Towards rural development in Sub-Saharan Africa through least-cost modeling of decentralized Energy-Water-Food systems

Case study Kpori, Ghana

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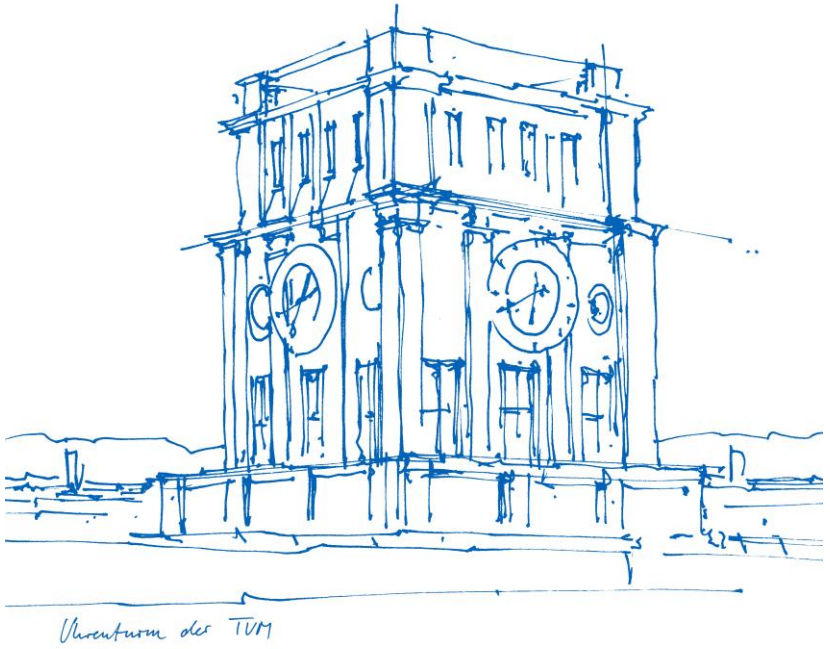
Technical University of Munich

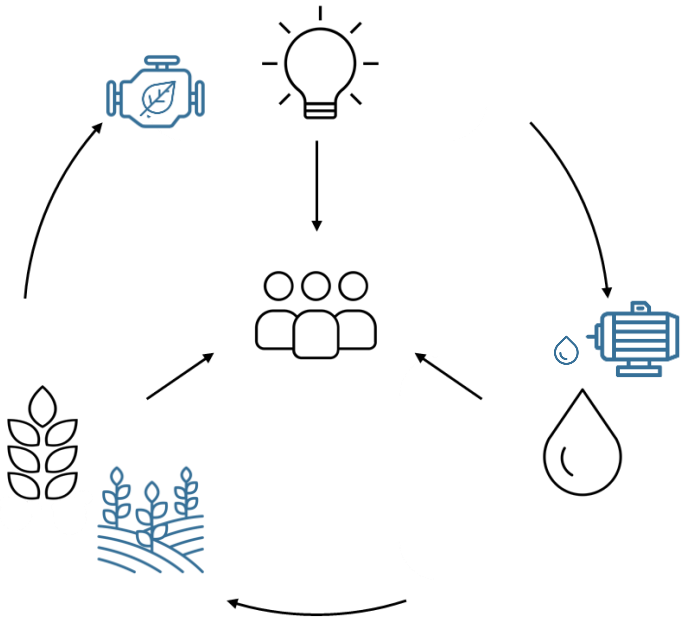
Munich, 14. February 2019



Motivation: Rural Electrification in Sub-Saharan Africa

Why Energy-Water-Food Systems (EWFS)?

Decentralized Rural EWFS



urbs

One-node linear economic model

- Synergies between Energy-Water-Food Subsystems: 4 Scenarios
- Dependencies and Trade-Offs: Sensitivity Analysis

Case Study: Kpori

- **Farming** Village
- **“Green Field“.**
  - No power grid connection
  - No water grid connection
- Ca. **308** Inhabitants
- **15 ha** Cultivable Land (50 ha Available Communal Land)

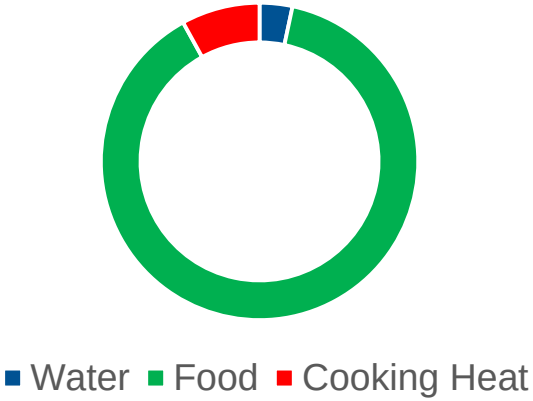
Model Input Data for EWFS:

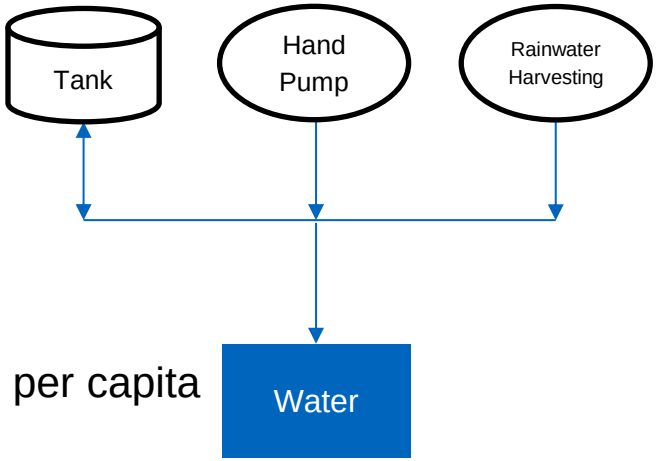
- Expert Opinions, questionnaires and literature
- Electric Load with **Monte Carlo Simulation** based on questionnaire for Neighbor Grid-Connected Village
- Weighted average costs of capital (**WACC**): **15% per year**

Decentralized Energy-Water-Food Systems: Status Quo

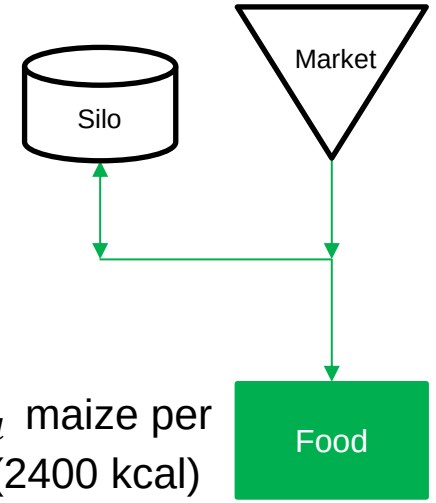
46,3 USD

per year per capita



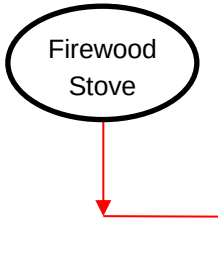


50 $^{l}/_{d}$ water per capita



658 $^{g}/_{d}$ maize per capita (2400 kcal)

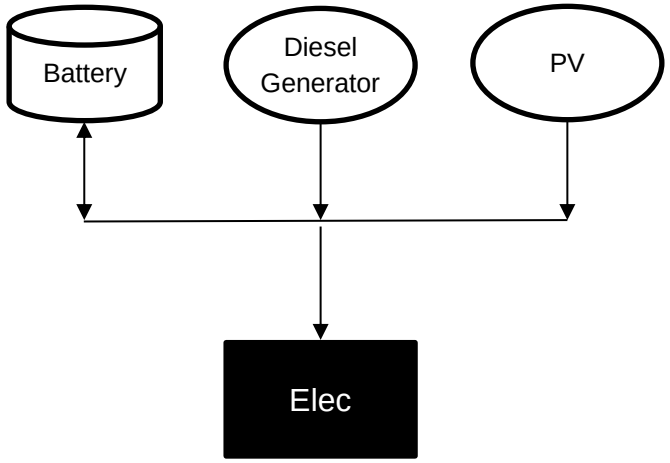
1 $^{meal}/_{d}$ per capita

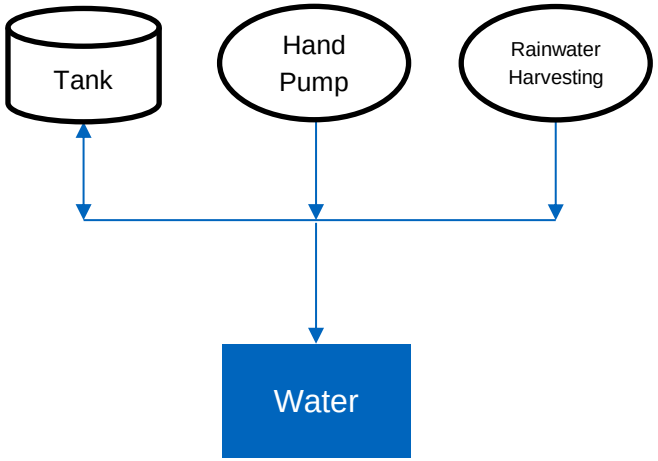


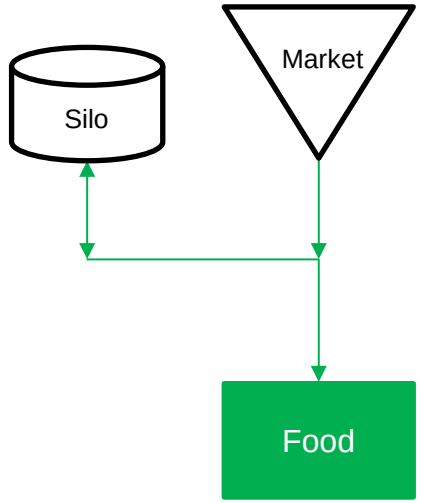
School
200 students

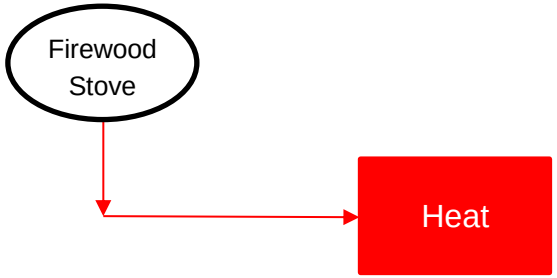
[Source: Institute Water for Africa e.V, US Department of Health and Human Services (2015)]

Scenario 1: Diesel + PV + Batteries









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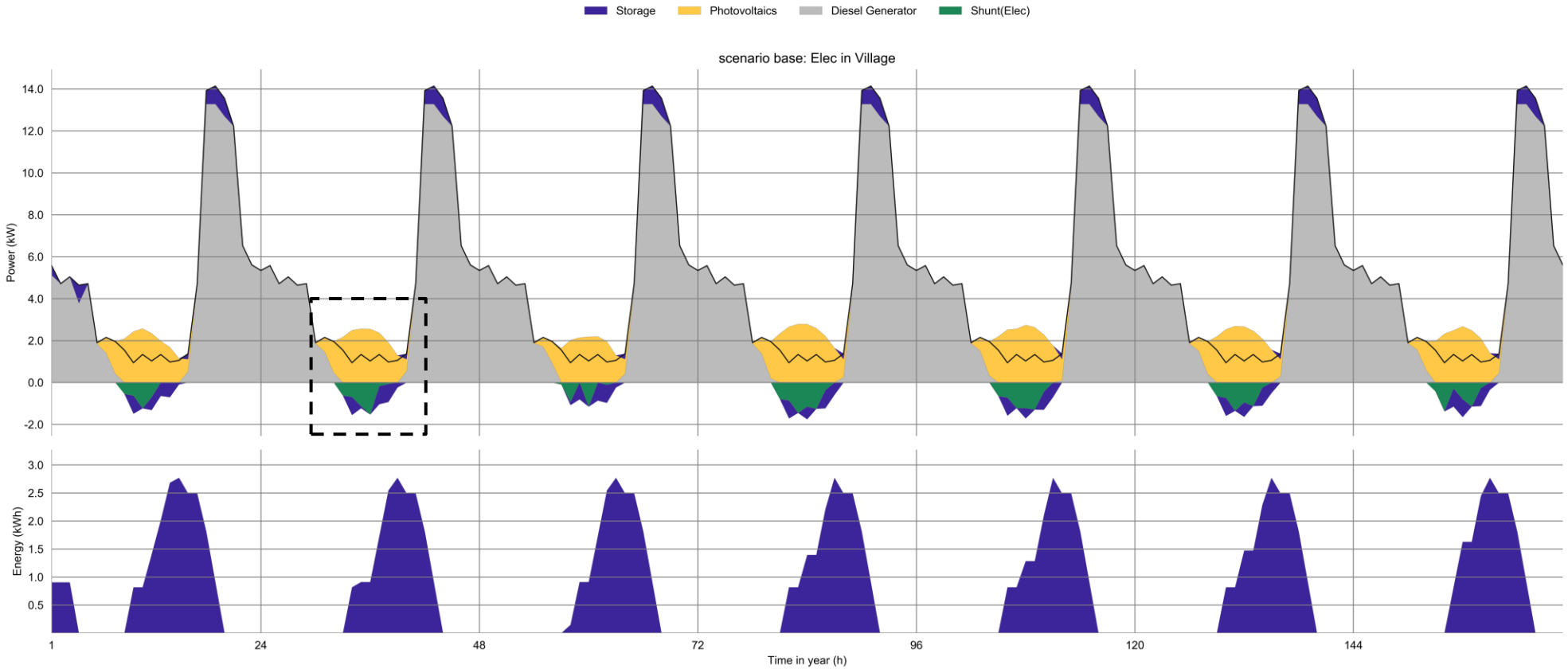
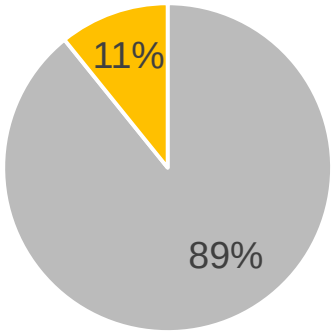
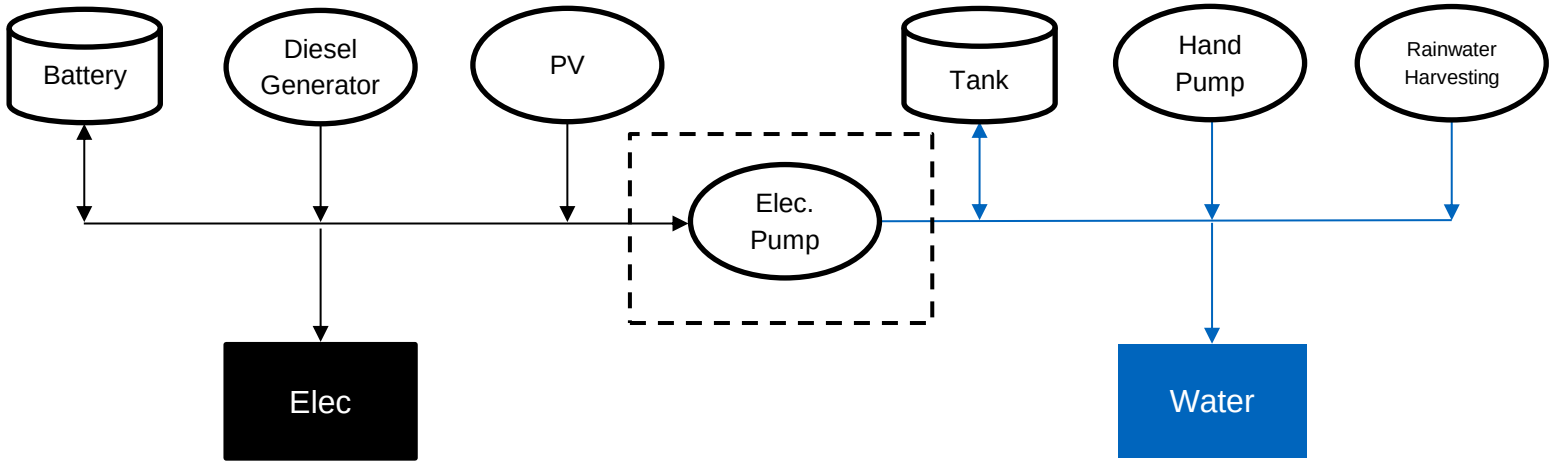


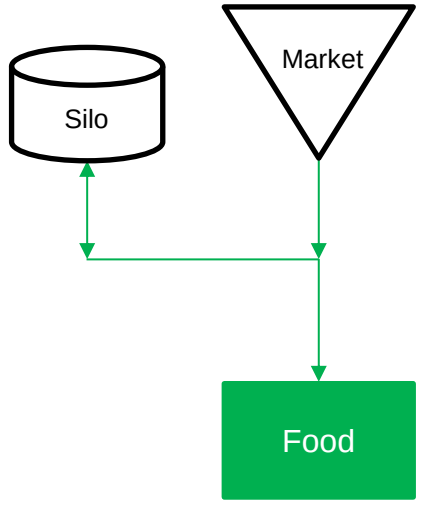


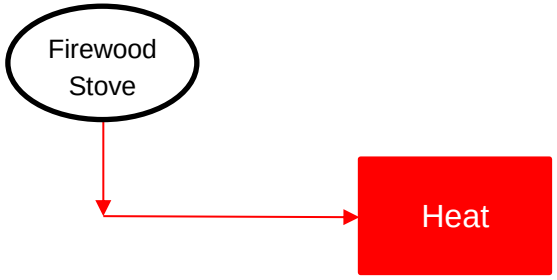
LCOE: 44,4 c/kWh

Annual Costs per Capita: 107,5 USD/year (before: 46,3)

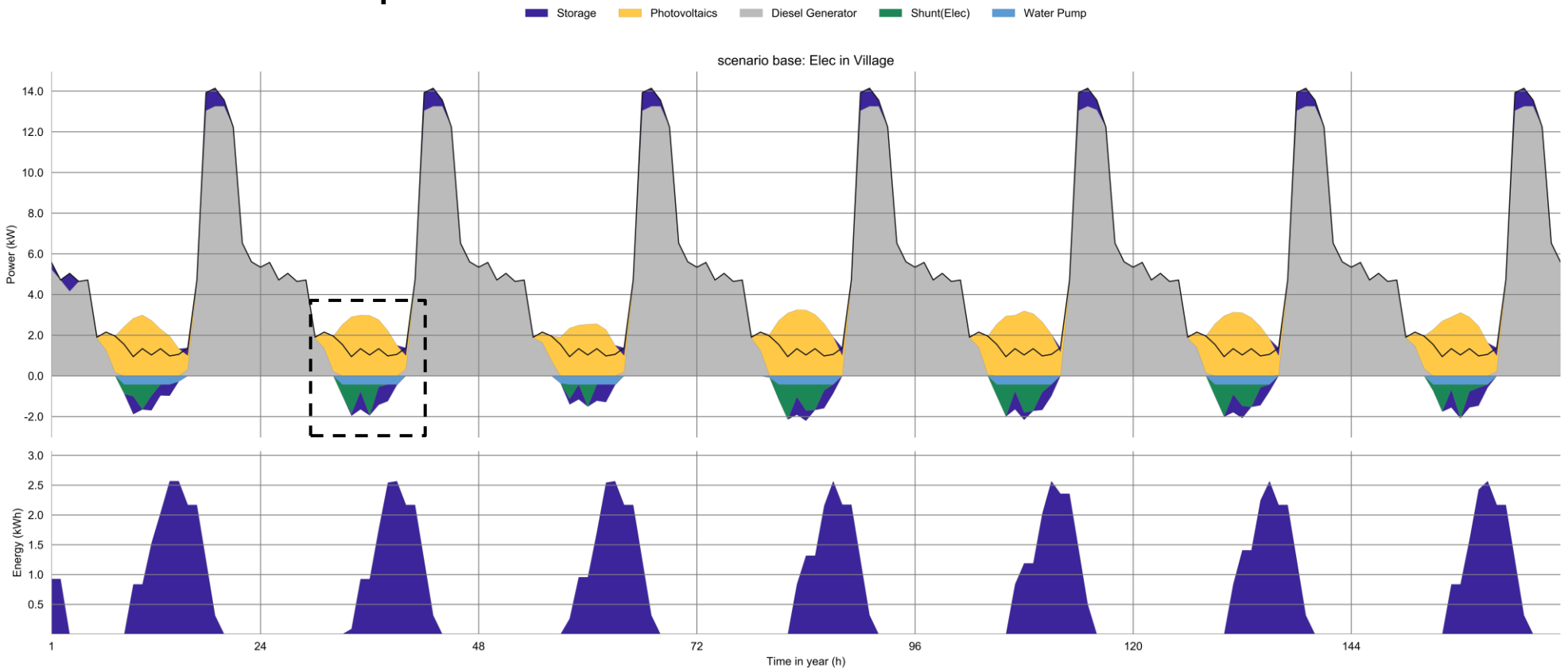
Scenario 2: + Water Pump

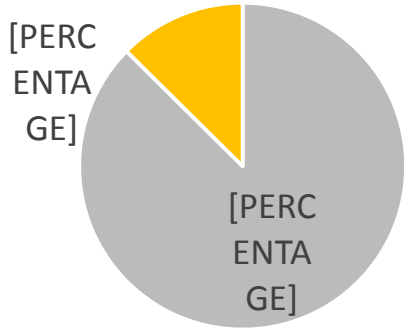






Scenario 2: + Water Pump

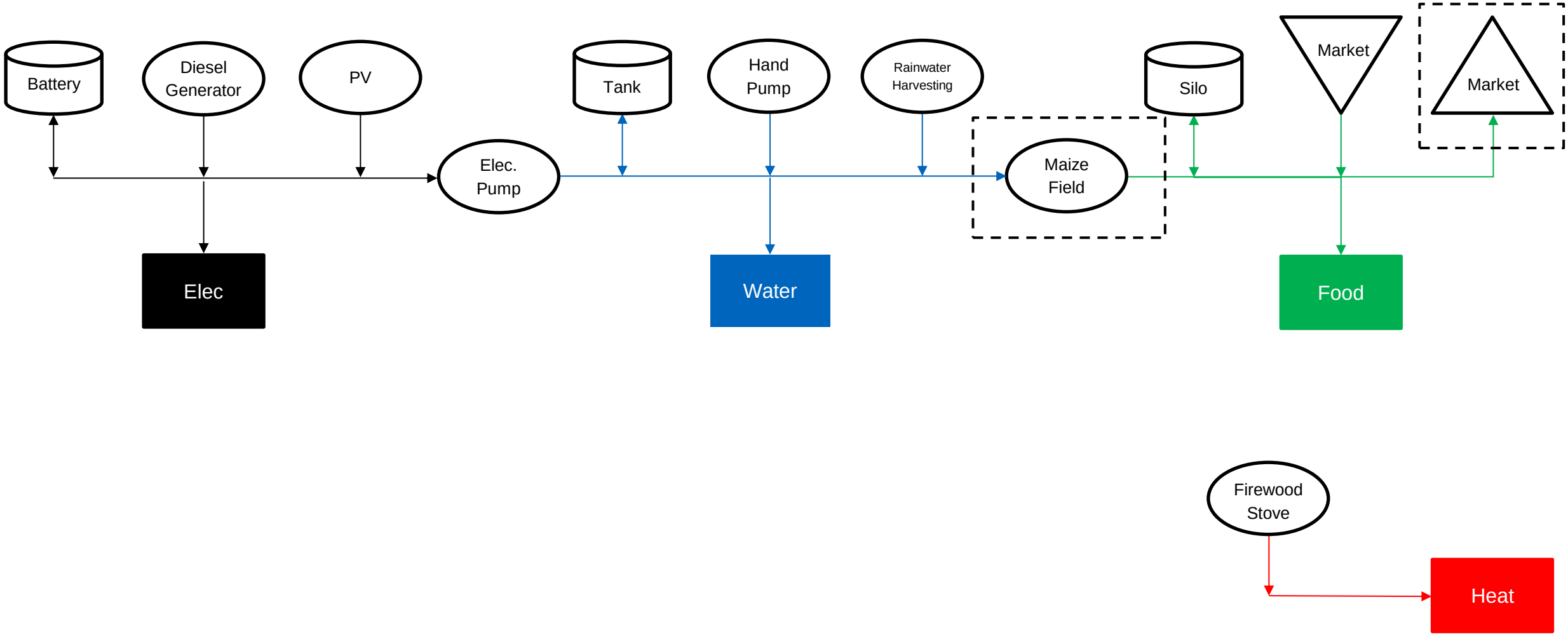




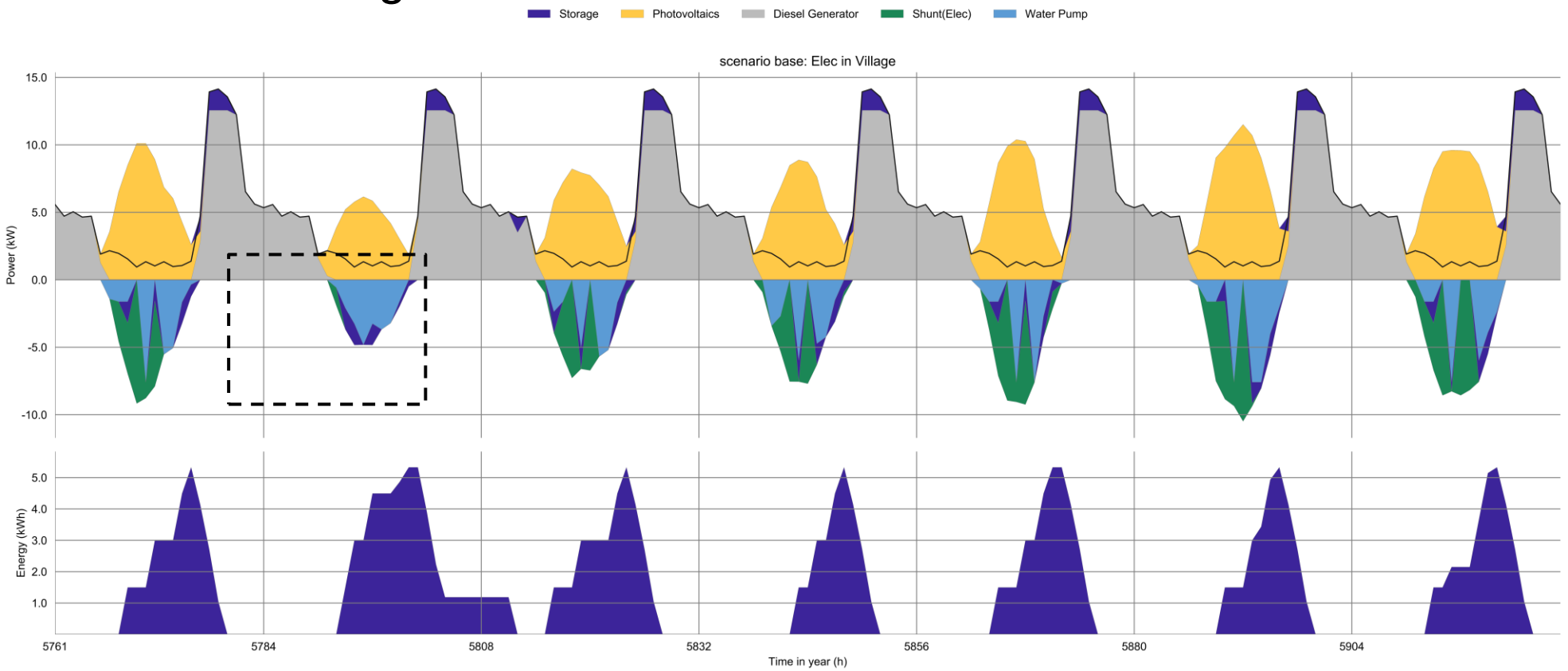
LCOE: 43,8 c/kWh (before: 44,4)

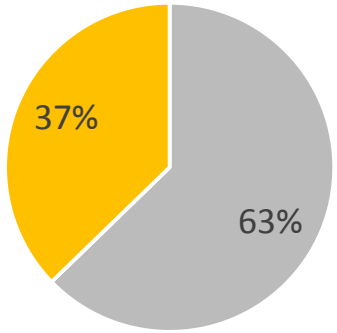
Annual Costs per Capita: 106,4 USD/year (before: 107,5)

Scenario 3: + Food Selling



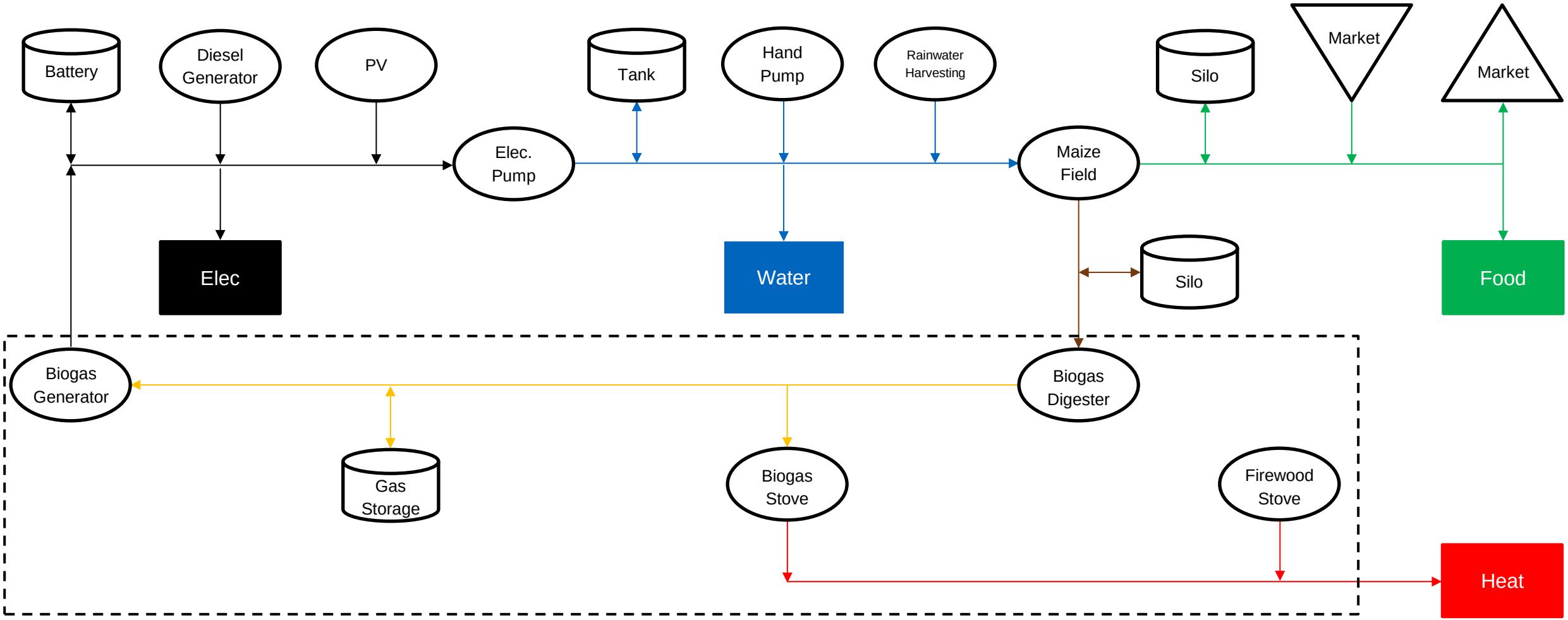
Scenario 3: + Food Selling



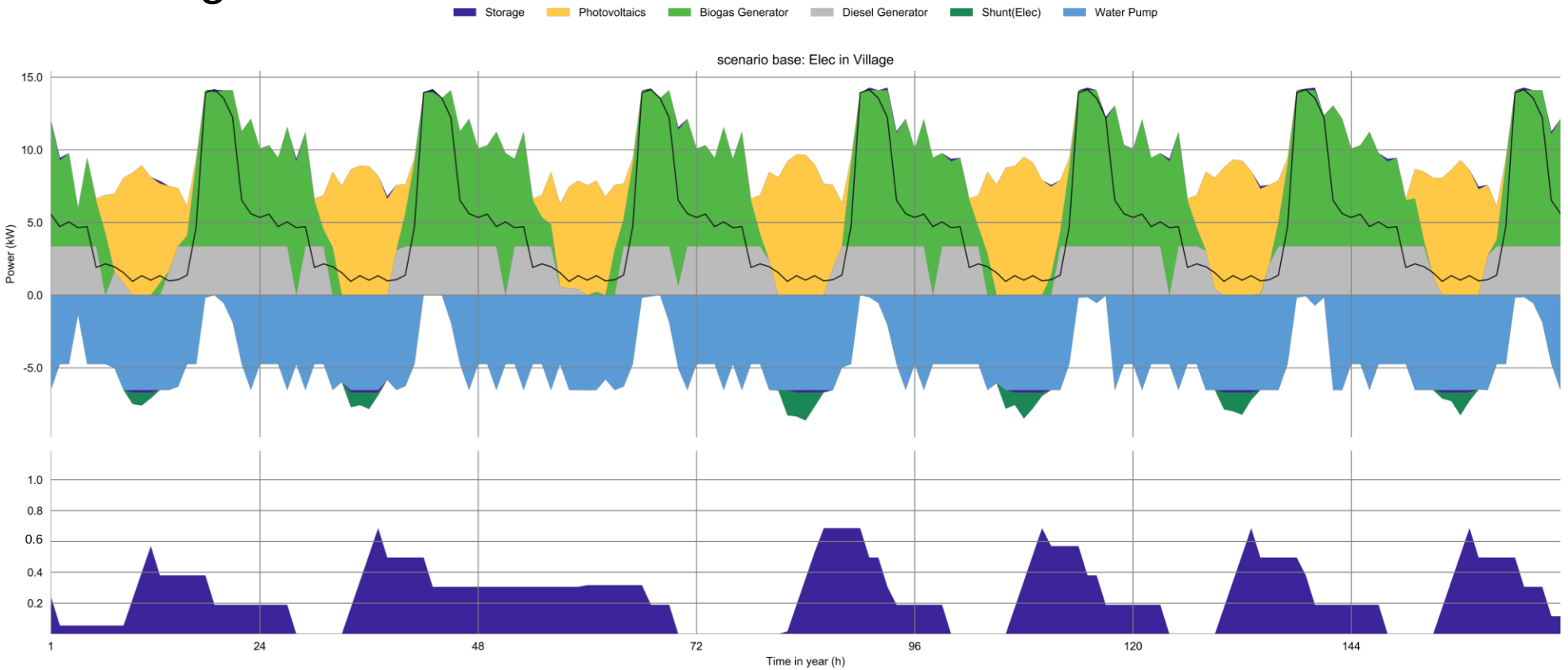


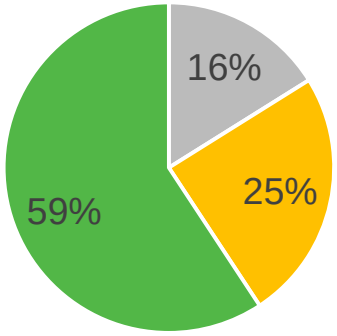
LCOE:	37,1 c/kWh (before: 43,8)
Annual Costs per Capita:	81,4 USD/year (before: 106,4)
Hectares Cultivated:	15 ha
Jobs in Farming:	25 Jobs

Scenario 5: + Biogas Stove



Scenario 4: + Biogas Stove





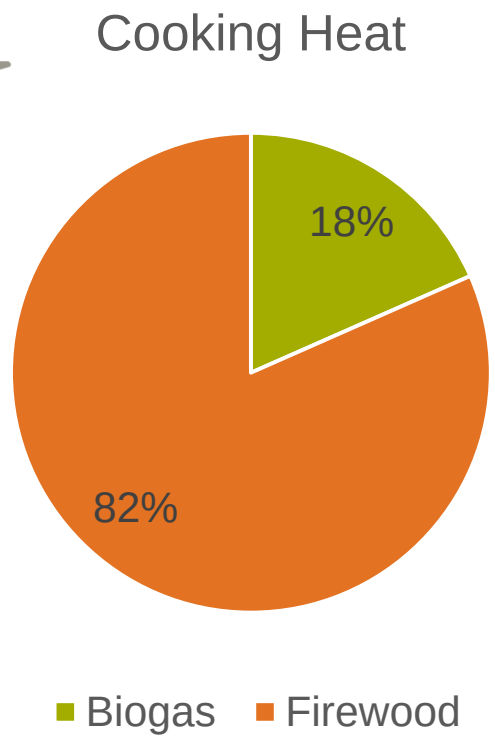
LCOE: 19,5 c/kWh (before: 37,1)

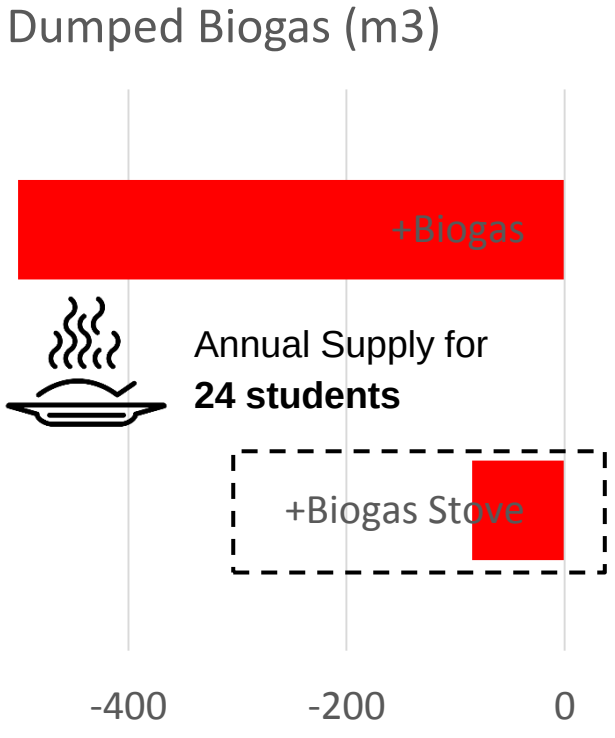
Annual Costs per Capita: 27,8 USD/year (before: 81,4)

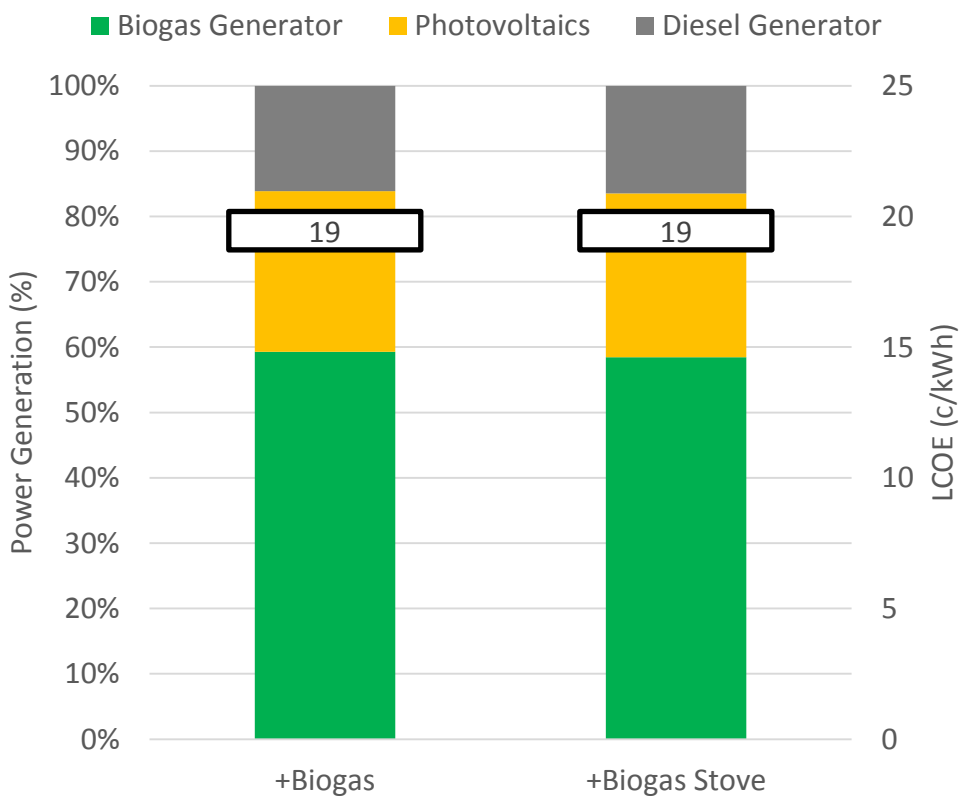
Hectares Cultivated: 15 ha

Jobs in Farming: 25 Jobs

Scenario 5: + Biogas Stove







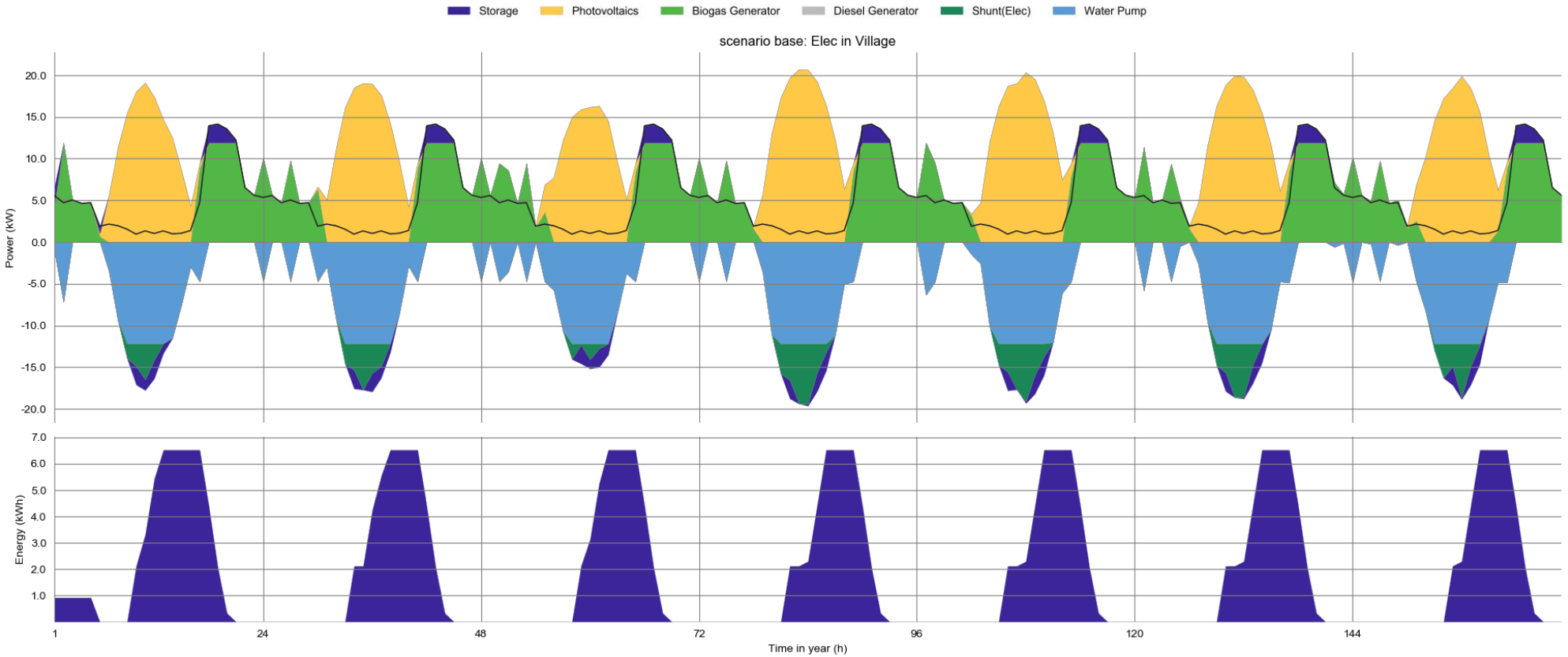
LCOE: 19,5 c/kWh (before: 19,5 c/kWh)

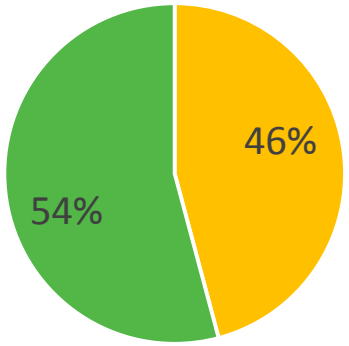
Annual Costs per Capita: 27,8 USD/year (before: 28.2 USD/year)

Sensitivity Analysis: Cutback of Electricity Generation Diversity

Only Renewables

Only Renewables





x 2

x 1,2

x 2

x 8

x 3

x 3

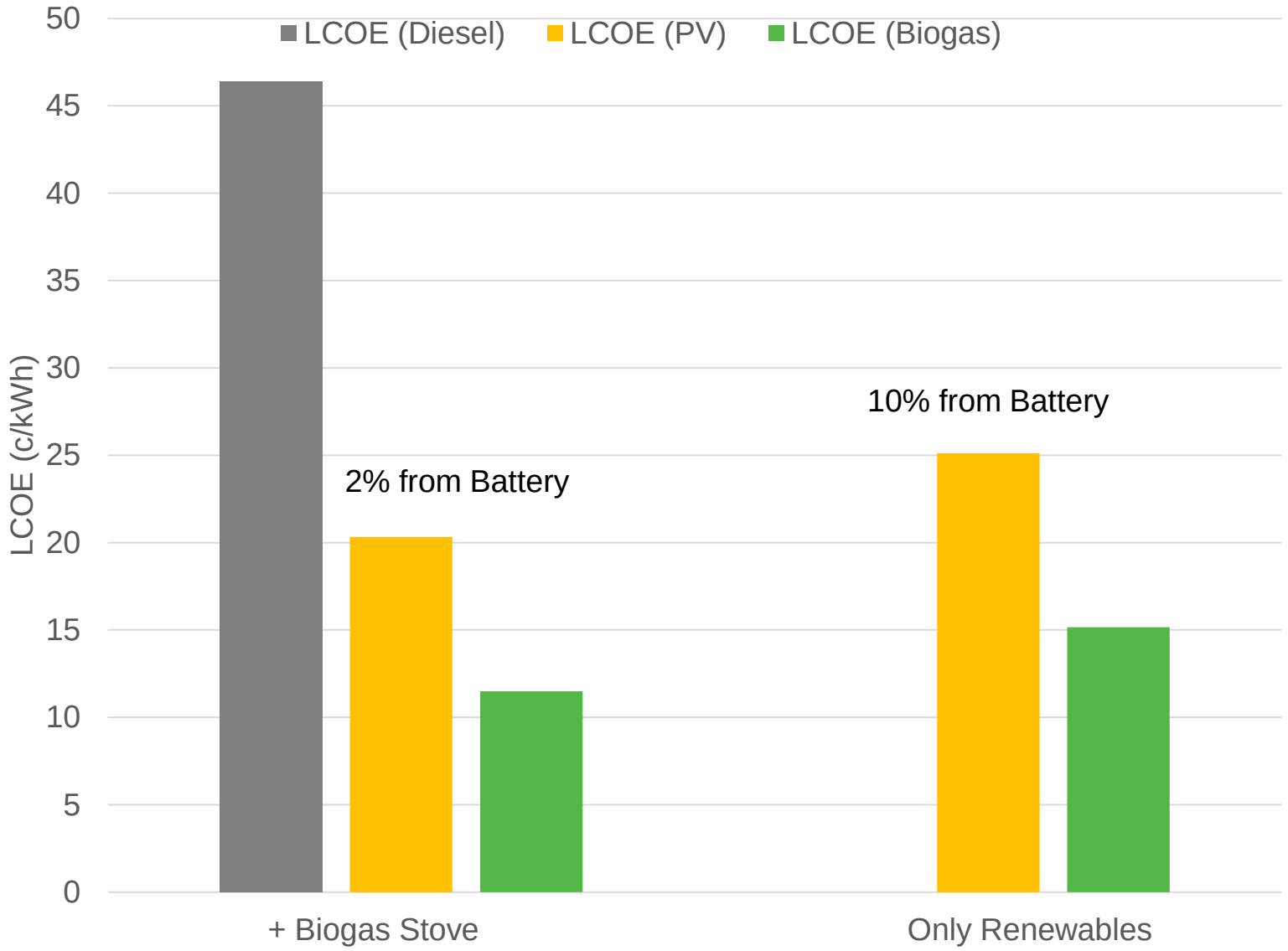
LCOE: 19,8 c/kWh

(before 19,5 c/kWh)

Annual Costs per Capita: 33,9 USD/year

(before: 27,8 USD/year)

Only Renewables



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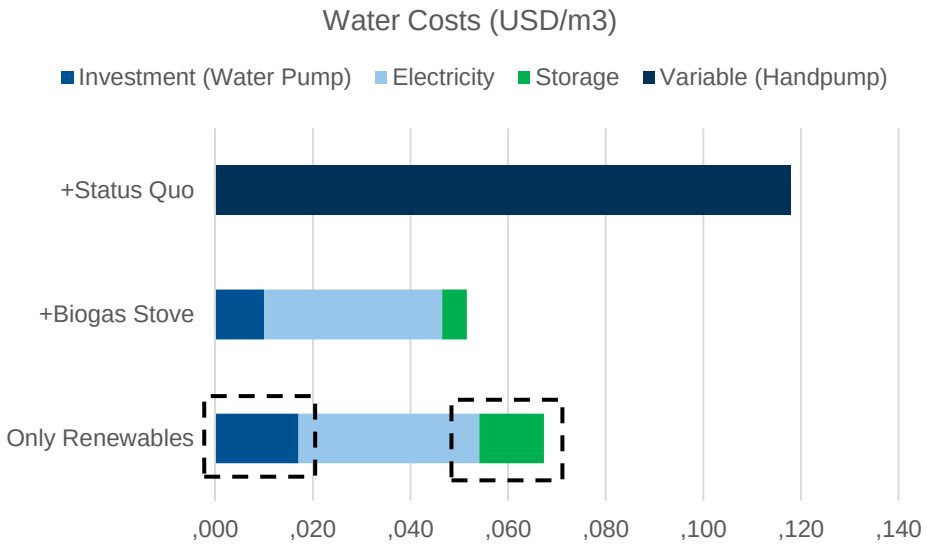
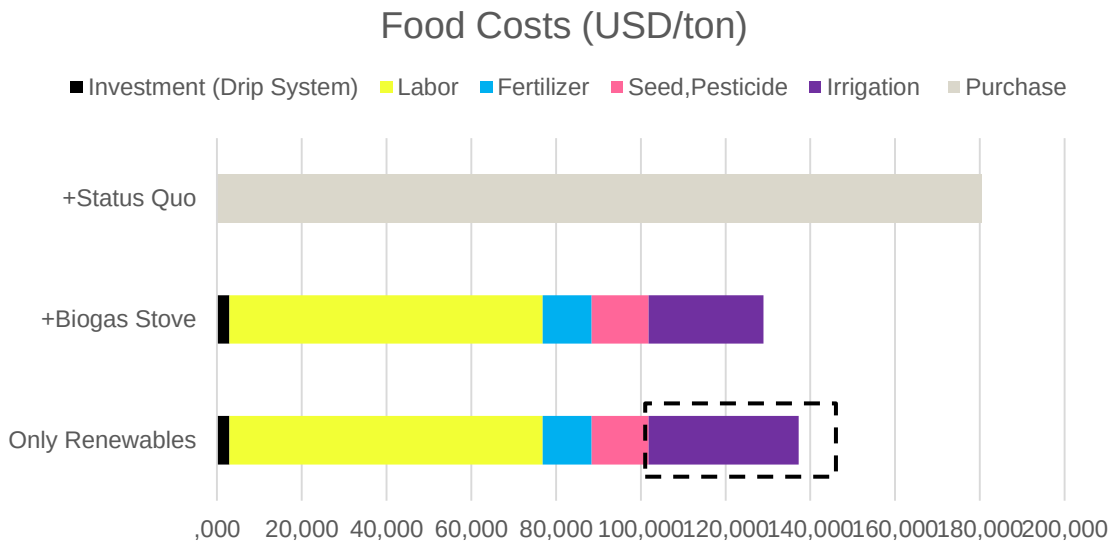
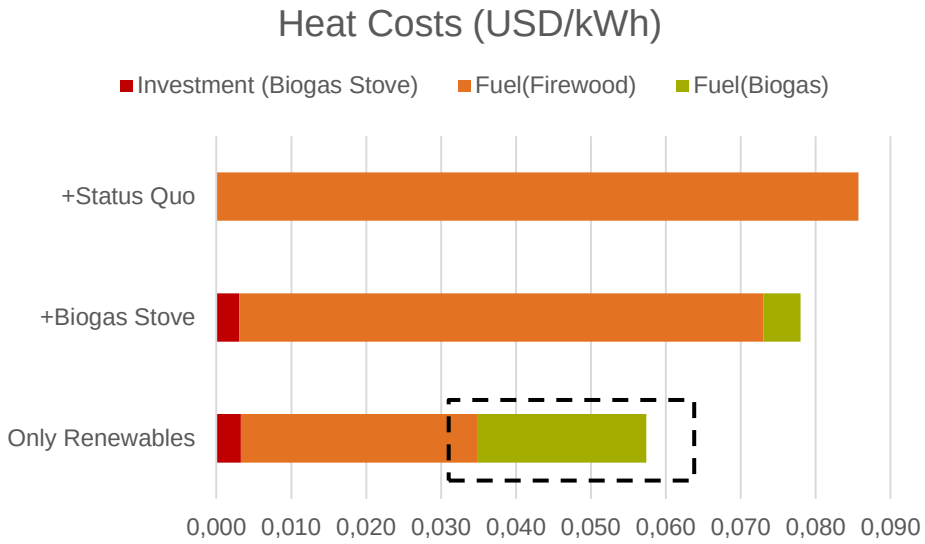
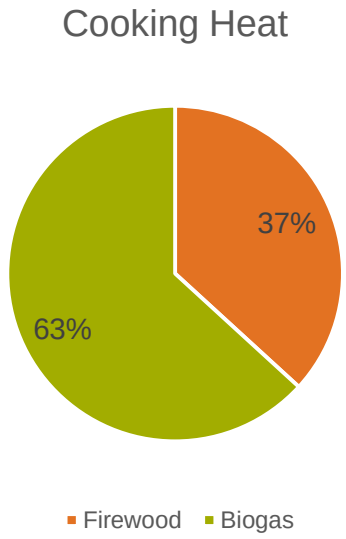








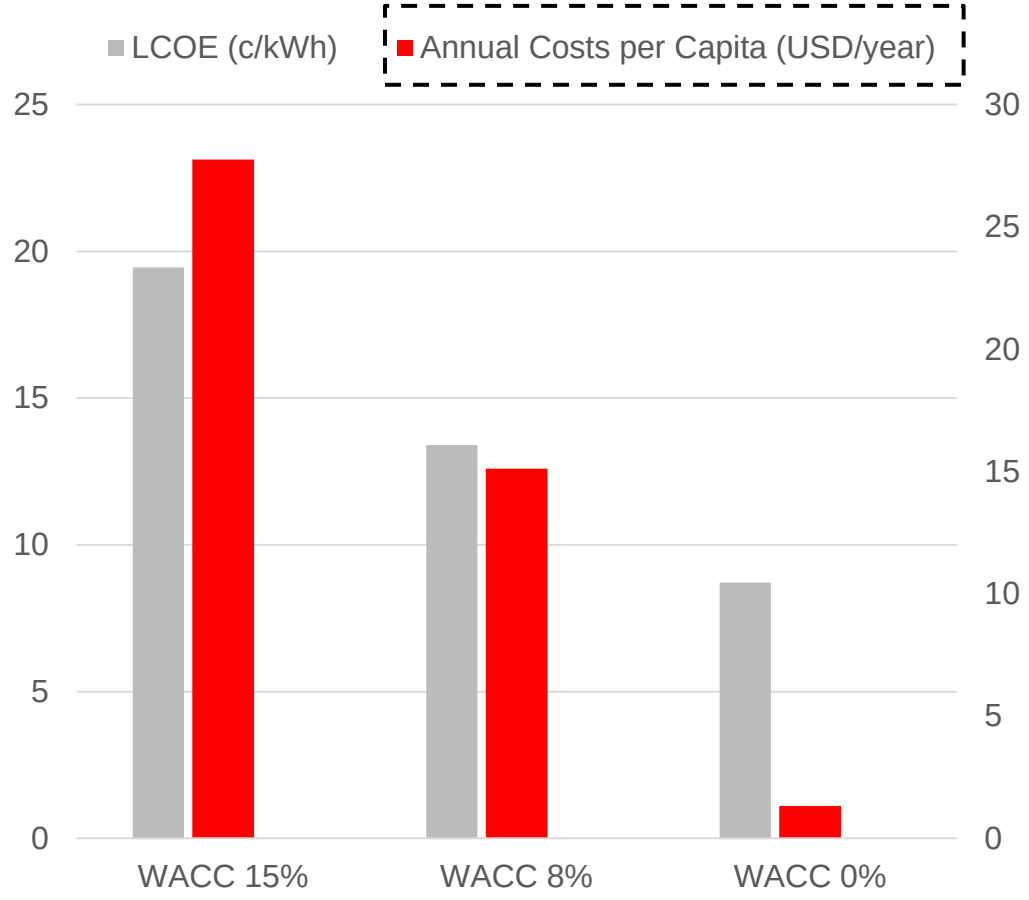
Summary

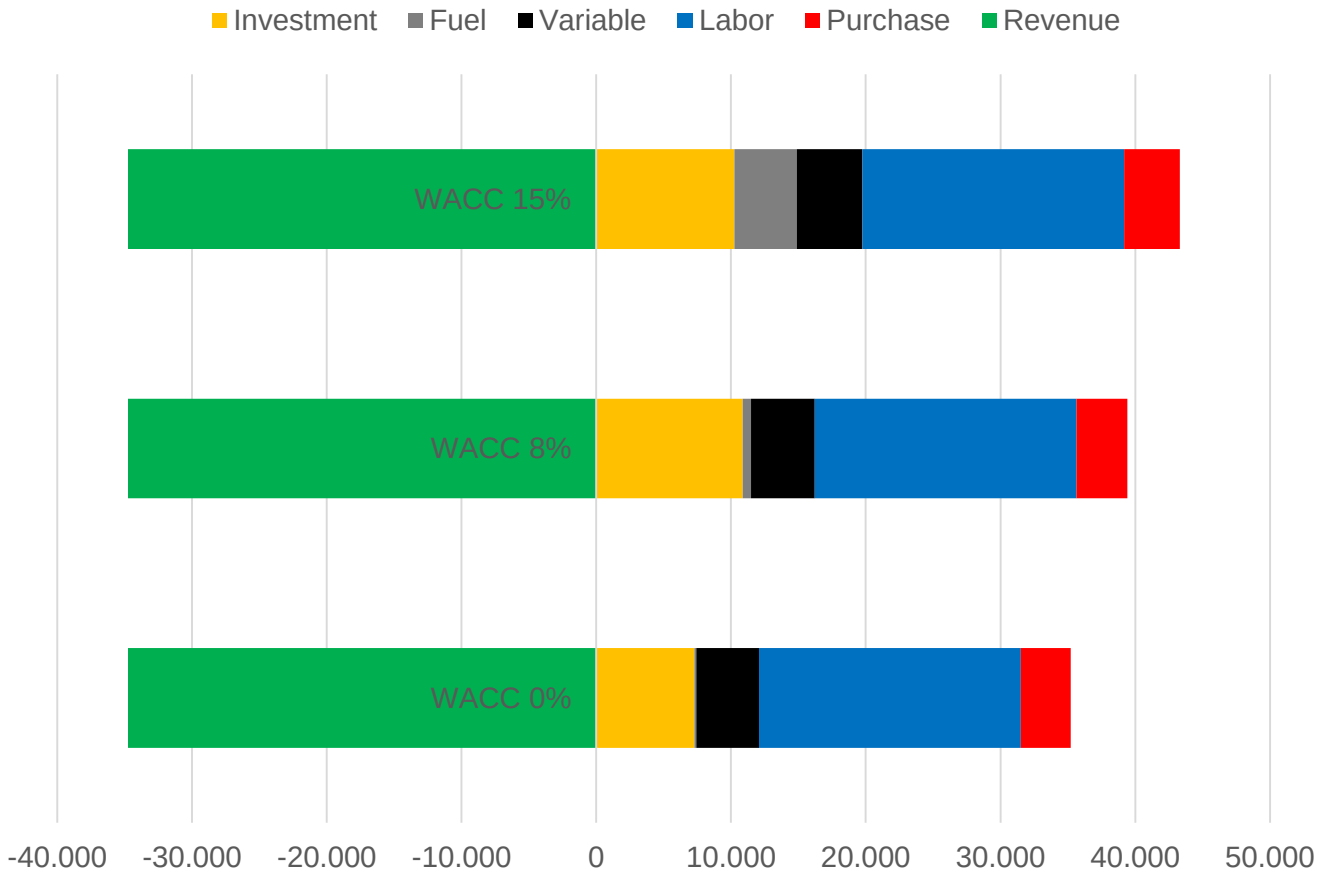

Power Generation (%)
Diesel Generator
Photovoltaics
Biogas Generator
Diesel+PV+Bat
+Water Pump
+Fields
+Selling
+Biogas
+Biogas Stove
Only Renewables
44.4 c/kWh
43.8 c/kWh
41 c/kWh
37.1 c/kWh
19.5 c/kWh
19.5 c/kWh
19.8 c/kWh
0%
20%
40%
60%
80%
100%
4 ha
Annual System Costs (USD)
Investment
Fuel
Variable
Labor
Purchase
Revenue
Diesel+PV+Bat
+Water Pump
+Fields
+Selling
+Biogas
+Biogas Stove
Only Renewables
Organic Fertilizer
-40.000
-20.000
0
20.000
40.000
60.000
80.000

Sensitivity Analysis: Improvement of Interest Rate Conditions

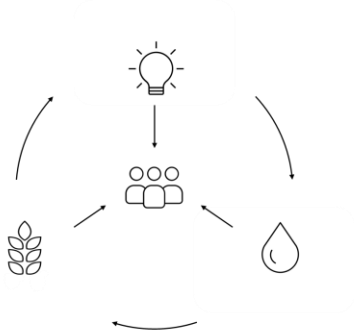
WACC 15% → WACC 8% → WACC0%

Sensitivity Analysis: WACC





Conclusions



Linear Model for Energy-Water-Food System for Rural Off-Grid Villages with ***urbs***

Depiction of Dependencies and Synergies between Energy-Water-Food Subsystems

Reproducible for further Off-Grid Village Analysis

Outlook

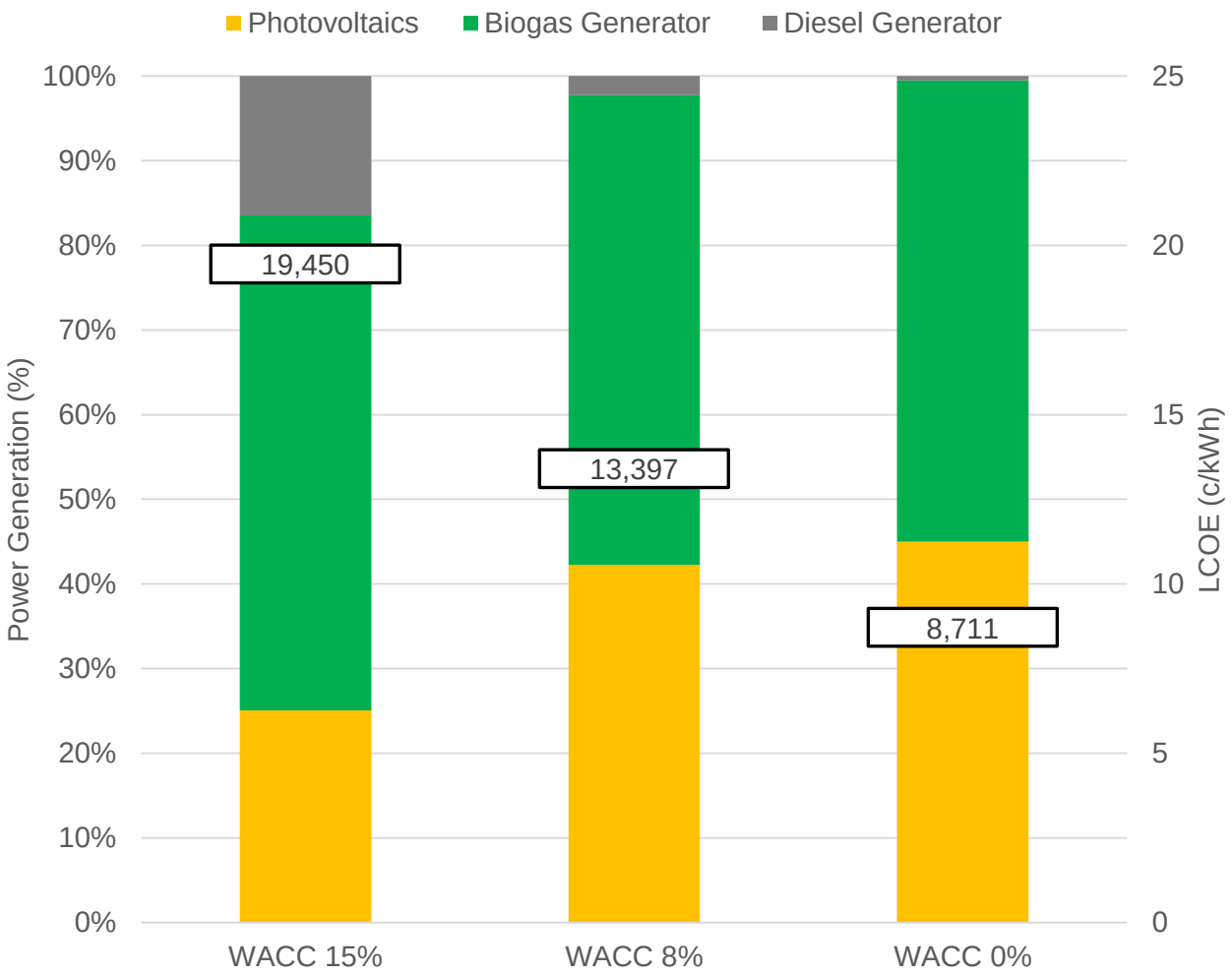
Modeling of several crop fields

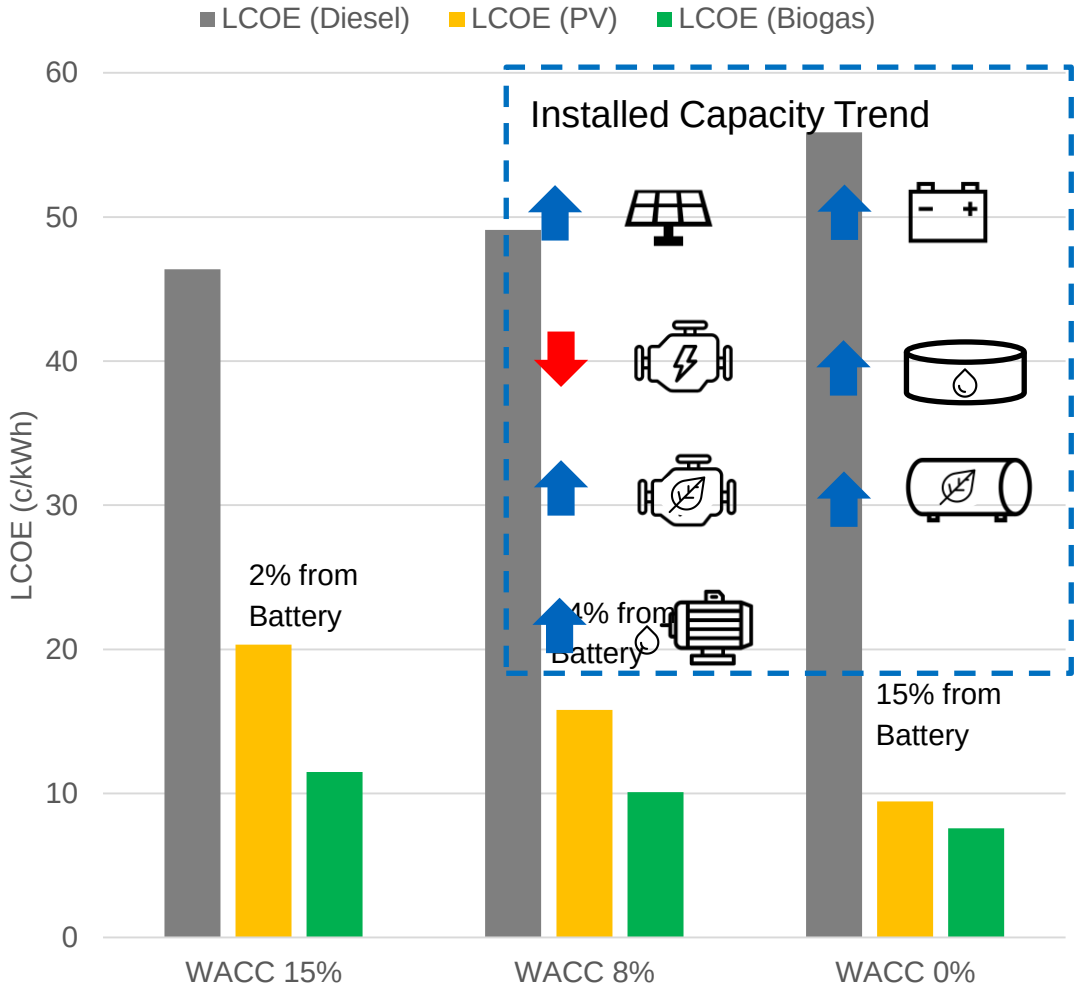
Enhaced modeling of processes:

- Implementation of part load (e.g diesel generator, biogas generator)

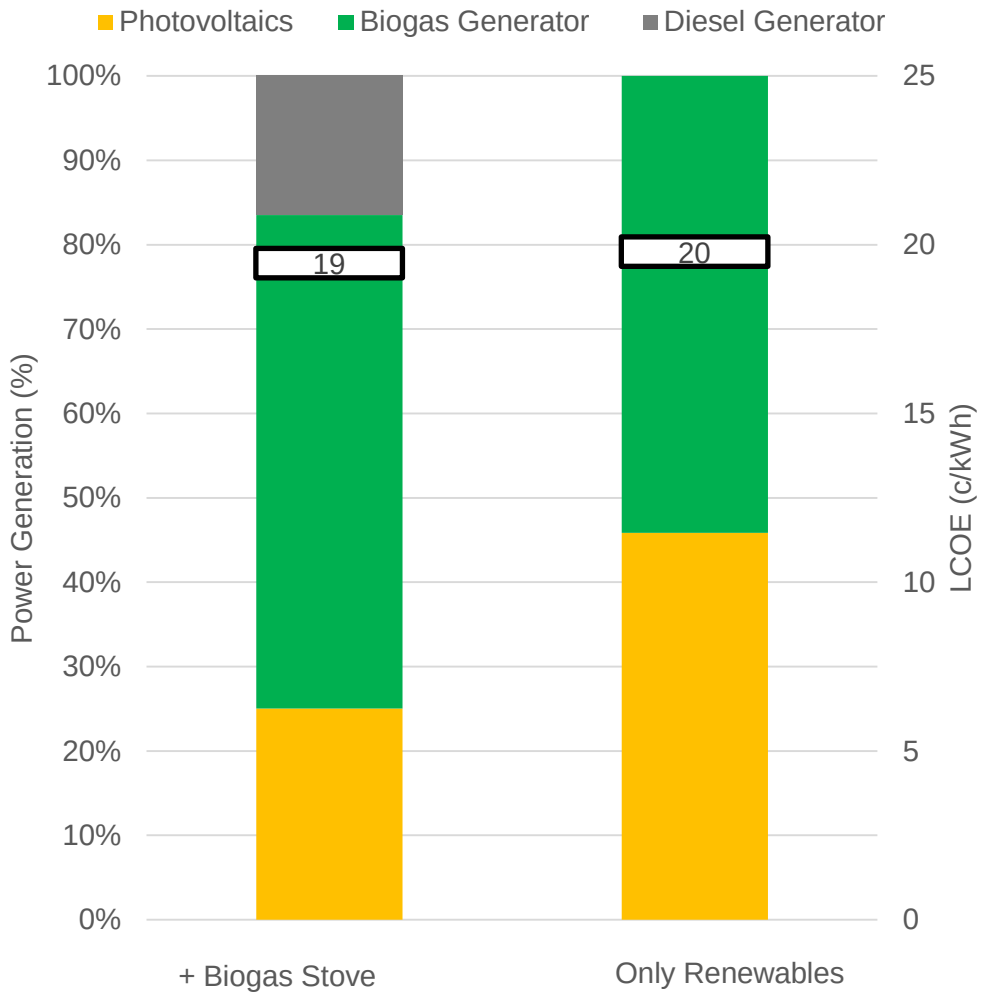
- Implementation of processes with storage capacity (e.g. Anaerobic digester)

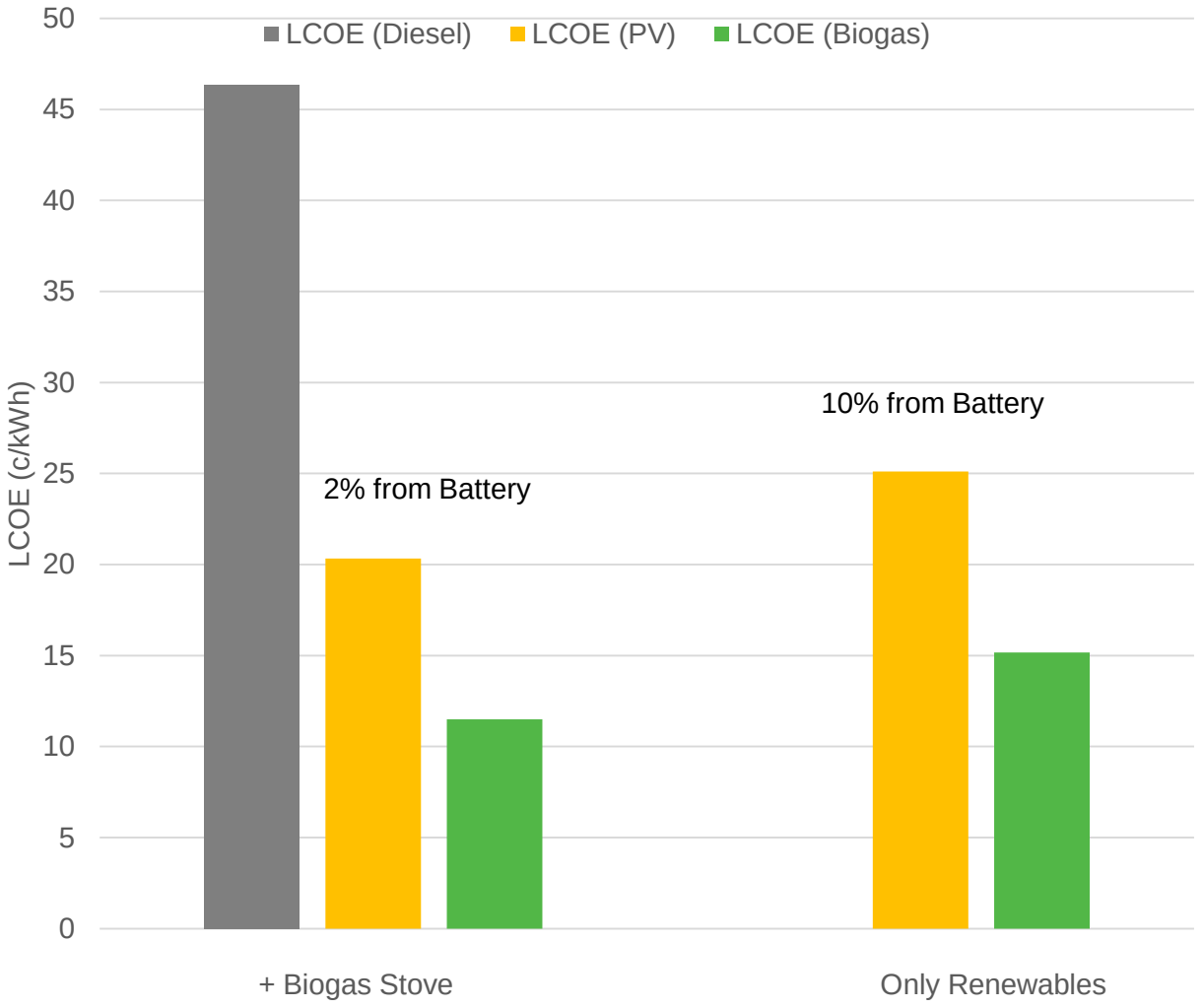
Sensitivity Analysis: WACC



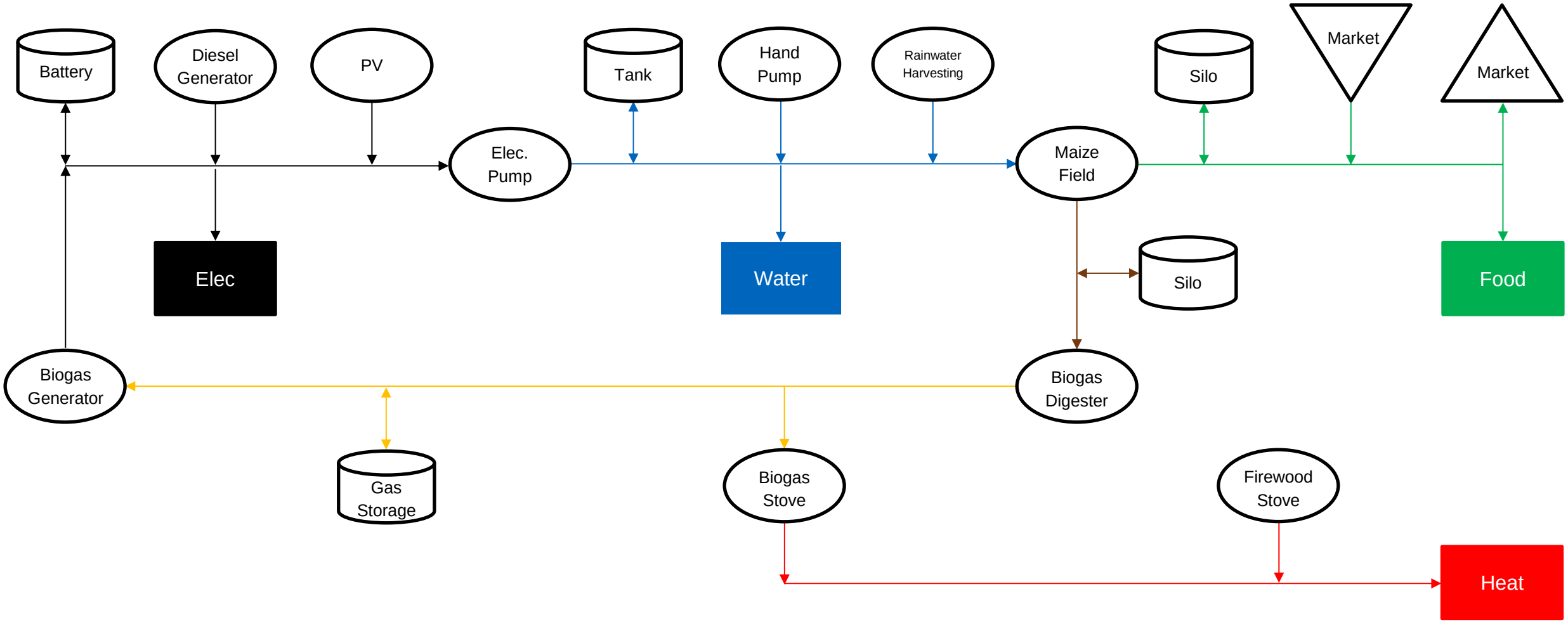


Only Renewables

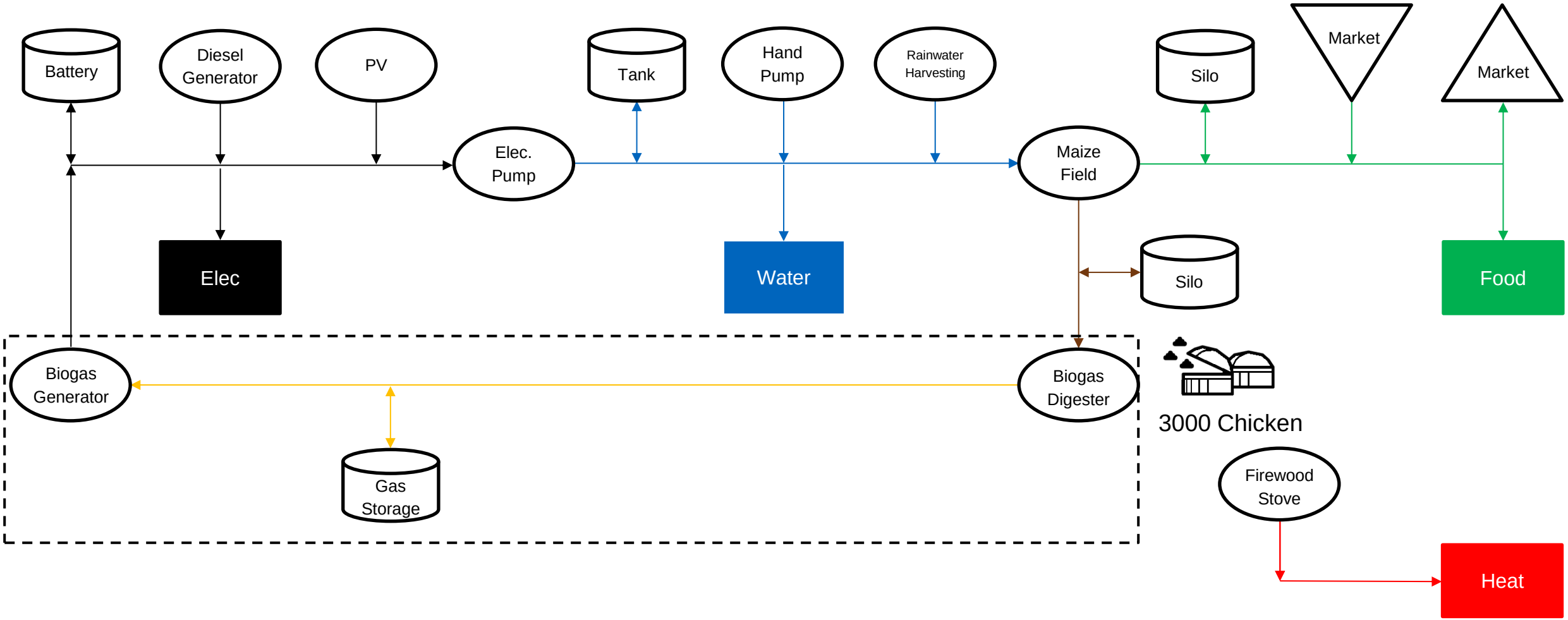




Decentralized Energy-Water-Food Systems: Proposal



Scenario 4: + Biogas



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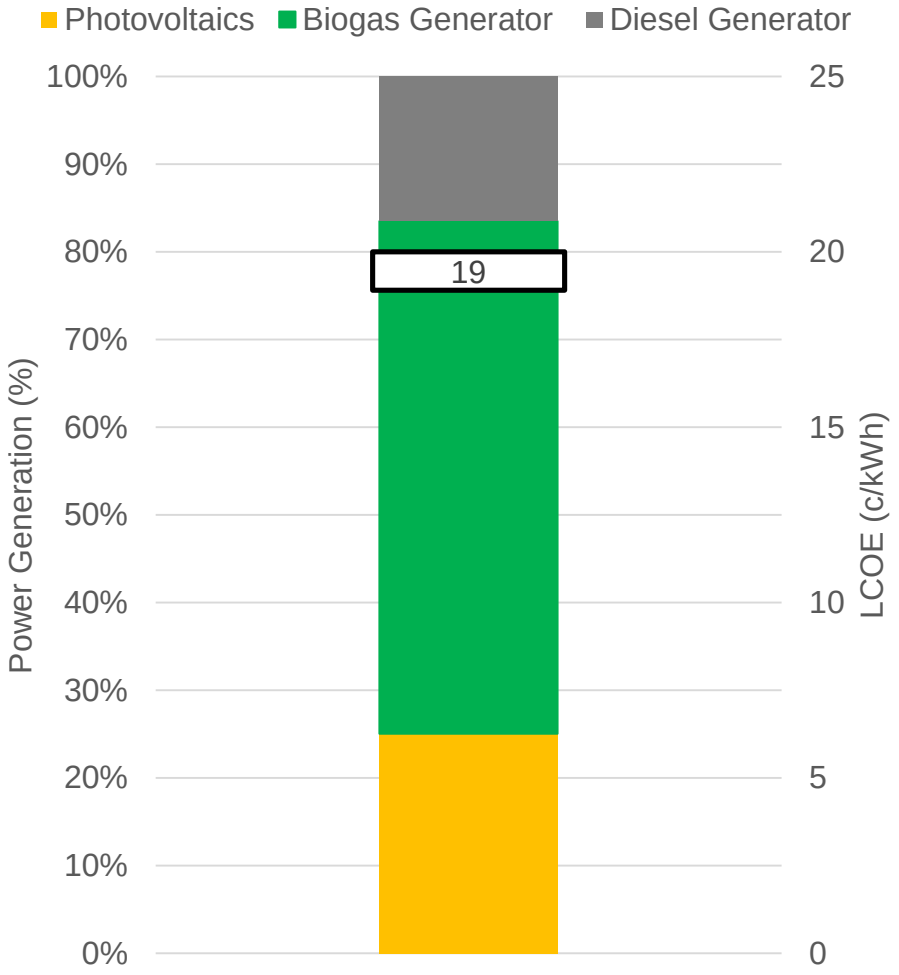
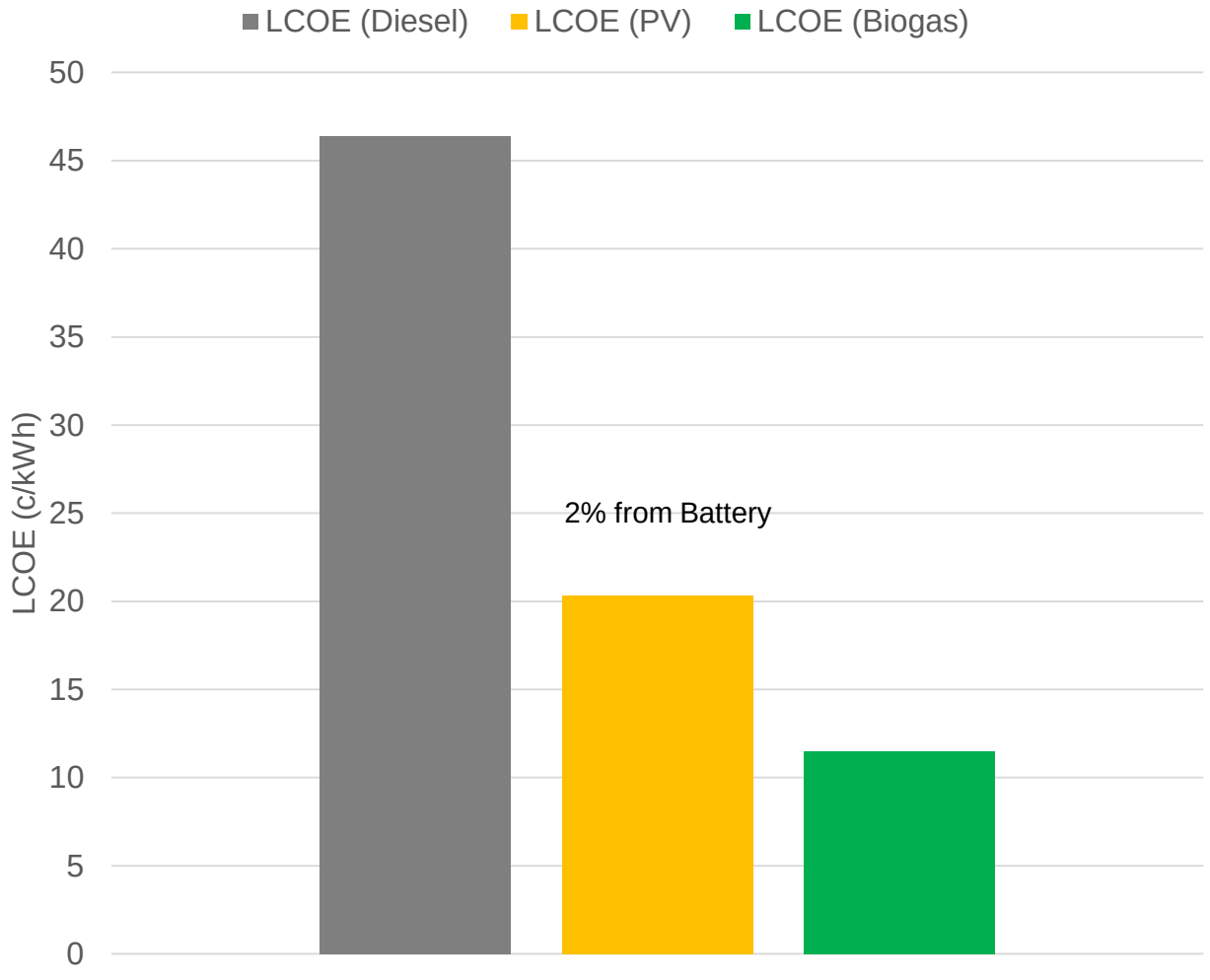


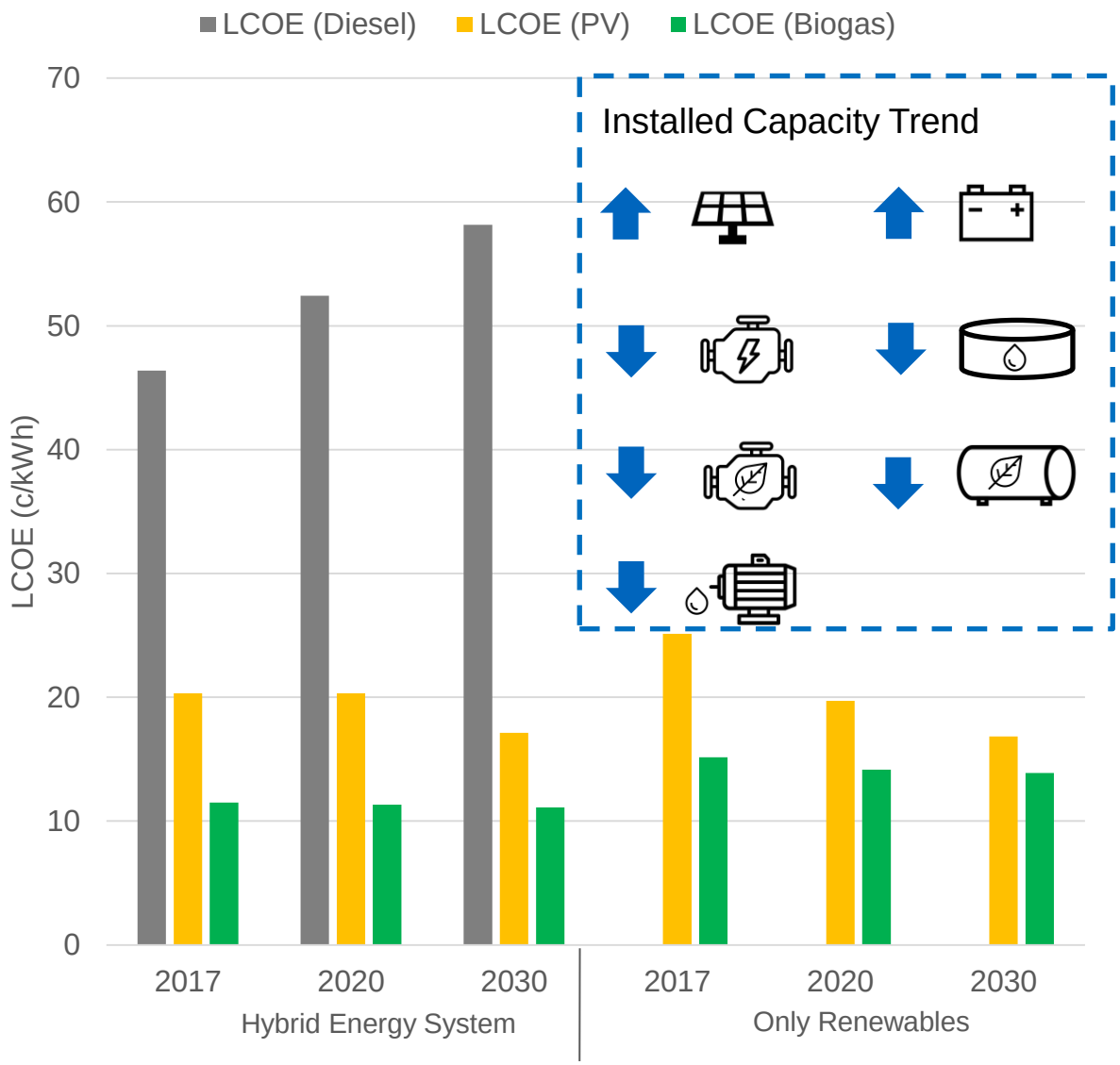


Sensitivity Analysis: PV and Battery Investment Costs

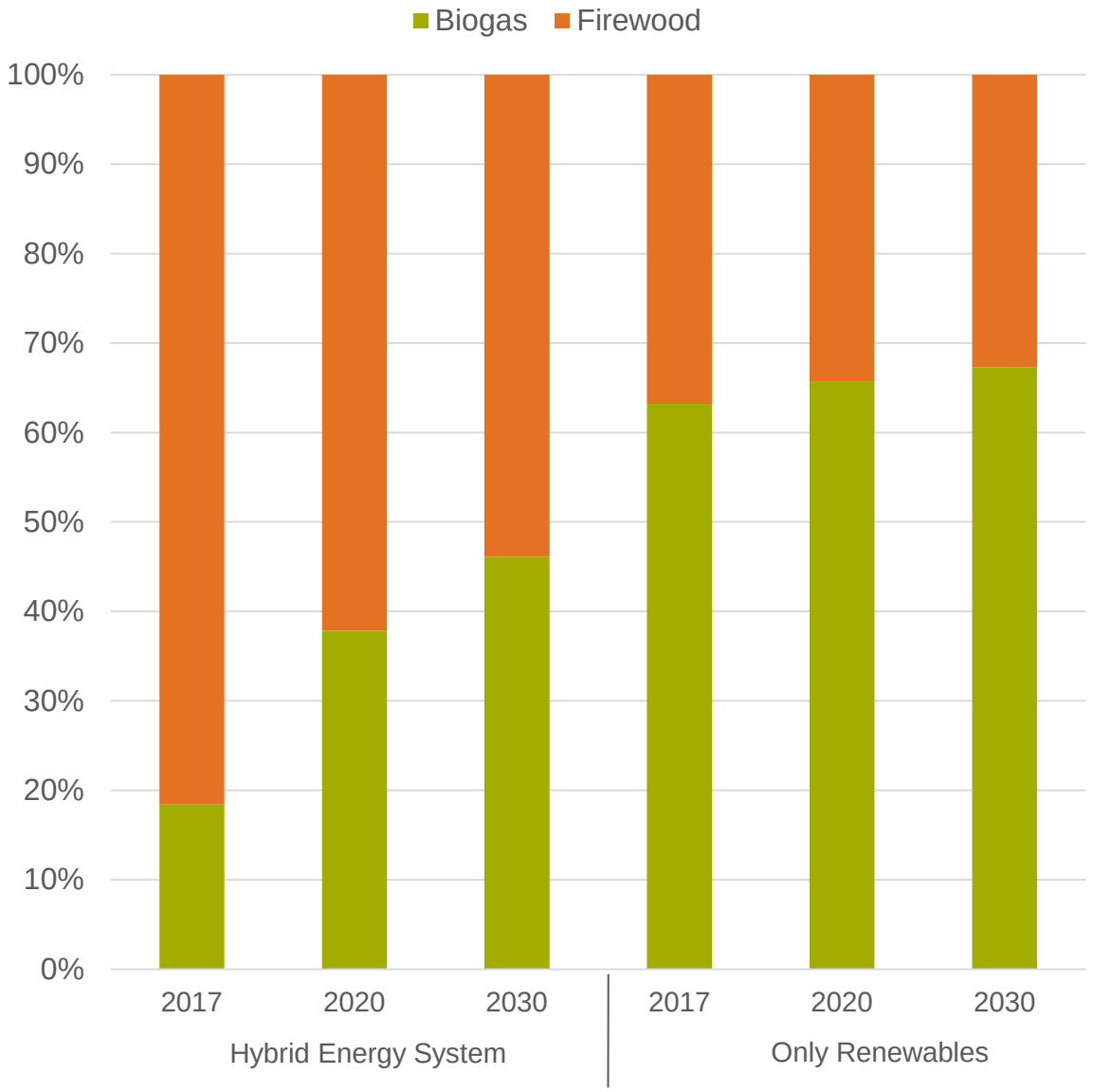
Outlook 2020 and 2030

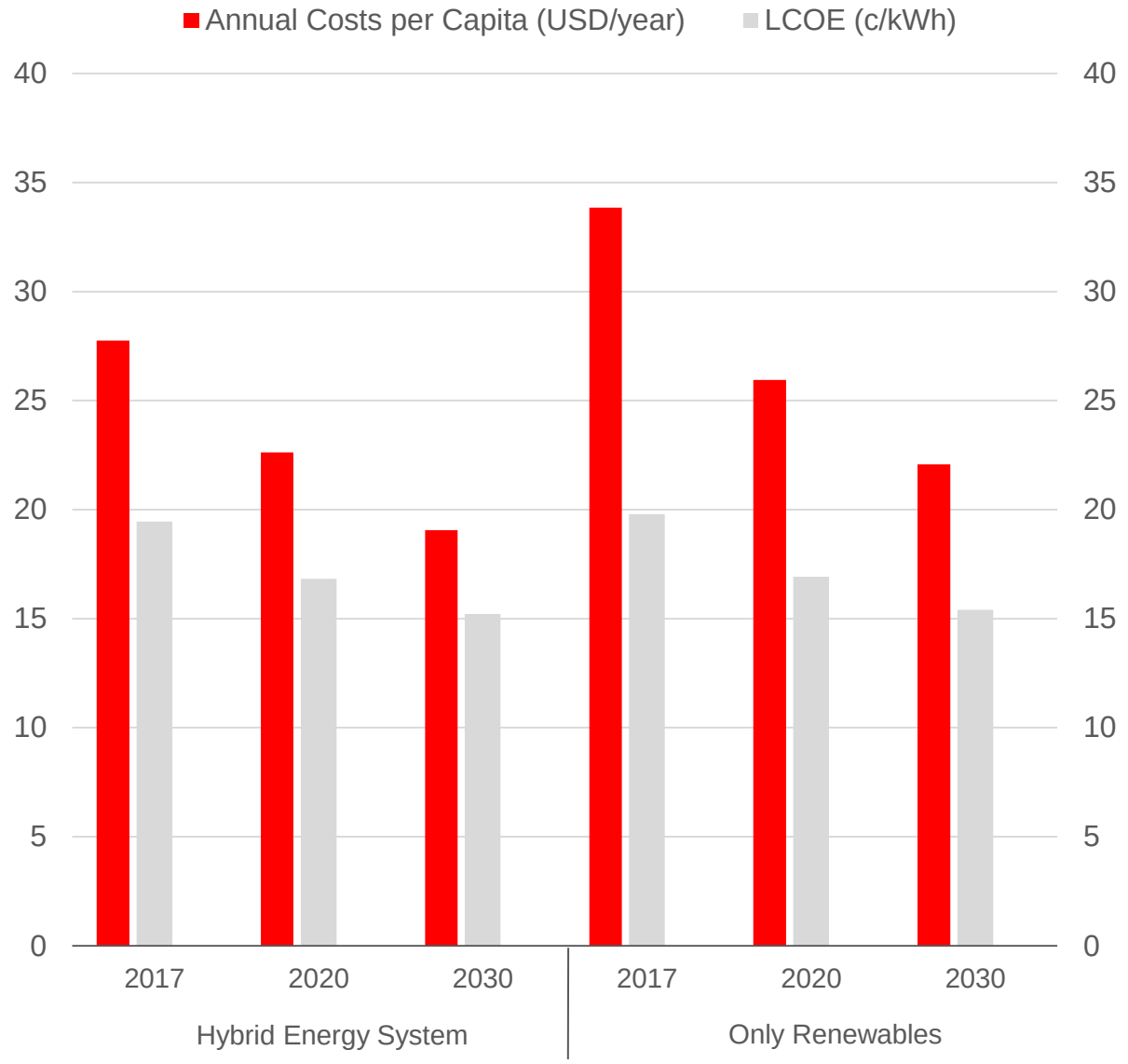
2017	2020	2030
1500 USD/kW	1000 USD/kW	800 USD/kW
350 USD/kWh	280 USD/kWh	210 USD/kWh

Outlook 2020 and 2030



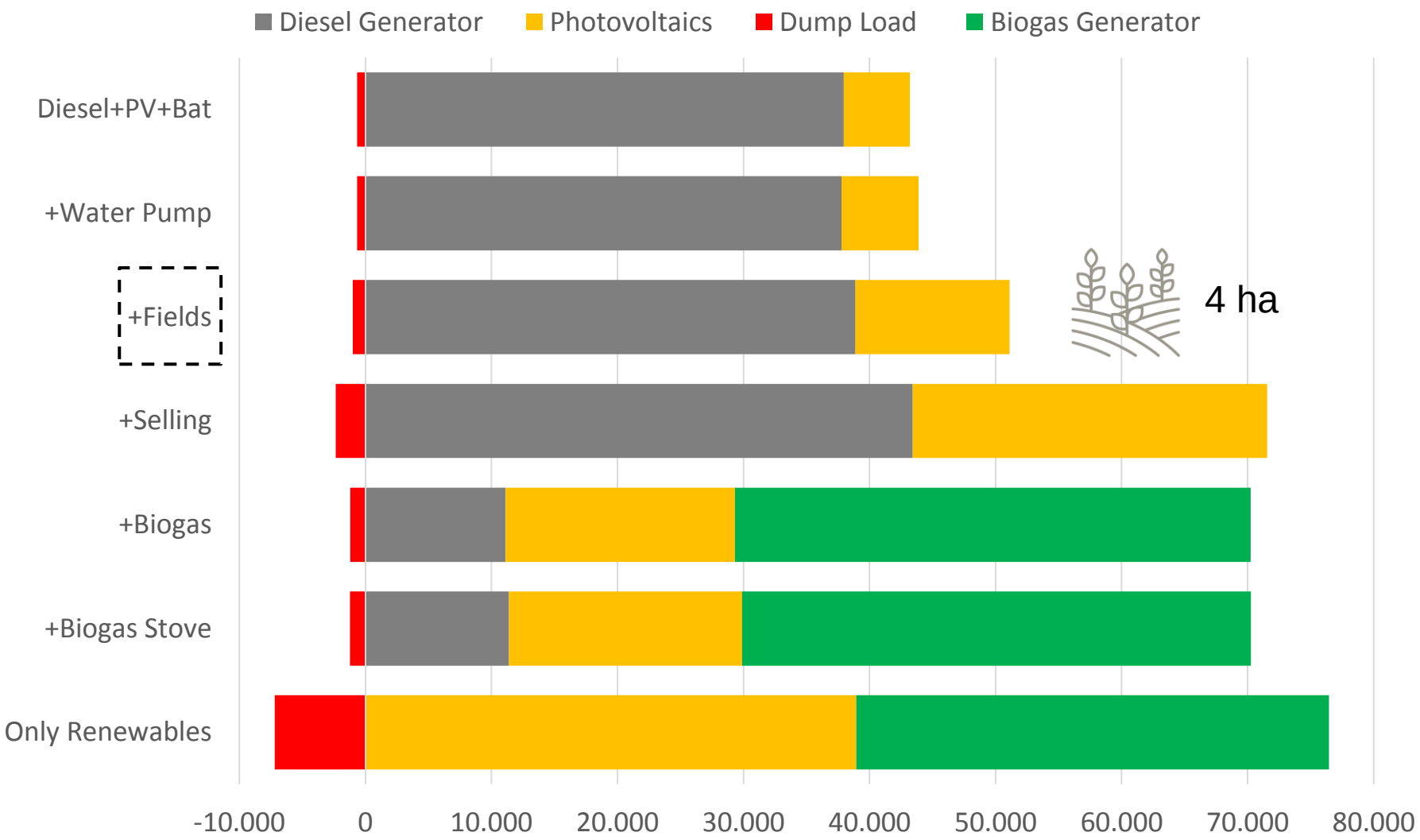
Outlook 2020 and 2030



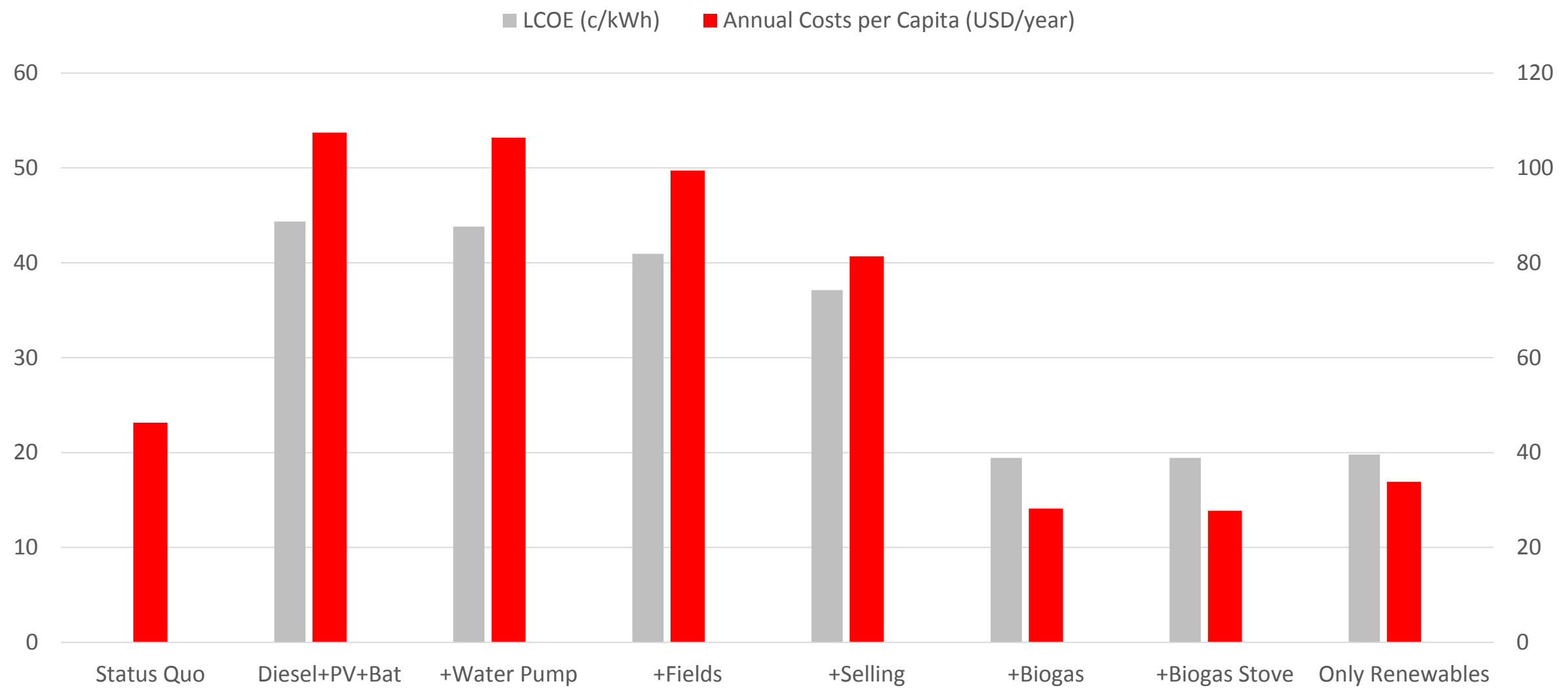


Backup

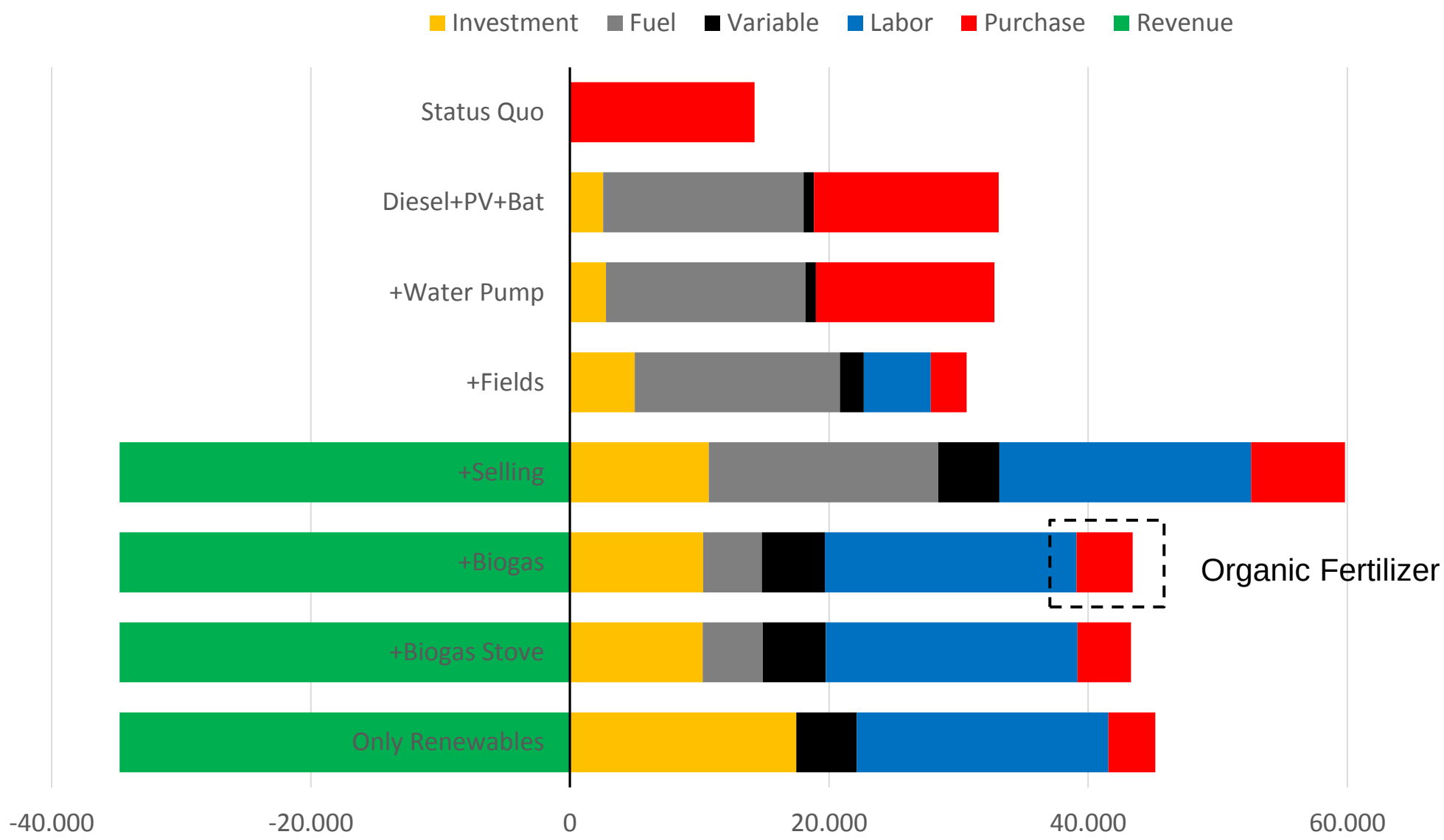
Summary – Annual Electricity Generation (kWh)



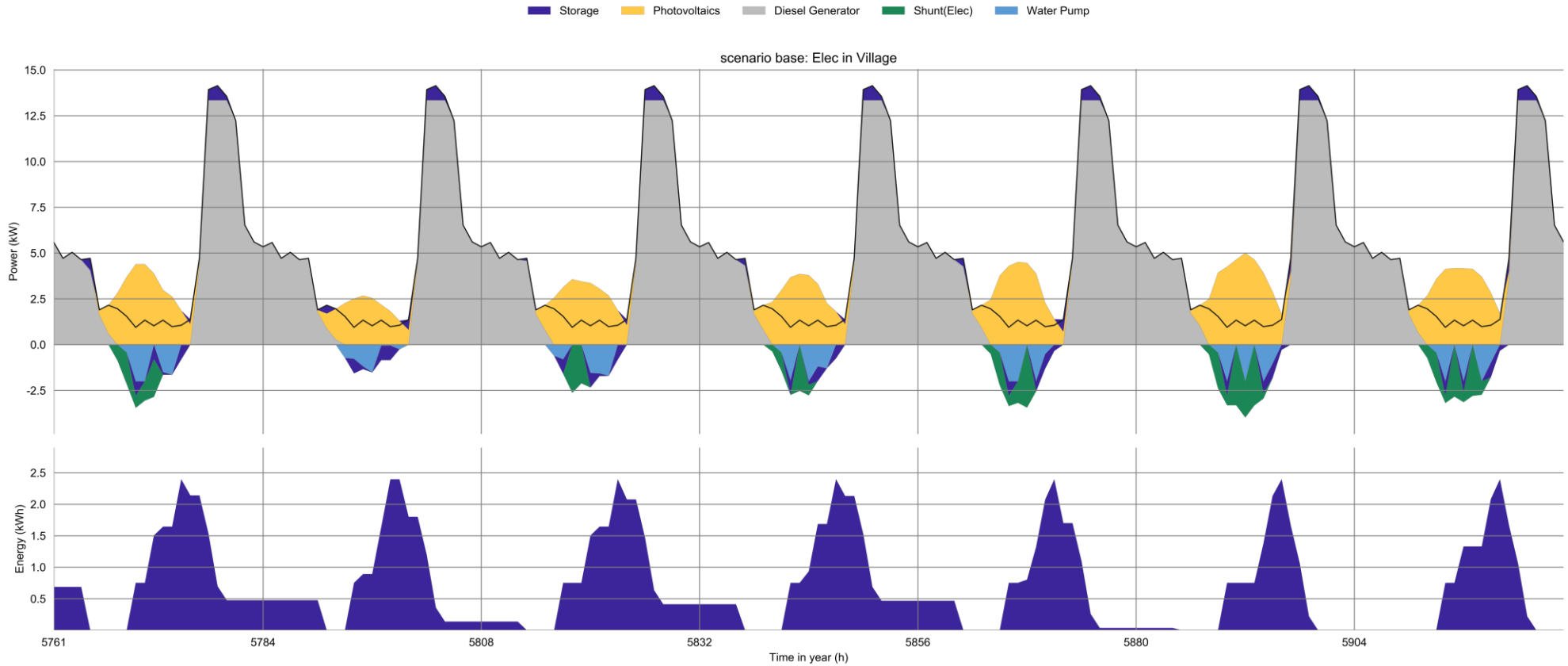
Summary – LCOE & Annual Costs per Capita

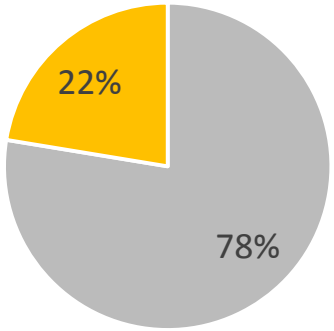


Summary – System Costs (USD/year)



Scenario 3: + Fields

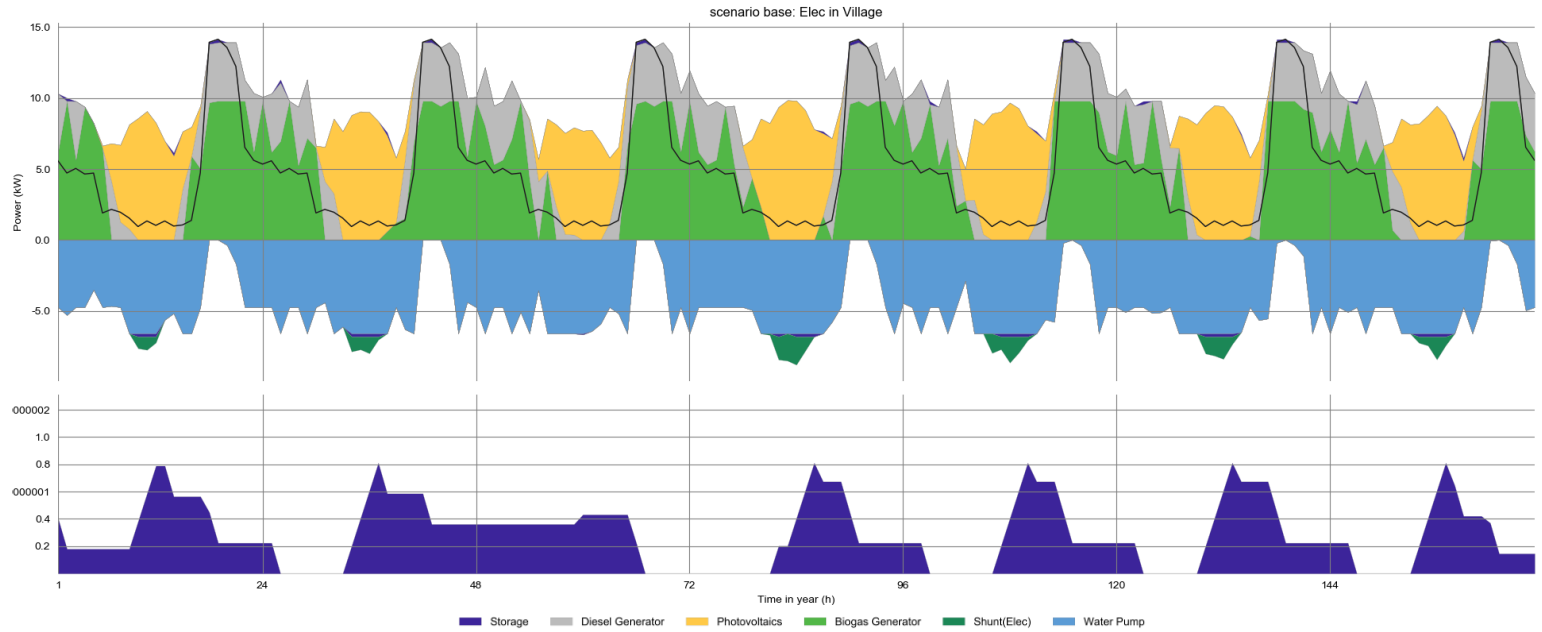




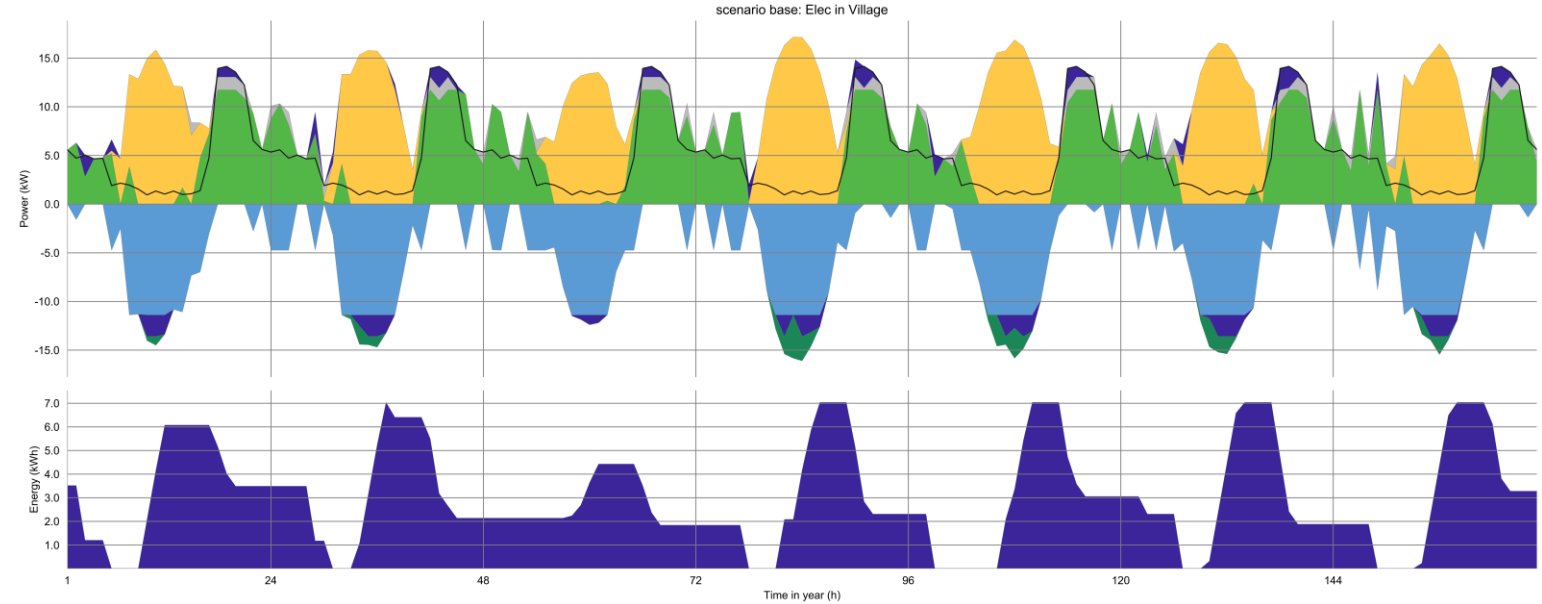
LCOE:	40,1 c/kWh (before: 43,8)
Annual Costs per Capita:	99,4 USD/year (before: 106,4)
Hectares Cultivated:	4 ha
Jobs in Farming:	6 Jobs

Sensitivity Analysis: WACC

WACC 15%

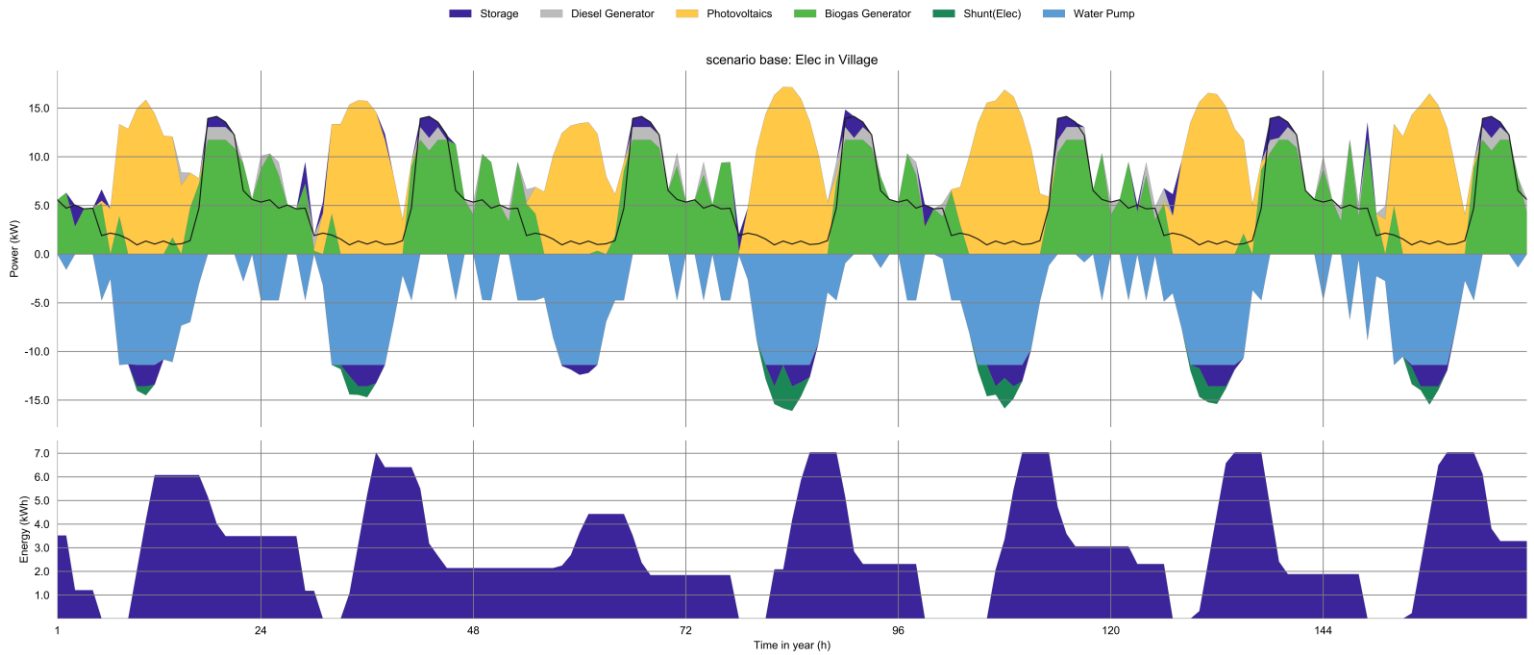


WACC 8%

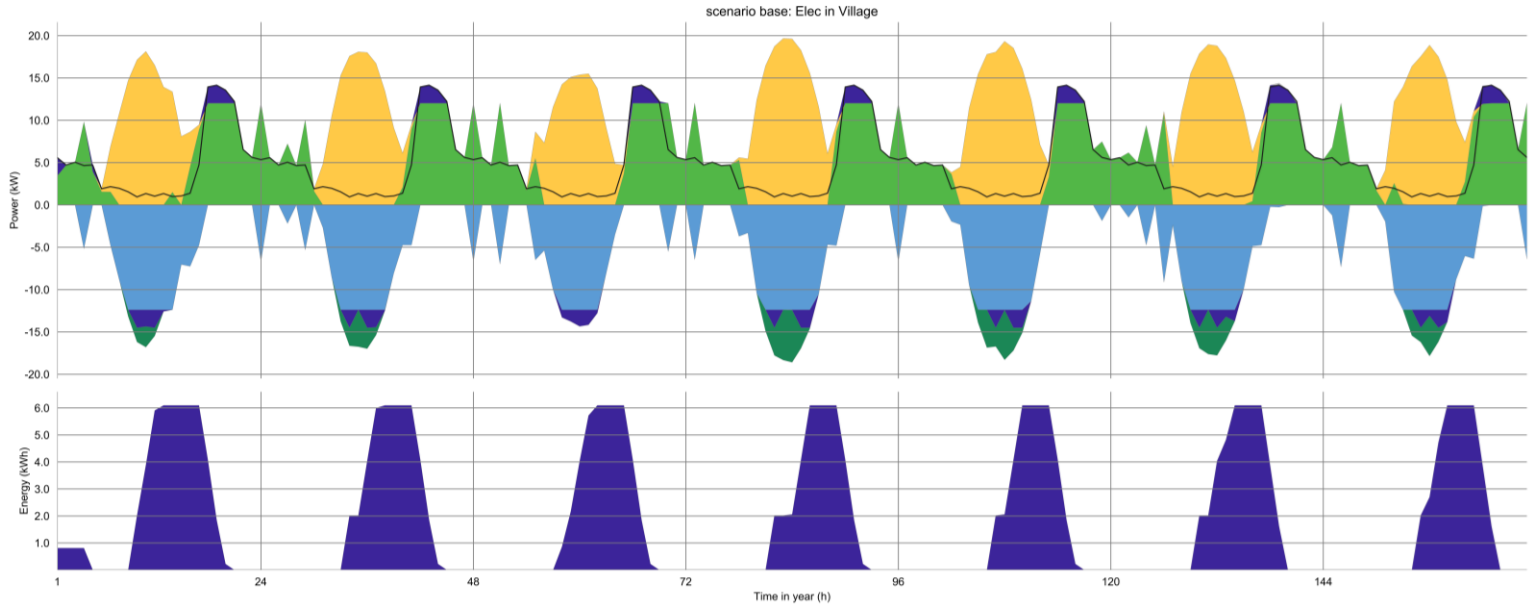


Sensitivity Analysis: WACC

WACC 15%

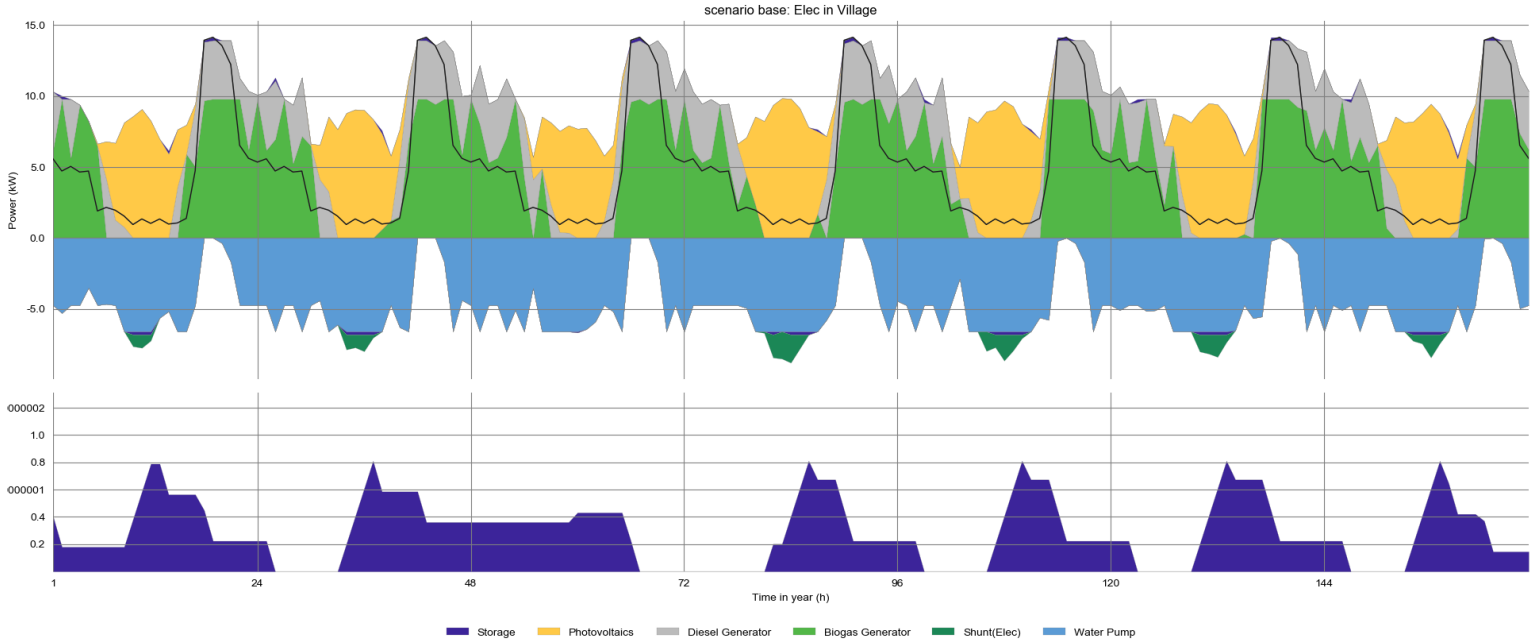


WACC 0%

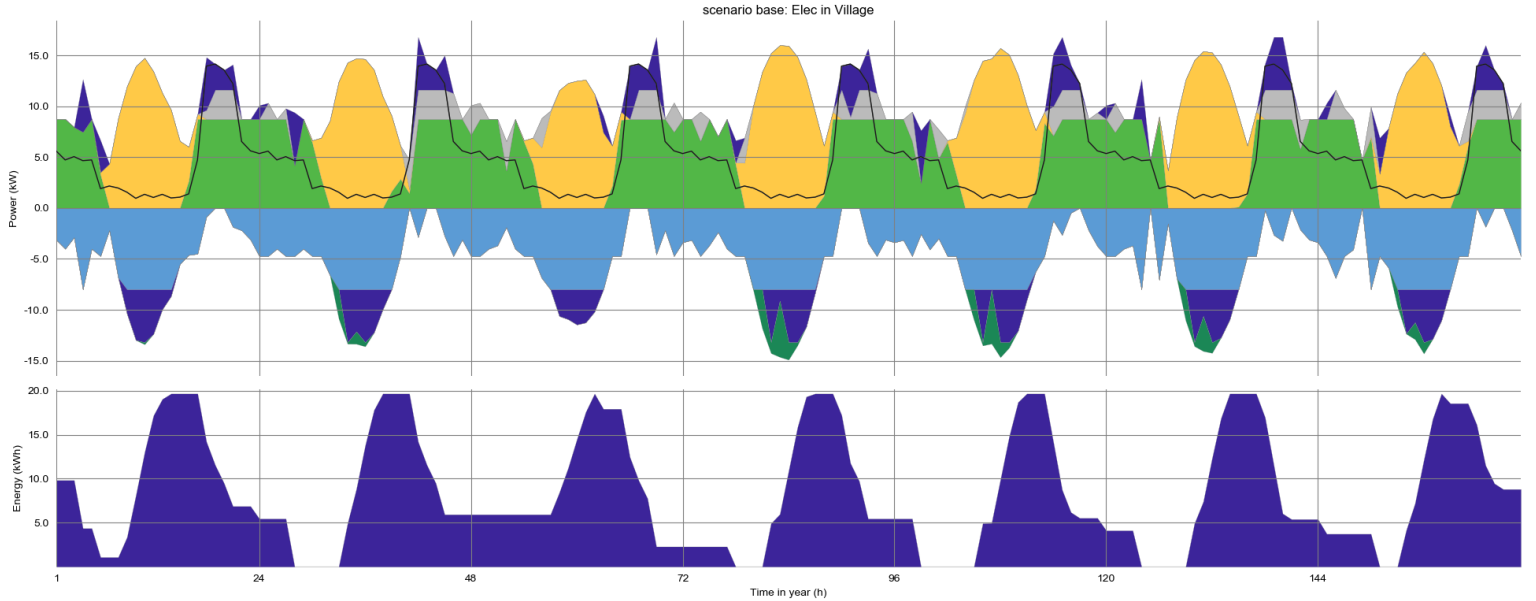


Outlook 2020 and 2030: Hybrid System

2017

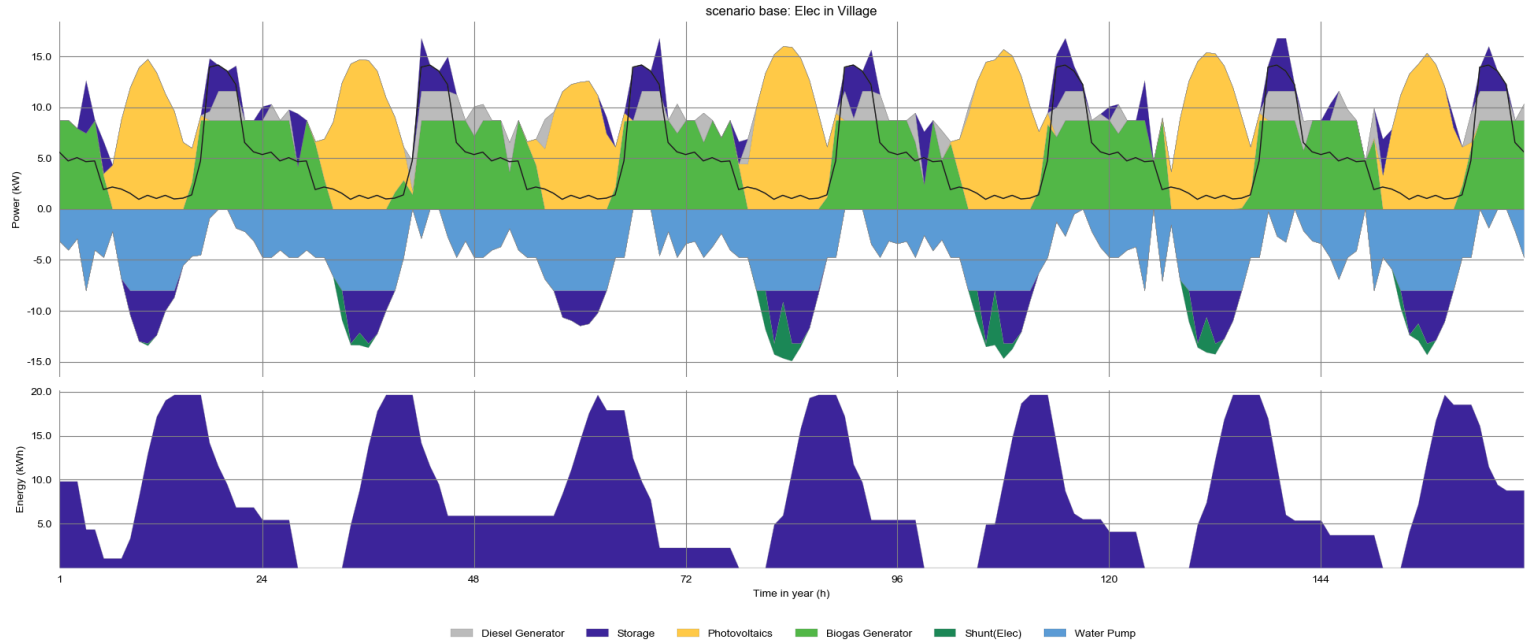


2020

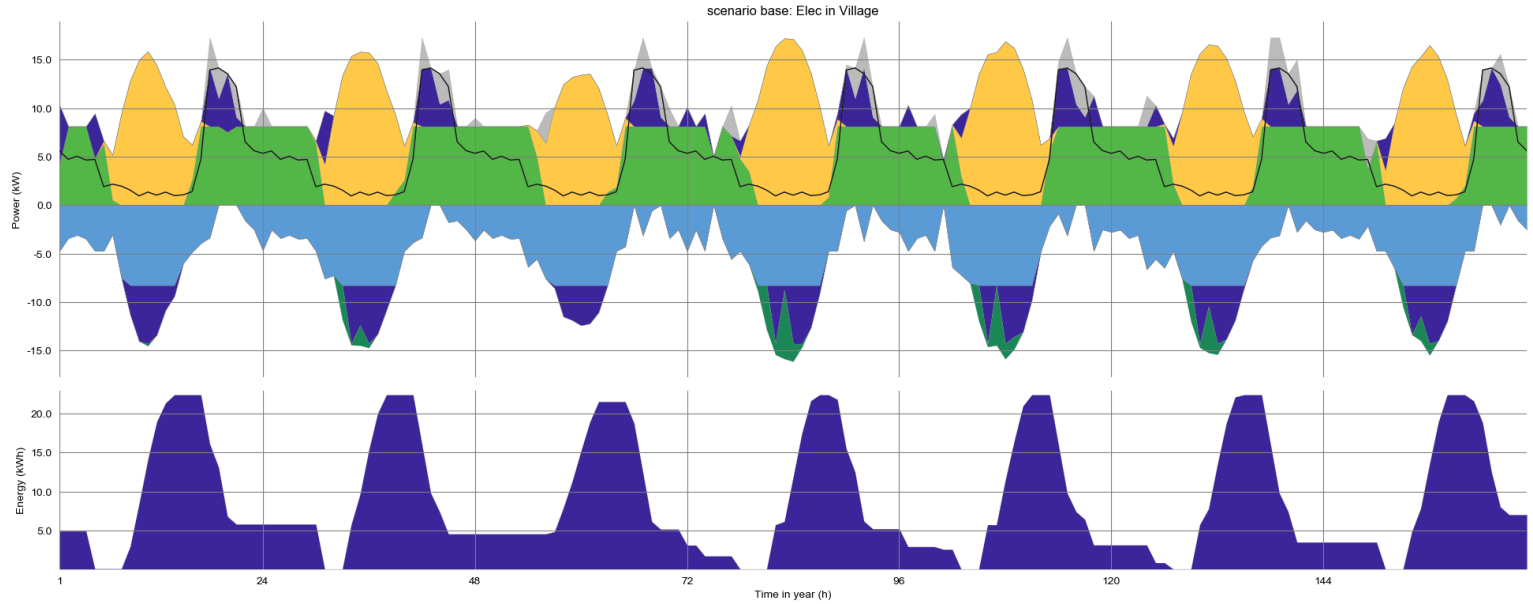


Outlook 2020 and 2030: Hybrid System

2020



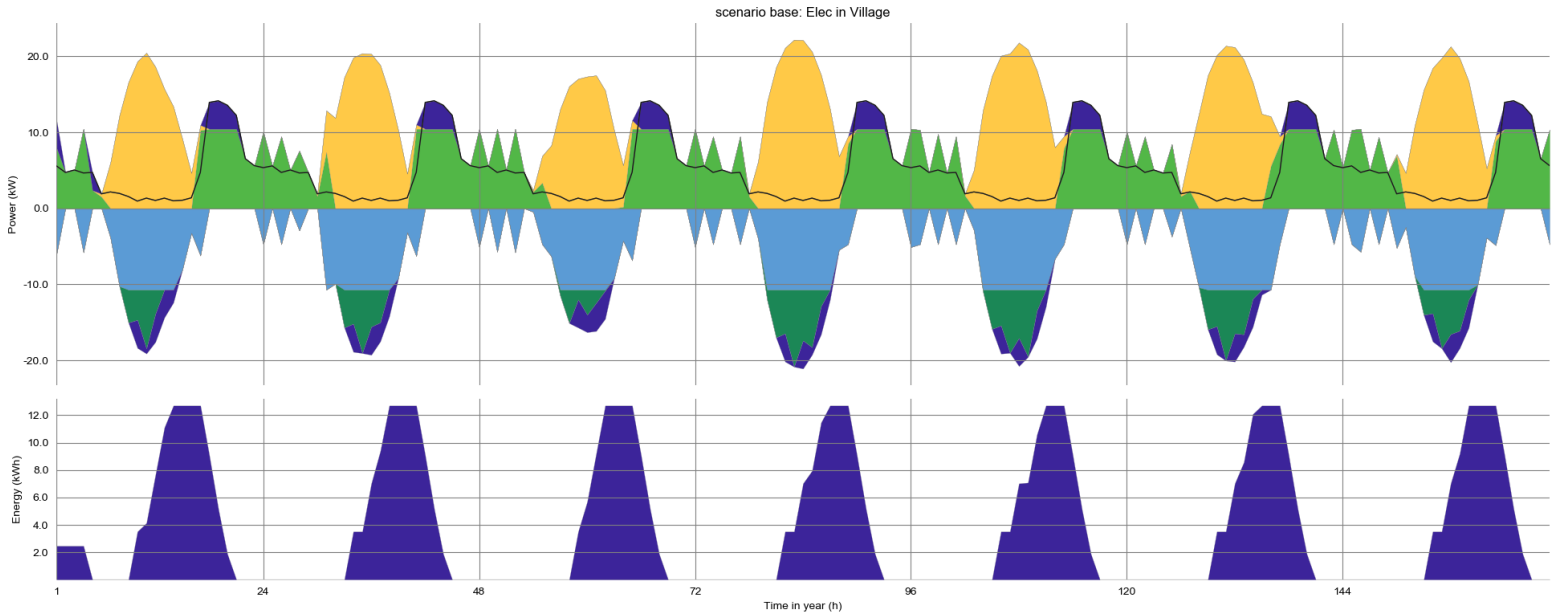
2030



Outlook 2020 and 2030: Only Renewables

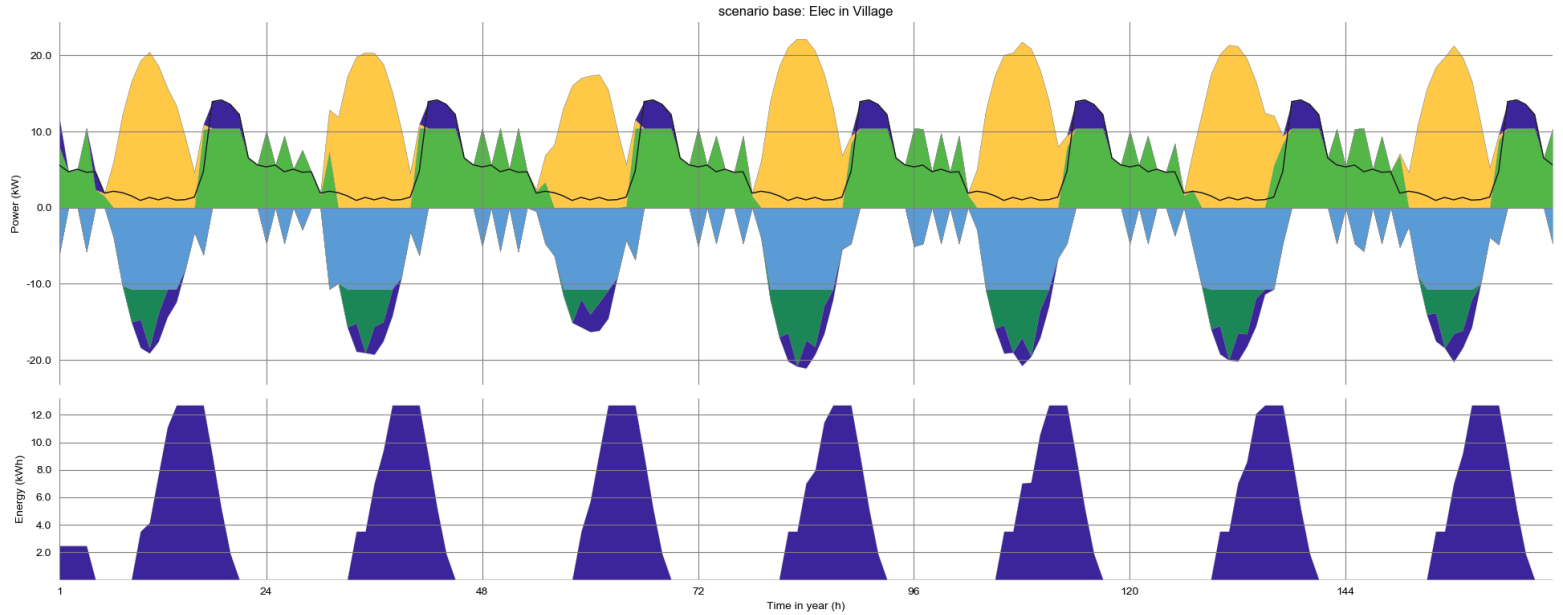
2017

2020

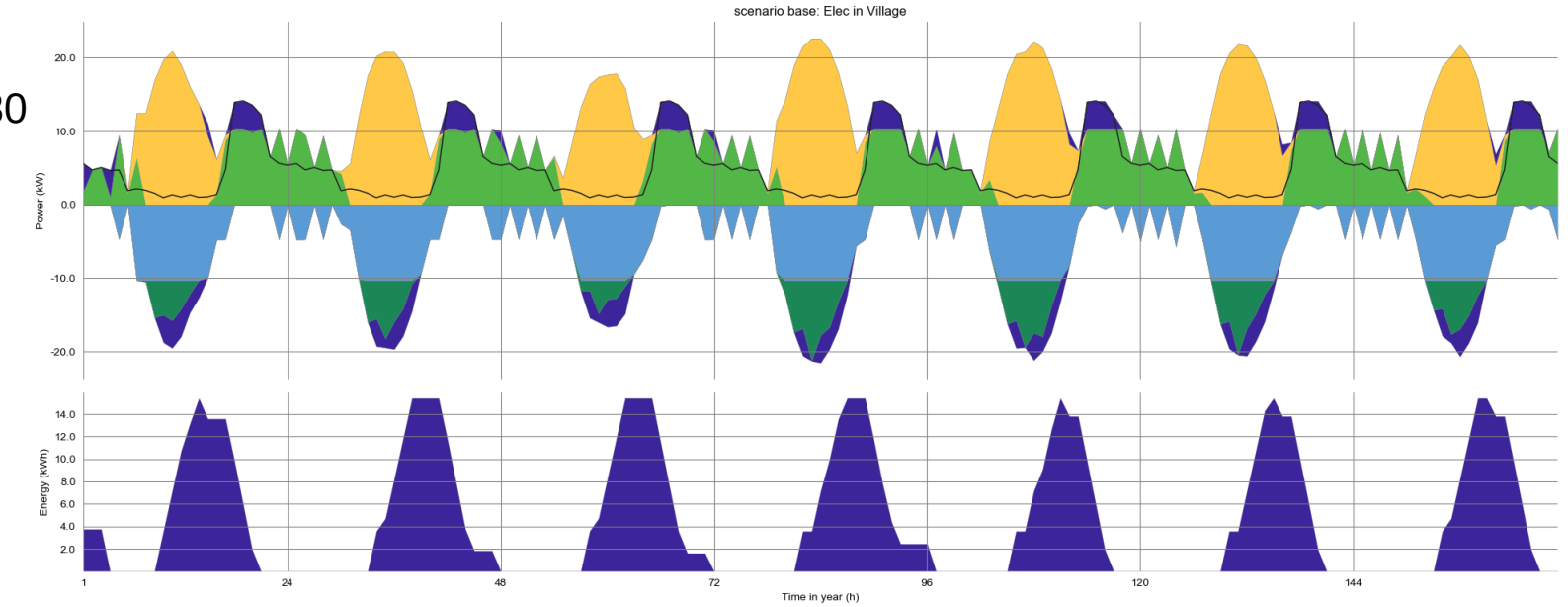


Outlook 2020 and 2030: Only Renewables

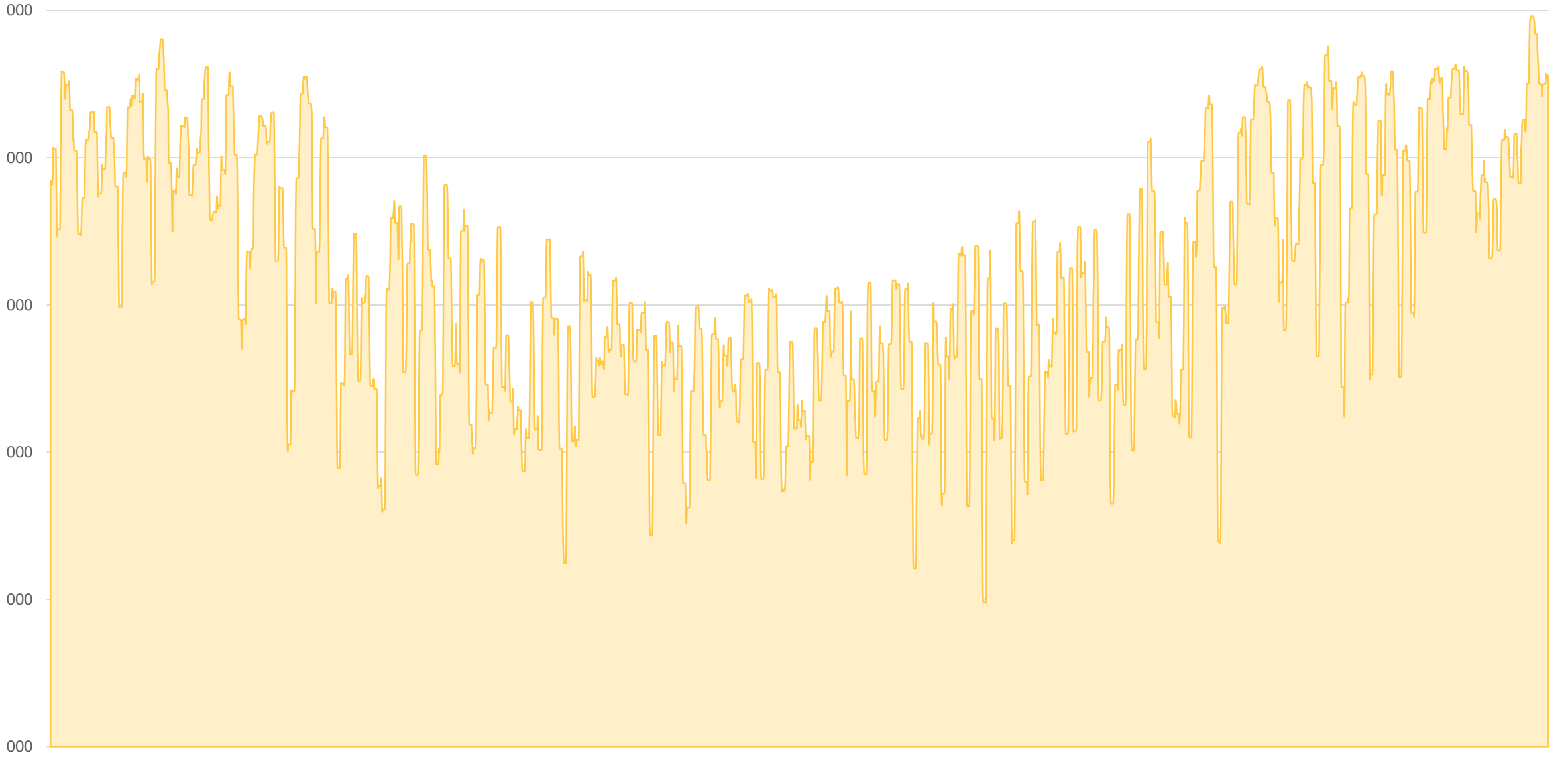
2020



2030



Average Solar Capacity Factor



Rainfall Series (mm/h)