euf

Europa-Universität
Flensburg

Energy system modelling

100% renewable energy systems

Agenda

1. Introduction to energy system modelling
2. Key challenges of electricity systems
3. Case study: 100% renewable Barbados
4. Building an own model?

Introduction to energy system modelling

Why we need energy system modelling?

- Providing Analysis to policy, NGO‘s, etc.
  - A energy model is a tool in order to answer specific research questions
    - E.g. what will be the CO2 emmissions of the energy system in 2050?
    - What will be the price of electricity with 10%, 50%, 100% of renewables?
    - What kind of storage do we need to include large scale PV inte the system?
- Gaining strategic insights considering a highly complex framework
  - Unsecurities: technical development, economic growth, etc.
  - Keep the model as simple as possible and only as complex as necesarry

Key challenges to model future electricity systems

- Fluctuation and flexibility requires high temporal resolution of models
    - Before it was common pactise to model electricity systems based on yearly balances of supply and demand
- Fluctuating renewables need detailed spatial information to be modelled (e.g. influence of local weather)
- Spatial/temporal resolution vs. computing time

Type terminology I

- A **simulation** tool simulates the operation of a given energy-system to supply a given set of energy demands. Typically a simulation tool is operated in **hourly time-steps** over a one-year time-period.
- A **scenario** tool usually combines a **series of years** into a long-term scenario. Typically scenario tools function in **time-steps of 1 year** and combine such annual results into a scenario of typically 20–50 years.
- An **equilibrium** tool seeks to explain the **behaviour of supply, demand, and prices in a whole economy** or part of an economy (general or partial) with several or many **markets**. It is often assumed that agents are price takers and that equilibrium can be identified.

Source:DTU

Type terminology II

- A **top-down** tool is a **macroeconomic tool** using general macroeconomic data to determine growth in energy prices and demands. Typically top-down tools are also equilibrium tools.
- A **bottom-up** tool identifies and analyses the **specific energy technologies** and thereby identifies investment options and alternatives.
- **Operation optimisation** tools optimise the operation of a given energy-system. Typically operation optimisation tools are also simulation tools optimising the operation of a given system.
- **Investment optimisation** tools optimise the investments in an energy-system. Typically investment optimisation tools are also scenario tools optimising investments in new energy stations and technologies.

Source:DTU

Types

	Simulation	Scenario	Equilibrium	Top-down	Bottom-up	Operation optimisation	Investment optimisation
BALMOREL	**Yes**	**Yes**	**Partial**	**–**	**Yes**	**Yes**	**Yes**
EnergyPLAN	Yes	Yes	–	–	Yes	Yes	-
HOMER	Yes	–	–	–	Yes	Yes	Yes
LEAP	Yes	Yes	–	Yes	Yes	–	–
MARKAL/TIMES	–	Yes	Yes	Partly	Yes	–	Yes
RAMSES	Yes	–	–	–	Yes	Yes	–
RETScreen	–	Yes	–	–	Yes	–	Yes
SIVAEL	–	–	–	–	–	–	–
STREAM	**Yes**	**–**	**–**	**Partly**	**Yes**	**–**	**–**
WILMAR	Yes	–	–	–	–	Yes	–

Source:DTU

Economic focus

Technology focus

Area/ time steps

Source:DTU

Tool	Geographical area	Scenario timeframe	Time-step
HOMER	Local/community	1 year[a]	Minutes
EnergyPLAN	National/state/regional	1 year[a]	Hourly
SIVAEL	National/state/regional	1 year[a]	Hourly
STREAM	**National/state/regional**	**1 year[a]**	**Hourly**
WILMAR Planning Tool	International	1 year[a]	Hourly
RAMSES	International	30 years	Hourly
BALMOREL	**International**	**Max 50 years**	**Hourly**
MARKAL/TIMES	National/state/regional	Max 50 years	Hourly, daily, monthly using user-defined time slices
RETScreen	User-defined	Max 50 years	monthly
LEAP	National/state/regional	No limit	Yearly

[a] Tools can only simulate 1 year at a time, but these can be combined to create a scenario of multiple years.

Energy sectors

Source:DTU

Tool	**Energy-sectors considered**			**Renewable-energy penetrations simulated**	
	Electricity sector	**Heat sector**	**Transport sector**	**100% electricity simulated**	**100% renewable energy-system**
Reports available detailing these renewable-energy penetrations					
EnergyPLAN	Yes	Yes	Yes	Yes	Yes
HOMER	Yes	Yes	–	Yes	Partly[a]
Reports NOT available detailing these renewable-energy penetrations					
LEAP	Yes	Yes	Yes	Yes	Yes
RETScreen	Yes	Yes	–	Yes	Partly[a]
SIVAEL	Yes	Partly	–	Yes	–
MARKAL/TIMES	Yes	Yes	Yes	–	–
STREAM	**Yes**	**Yes**	**Yes**	**–**	**–**
WILMAR	Yes	Partly	Partly	–	–
BALMOREL	**Yes**	**Partly**	Partly	**–**	**–**
RAMSES	Yes	Partly	–	–	–

[a] Have simulated a 100% renewable-energy penetration in all the sectors they consider.

Europa-Universität Flensburg

Erasmus+

LEAP (Long-range Energy Alternatives Planning)

- Integrated modelling tool that can be used to track energy consumption, production, and resource extraction in all sectors of an economy
- **It is free** to qualified users in developing countries
- Currently LEAP has over 5000 users in 169 countries
- LEAP typically requires three or four days of training (online training is available in English)
- LEAP is usually used to **analyse national energy-systems**. It functions using an **annual time-step**, and the time horizon can extend for an unlimited number of years (typically between 20 and 50)
- LEAP does **not currently support optimisation modelling**

HOMER

- **user-friendly micropower design tool** developed in 1992 by the National Renewable Energy Laboratory in the USA
- Objective: **evaluate the economic and technical feasibility for a large number of technology options**, while considering variations in technology costs and energy resource availability.
- **(Free to use)**
- simulates and optimises stand-alone and grid-connected power systems with any combination of wind turbines, PV arrays, run-of-river hydro power, biomass power, internal combustion engine generators, microturbines, fuel cells, batteries, and hydrogen storage, serving both electric and thermal loads
- The simulation considers a **one-year time-period using a minimum time-step of 1 min**

The strength of open source/ open data modelling

- Example for often critised modelling: EU used PRIMES model of Athen‘s NTU
  - *“The economic model, known as “Primes”, is owned by the National Technical University of Athens and is designed to show how using different mixes of energy sources affect the wider economy. The European Commission has used it for many years to help guide […] energy policies but* ***industry critics complain its assumptions are impossible to question because the model is privately owned****. One trade group, Business Europe, has called for the Commission to use other, more transparent models.”* (source: financial times 2011, url: https://www.ft.com/content/9cf8f93e-0865-11e1-bc4d-00144feabdc0)

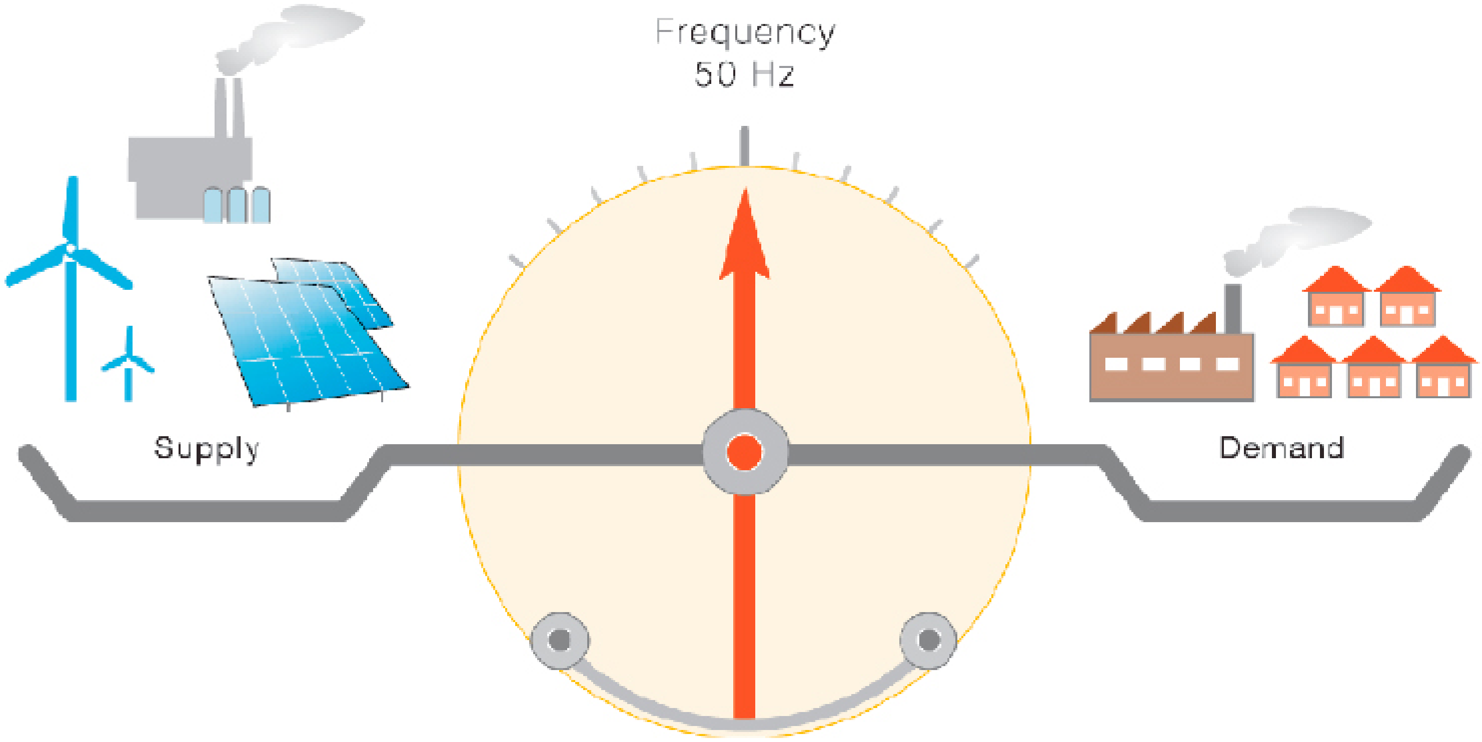
The strength of open source

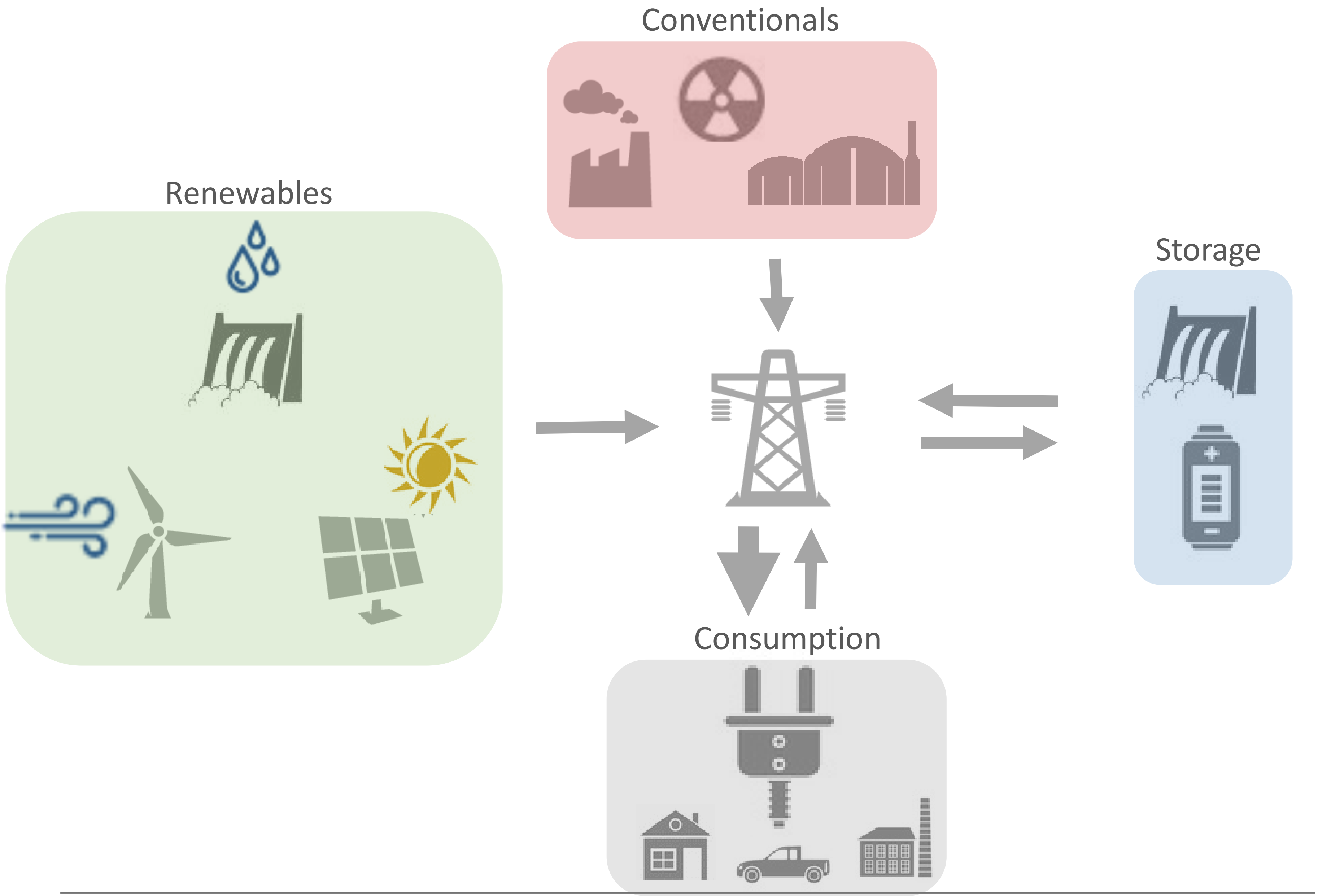
„Open source is a development method that harnesses the power of distributes peer review and transparency of process. The promise of open source is better quality, higher reliability, more flexibility, lower cost and an end to predatory vendor lock-in“ (Open source inititive 2013)

- Reproducibility of results
- Transparency of methodology and data
- Gives extenxive participation possibilities
  - International collaboration
  - Potential to increase the quality of the model
- No discrimination (free to use by everyone)
  - Free to use does NOT necesarilly mean open source!

Key challenges of electricity systems

Key challange: Balance of supply and demand





Conventionals

Renewables

Storage

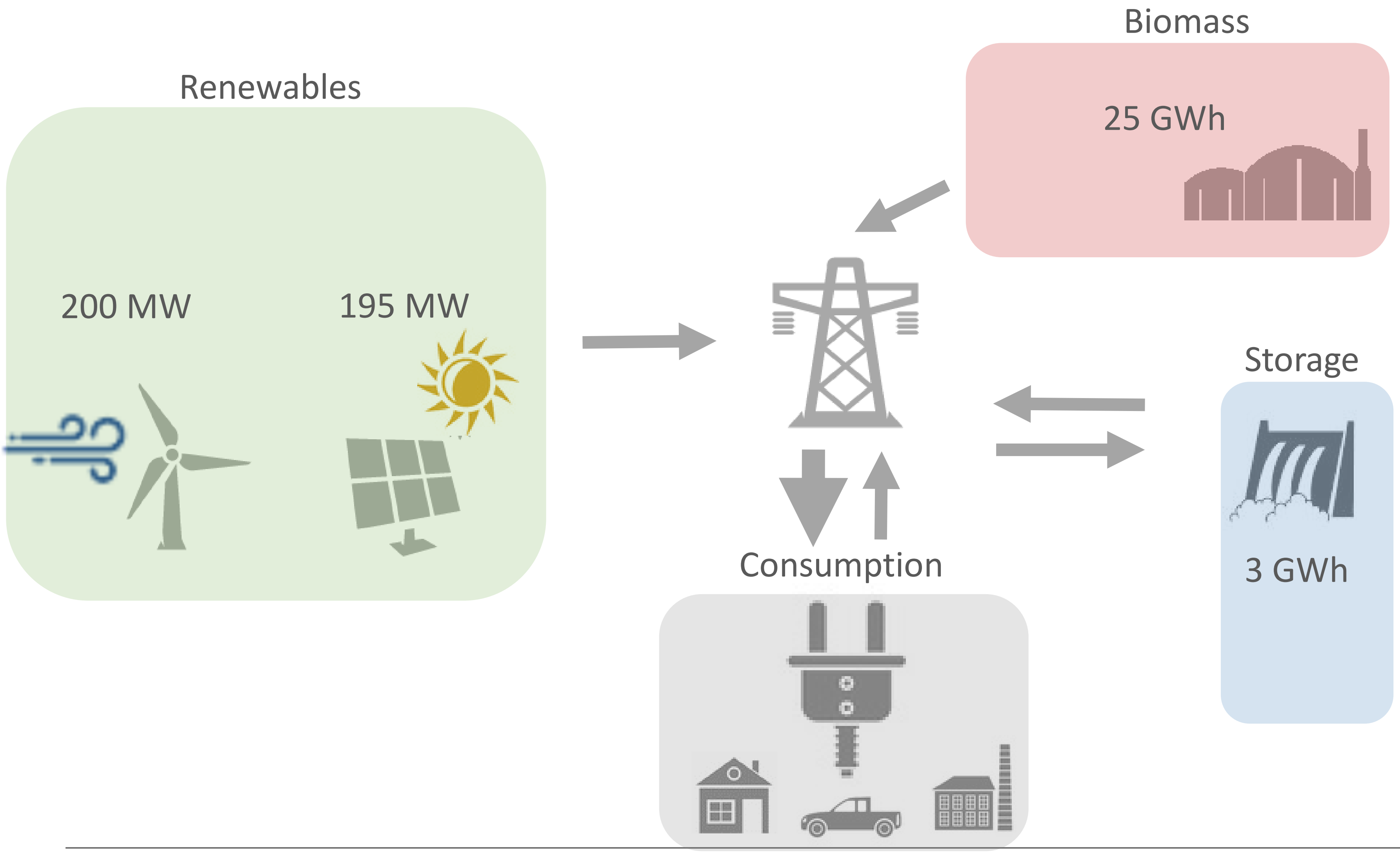
Consumption

A model can only be as good as it‘s input data!

- Demand
  - Heat
  - Electricity
  - Transportation
  - Growth rates
    - GDP
    - Population
- Supply
  - Conventional power plants
  - Renewable power plants
  - (Storage)
- Weather
  - Wind
  - Solar radiation
  - Temperature
- Transmission
  - High voltage grid
  - Low voltage grid
- Economics
  - Costs
    - Construction
    - Operation
  - Fuelprices
  - Interest rates

Case study: 100% renewable energy system for Barbados

Case study: 100% renewable energy system for Barbados



Renewables

200 MW

195 MW

Biomass

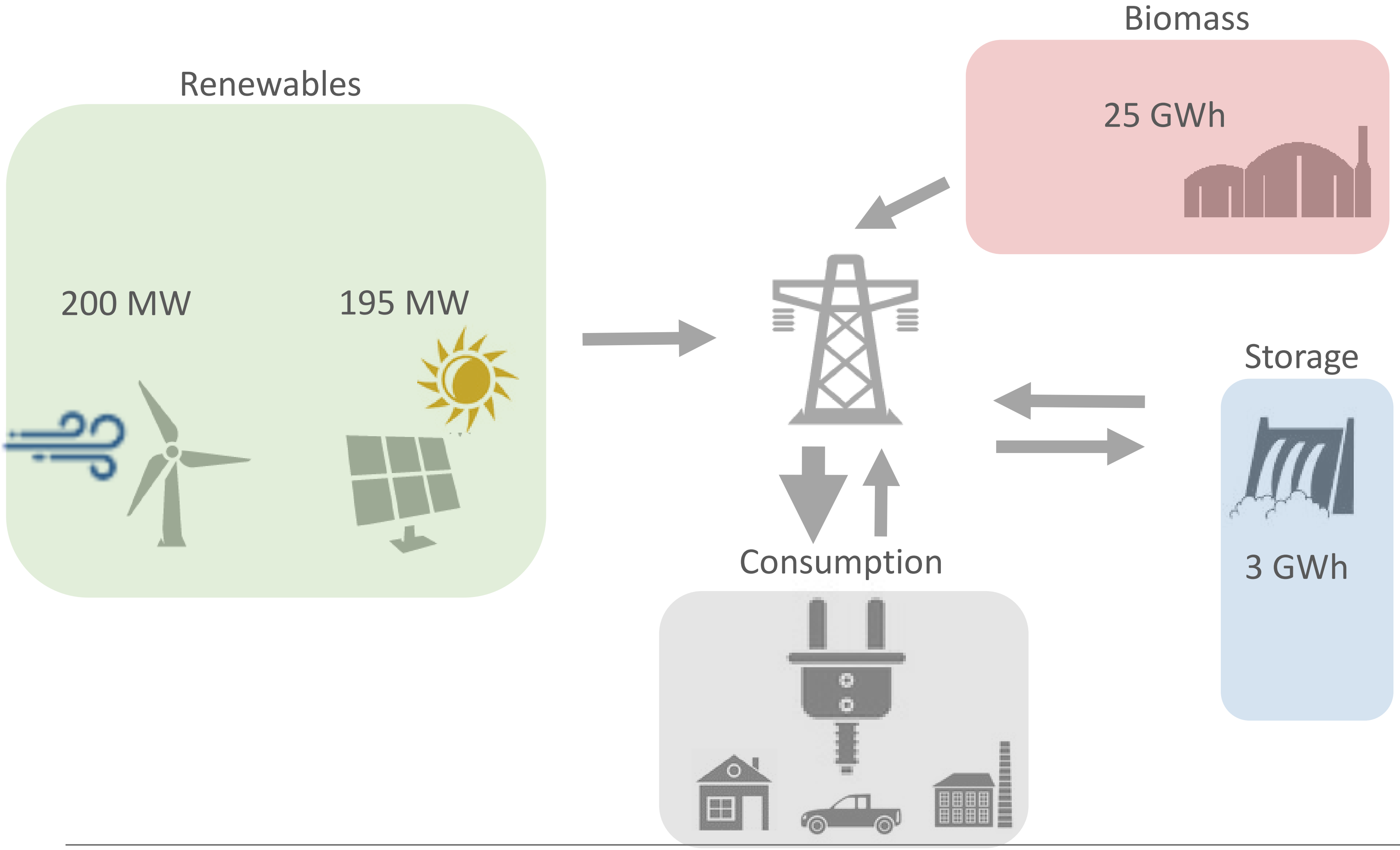
25 GWh

Storage

3 GWh

Consumption

Consumption



Biomass

25 GWh

Renewables

200 MW

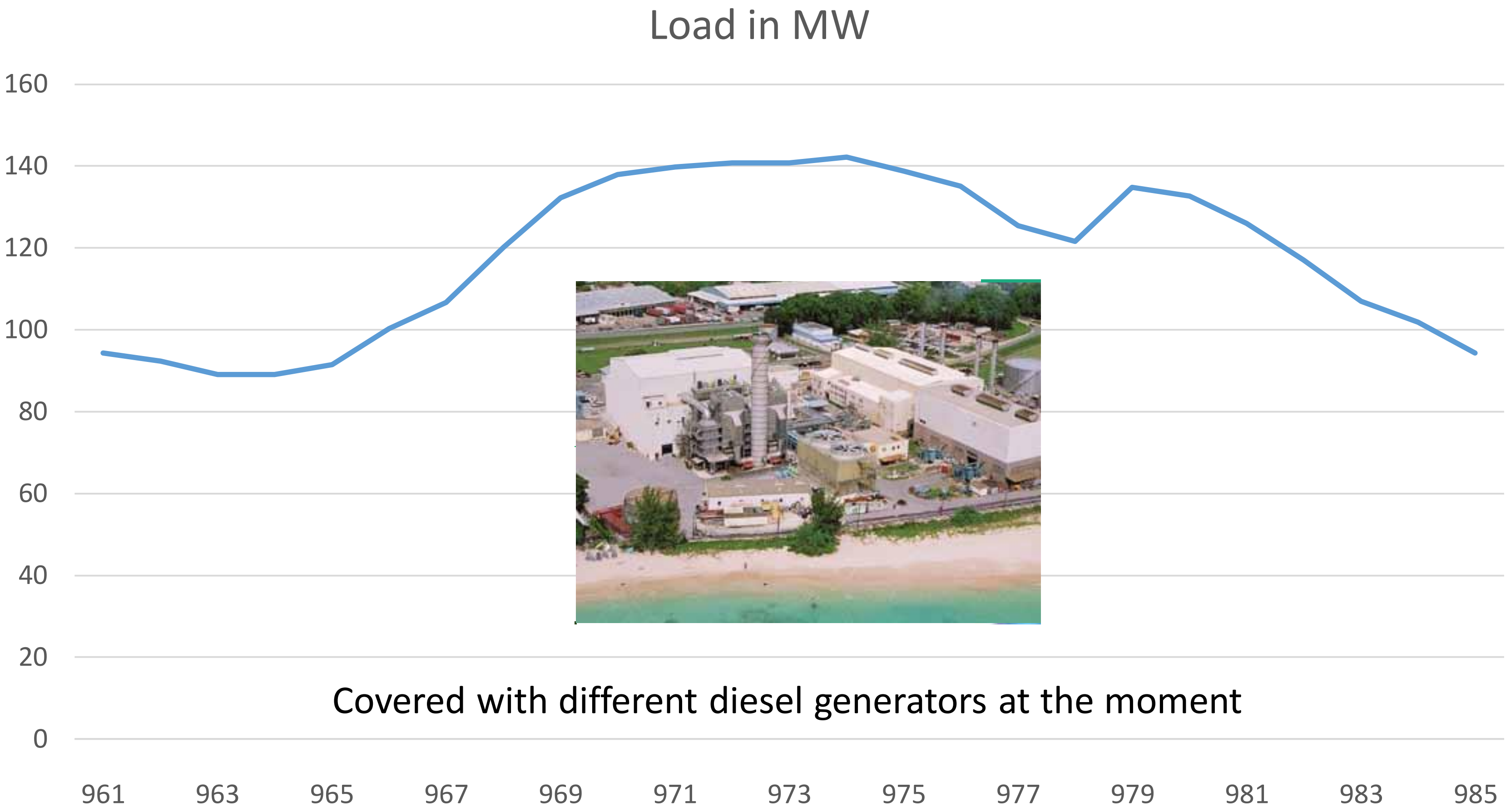
195 MW

Storage

3 GWh

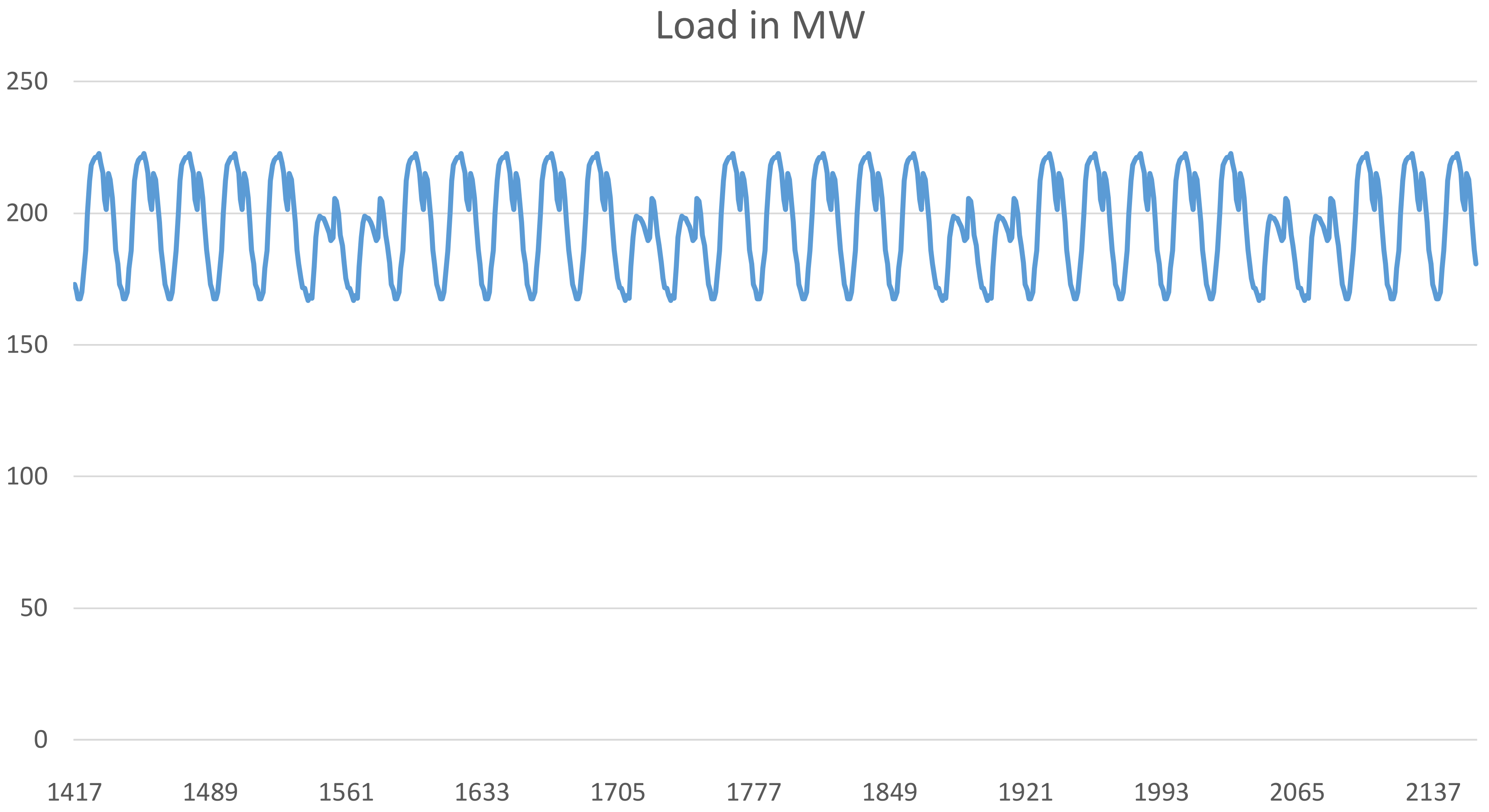
Consumption

Electrical load for Barbados (Feb. 9th)

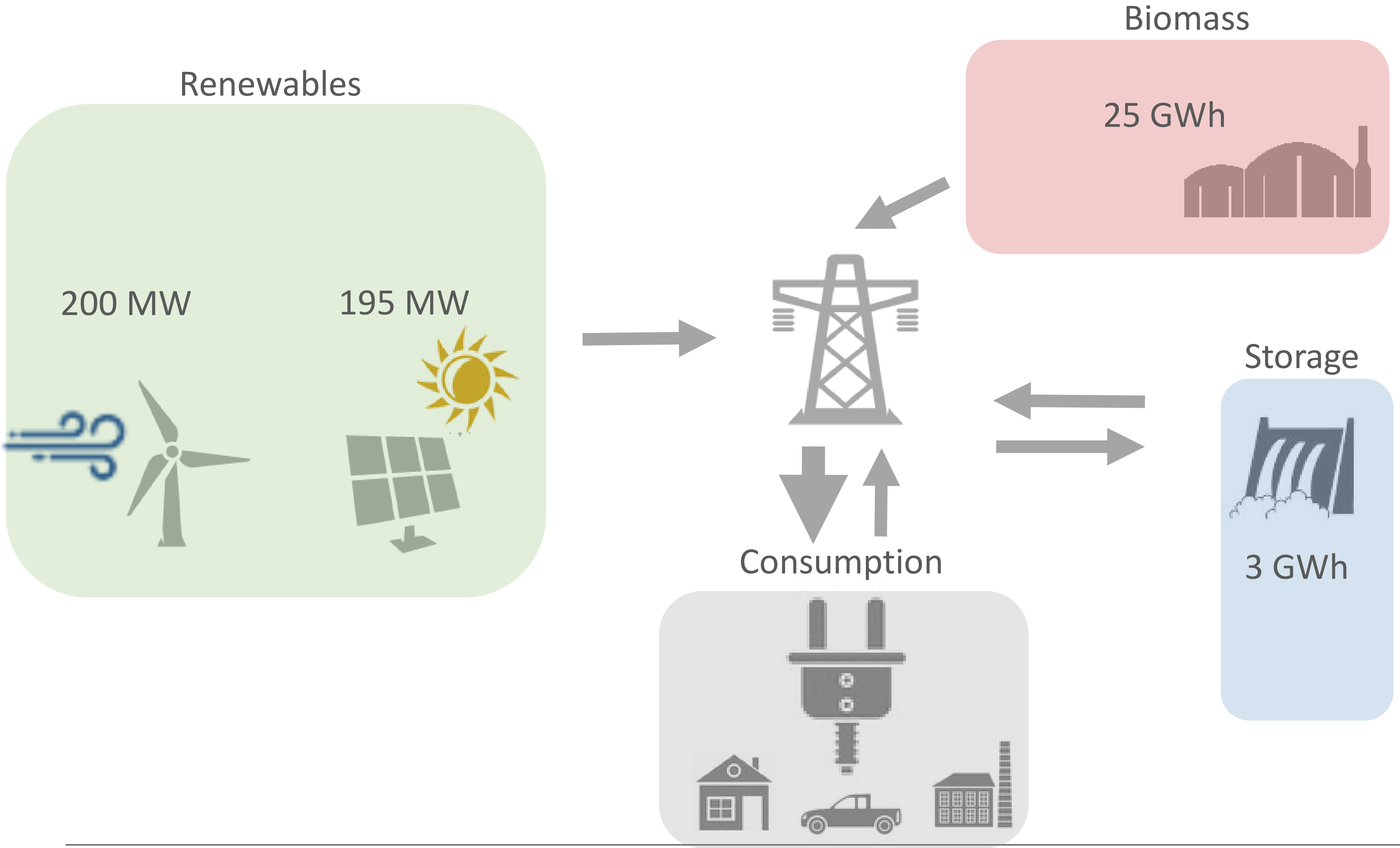


Covered with different diesel generators at the moment

Hourly load curve for Barbados in March



Generation: Renewables



Biomass

25 GWh

Renewables

200 MW

195 MW

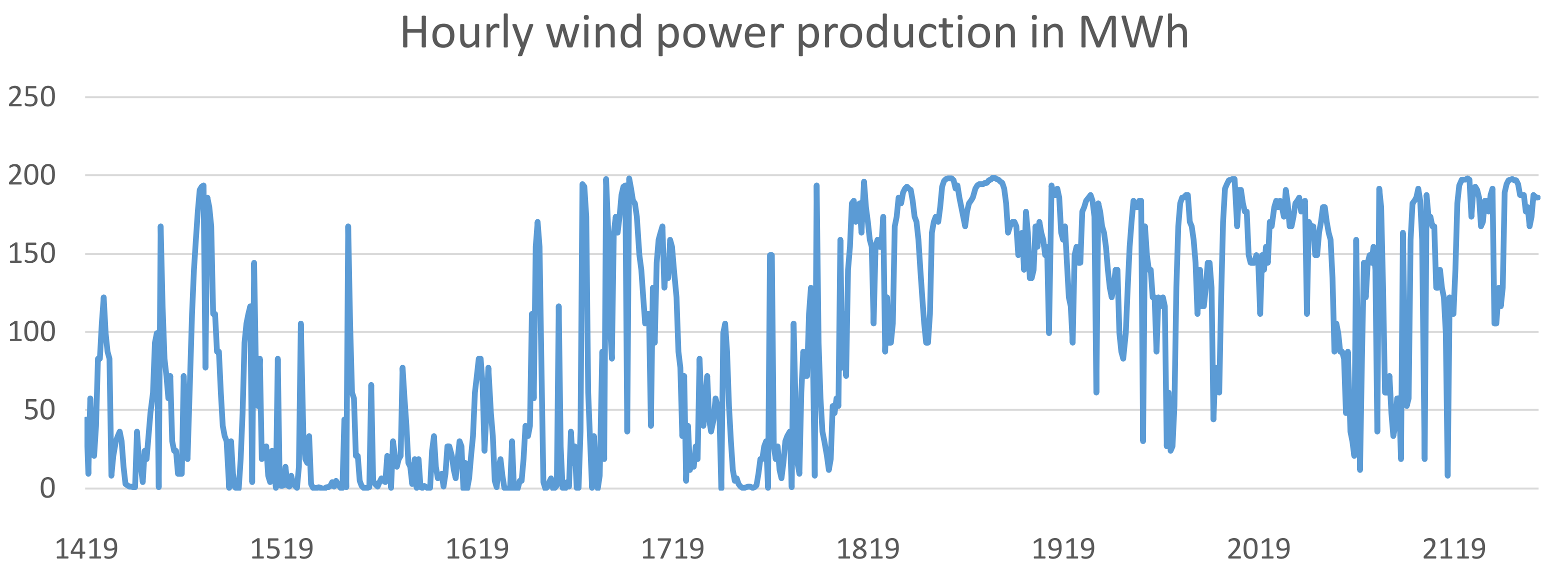
Storage

3 GWh

Consumption

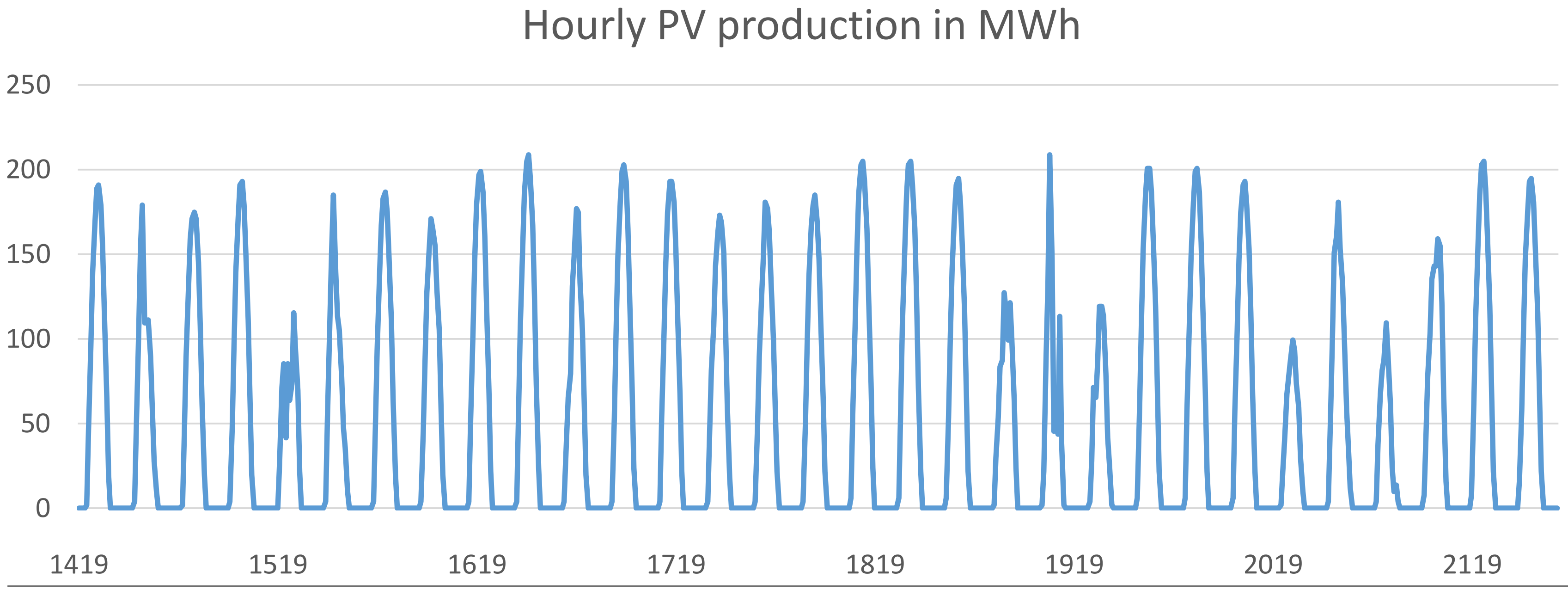
Wind energy on Barbados (March)

1. Size of the island: 430 km^2
2. Theoretical potential on shore: 4.3 GW
3. Costs per kWh: 0.07 BBD/kWh

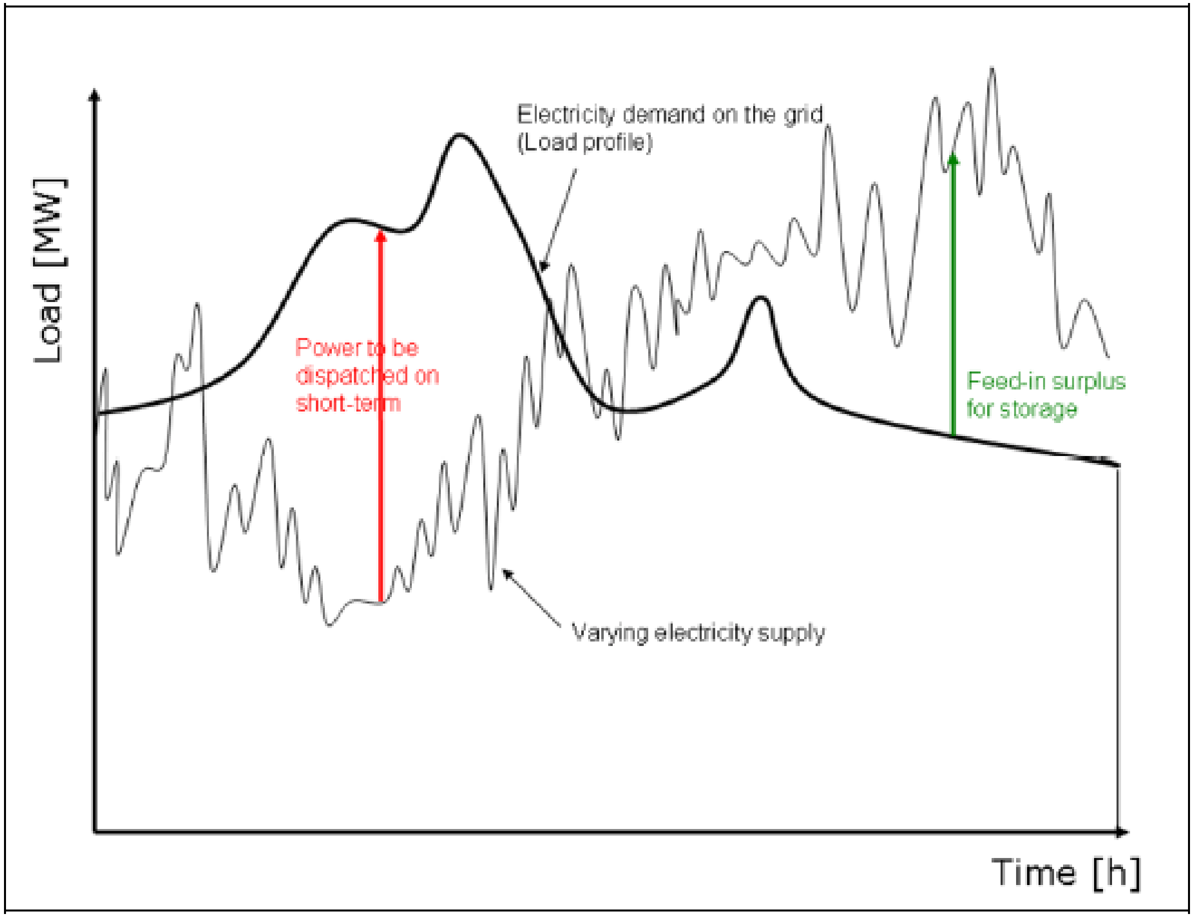


PV on Barbados (March)

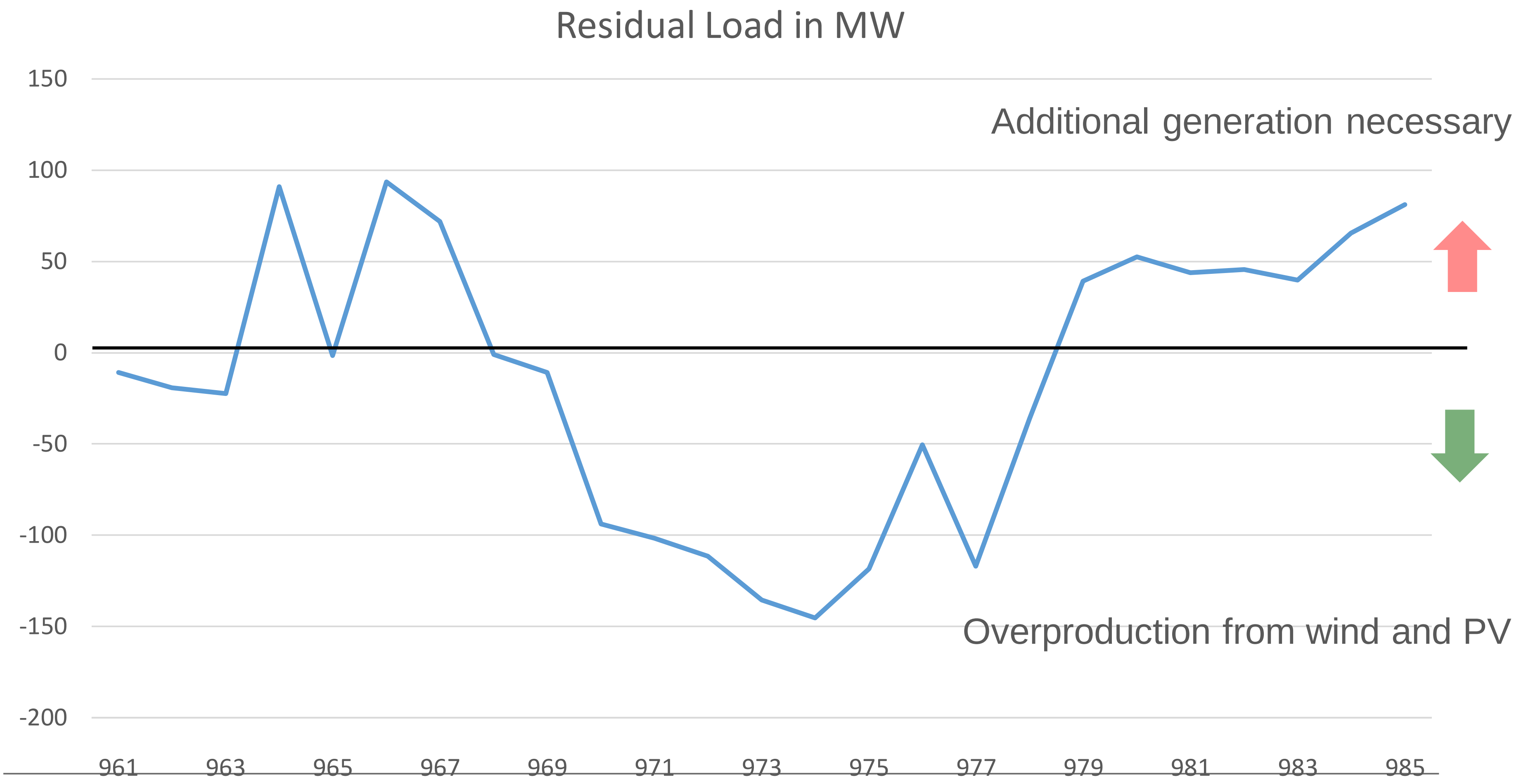
1. Size of the island:	430 km^2
2. Theoretical PV potential:	5 375 GW
3. Costs per kWh:	0.252 BBD/kWh



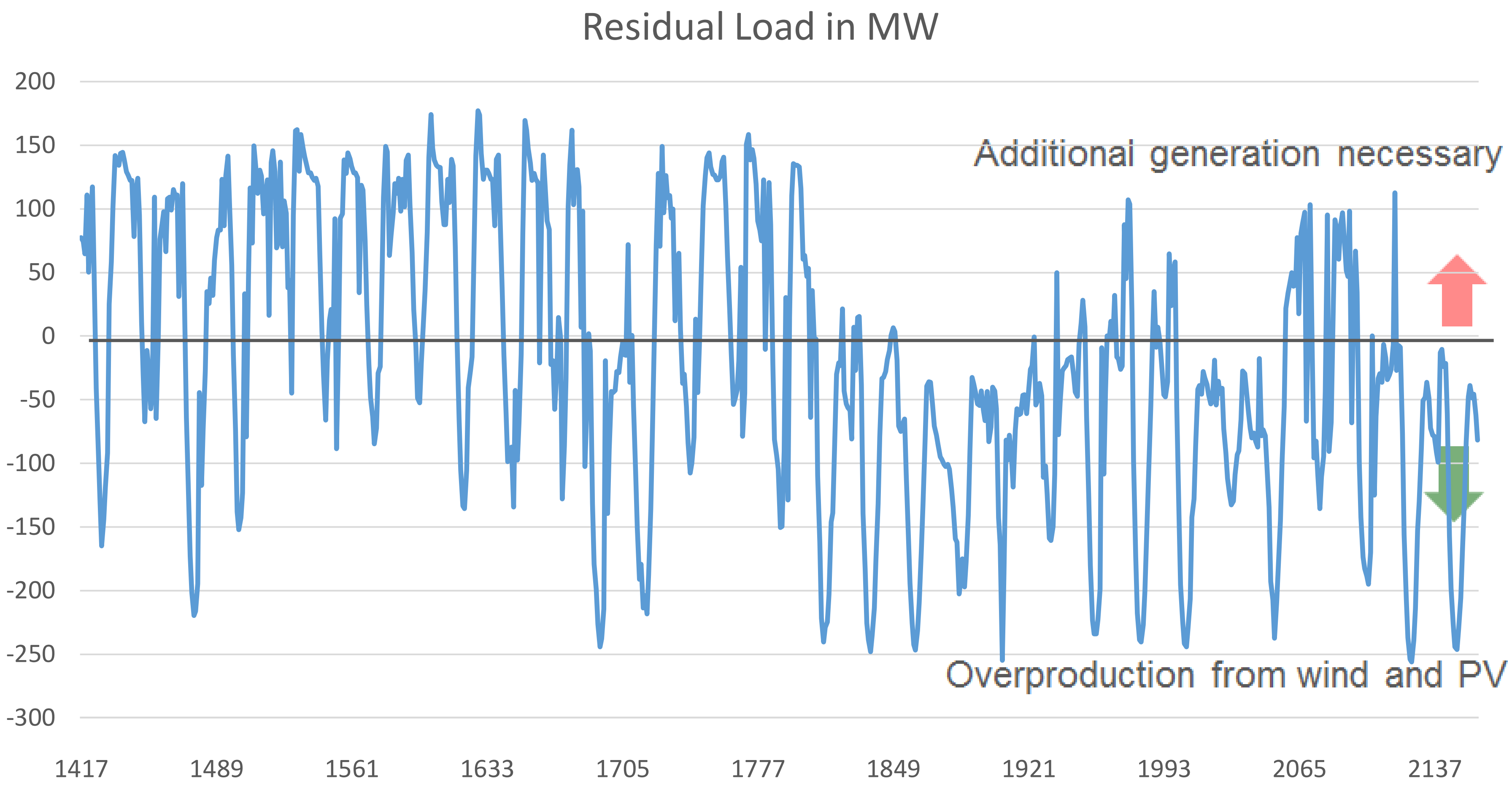
From load to residual load: The need for storage



Residual load for 100% REN Barbados (Feb. 9th)

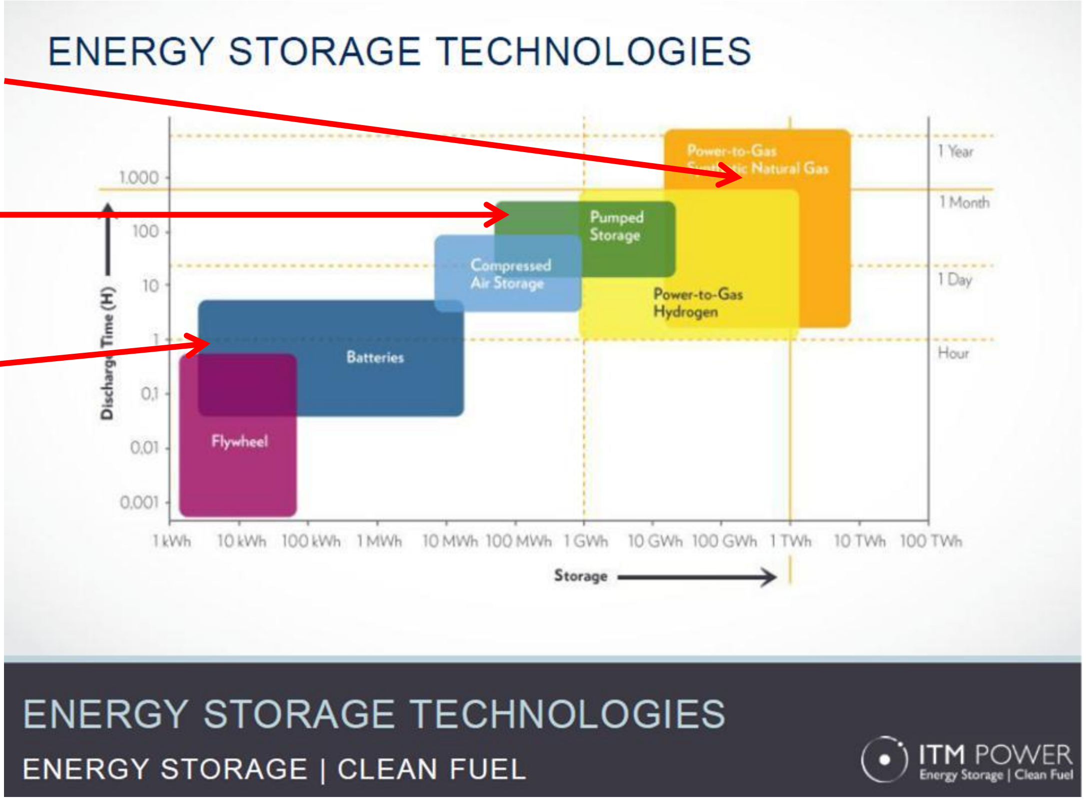


Residual load for March

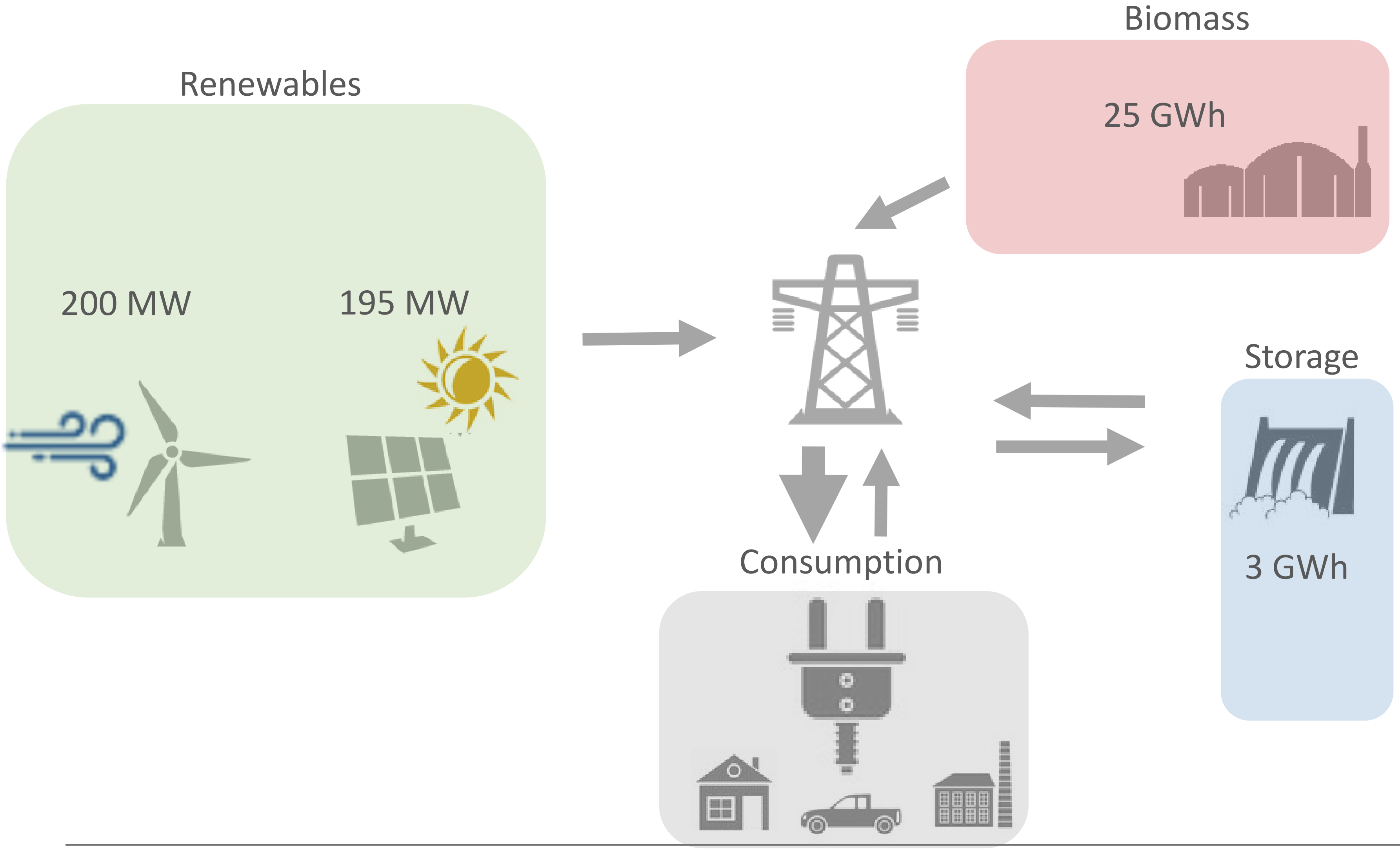


Storage options

- Power to gas (to power)
- Pump storage hydropower
- Battery storage



Storage



Biomass

25 GWh

Renewables

200 MW

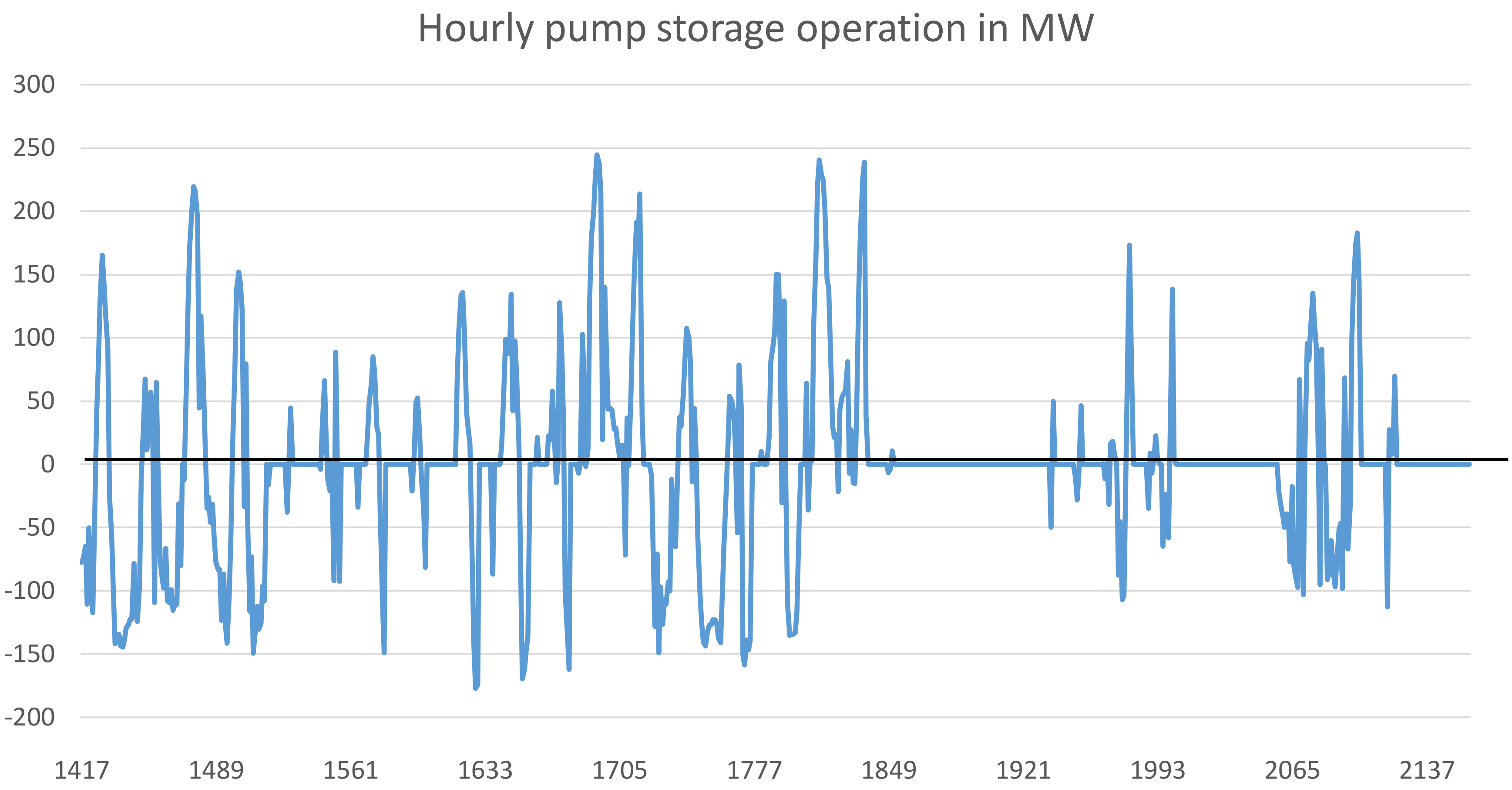
195 MW

Storage

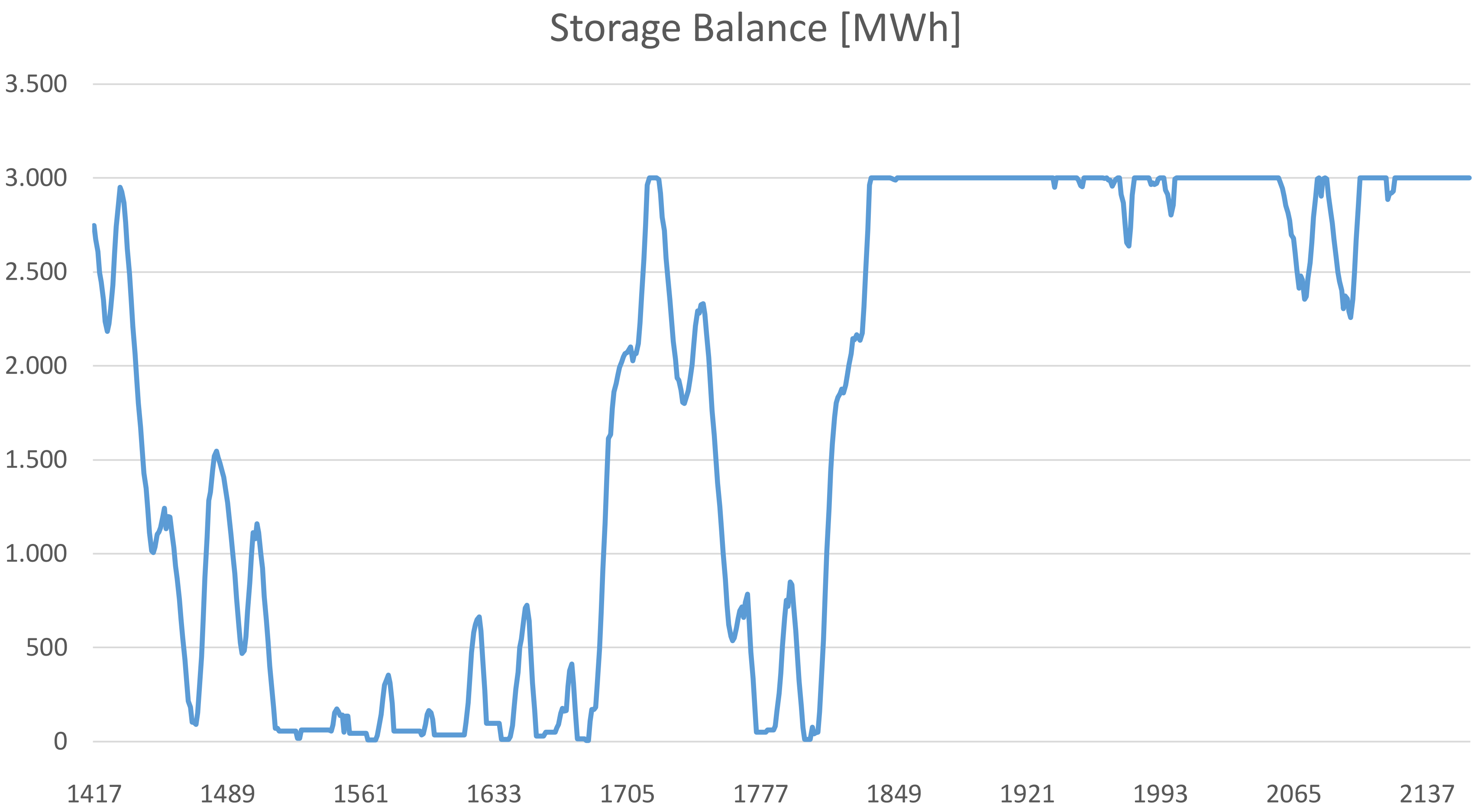
3 GWh

Consumption

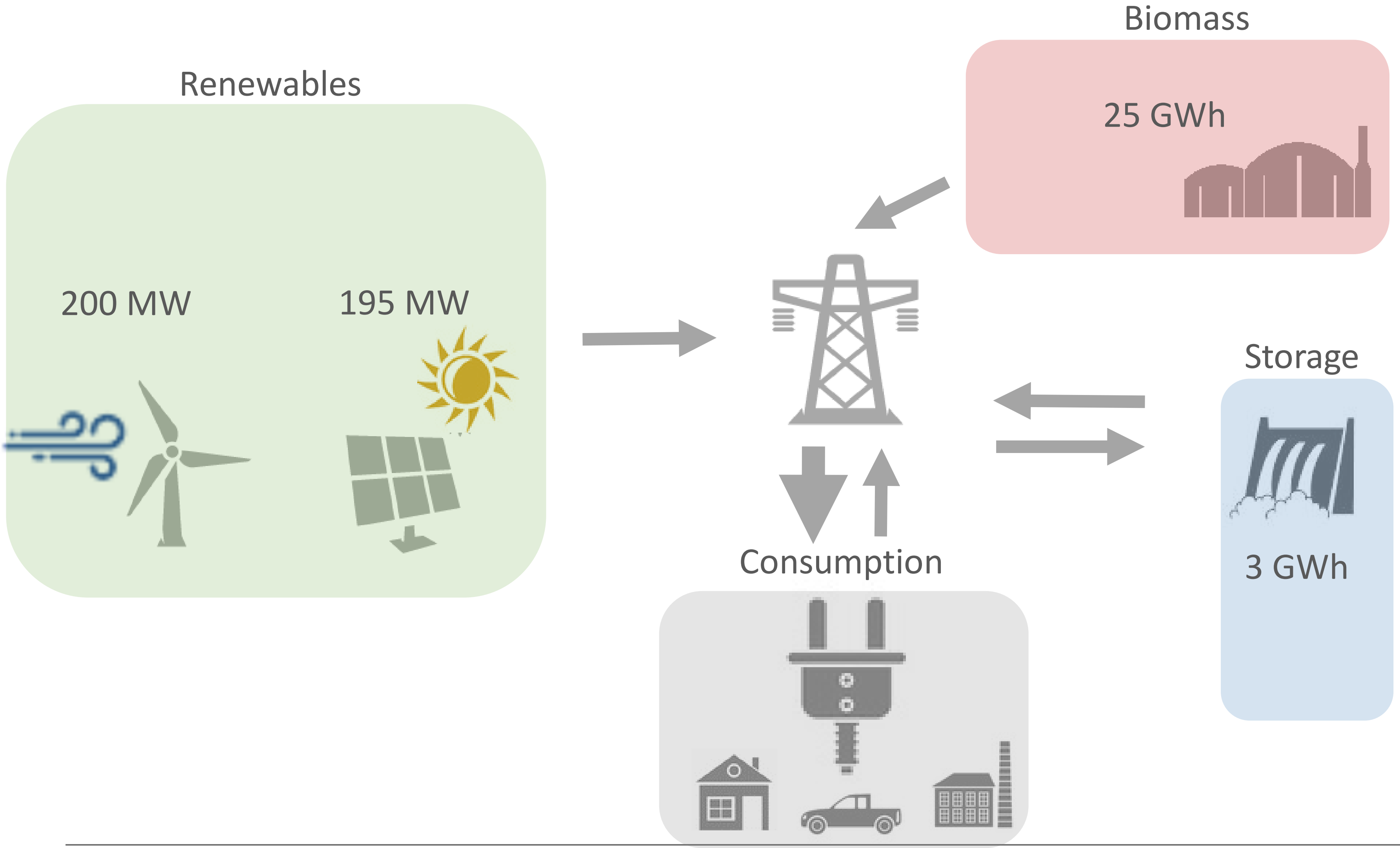
Pump storage for March



Storage filling level in March



Generation: Biomass



Renewables

200 MW

195 MW

Biomass

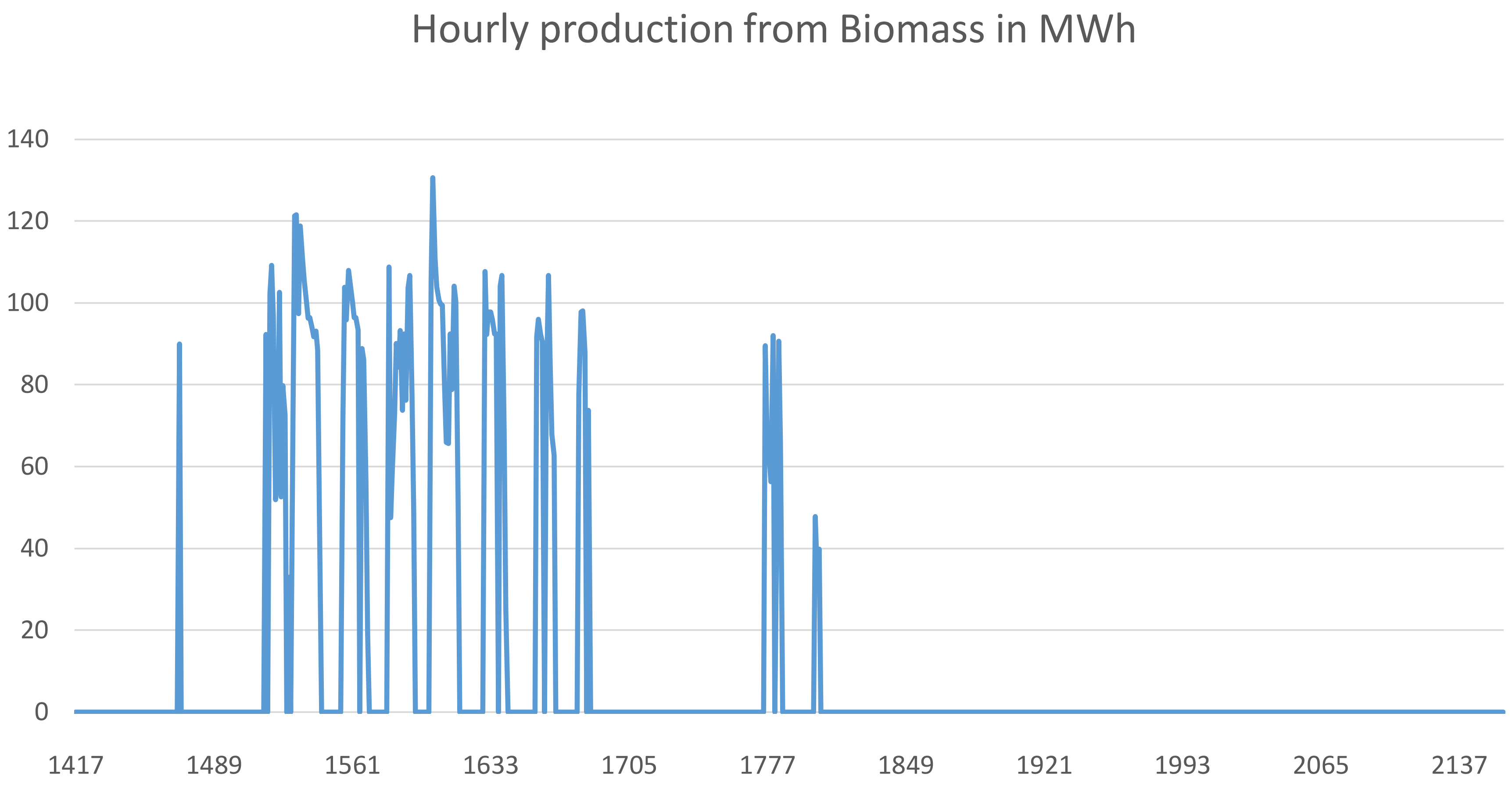
25 GWh

Storage

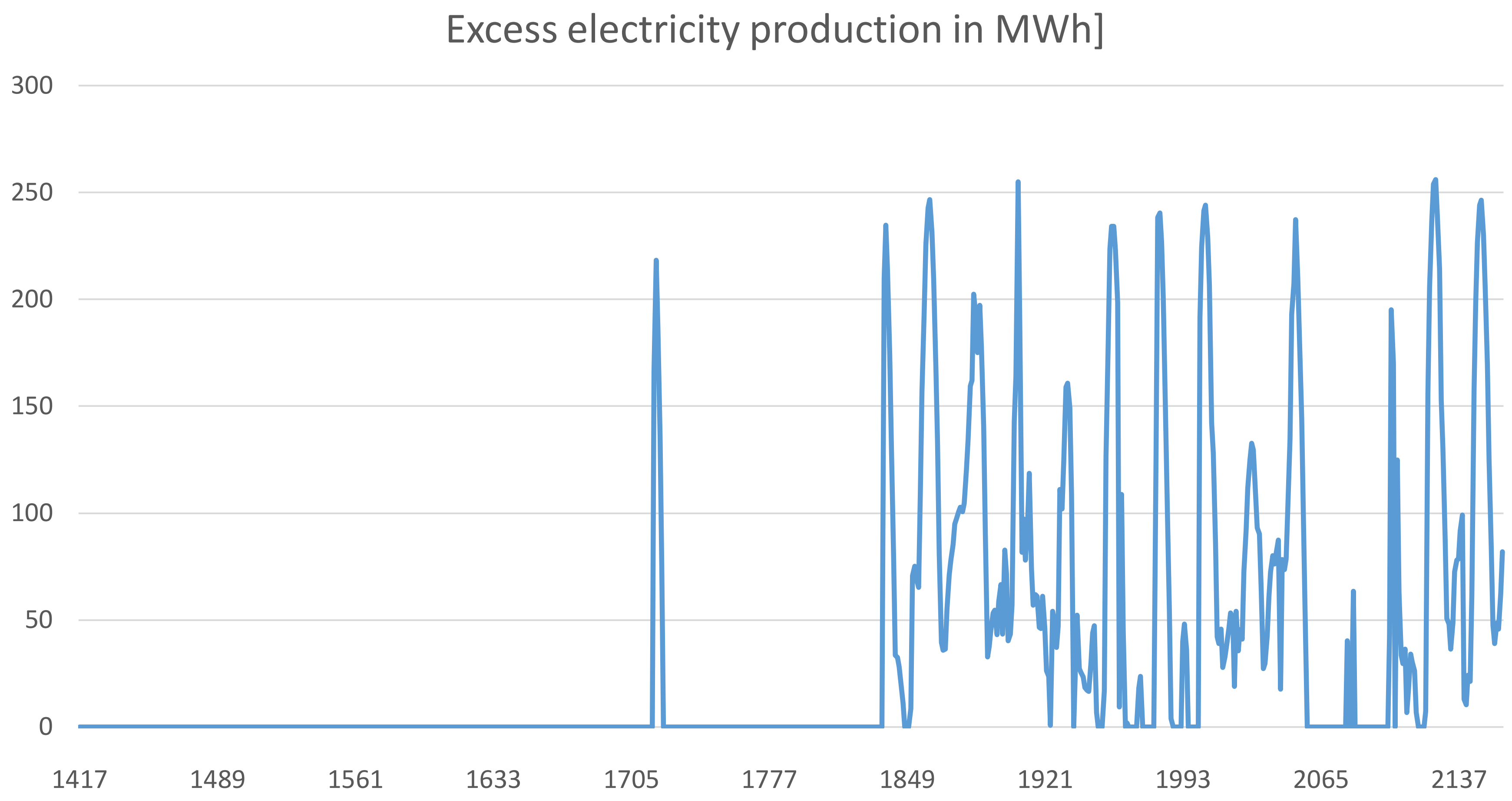
3 GWh

Consumption

Use of biomass in March to match the load not met by wind, PV or pump storage

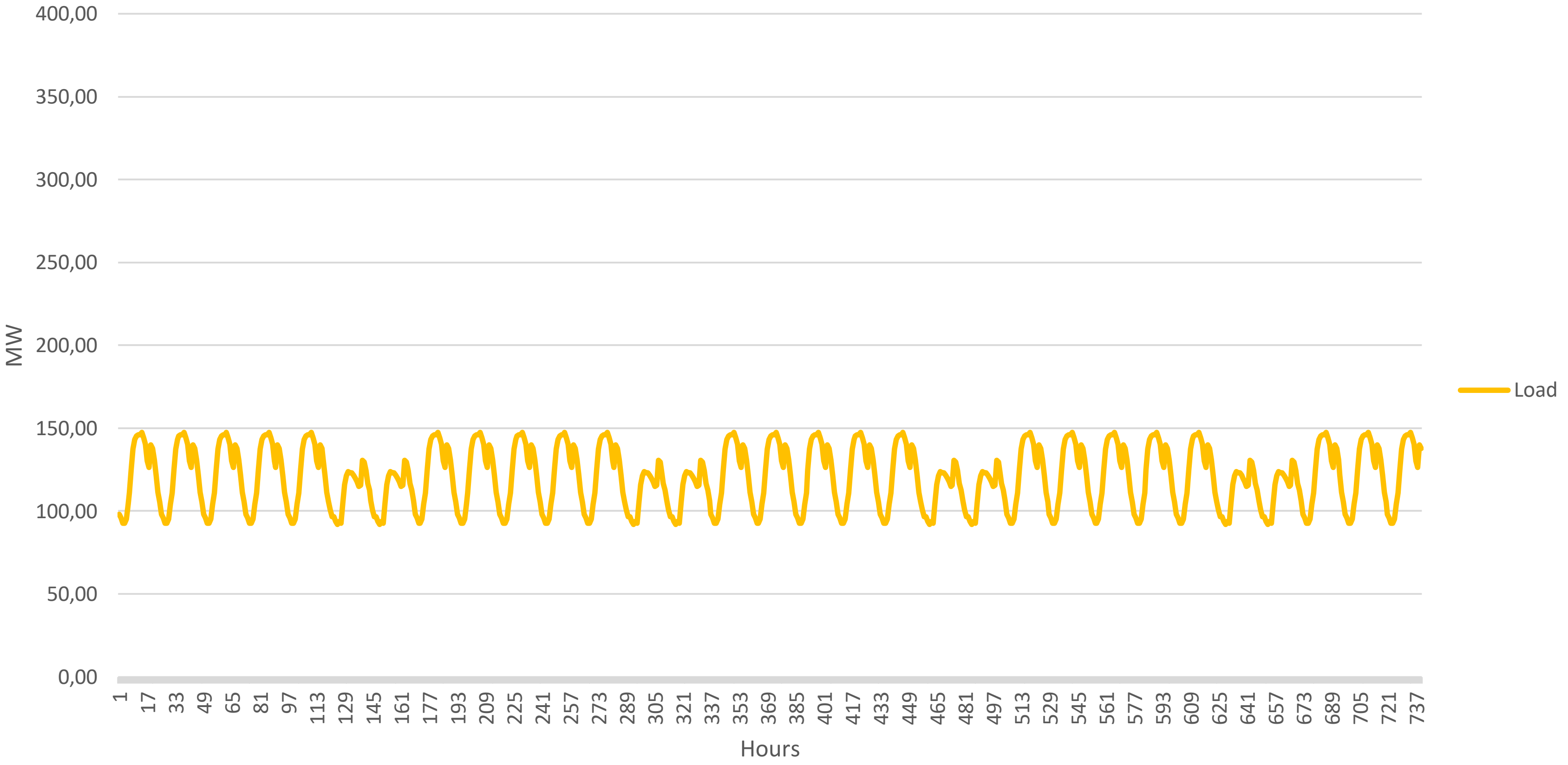


Power overproduction in March from wind and PV

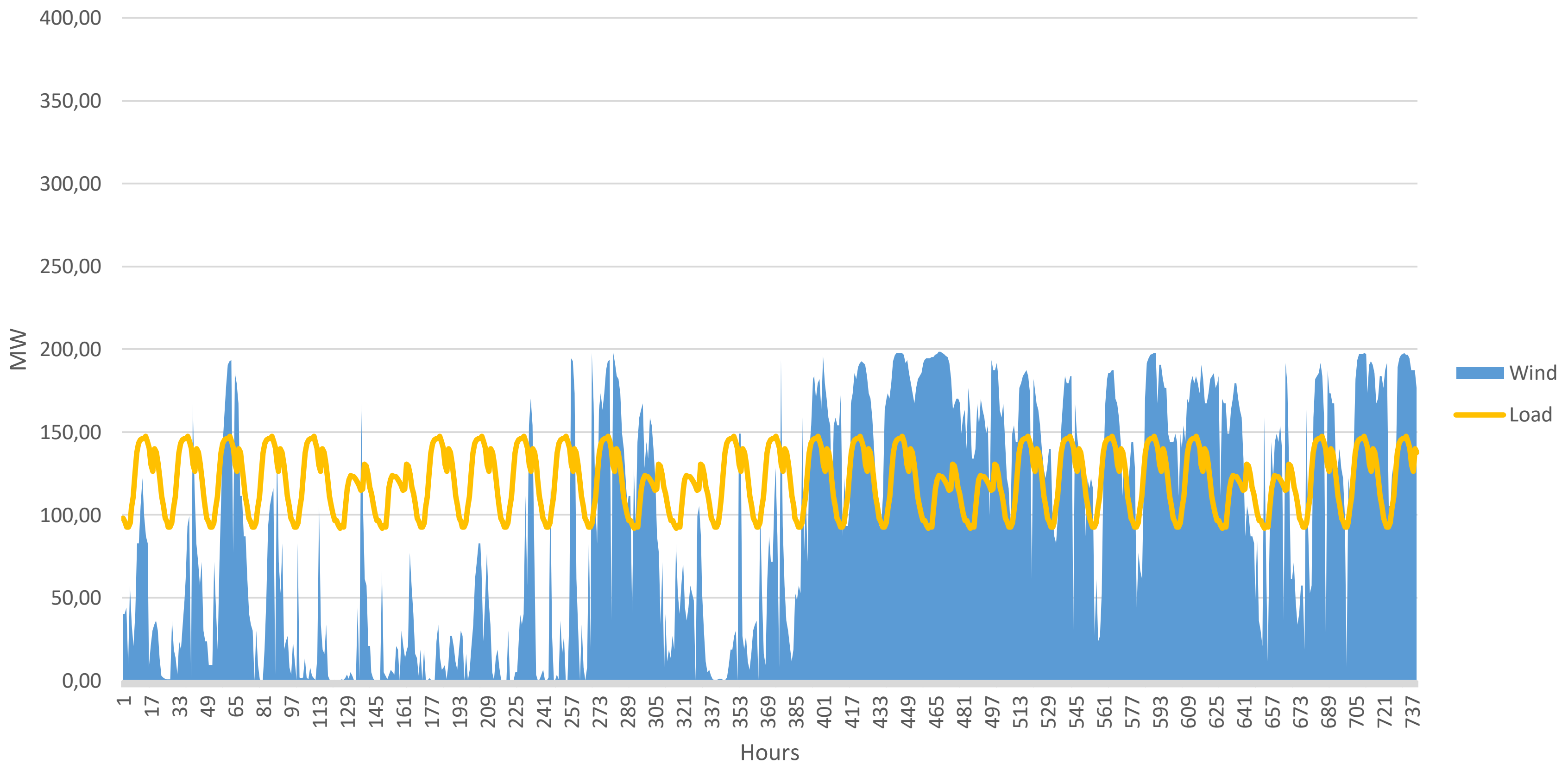


All together…

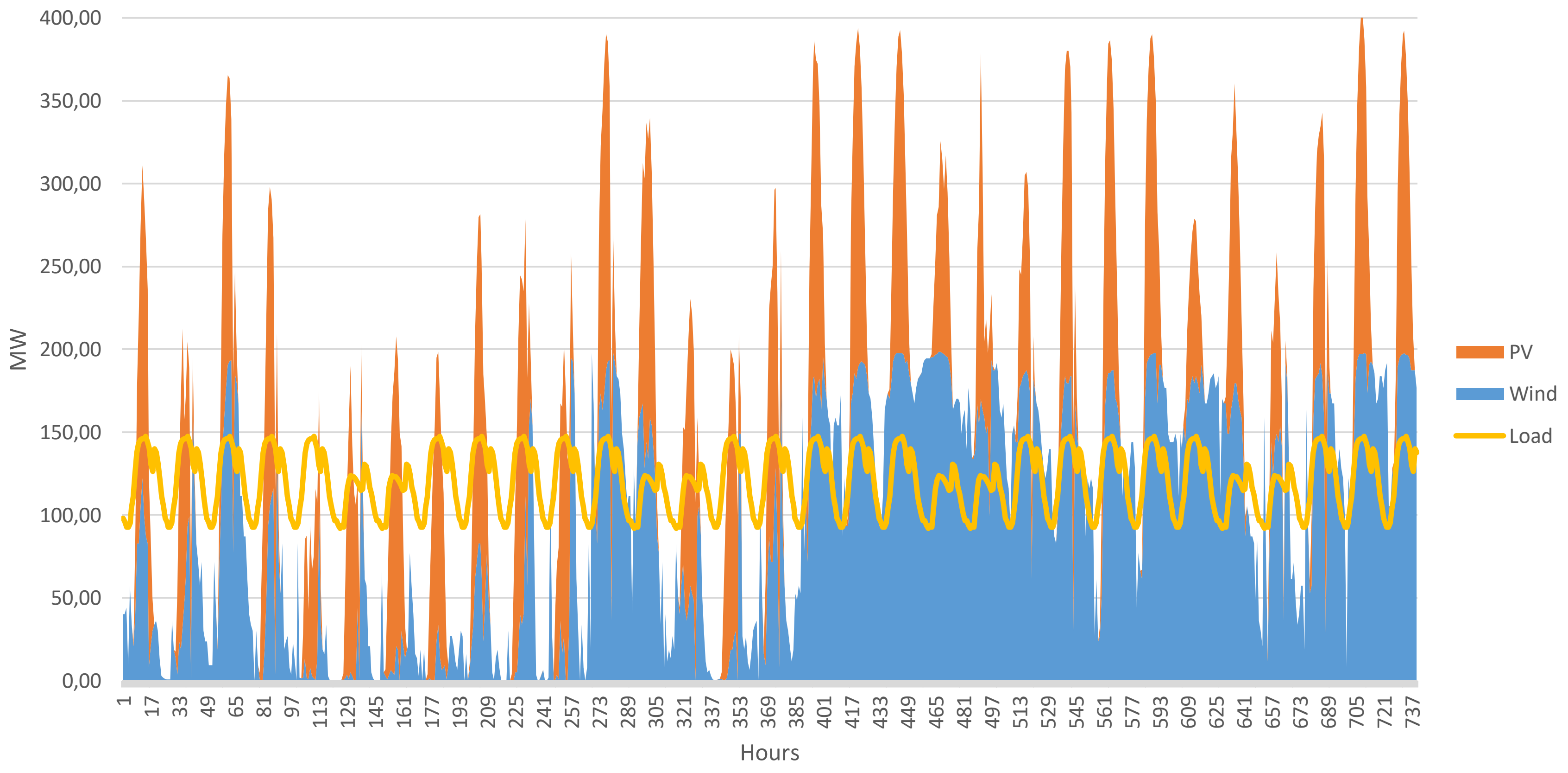
Simulation of 100% RE in Barbados (March)



Simulation of 100% RE in Barbados (March)



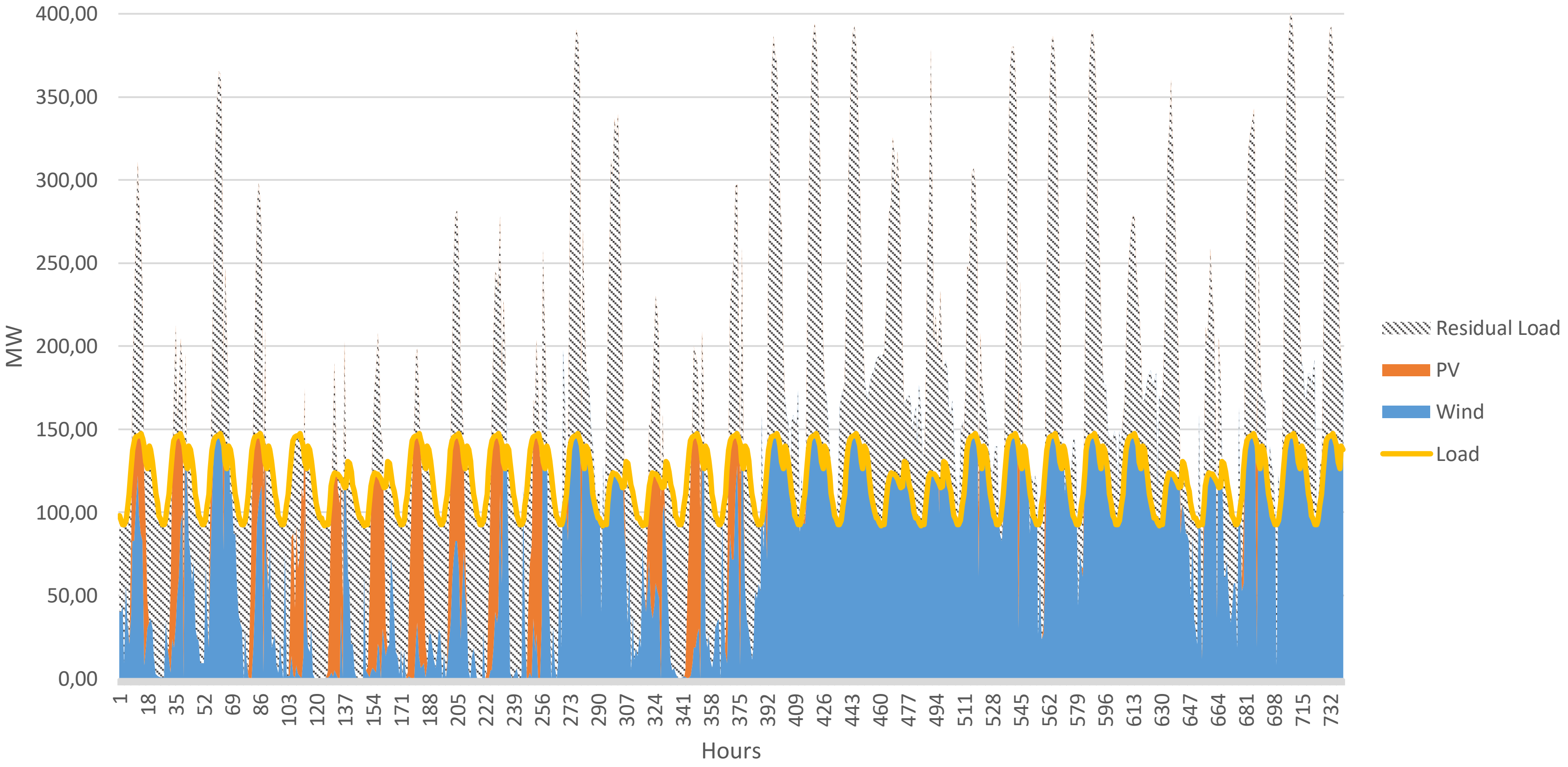
Simulation of 100% RE in Barbados (March)



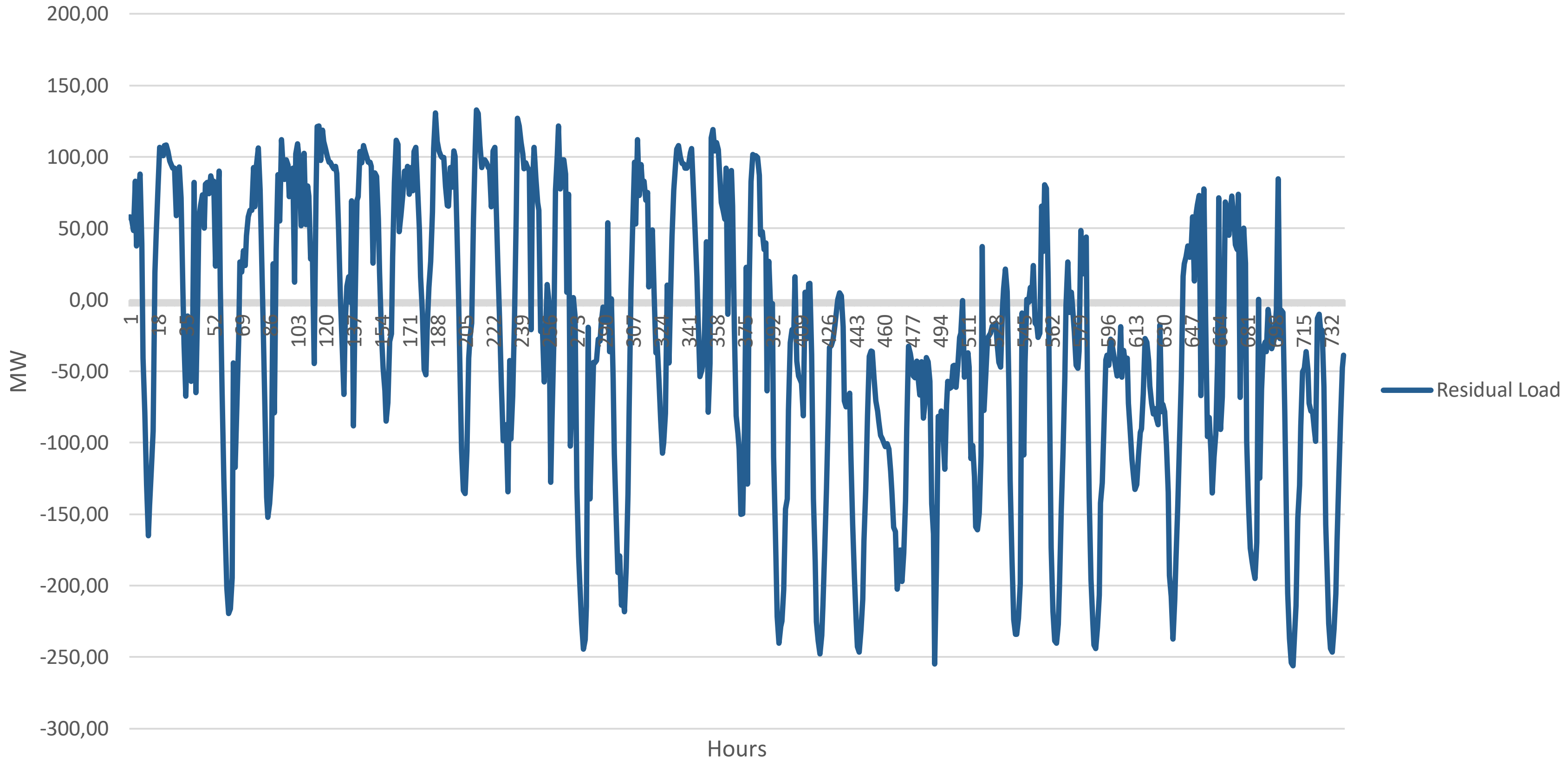
Europa-Universität Flensburg

Erasmus+

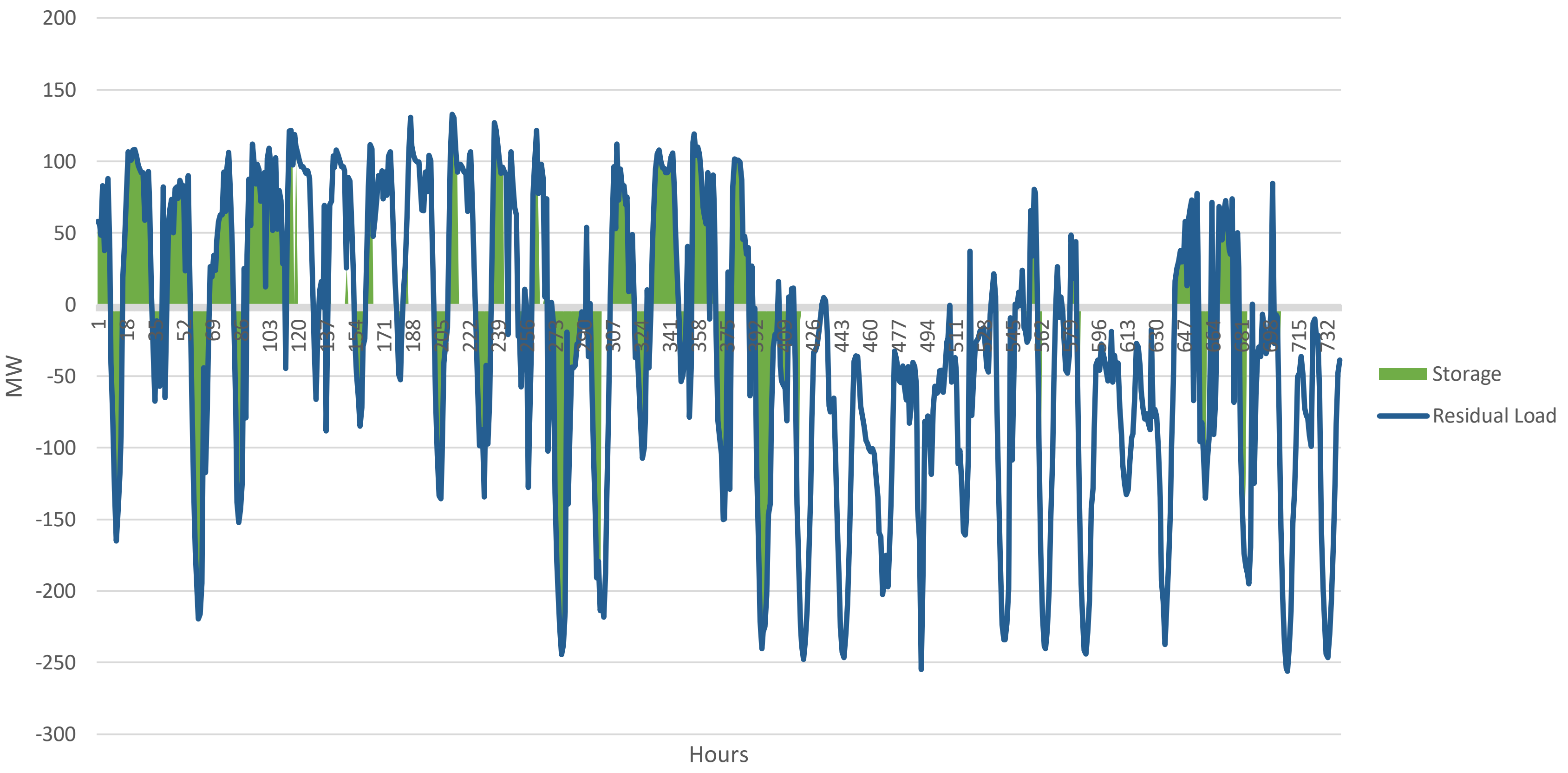
Simulation of 100% RE in Barbados (March)



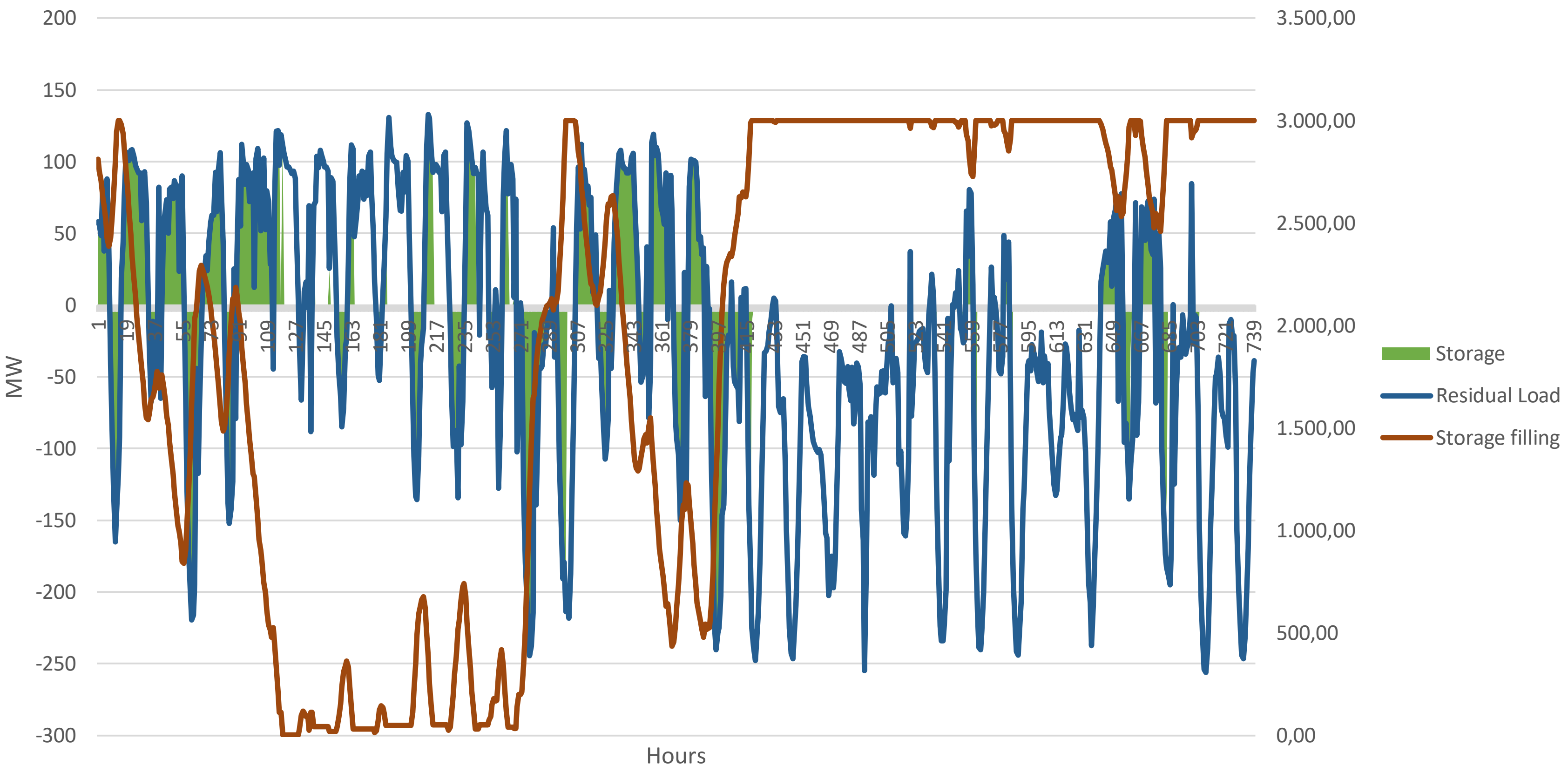
Simulation of 100% RE in Barbados (March)



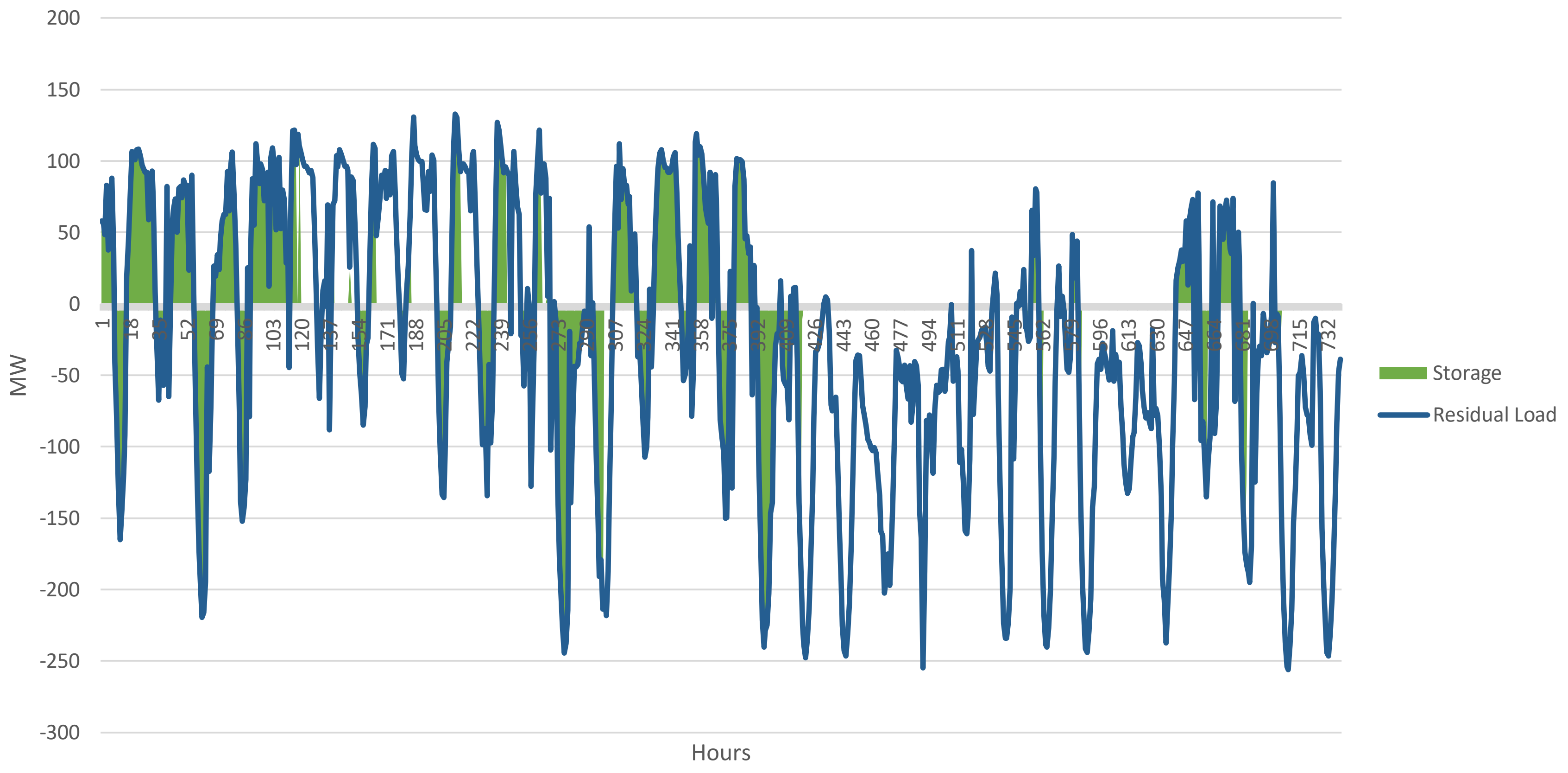
Simulation of 100% RE in Barbados (March)



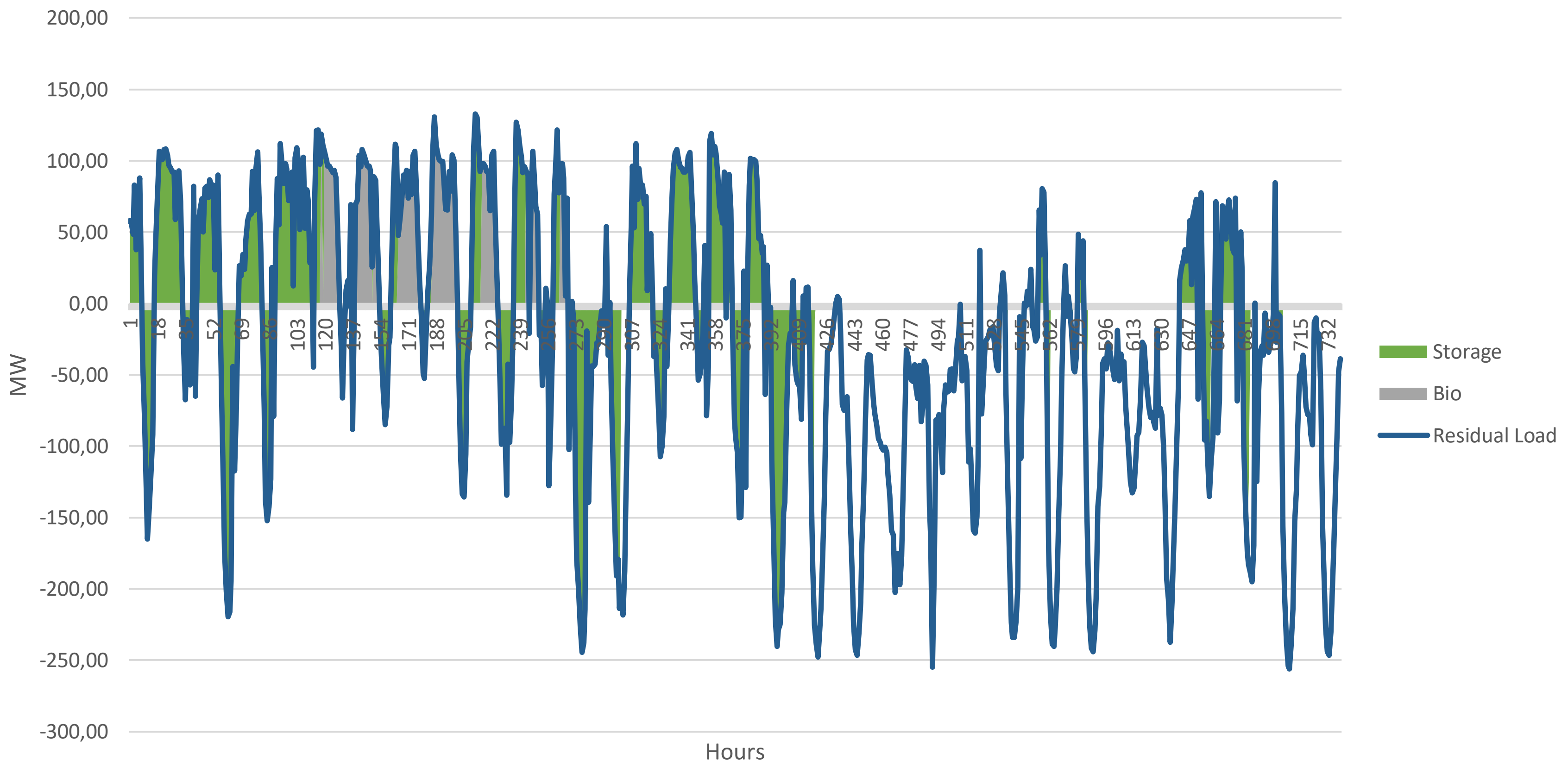
Simulation of 100% RE in Barbados (March)



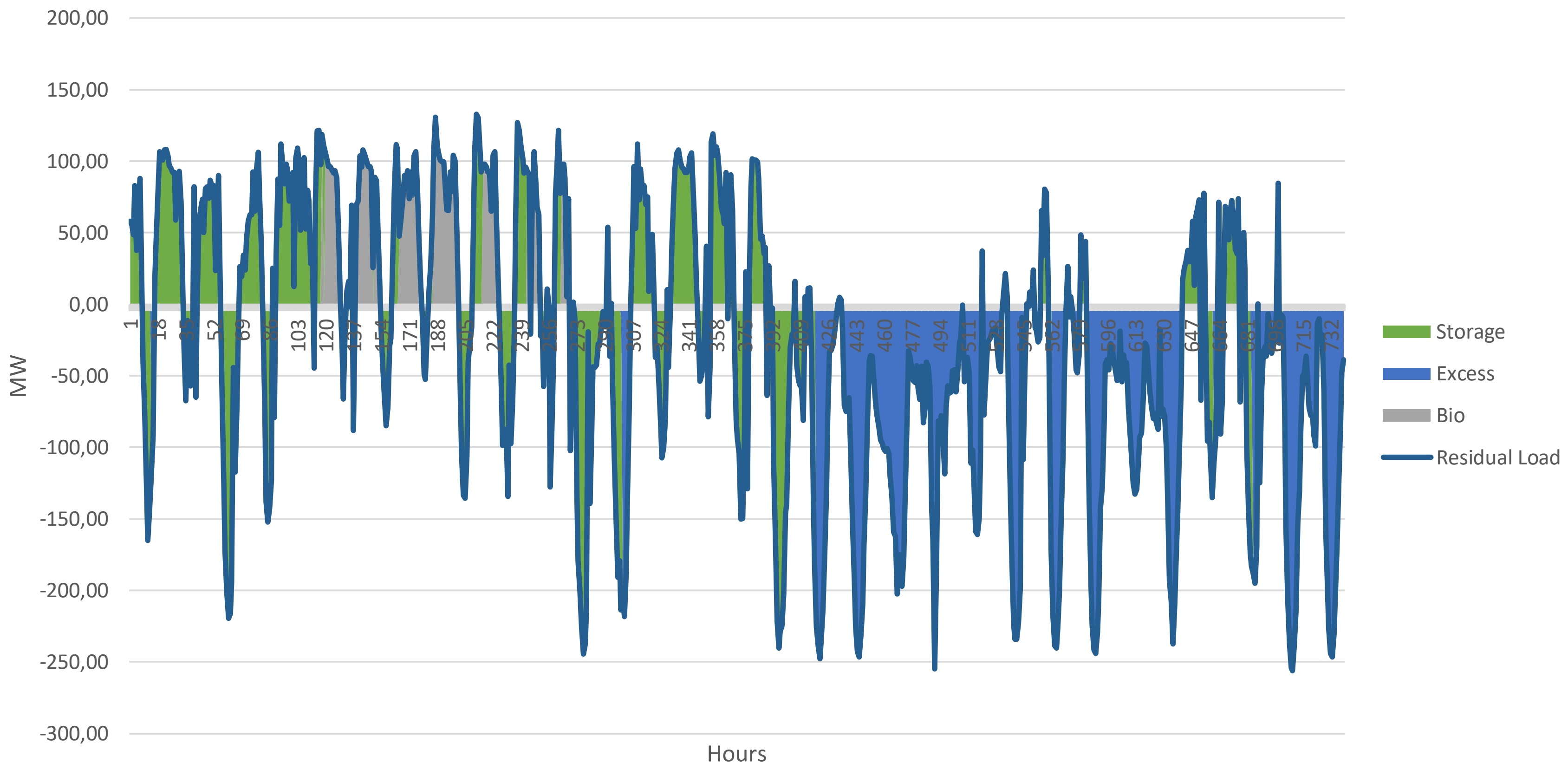
Simulation of 100% RE in Barbados (March)



Simulation of 100% RE in Barbados (March)

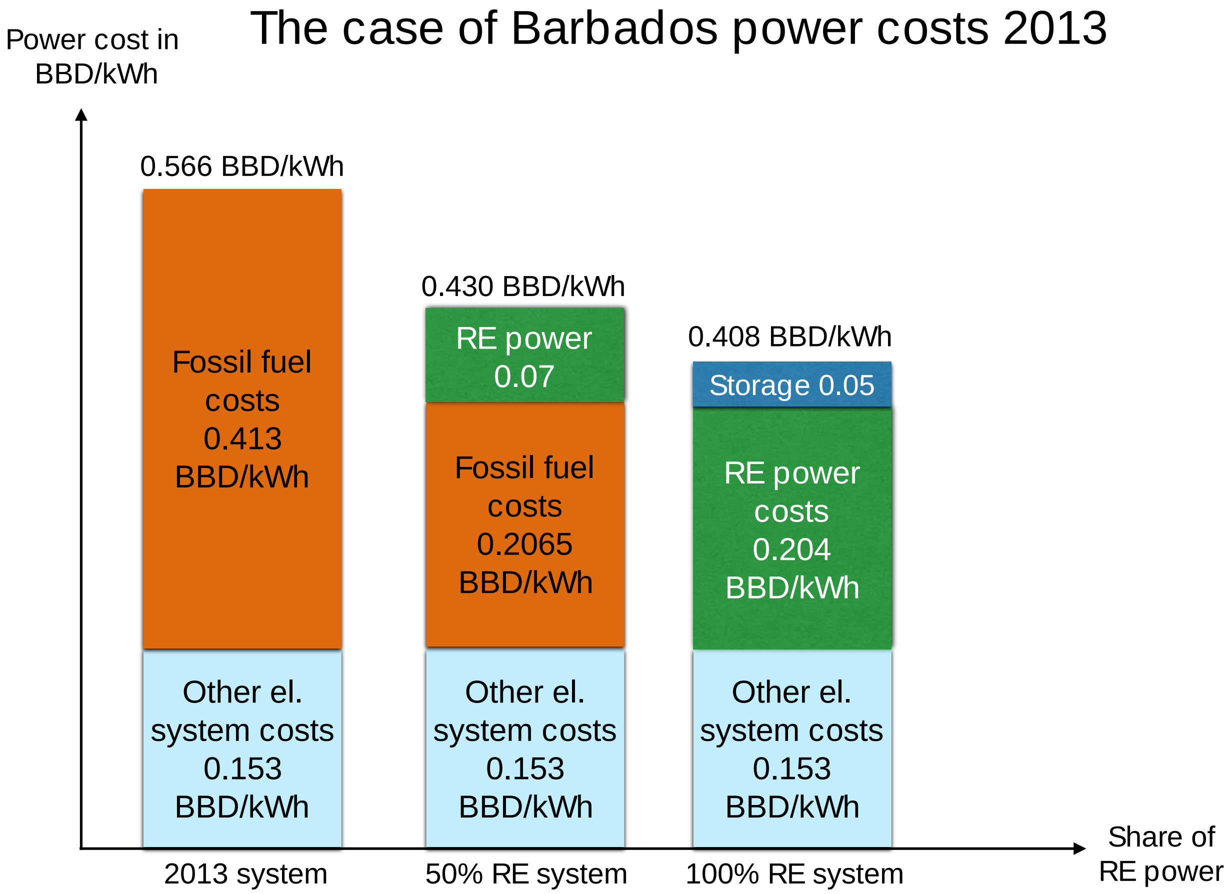


Simulation of 100% RE in Barbados (March)



Costs

Electricity cost reductions 2013 by 50% or 100% renewable power production for Barbados

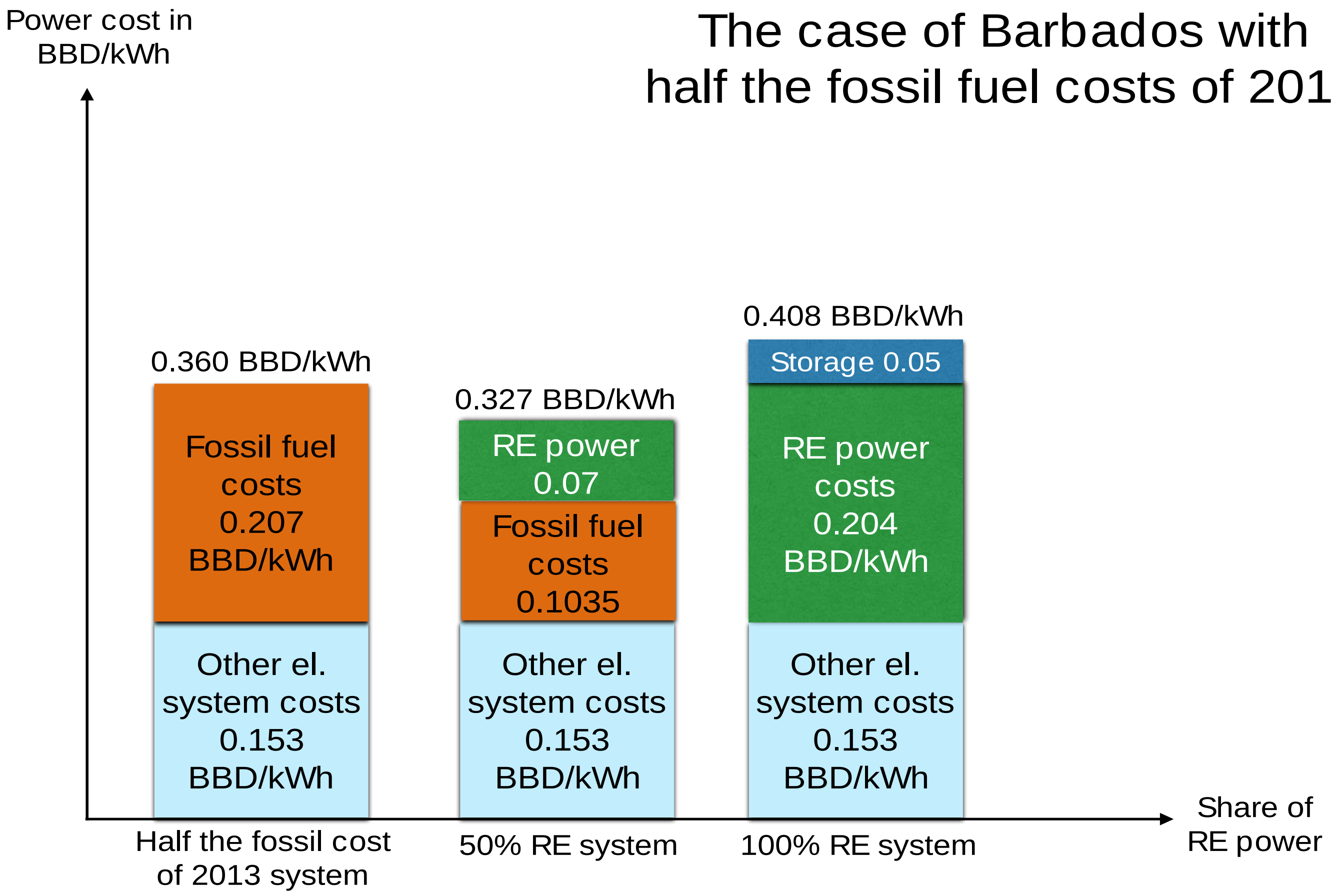


Europa-Universität Flensburg

Erasmus+

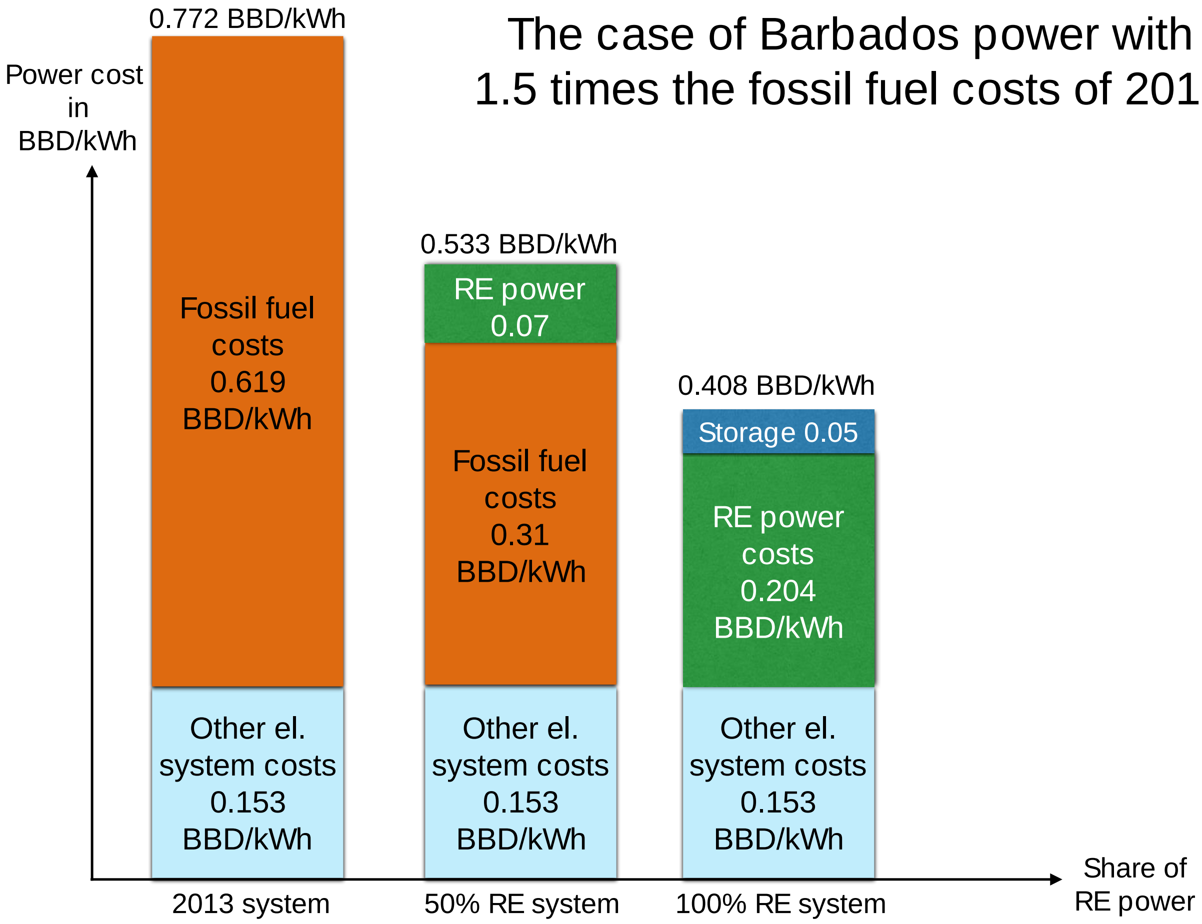
Electricity cost changes for Barbados at half the fossil price of 2013

The case of Barbados with
half the fossil fuel costs of 2013



Electricity cost changes for Barbados 1.5 times the fossil price of 2013

The case of Barbados power with
1.5 times the fossil fuel costs of 2013



A povocative statement

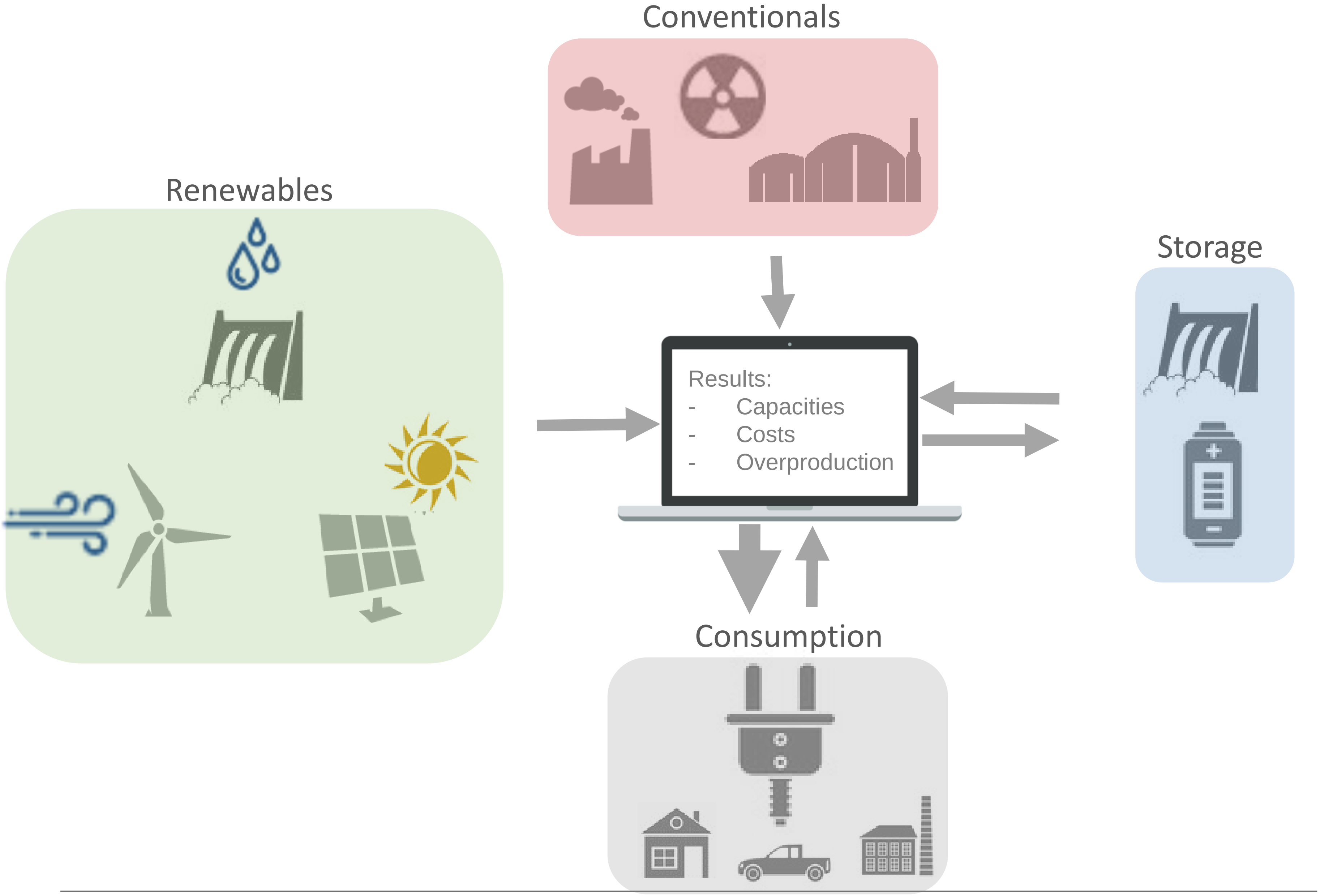
- 100 % renewables in Cambodia is possible
- Cheaper electricity cost than from coal and hydro
- Higher employment of Cambodian people
- Less emissions!

You don‘t think so?!

We should proof it:

- Conduct data analysis (demand, wind, solar radiation, grid…)
- Develop a proper optimisation/simulation
- Finance the first steps through NAMA?!

Building your own hourly simulation model!



Conventionals

Renewables

Storage

Results:
- Capacities
- Costs
- Overproduction

Consumption

Modules needed

Input module

Consumption module

Wind module

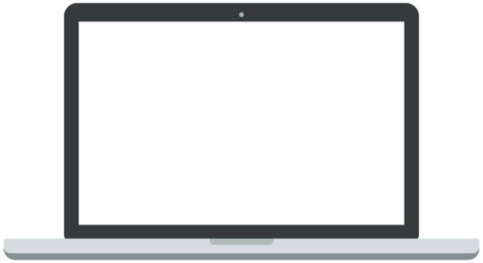
PV module

Biomass module

Hydro module

Conventional module

Storage module



Dispatch module

Results module

Graphics module

Basic model calculations: Dispatch module

- $R1_t = L_t - PV_t - Wind_t$
- If $R1_t > 0$, and $S_t > R1$, then $S_{(t+1)} = S_t - R1_t$
- If $R1_t > 0$, and $S_t < R1_t$, then $R2_t = R1_t - S_t$,
- $S_{(t+1)} = 0$, and $Biom_t = R2_t$
- If $R1_t < 0$, and $S_{max} - S_t >= R1_t$ then $S_{(t+1)} = S_t + R1_t$
- If $R1_t < 0$, and $S_{max} - S_t < R1_t$, then $DRP_t = R1_t - (Smax - S_t)$

With:

- R_t = Residual load [MWh/t]
- S_t = Storage [MWh]
- $Biom_t$ = Biomass [MWh/t]
- DRP_t = Down regulated power [MWh]

As a result, the electricity demand is covered 100% every hour of the year!

Who is interested?

Thanks for your attention!

M. Eng. Kristian Reincke

Centre for sustainable energy systems (ZNES)
Europauniversität Flensburg
Munketoft 3b
24937 Flensburg

Fon: +49 (0) 461 805 3016
Mail: kristian.reincke@uni-flensburg.de
Web: www.uni-flensburg.de/eum
www.znes-flensburg.de