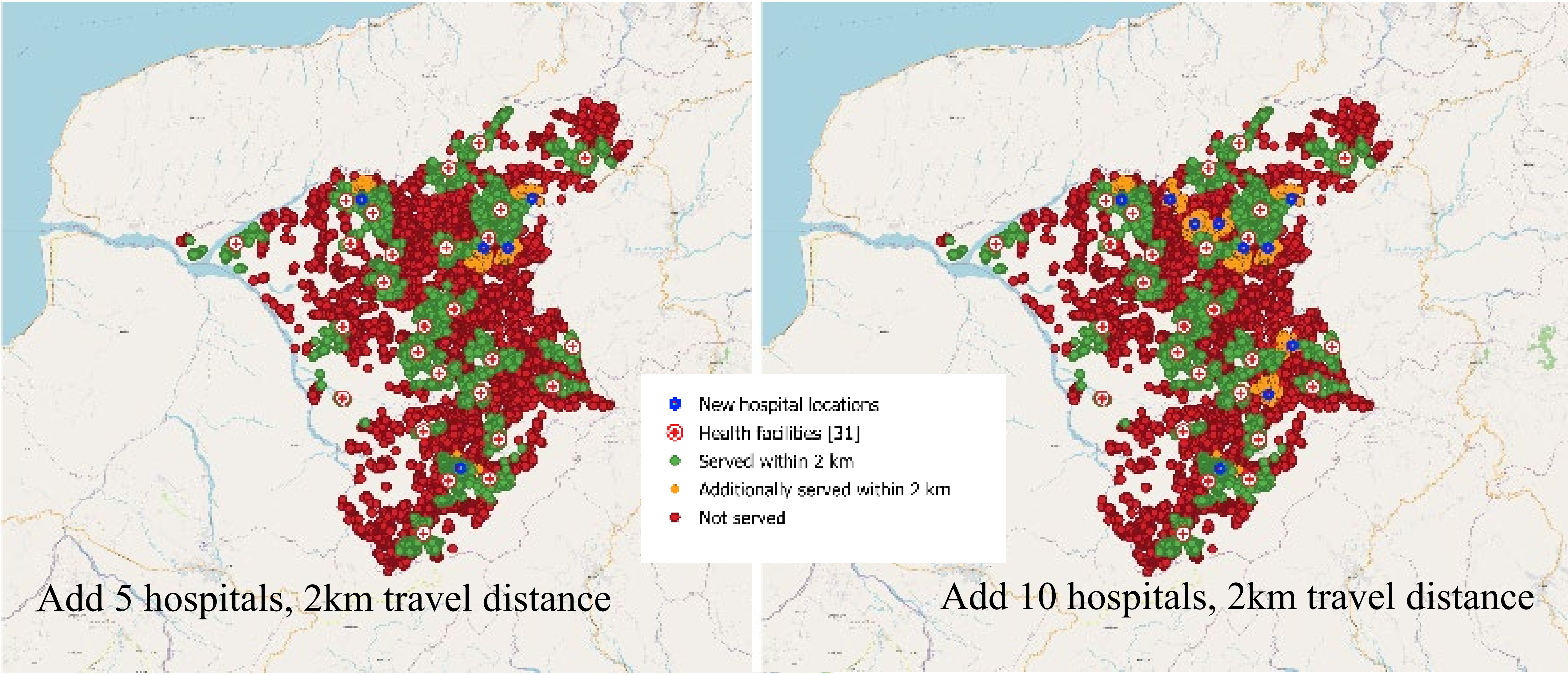
within 2 kilometers (green)

or 5 kilometers (green + blue)

from existing hospitals

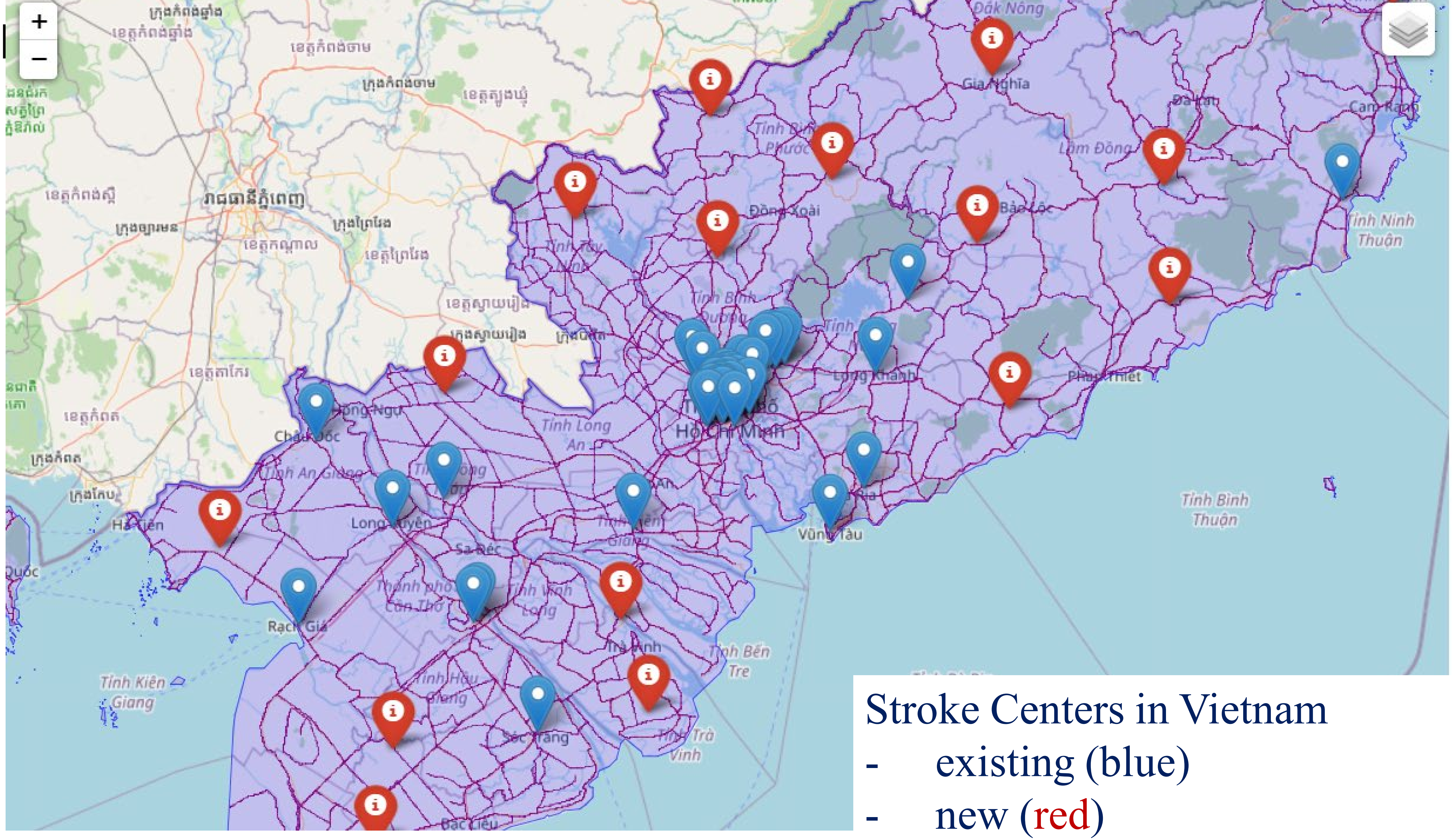


Ermera



Add 5 hospitals, 2km travel distance

Add 10 hospitals, 2km travel distance



Stroke Centers in Vietnam

- existing (blue)
- new (red)

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UN Sustainable Development Goals

ABW - Institute

- Impactful projects
- Worldwide seminar series
- Repository
- Academy
- Scientific journal
- Courses in Bachelor and Master Programs

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ORTEC

Massachusetts Institute of Technology

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Thank you!

Acknowledgement: Several of the slides are (adapted) from slides made by Hein Fleuren and Koen Peters.

Optimization of dike heights

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Optimization of radiotherapy

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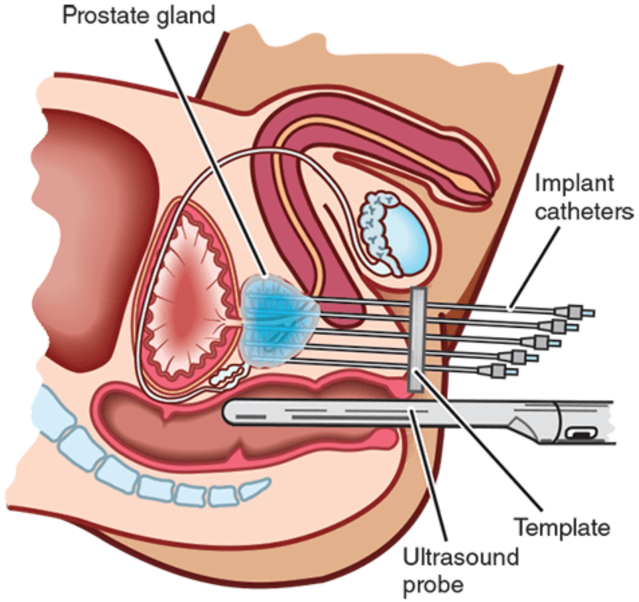
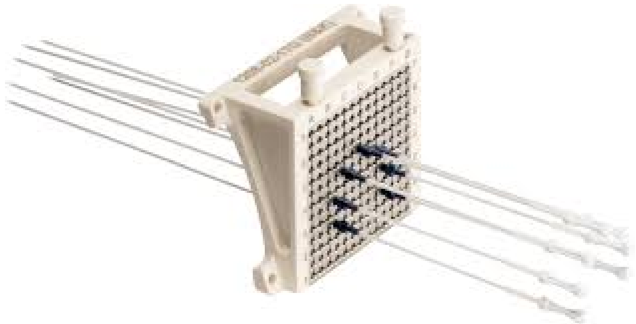
3 GOOD HEALTH AND WELL-BEING

Optimization Brachytherapy





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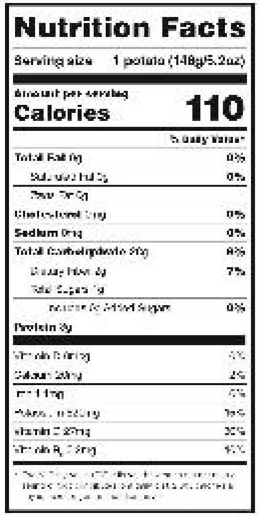
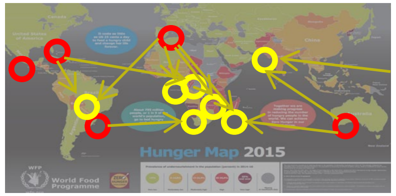
2 ZERO HUNGER

Analytics for Zero Hunger

WFP
United Nations
World Food
Programme





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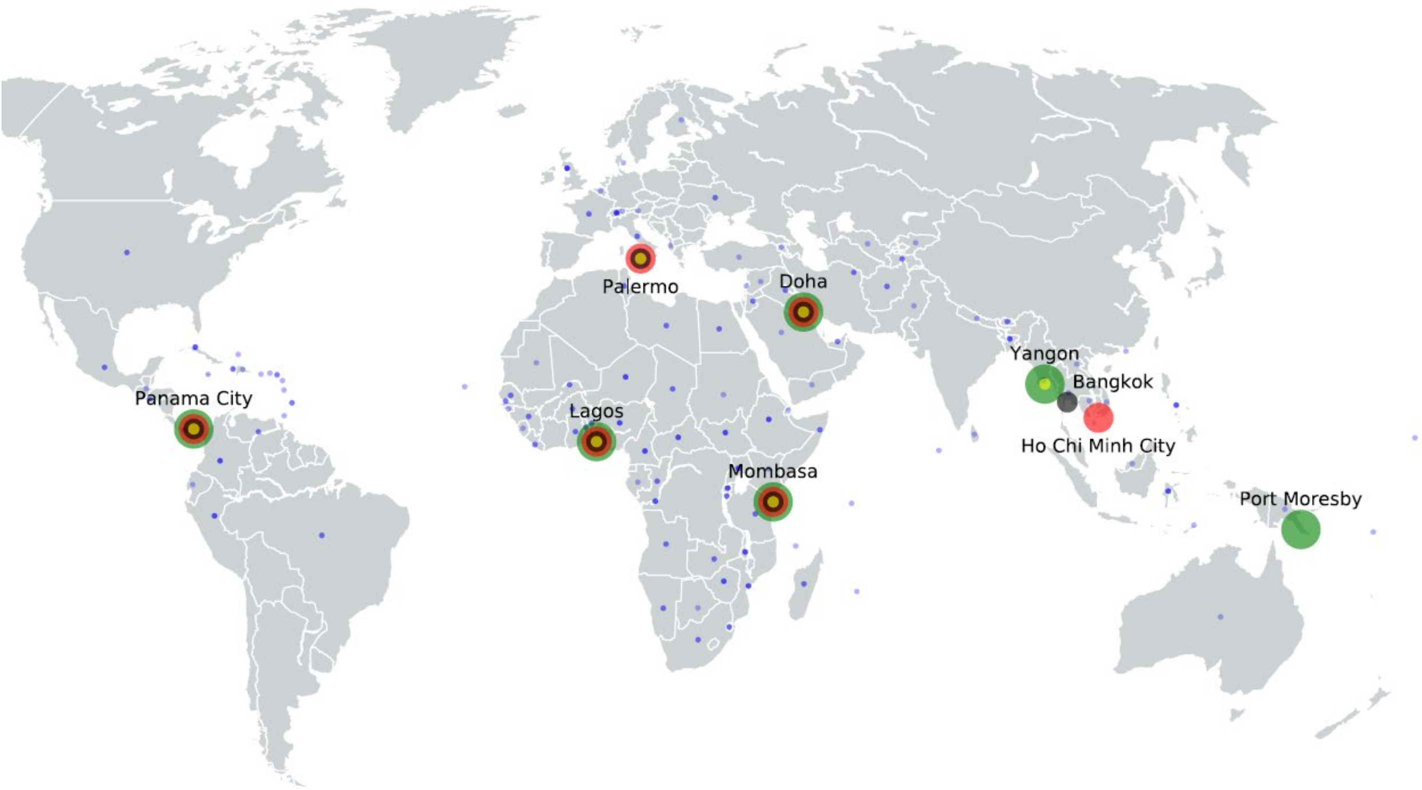
Investment infrastructure Timor Leste

Optimal Locations UN Humanitarian Response Depots



Optimizing feed for cattle for small farmers

SINGLE SPARK
Business-in-a-Box!

Total Feedcalculator users

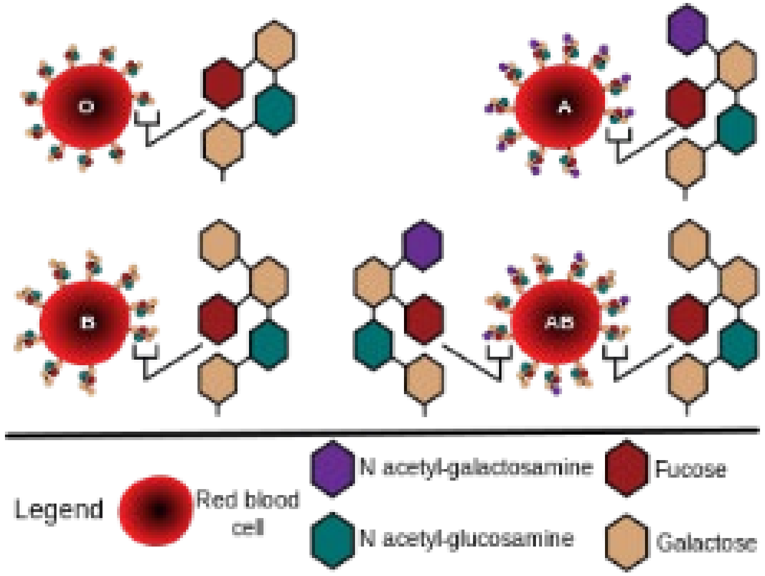
3107

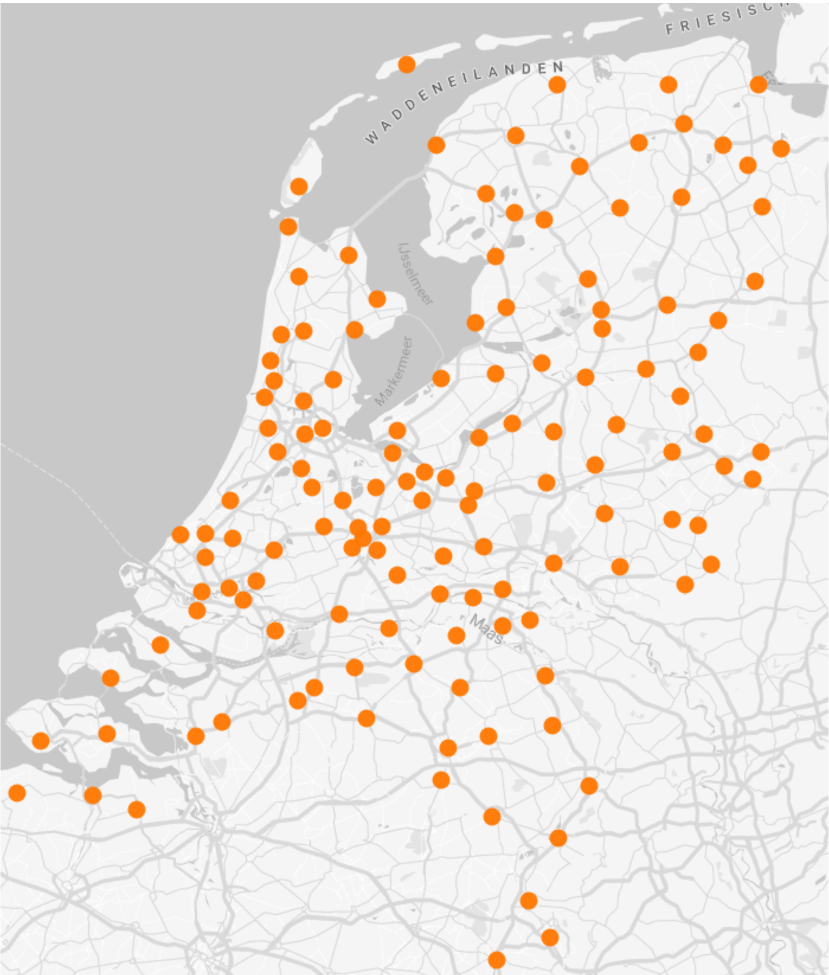
Source: FeedCalculator website

3 GOOD HEALTH AND WELL-BEING

Optimizing blood supply chain in NL

Sanquin
Bloedvoorziening





Source: Sanquin website

Thank you!

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Comparing procurement costs of a flexible basket to a fixed basket plan

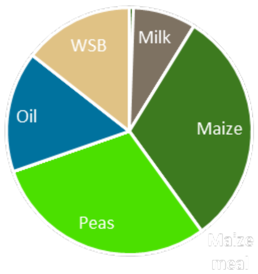
Scenario: The price of Peas increases by 30 percent regionwide in month 2

Month 1 | **Month 2** | **Procurement Cost**

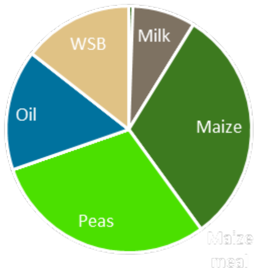
Peas — Month 2: +30%

Fixed basket

Month 1:

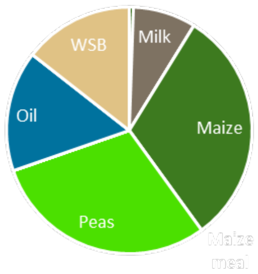


Month 2:



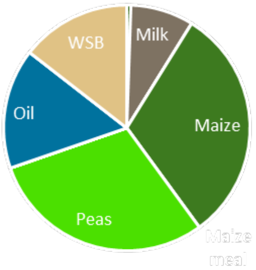
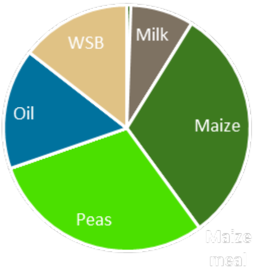
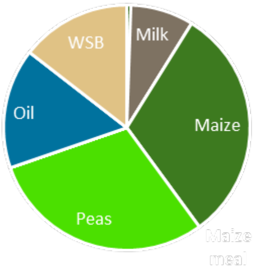
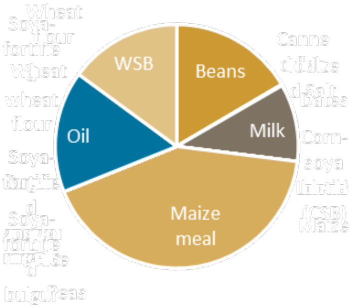
Flexible basket

Month 1:



When prices rise, the flexible food basket adapts to be most cost-effective

Scenario: The price of Peas increases by 30 percent regionwide in month 2

	Month 1	Month 2	Procurement Cost
Peas		+30%	
Fixed basket			$ 11.07 / beneficiary / month
Flexible basket			- $ 0.56 / beneficiary / month

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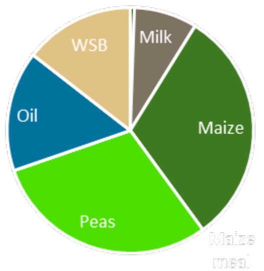
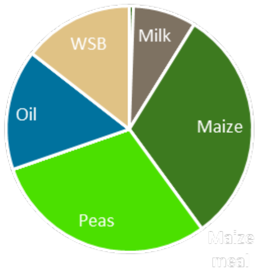
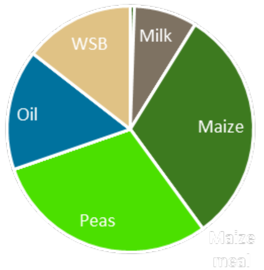
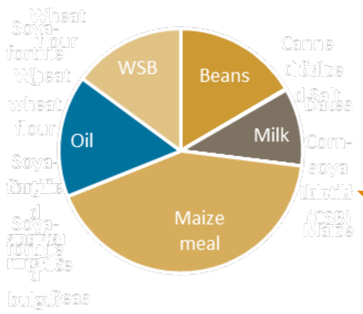
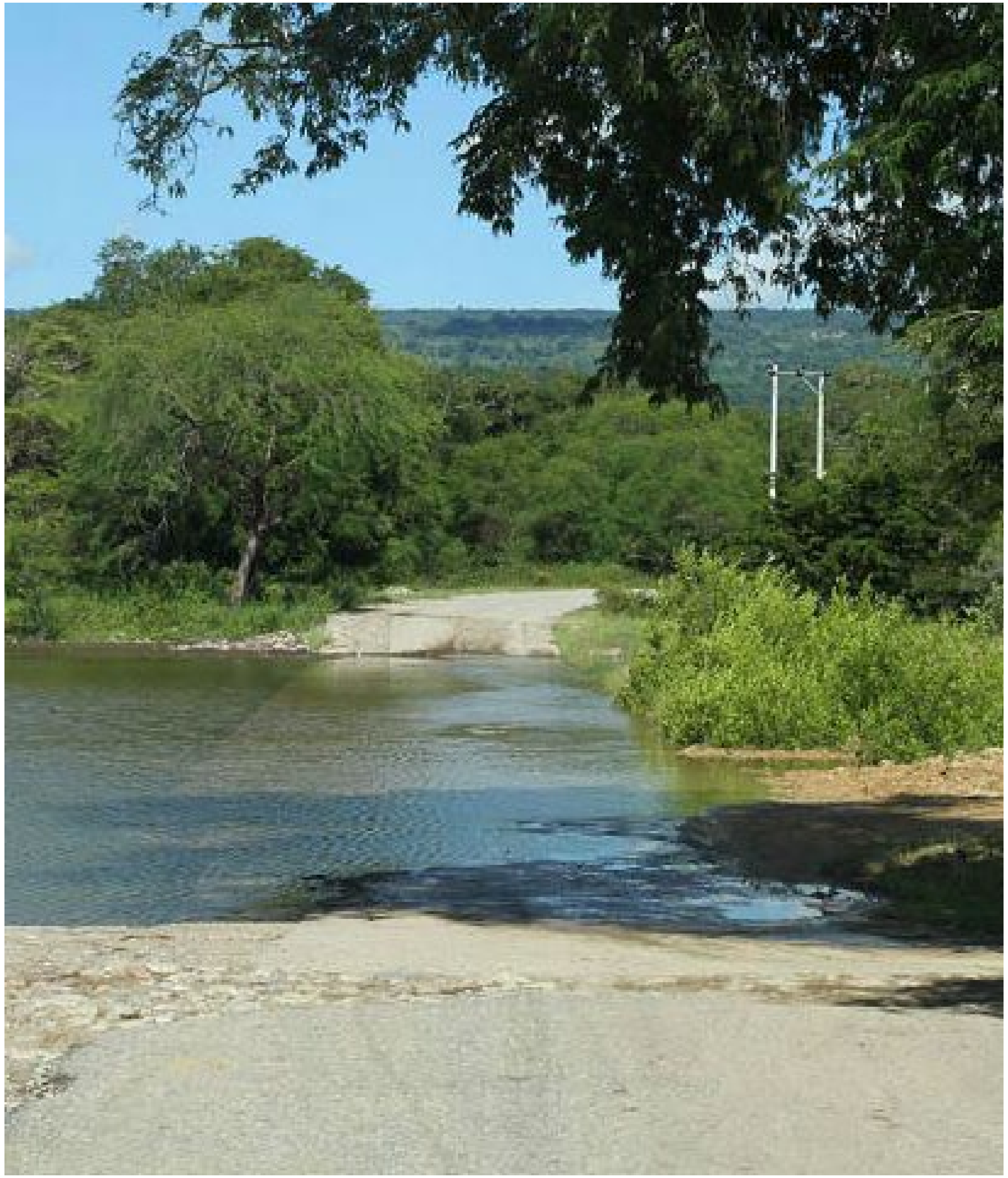
When prices rise, the flexible food basket adapts to be most cost-effective

Scenario: The price of Peas increases by 30 percent regionwide in month 2

	Month 1	Month 2	Procurement Cost
Peas		+30%	
Fixed basket			$ 11.07 / beneficiary / month
Flexible basket			- $ 0.56 / beneficiary / month

Extensions for future

- Take flooding into account



Extensions for future

- Where should roads be added or improved to improve hospital accessibility?

Extensions for future

- Use the tool for other kinds of facility locations, e.g. schools

Extensions for future

- Apply to other countries:
  - Vietnam: Stroke & Heart Attack centres
  - Nepal: Covid-19 test centres

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Mathematical Model

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3 GOOD HEALTH AND WELL-BEING

Hospital location optimization in Timor-Leste

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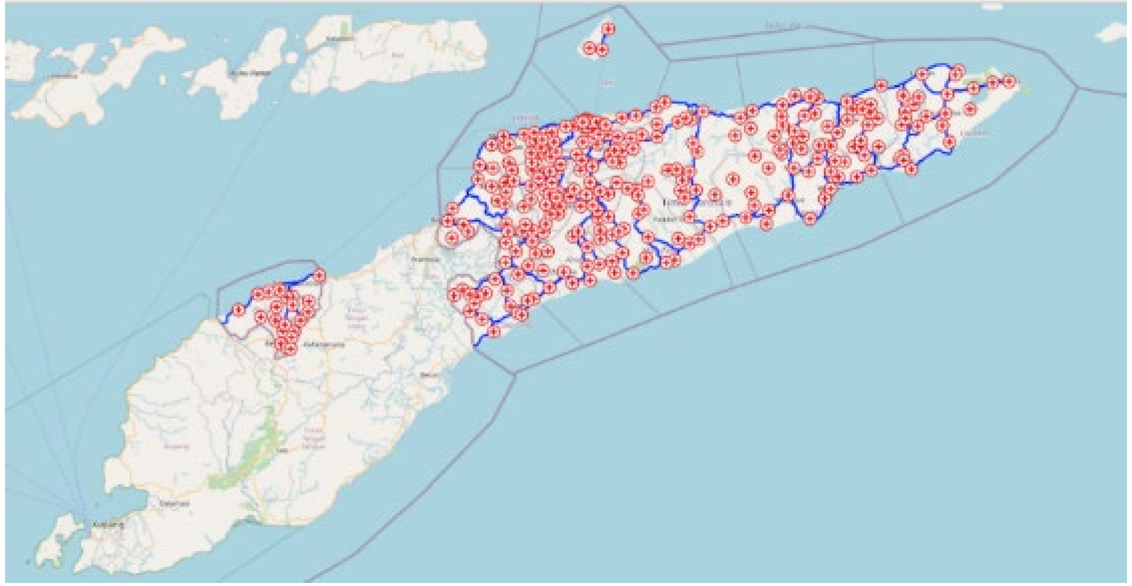
The goal is that as many people as possible are able to reach a healthcare facility within a preset maximum travel distance.



Step 1:
Define the variables needed for the model

Variables & Parameters

Sets

I = Index set of households, $i = 1, \dots, n$

J = Index set of all hospital sites, where indexes $j = 1, \dots, m$ are corresponding to the already existing hospitals and indexes $j = m + 1, \dots, M$ are corresponding to potential hospital locations

Parameters

v_i = the number of people in household or cluster of households i

d_{ij} = travel distance from household (or cluster) i to hospital facility j

S = the maximum travel distance from a household to a hospital

p = the number of additional hospitals located

Variables

$$x_j = \begin{cases} 1 & \text{if hospital } j \text{ is opened} \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1 & \text{if demand at node } i \text{ is served by hospital } j \text{ and } d_{ij} \leq S \\ 0 & \text{otherwise} \end{cases}$$

Step 2:
Define the objective of the model

Objective

- The goal is that as many people as possible are able to reach a healthcare facility.
- We maximize the number of people that are served by a healthcare facility.

$$\max \sum_{i \in I} \sum_{j \in J} v_i y_{ij}$$

Step 3:
Define the constraints of the model

Optimization model

$$max \sum_{i\in I}\sum_{j\in J} v_i y_{ij}$$

Such that:

1. The already existing hospitals are included in the model as opened
   $x_j = 1 \quad \forall j = 1, \dots, m$
2. The number of hospitals additionally opened is at most p
   $\sum_{j=m+1}^{M} x_j \leq p$
3. Only assign people to a facility if that facility is opened
   $\sum_{i\in I} y_{ij} \leq n x_j \quad \forall j \in J$
4. People can only be assigned to one hospital
   $\sum_{j\in J} y_{ij} \leq 1 \quad \forall i \in I$
5. People are not served by a facility if the travel distance to the facility is higher than the maximum travel distance
   $y_{ij} = 0 \quad \forall i \in I, \forall j \in J, d_{ij} > S$
6. The decision variables are binary
   $x_j, y_{ij} \in \{0,1\} \quad \forall i \in I, \forall j \in J$