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Optimization of decentralized energy systems using biomass resources for rural electrification in developing countries

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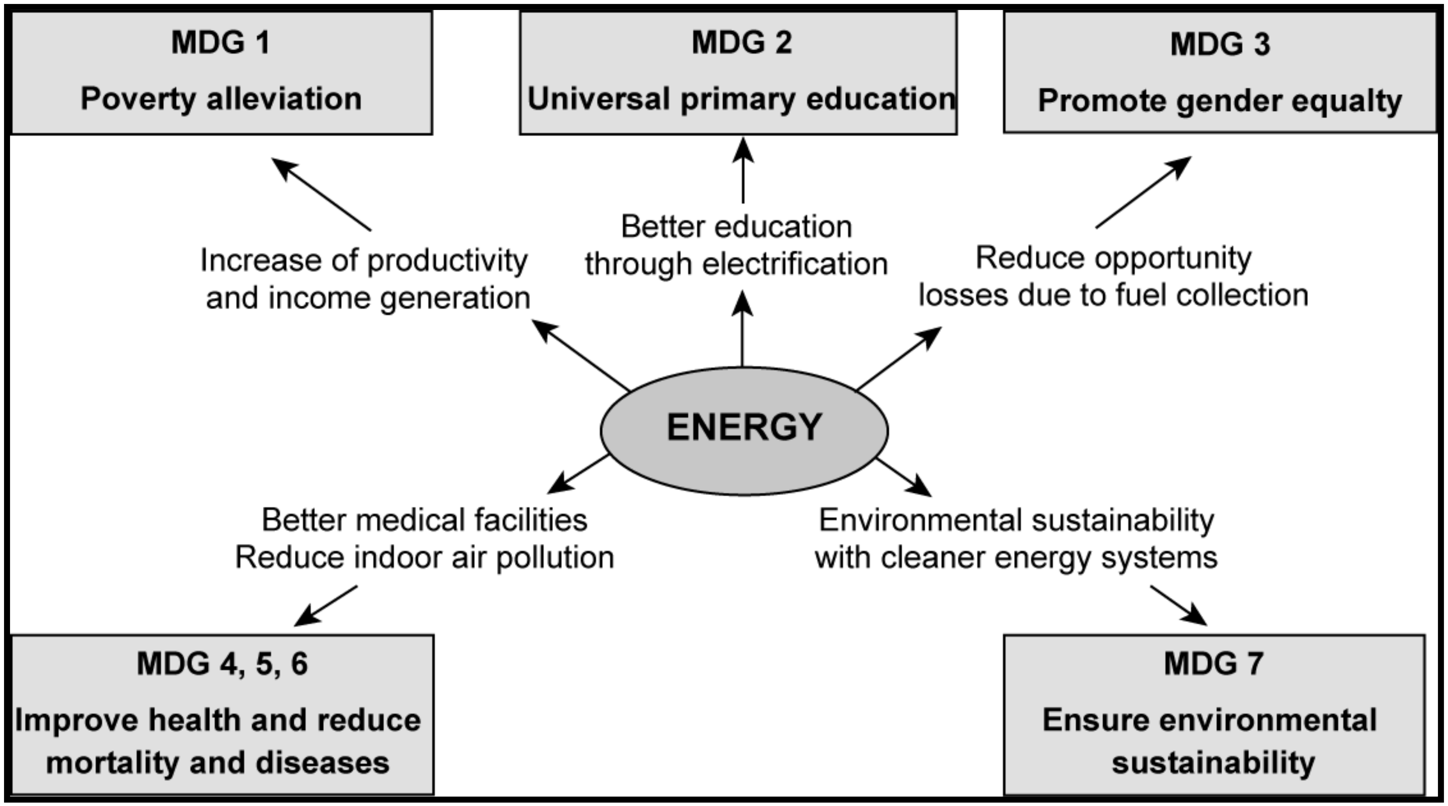
Energy access and the MDGs

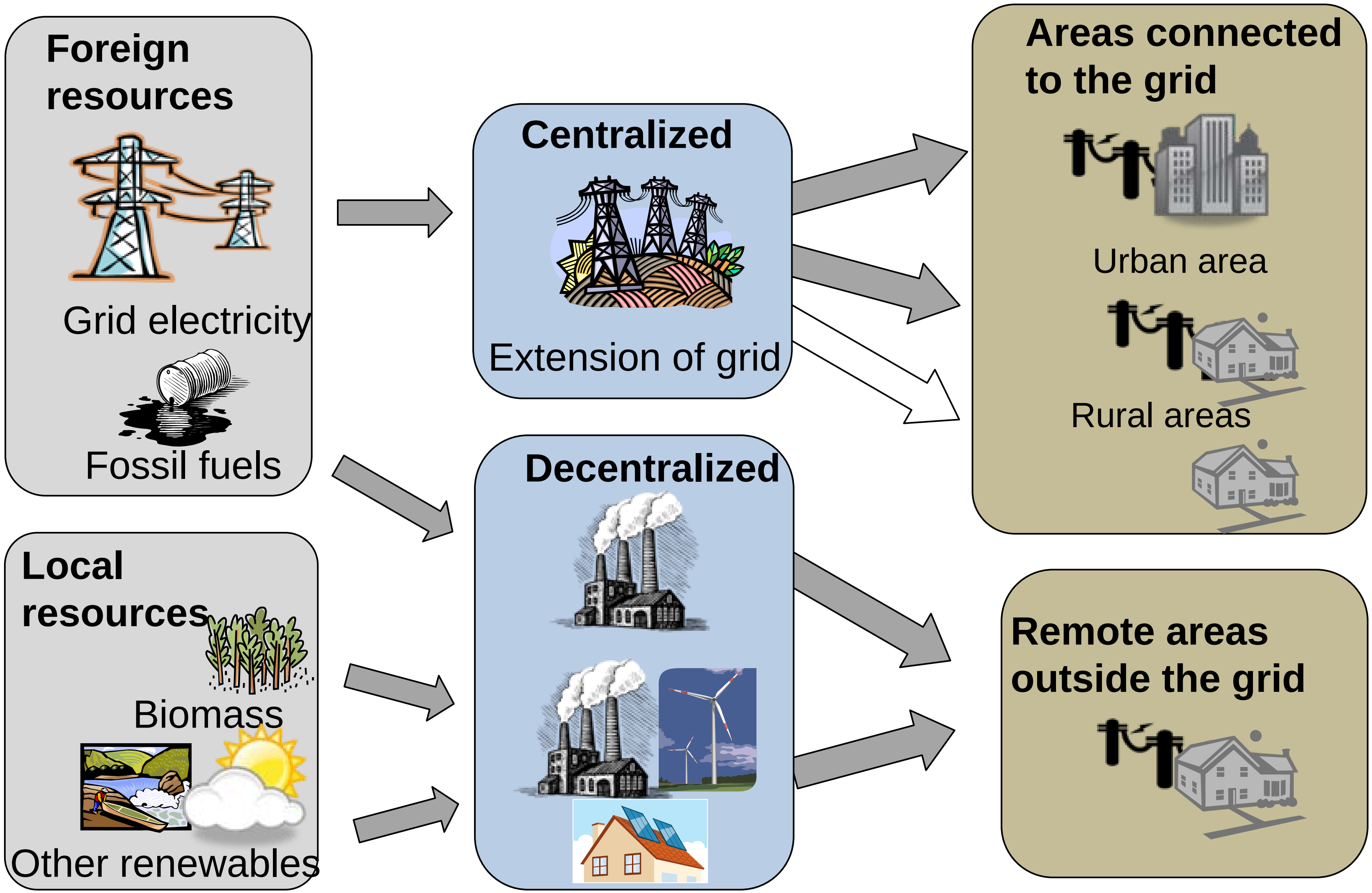


1.6 billion without electricity in 2005 (IEA)

2.4 billion rely on traditional biomass in 2005 (IEA)

1.6 million deaths due to indoor air pollution in 2004 (WHO)

Electrification schemes



Previous studies - Rural electrification

- Evaluation of technologies or a set of technologies.
- Decentralized electrification with renewables or combined with diesel (hybrid configurations).
- Allocation of agricultural resources for energy.
- Optimization methodology is most common approach.

Research goal

- Evaluate a decentralized energy system for rural electrification in developing countries using local biomass resources.

- Incorporate into the optimization differences in energy consumption and income levels between urban and rural areas.

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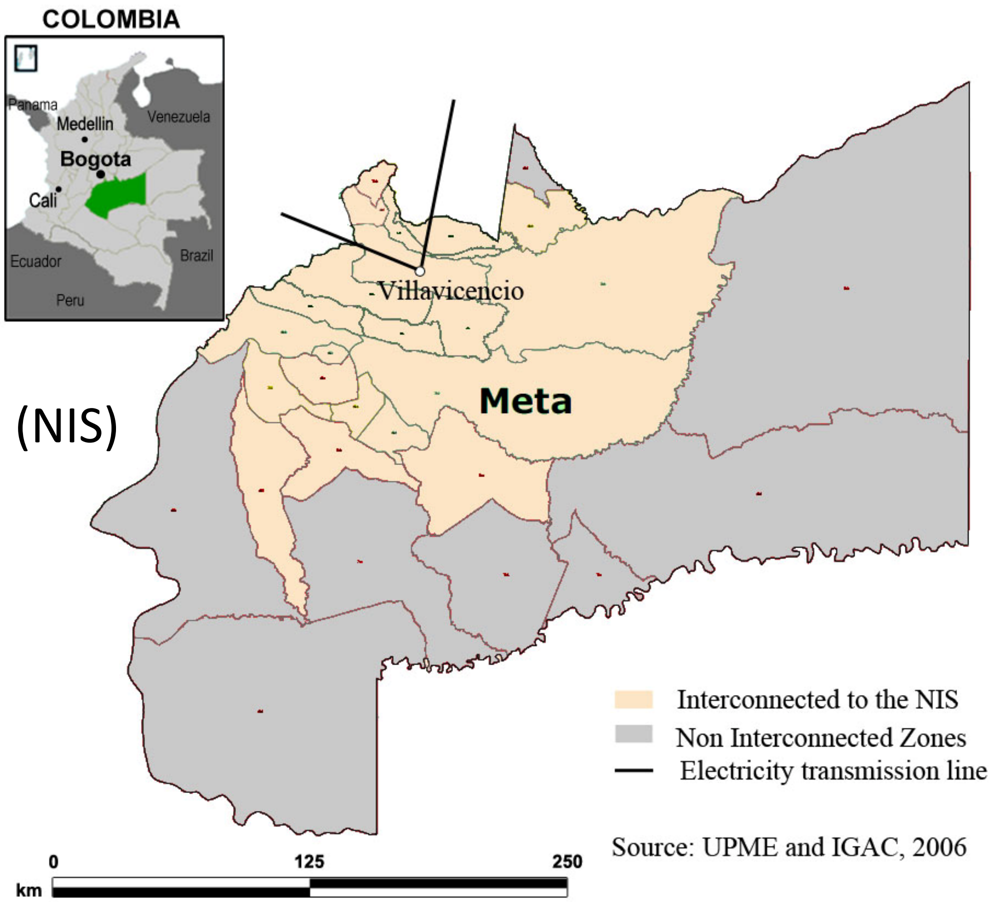
Target area

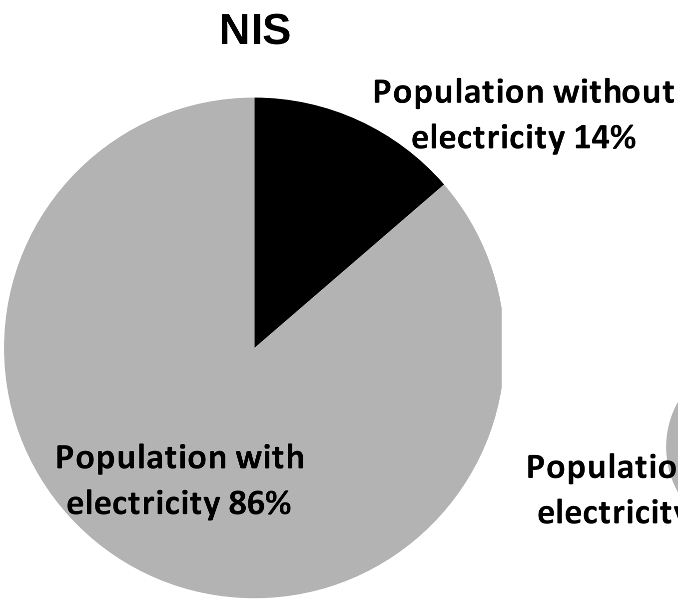
- South America, Colombia, Meta department
- Proximity to capital city
- Agricultural activities
  - Rice, sugarcane, oil palm
- Areas connected to the electricity grid
  - National Interconnected System (NIS)
- Areas not connected to the electricity grid
  - Non Interconnected zones (NIZ)



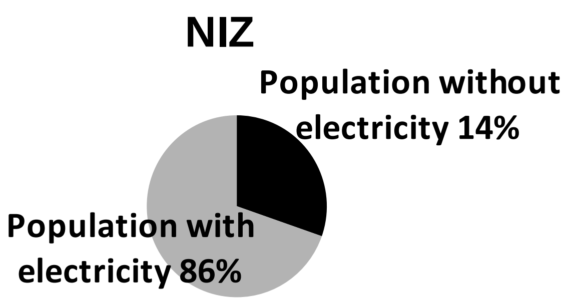
Source: UPME and IGAC, 2006

Target area

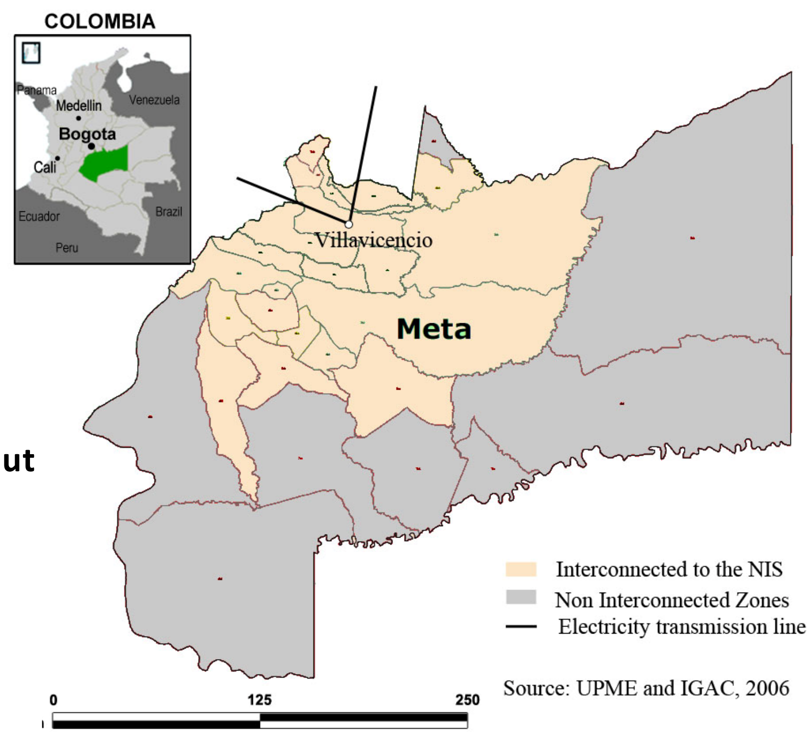
- Energy supply expensive in remote areas (NIZ)
  - Electricity price is same as paid by middle income houses in the interconnected area
  - Diesel fuel 1.8 times more expensive



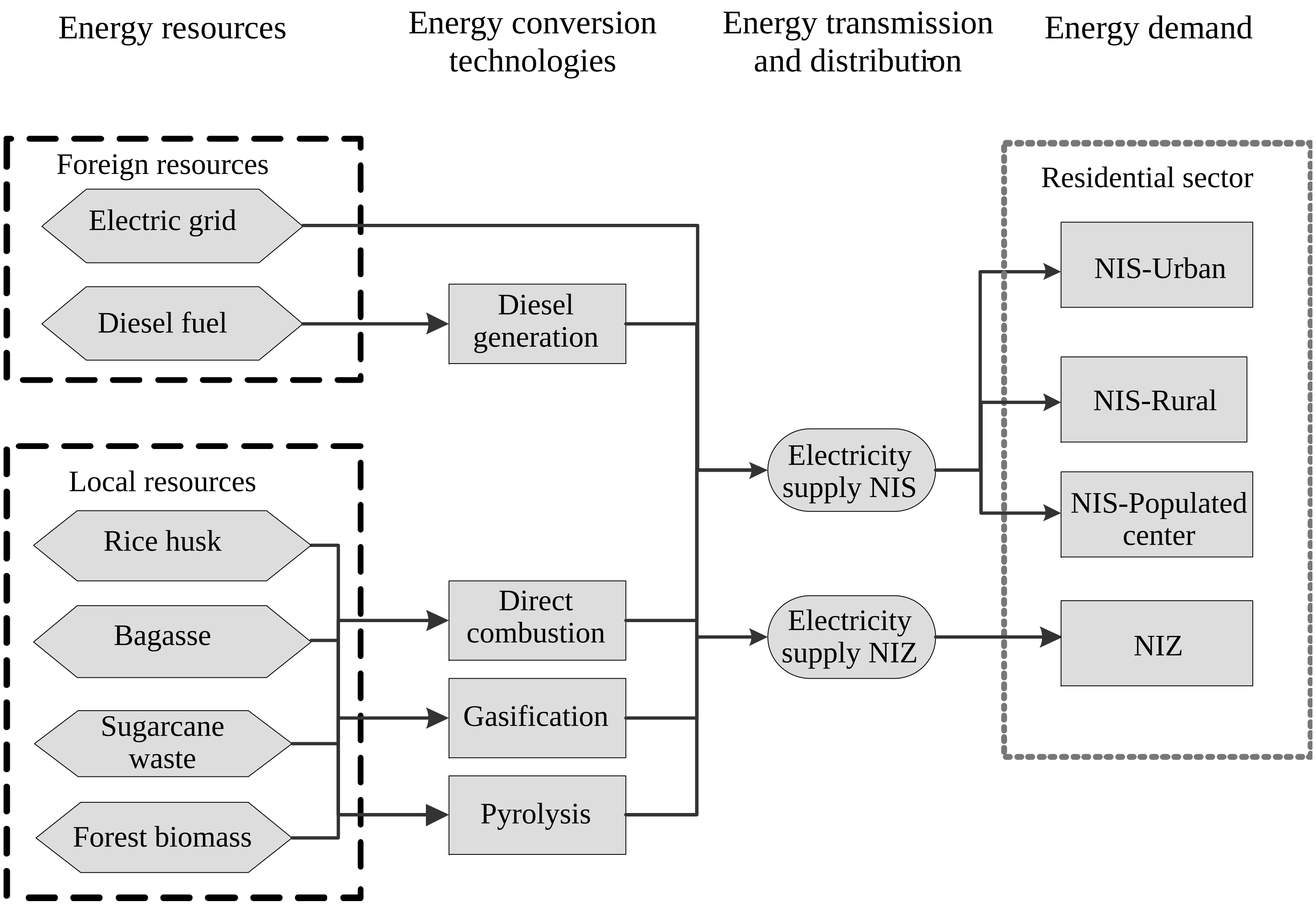
Total population 724,929



Total population 18,668



Proposed energy system



NIS: National interconnected system
NIZ: Non interconnected zones

Flow of analysis

Input data

Parameters
- Costs of technologies and resources
- Conversion efficiency

Constraints
- Energy resources stock
- Electricity demand
- Resource location
- Utilization of agricultural wastes

Additional input
- Urban-rural differences (prices, resources)
- Socio-economic strata (prices)

Optimization model

Linear programming
- Minimum overrun (net) costs

Sensitivity analysis
- Biomass share

Results

Energy system structure
- Technologies
- Resource allocation

Energy system performance
- Costs
- CO_2 emissions
- Regional differences

Optimization

- Linear programming (LP) formulation

Minimize overrun costs : Min B

$$B = (Total\_costs) - (Total\_revenue) = \sum_k \sum_l b_{kl}$$

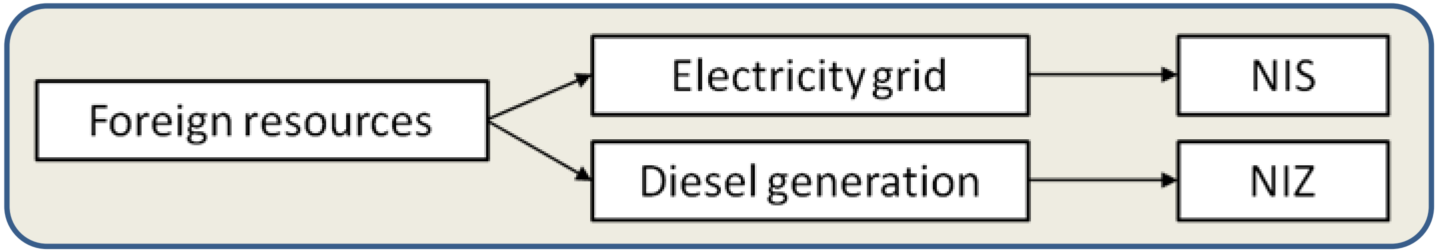
$$\left[\frac{\sum_j \sum_i c_{ijk} \eta_j q_{ijk}}{\sum_l d_{kl}} \right] \times d_{kl} - b_{kl} = p_{kl} d_{kl}$$

$$\sum_j \sum_k q_{ijk} \le r_i$$

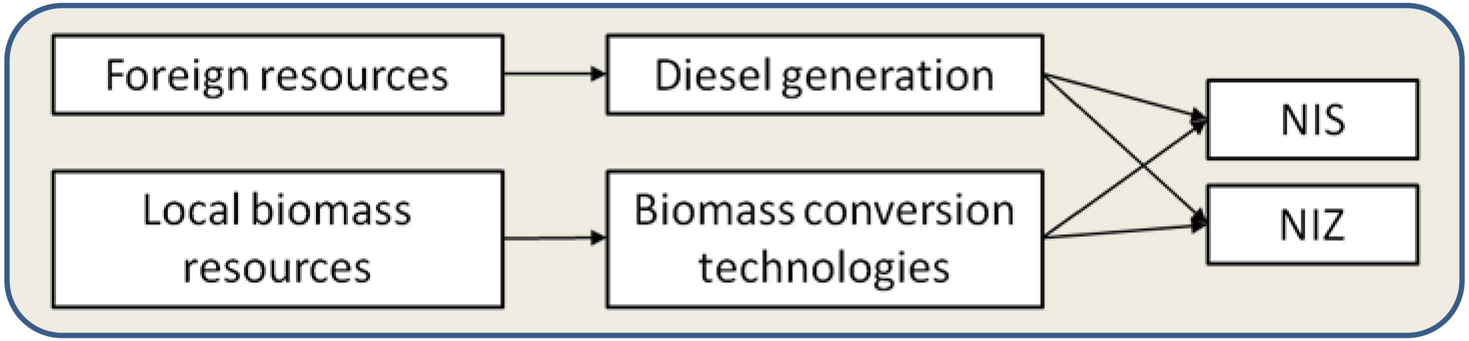
b_{kl} : overrun costs (net costs)
B : total overrun costs
c_{ijk} : unit electricity generation cost
d_{kl} : electricity demand
p_{kl} : unit price of electricity
q_{ijk} : primary energy resource
η_j : electricity conversion efficiency
i : energy resource
j : energy conversion technology
k : location
l : energy demand sector and socio-economic stratum

Case setting

- Baseline



- Cases analyzed
  - **Biomass-Remote**: biomass based electricity for areas outside the grid
  - **Biomass-Rural**: biomass based electricity for all rural areas
  - **Biomass-All**: biomass based electricity for all areas



Input data

Availability and cost of resources

Resource	Stock	Cost
	ton/yr	US$/kg
Diesel fuel	-	0.290*
Rice husk	43,840	0.080
Bagasse	14,577	0.010
Sugarcane wastes	23,122	0.014
Natural forest wastes	198,158	0.030
Planted forest wastes	138,772	0.030

*Diesel fuel cost for NIZ is US$0.530/kg
Calculated based on data from UPME (2003).

Input data

Features of conversion technologies considered			
Conversion technology	Efficiency	Capital cost	O&M costs
	%	US$/kW	US¢/kWh
Diesel	30	300	1.70
Direct Combustion	17.5	2,300	0.05
Gasification	23.9	4,200	0.07
Pyrolysis	24.7	3,600	0.21

Data from Solantausta and Huotari (1999) and UPME (2000)

Scale of plants = 2 MW

Rate of return = 10%, lifetime = 20 years.

Baseline for emissions reduction : NIS served with the grid and NIZ with diesel generation

CO_2 emissions factor for grid electricity and diesel generation are 0.439 kg/kWh and 0.882 kg/kWh respectively.

Input data

Location	Electricity demand GWh/yr
NIS-Urban	192,011
NIS-Rural	28,351
NIS-Populated center	5,984
NIZ	3,517
Demand-Total	228,819

Calculated from data in UPME (2000) and SSP-SUI database.

Electricity price by socio-economic stratum US¢/kWh						
1	2	3	4	5	6	Other
3.5	4.2	6.0	7.0	8.4	8.4	8.4
6.0	n.a.	n.a.	n.a.	n.a.	n.a.	14.4

Ramirez Gomez, S. (2007).

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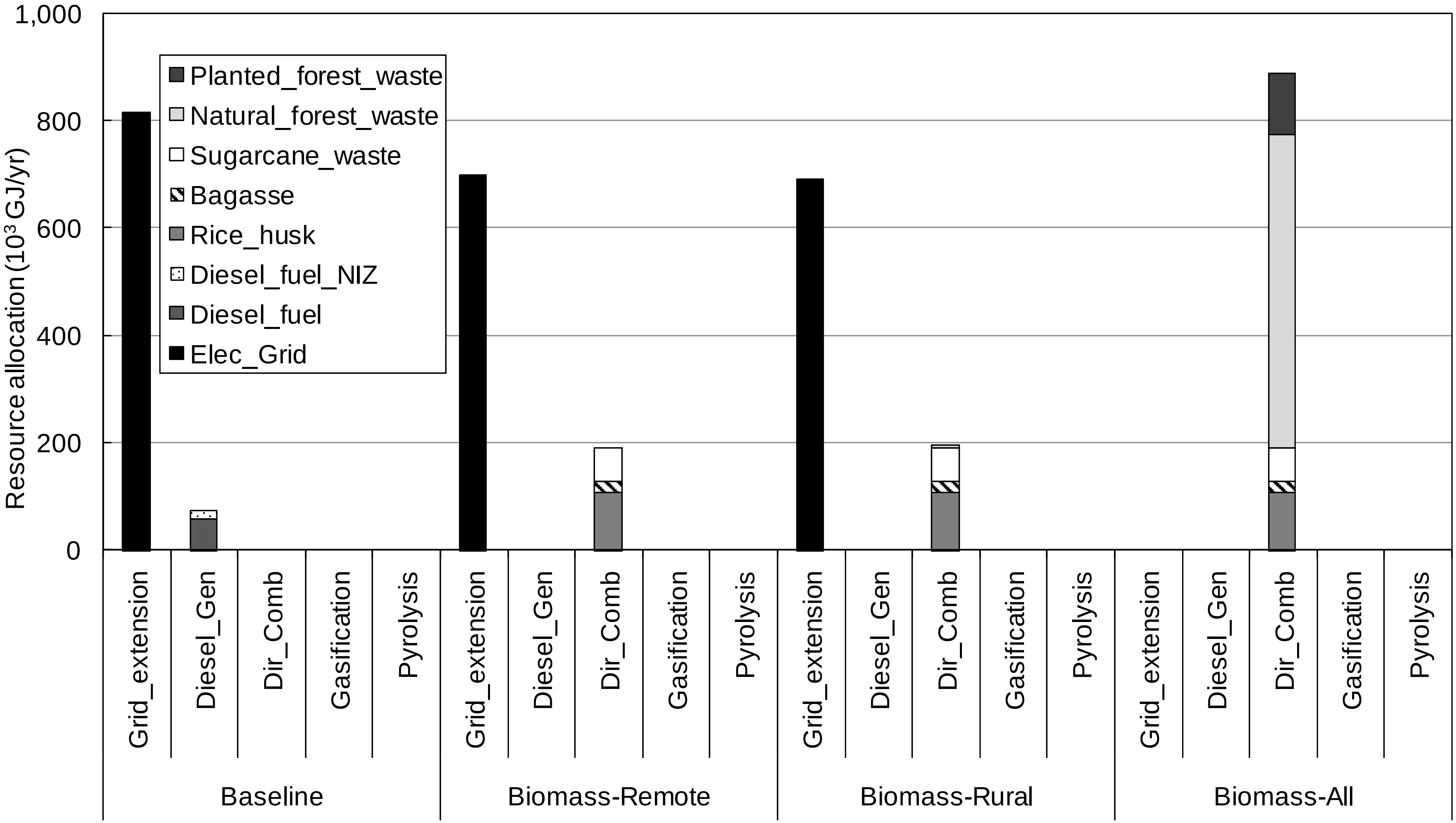
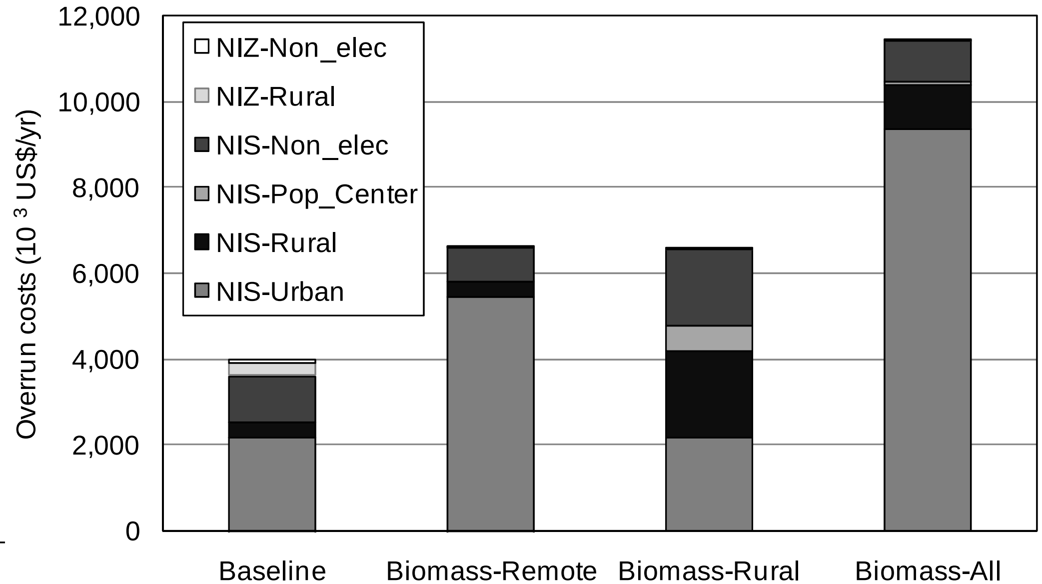
Energy system structure

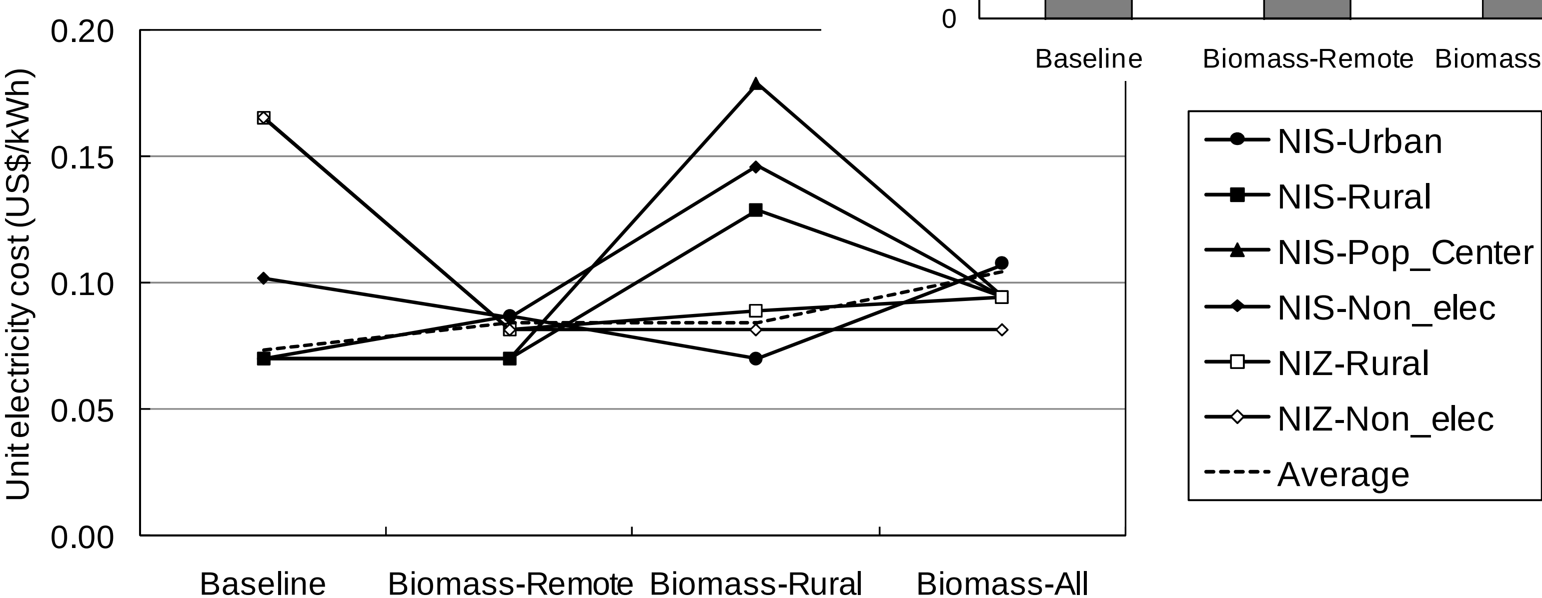


System performance

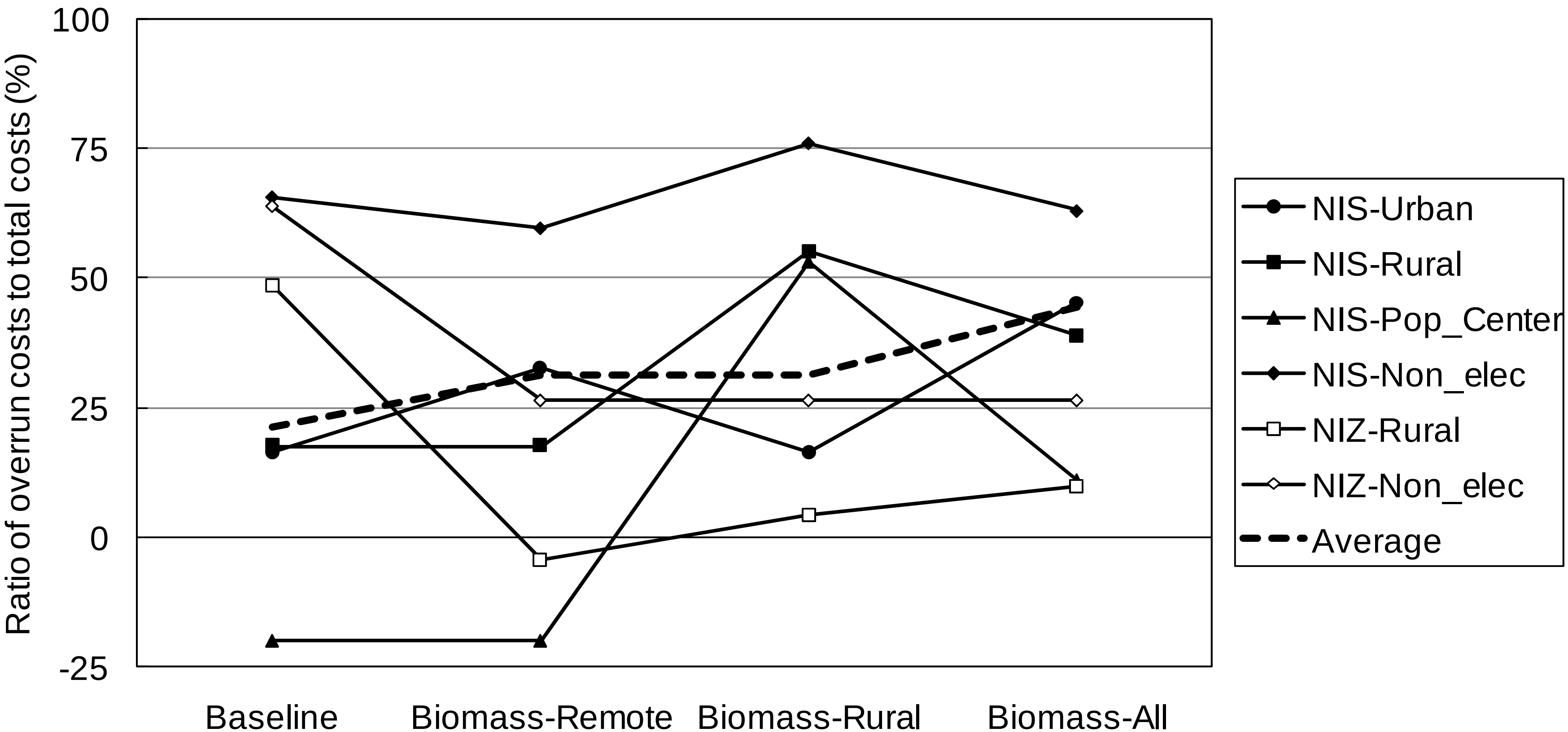
		Baseline	Biomass-Remote	Biomass-Rural	Biomass-All
Overrun costs	10^3 US$	3,889	6,539	6,588	11,463
Unit electricity cost	UScent/kWh	7.4	8.4	8.5	10.4
Ratio of overrun costs to total costs	%	21	31	32	44
Total CO_2 emissions	10^3 t-CO_2	117,452	85,211	84,331	0
Unit emissions reduction	kg-CO_2/kWh	0.00	0.13	0.13	0.48

Urban/rural differences

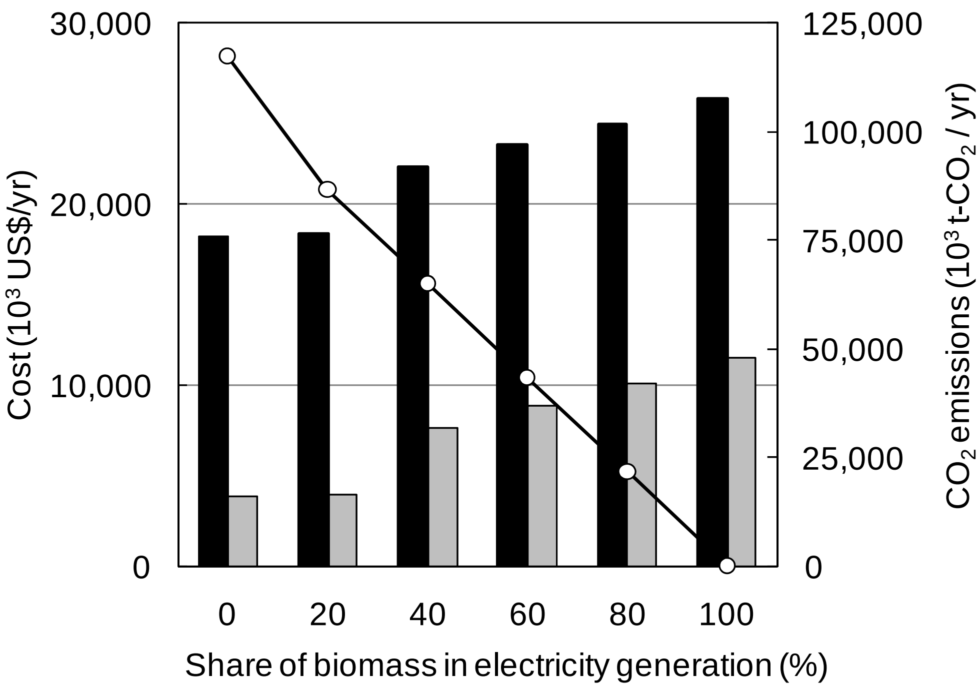


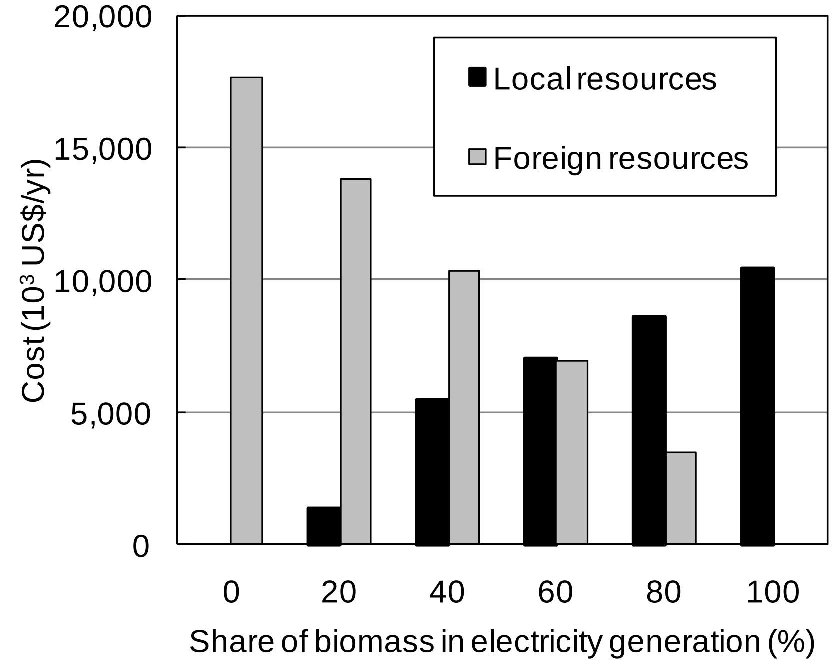


Urban/rural differences



Sensitivity analysis





Discussion

- Biomass potential for electricity generation (direct combustion of biomass).
- Opportunities and barriers for decentralized electrification with local biomass resources.
  - Emissions reduction.
  - Reduced overrun costs in remote areas.
  - Impact on rural (local) development, local business, income and employment (biomass energy supply chain).
  - Balancing costs of foreign resources with use of local resources.
  - Stable supply of electricity.
  - Costs, investments, prices (transportation), financial mechanisms (subsidies).

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Conclusion

- Possibility of decentralized electrification with local biomass resources (direct combustion of agricultural and forest wastes).
- Optimal system for decentralized electrification results in
  - Electricity cost 8.4-10.4 UScent/kWh, higher than baseline (7.4 UScent/kWh).
  - Overrun costs of biomass based system 1.5 to 4 times larger.
  - Emissions reduction $120x10^3$ t-CO_2/yr compared to baseline.
- Impact on rural development.
  - Smaller differences in the proportion of overrun costs.
  - Costs of local and foreign resources.

Further analysis

- Improvements with respect to factors overlooked by the model (transportation, stable supply).
  - Enlarged scope of the energy system (heat demand, other sectors).
  - Plant scale considerations.
  - Transport costs, resource geographical distribution (GIS).
- Alternative model formulation (multi-objective programming, dynamic programming).

THANK YOU FOR YOUR ATTENTION!