

Shaping sustainable energy systems using simple hourly simulation models

A. The case of 100% renewable Barbados

B. Building your own hourly simulation model

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Yangon, 10.10., Vientiane 16.10. and Phnom Penh, 24.10.2017

(Based on a BREA Energy Lecture
held at Bridgetown, Barbados, November 10th, 2014)

Structure of the presentation

A: The case of a 100% renewable power supply for Barbados

1. The present electricity demand and supply of Barbados
2. The possible renewable contributions and their costs
3. How to balance the system every hour of the year?
4. A 100% power scenario for Barbados and its costs
5. Economic effects of a 100% renewable Barbados
6. Outlook: 100% renewables for electrical cars

Part II: How to build your own system model

Basic facts about Barbados

- | | |
|-----------------------------|---------------------|
| 1. Population 2010: | 278 000 |
| 2. Area: | 431 km ² |
| 3. GDP/cap: | 16 700 USD/cap |
| 4. HDI: | 0,78 |
| 5. Electricity demand 2013: | 912 GWh/h |

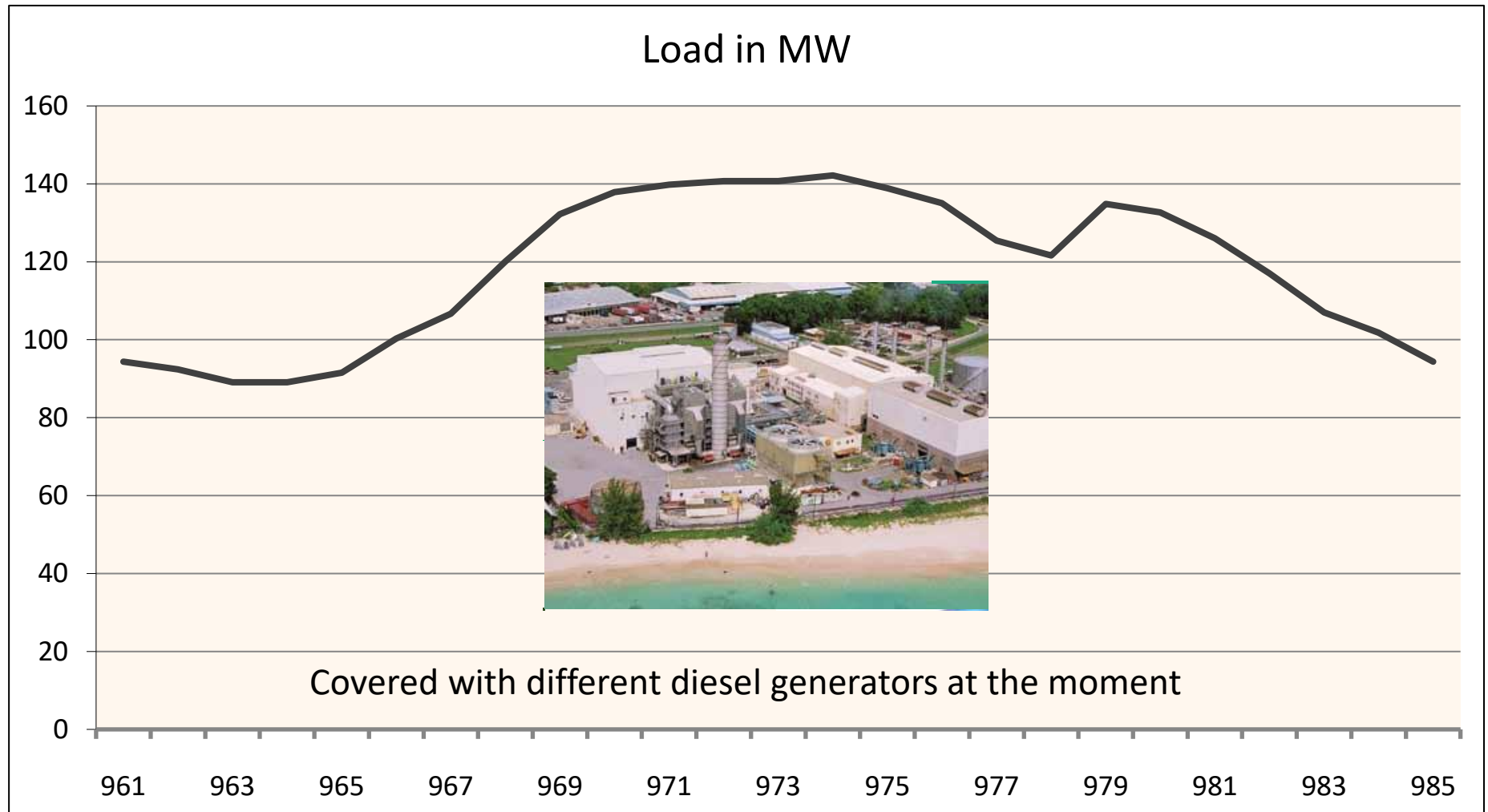


Present electricity demand and supply

1. Demand 2013: 912 GWh/a
2. Total production 2013: 970 GWh/a
3. Total operating expenses: 516.5 Million BBD (2 BBD = 1 USD)
4. Fuel costs: 376.7 Million BBD
5. Total costs per kWh: 0.566 BBD/kWh
6. Fuel costs per kWh: 0.413 BBD/kWh

1. Virtually all BL&P production based on HFO/diesel or jet fuel
 - 2 steam turbines 40 MW (HFO)
 - 6 low speed diesel 113.5 MW (HFO)
 - 5 gas turbines 86 MW (diesel and jet fuel)

Electrical load for Barbados (Feb. 9th)



A 100% renewable power system proposed for Barbados

195 MW PV



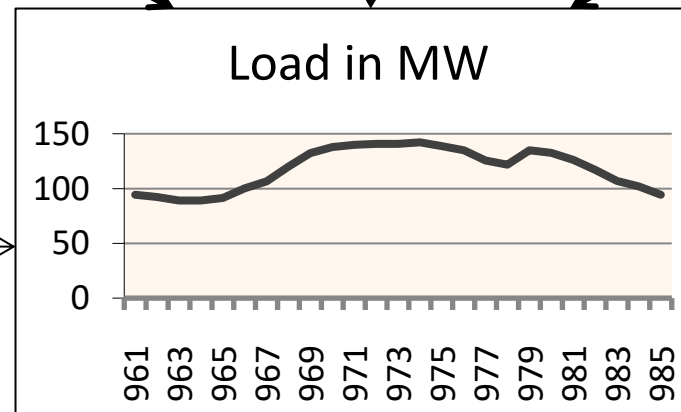
3 GWh PSH



200 MW wind



25 GWh biomass



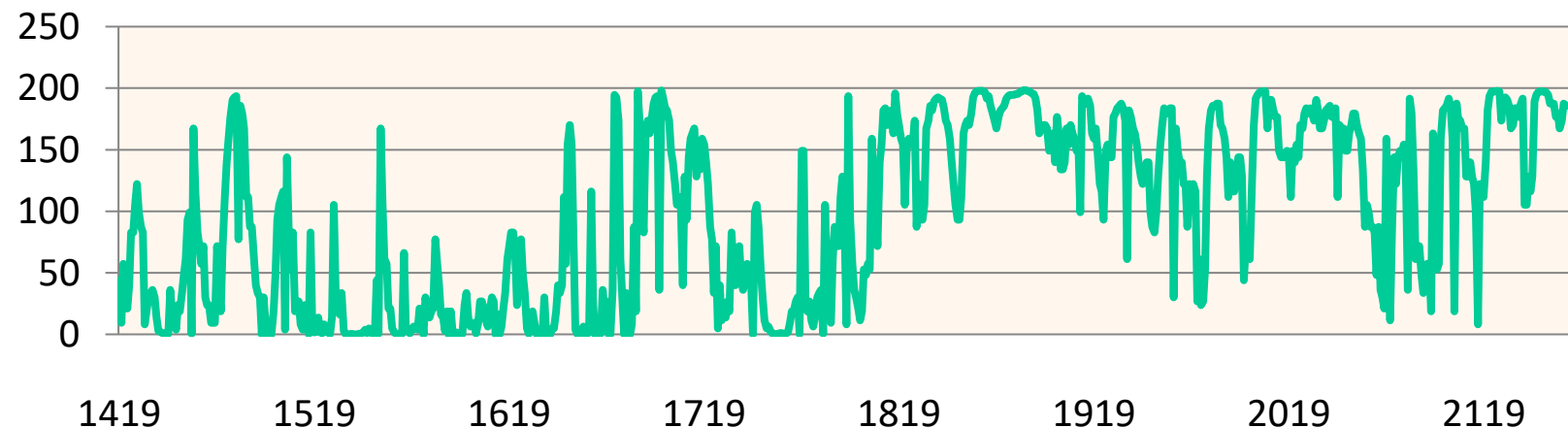
Wind energy on Barbados

1. Size of the island: 430 km²
2. Theoretical potential on shore: 4.3 GW
3. Costs per kWh: 0.07 BBD/kWh

Example: March

Hourly wind power production in MWh

200 MW installed

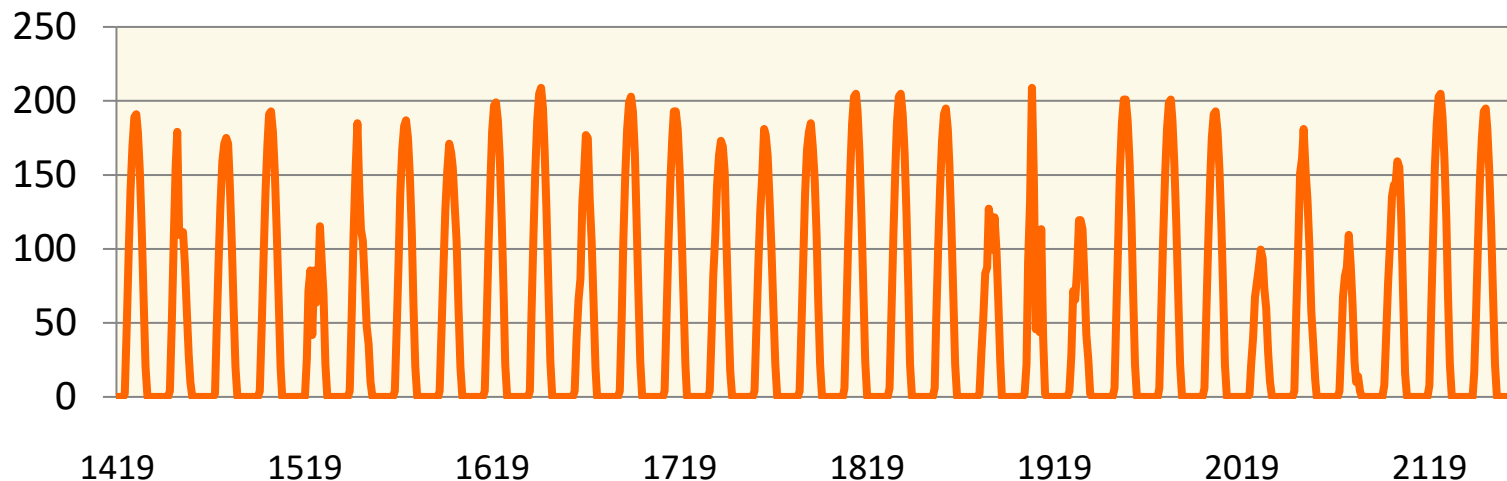


1. Size of the island: 430 km²
2. Theoretical PV potential: 5 375 GW
3. Costs per kWh: 0.252 BBD/kWh

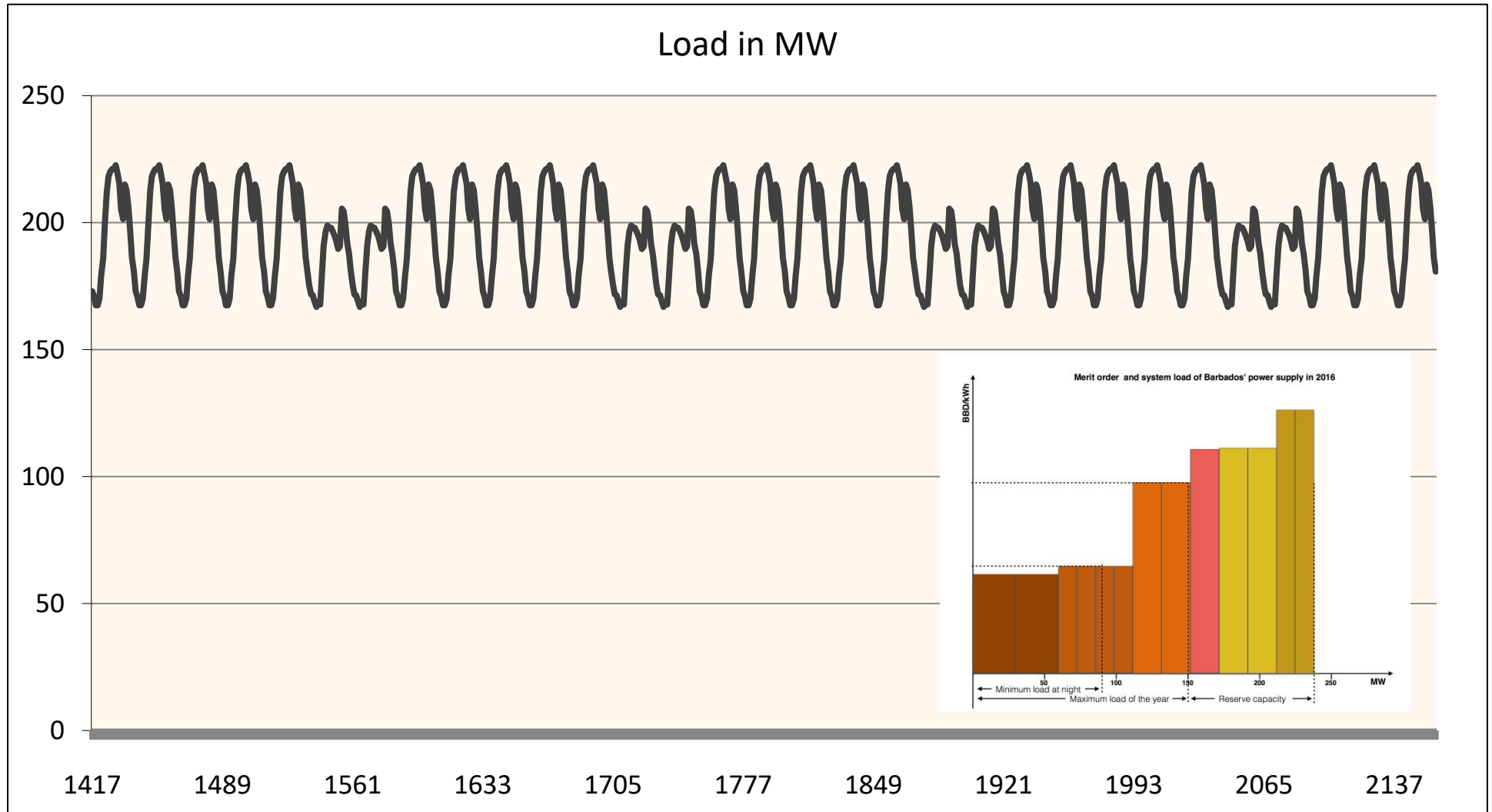
Example: March

Hourly PV production in MWh

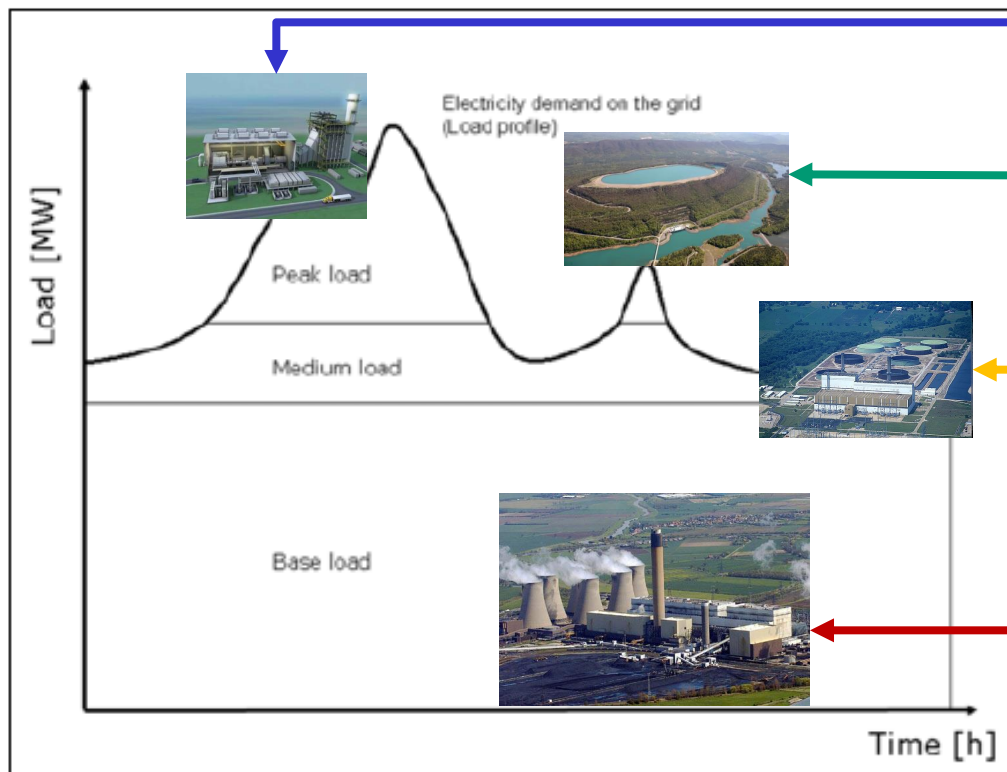
195 MW installed



Hourly load curve for Barbados in March



Schematic graphic of how daily electricity demand is met in the current electricity system

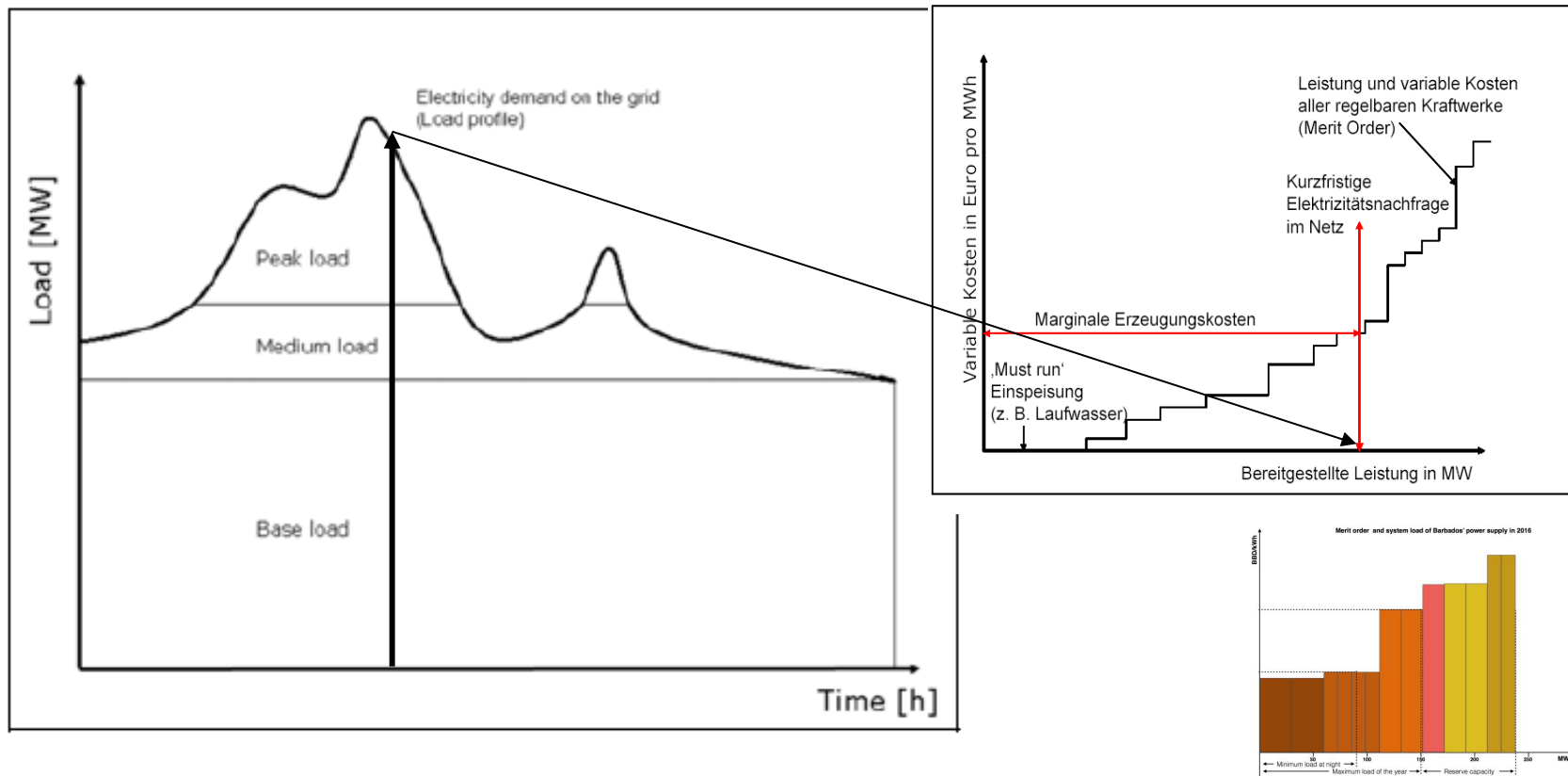


Source: SRU 2011, p.142

Dispatch and Merit Order in the Past

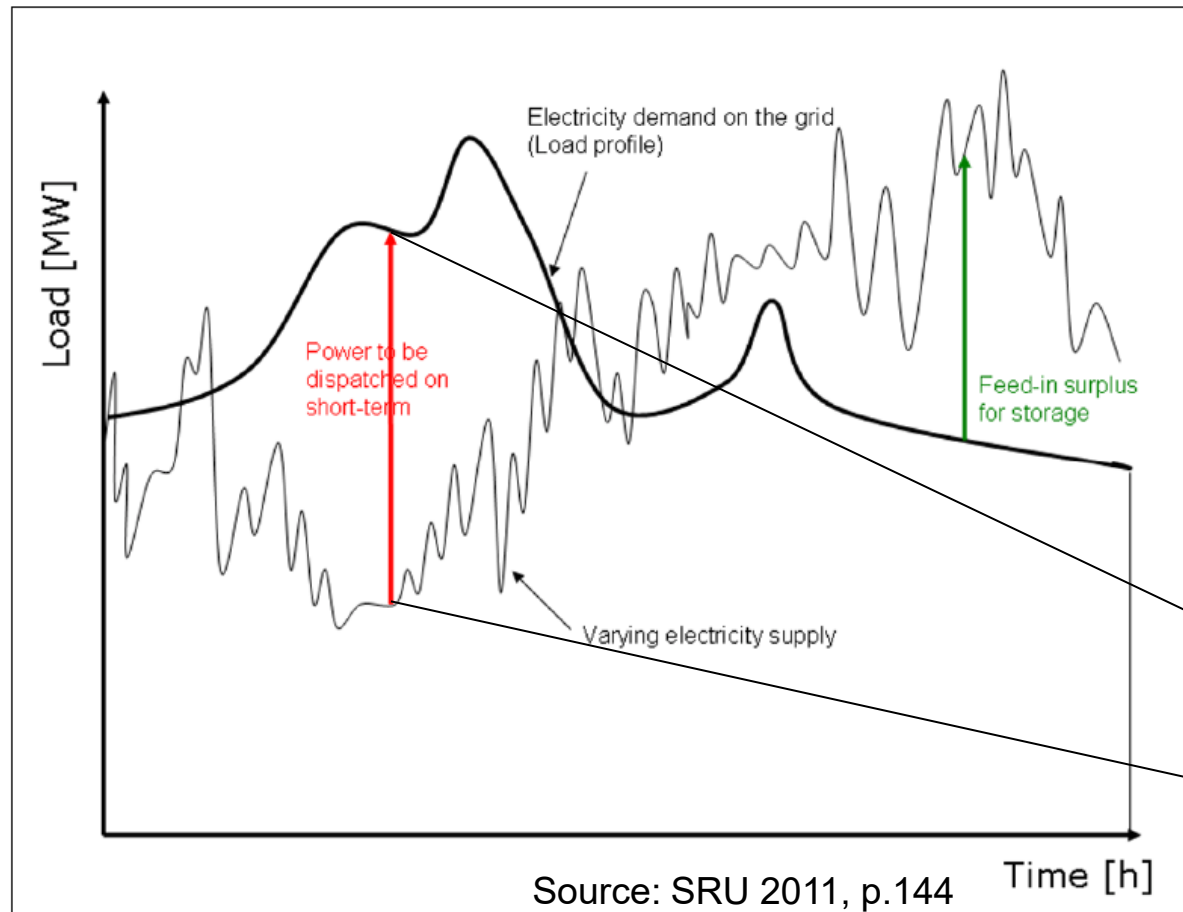
Schematic graphic of how daily electricity demand is met in the current electricity system

Merit order

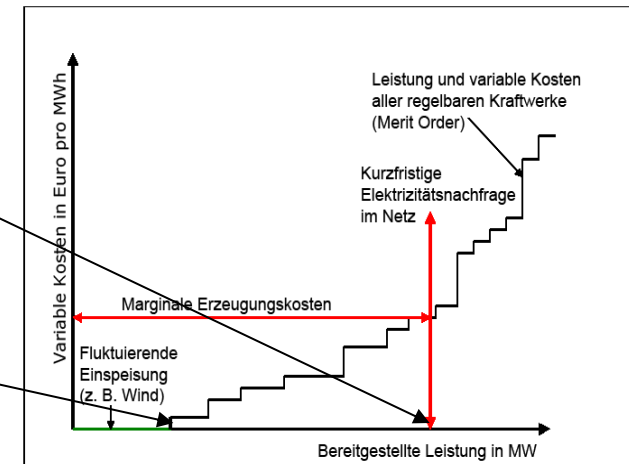


Source: SRU 2011, p.142

Meeting daily electricity demand in an electricity system with a high proportion of wind power

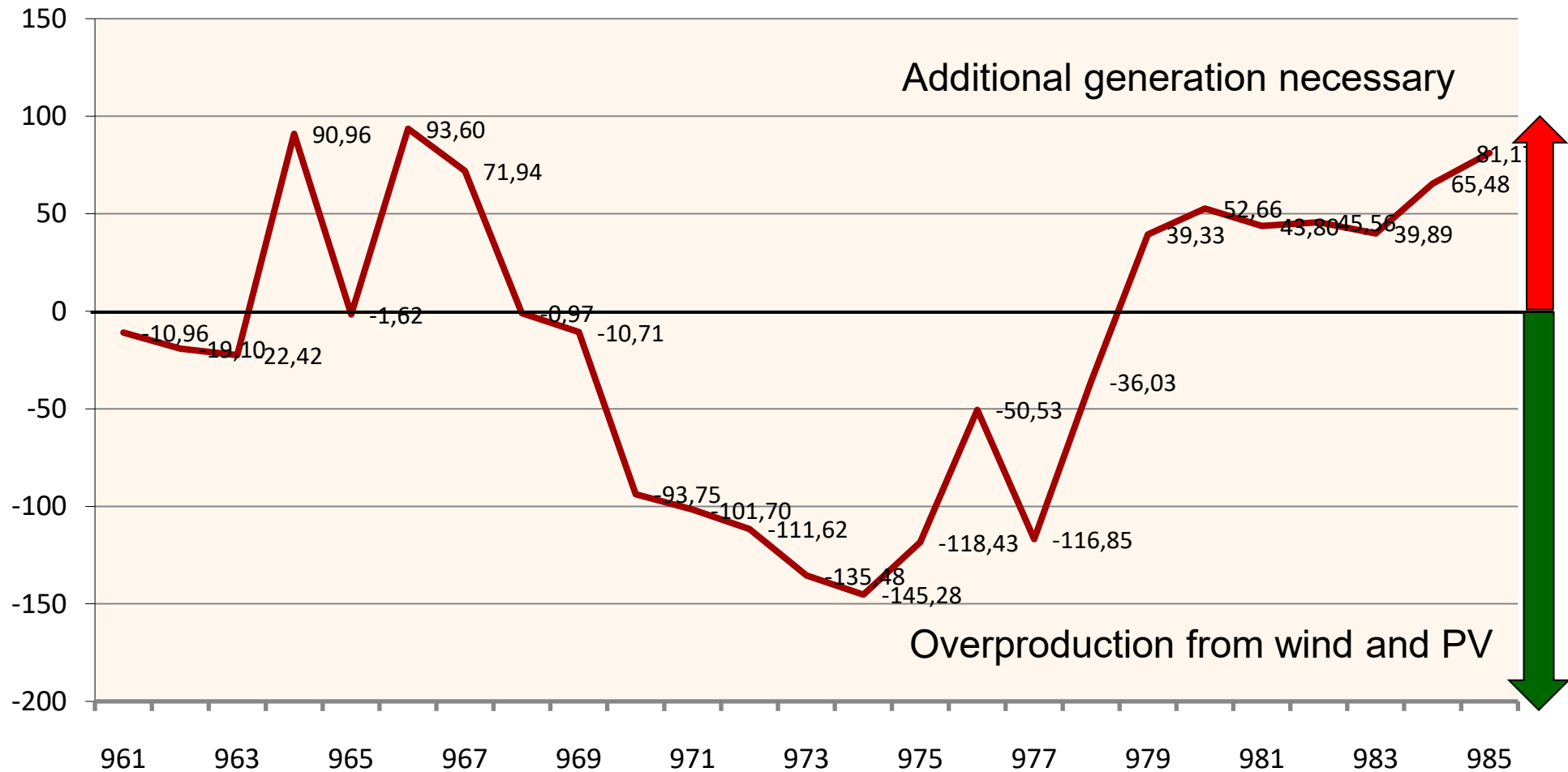


Source: SRU 2011, p.144

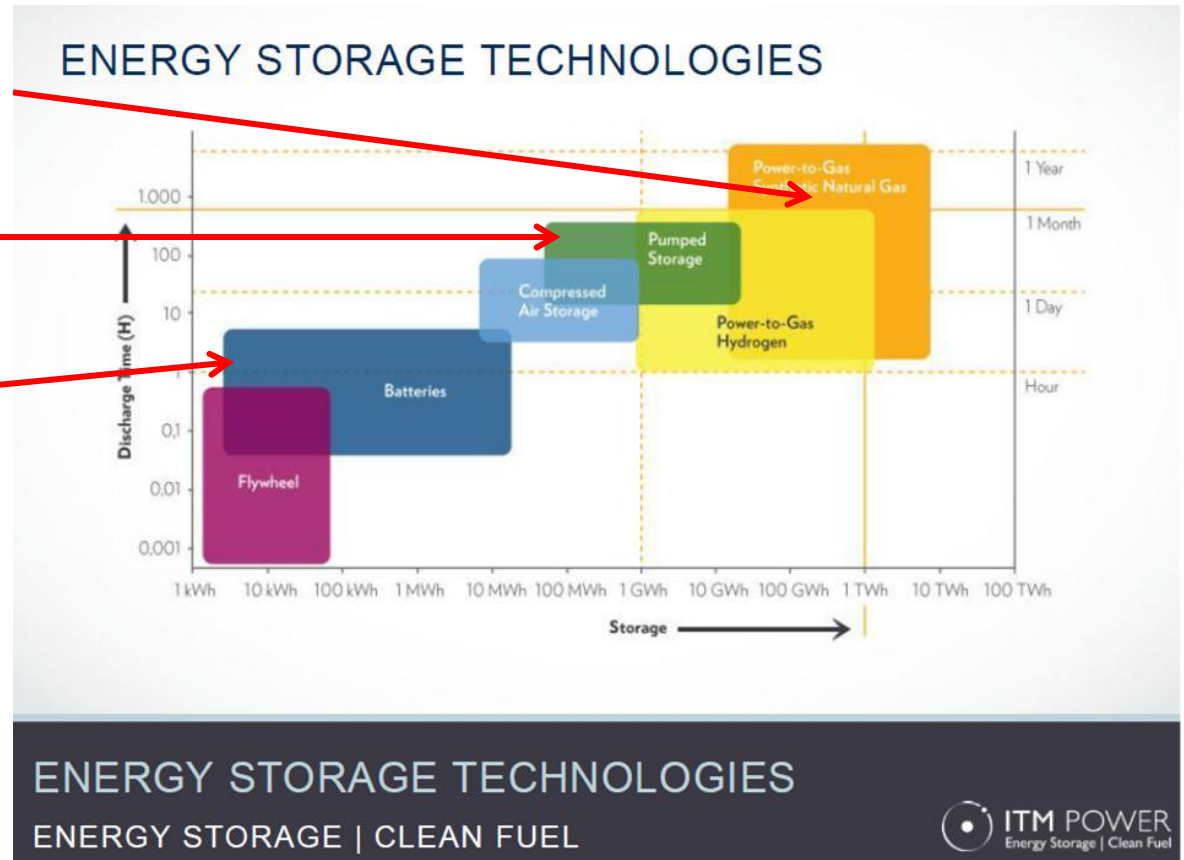


Residual load for 100% REN Barbados (Feb. 9th)

Residual Load in MW



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

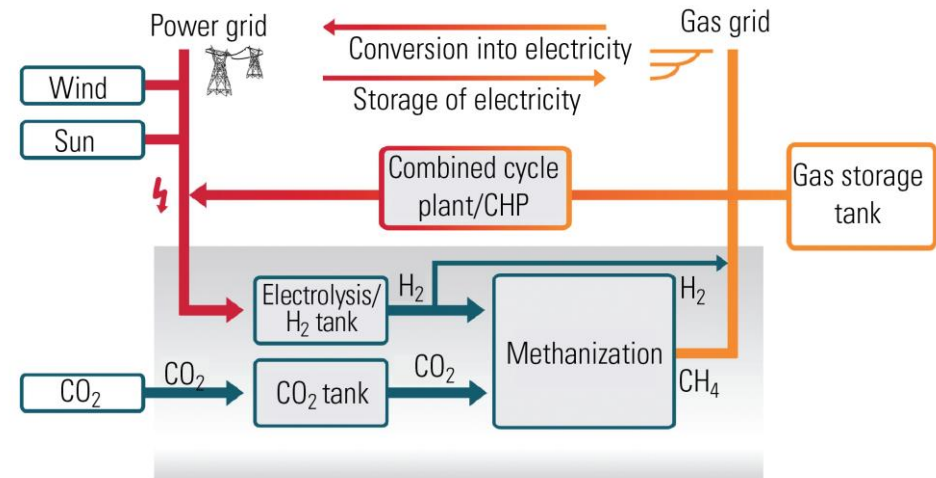


Storage options for Barbados

Power to gas (to power)

Power to gas to power:

- Appropriate size GWh
- Very low efficiency
- High costs
- Technology in infancy
- Could use old gas fields as very large storage



Storage options for Barbados

Battery storage

Battery storage:

- Easy to install
- High efficiency
- Electricity loss over time
- Relatively expensive (500-600 US\$/kWh storage)
- Too small for Barbados (MWh range)

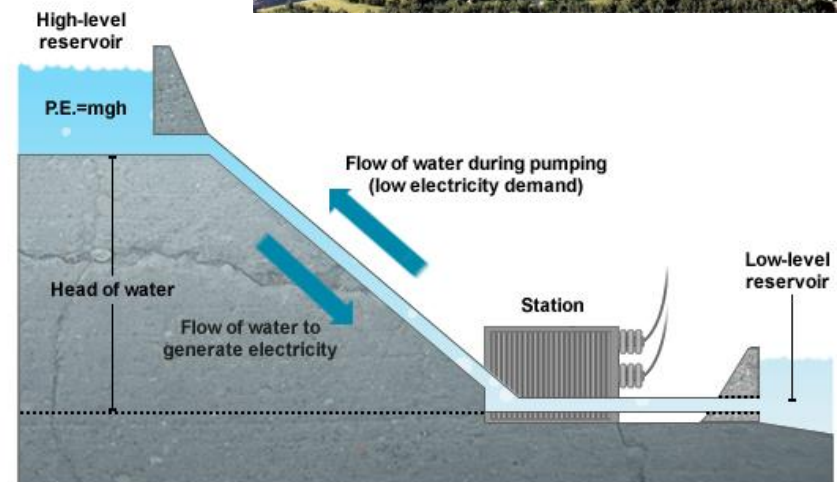


Storage options for Barbados

Pump storage hydropower

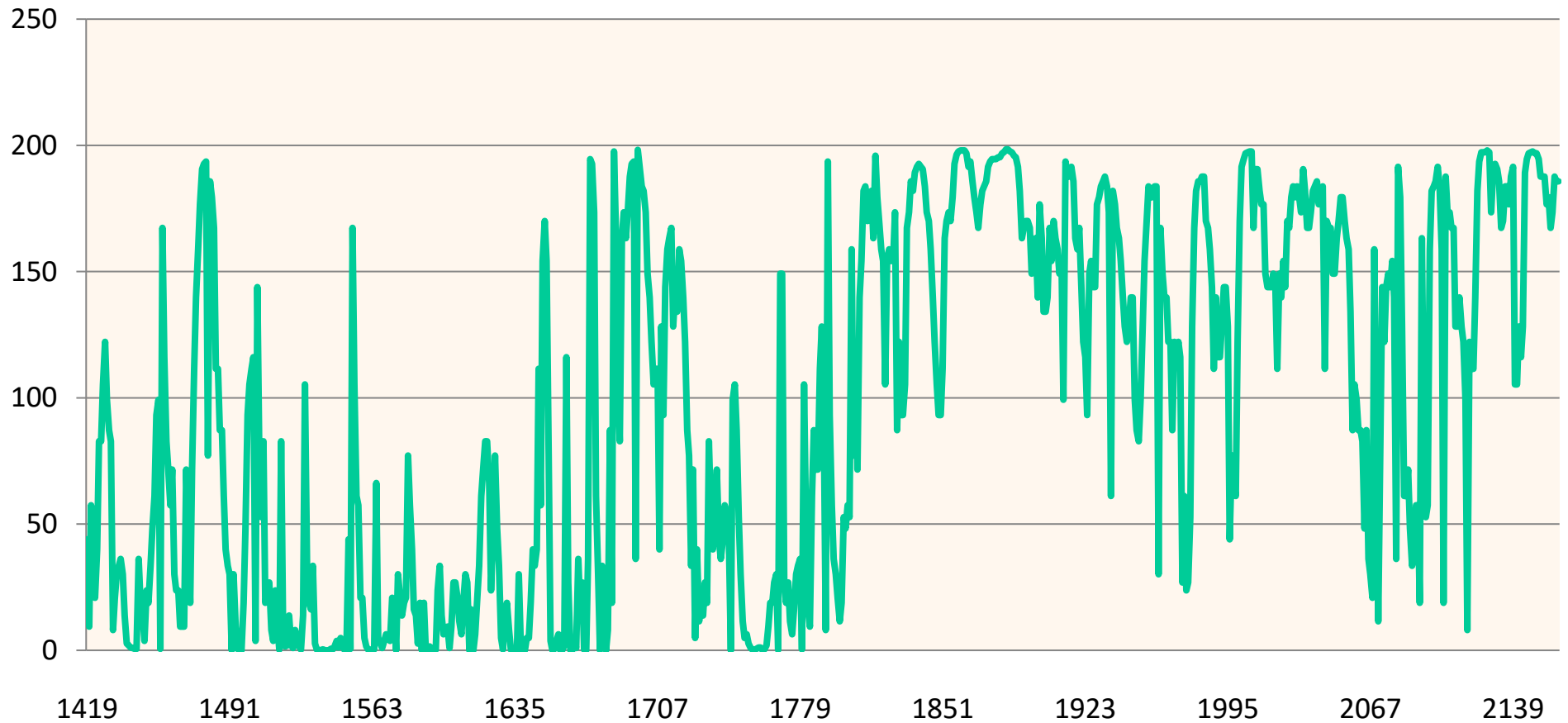
Pump storage hydropower:

- Appropriate size GWh
- Low cost per MWh storage (<100 US/ kWh storage)
- Major construction needed
- Only special locations with large altitude difference possible
- Technology chosen for the modelling (3 GWh)



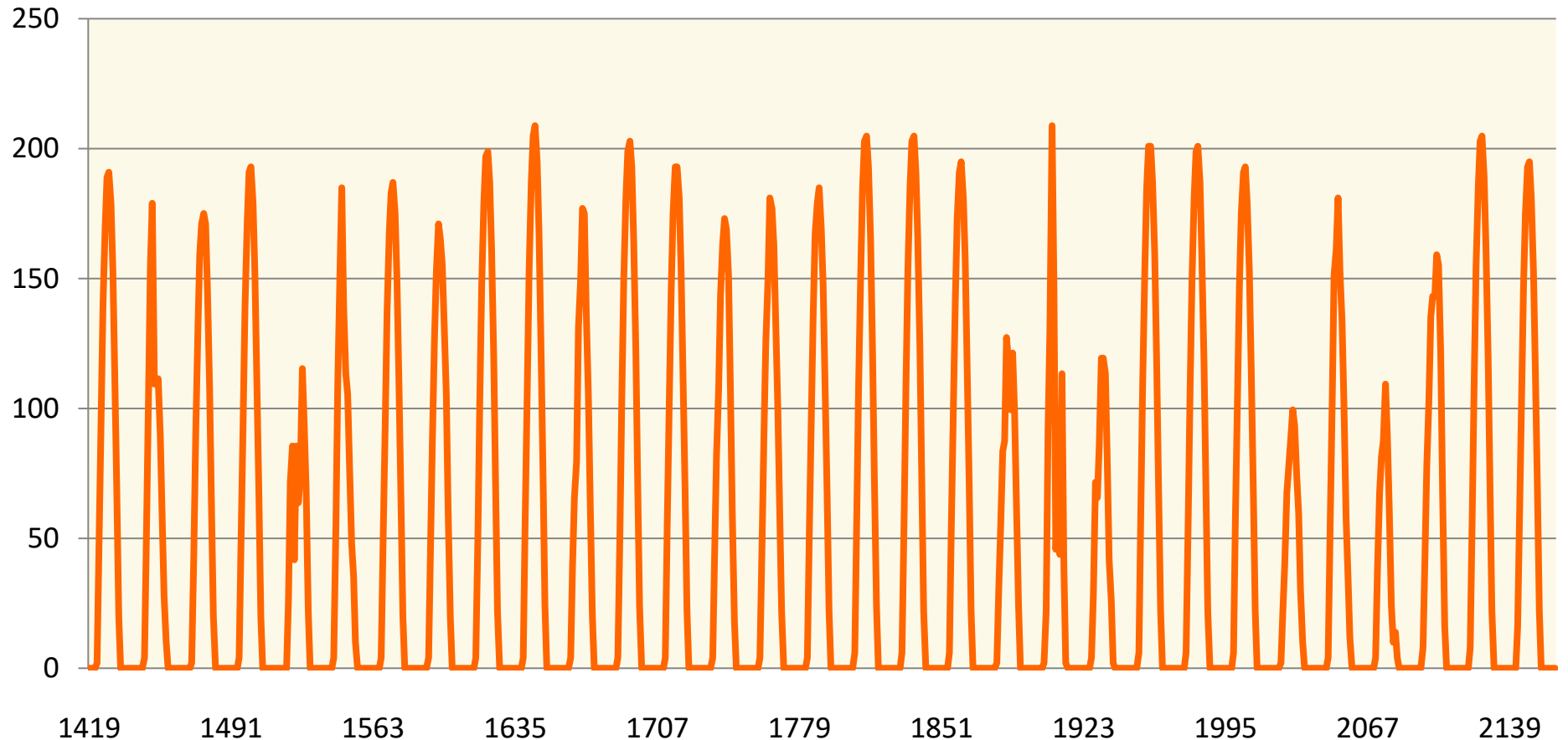
Wind energy production in March

Hourly wind power production in MWh

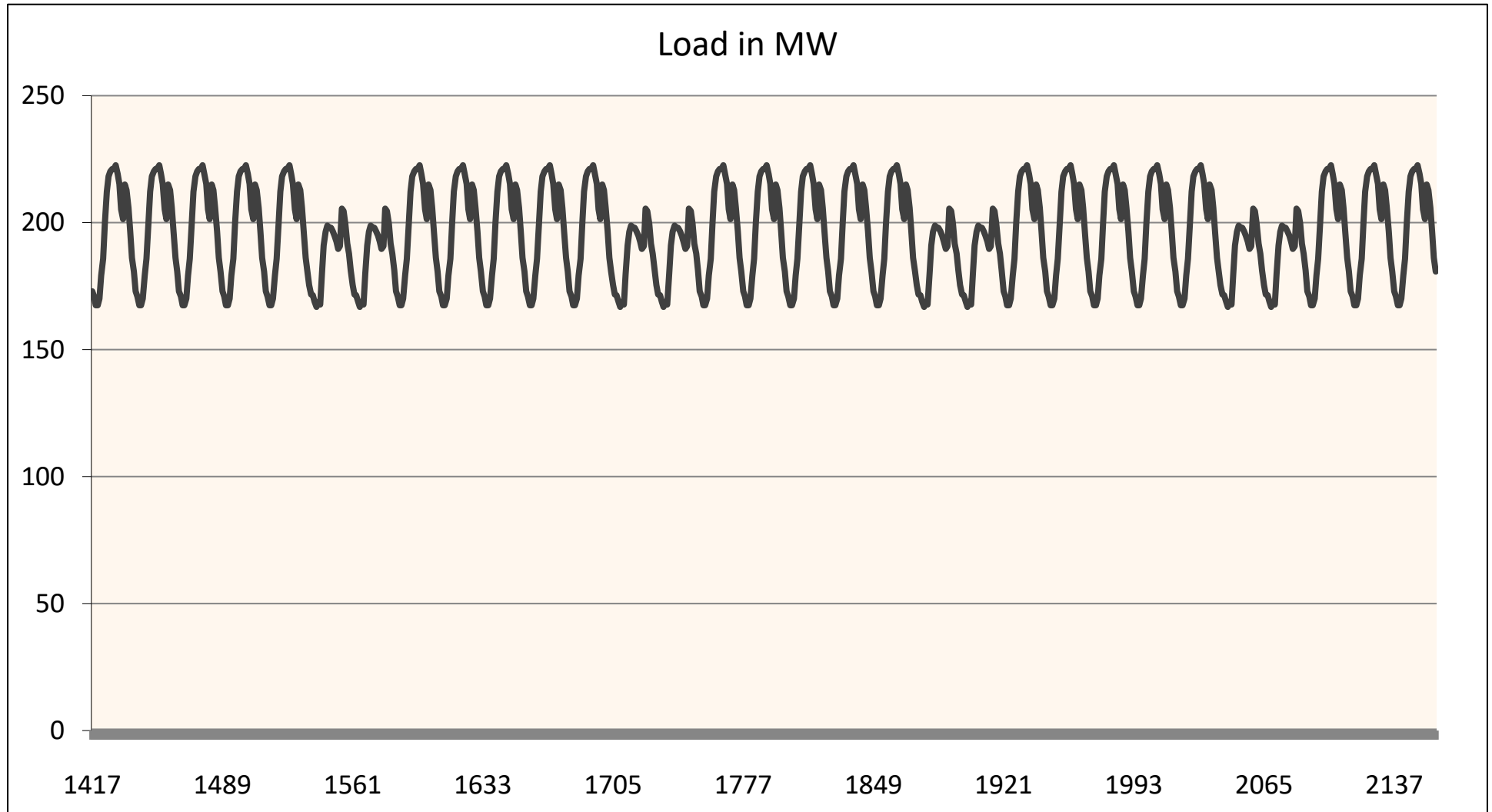


Solar PV energy production in March

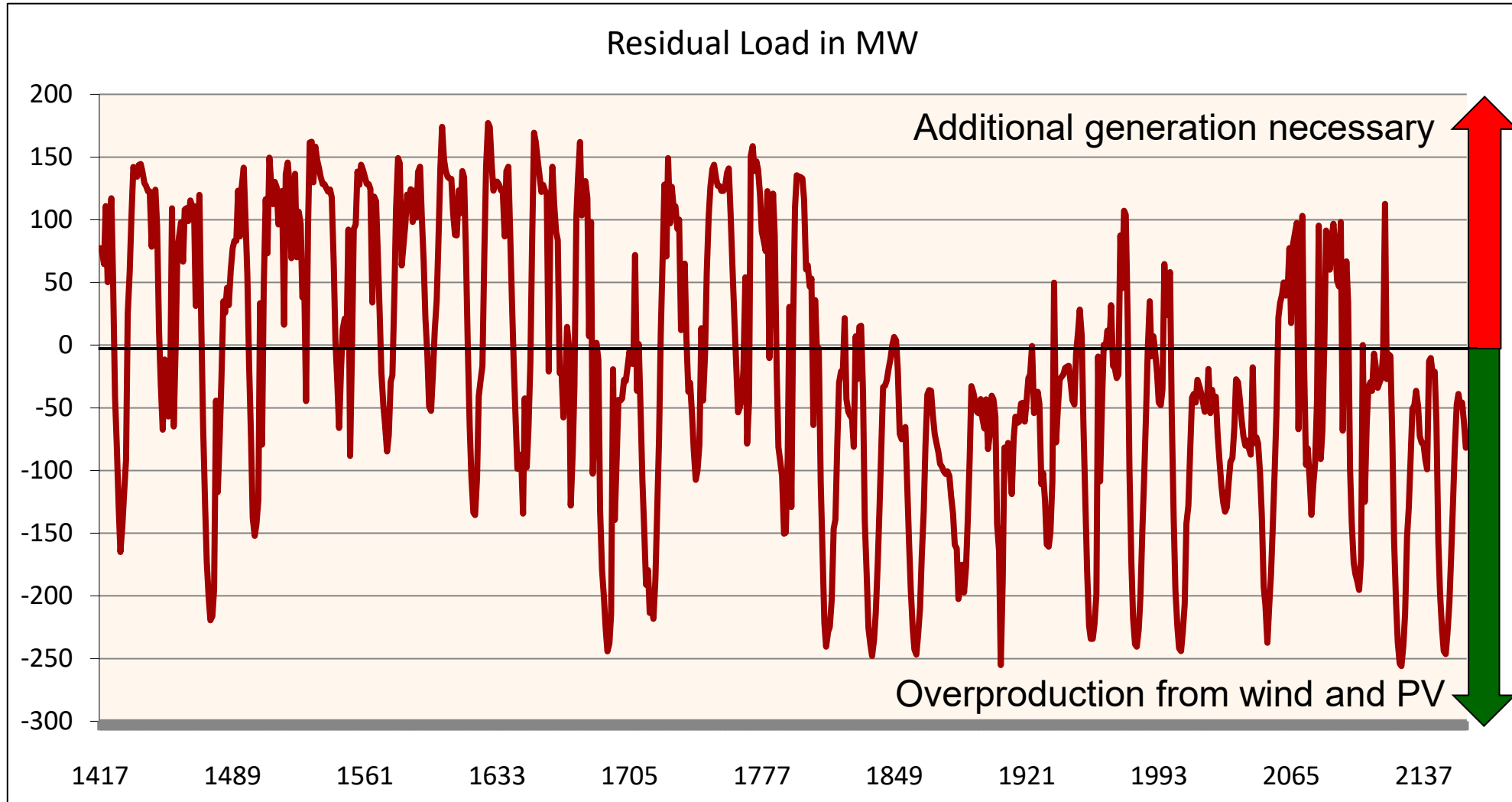
Hourly PV production in MWh



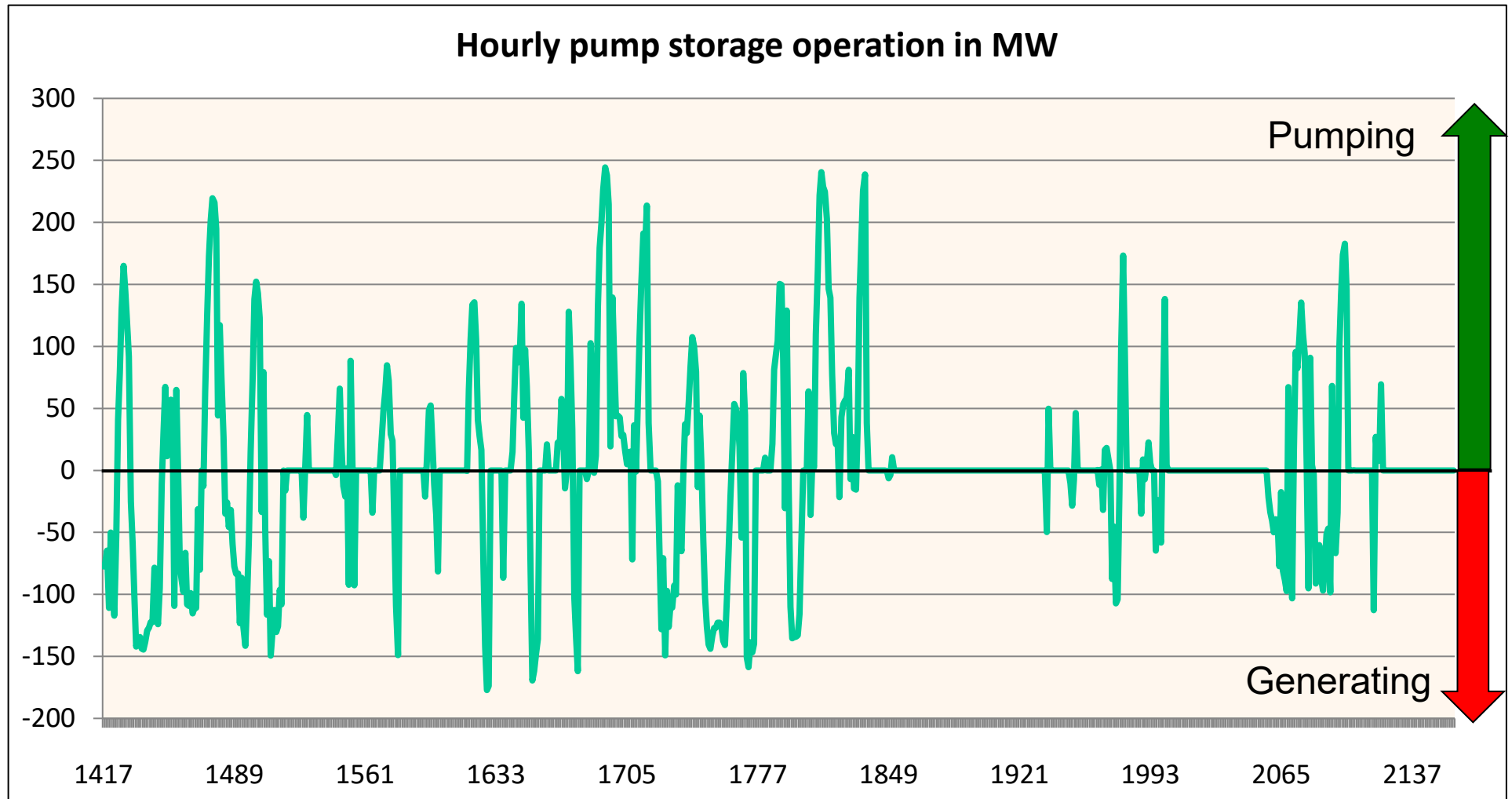
Hourly load curve for Barbados in March



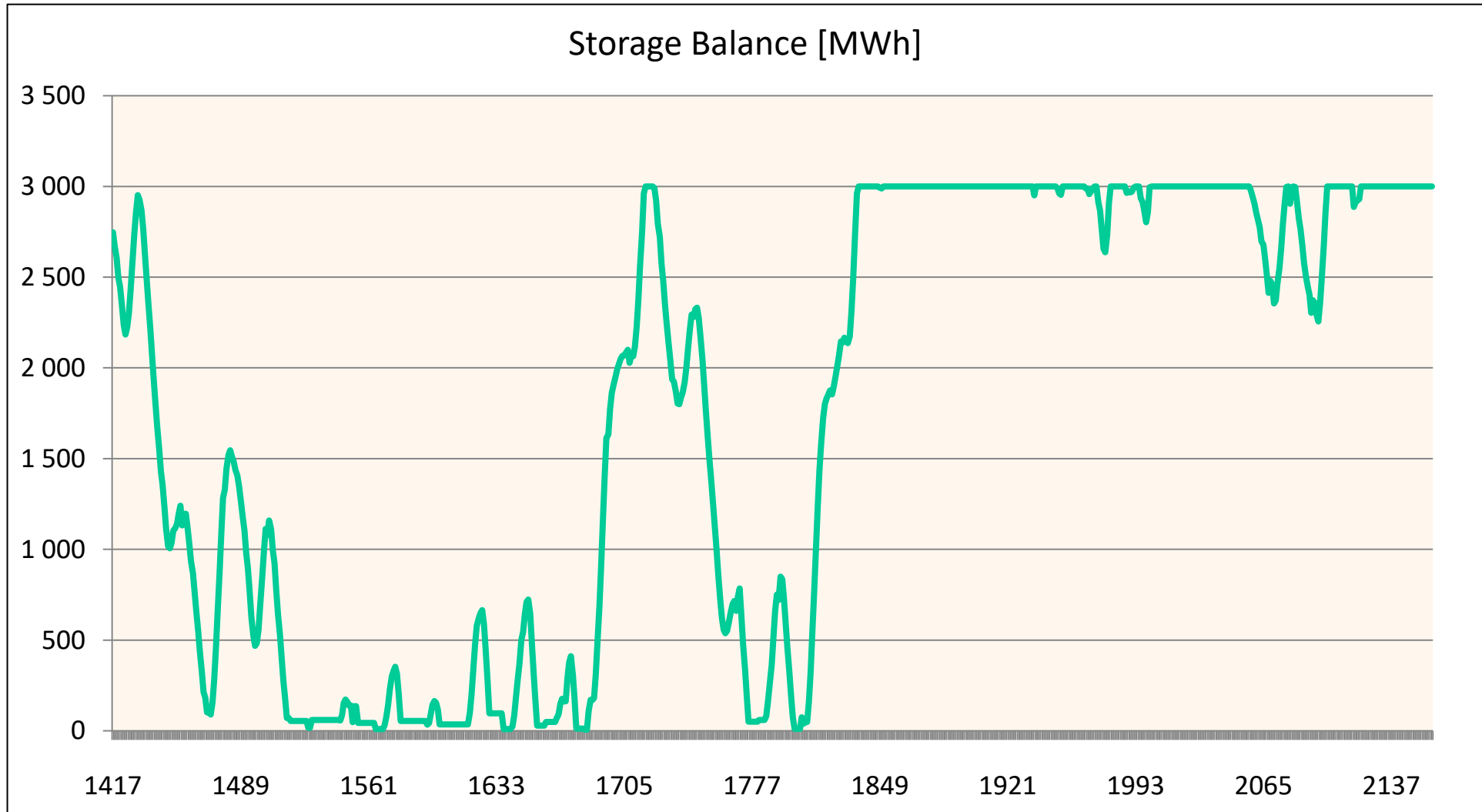
Residual load for March



Pump storage for March

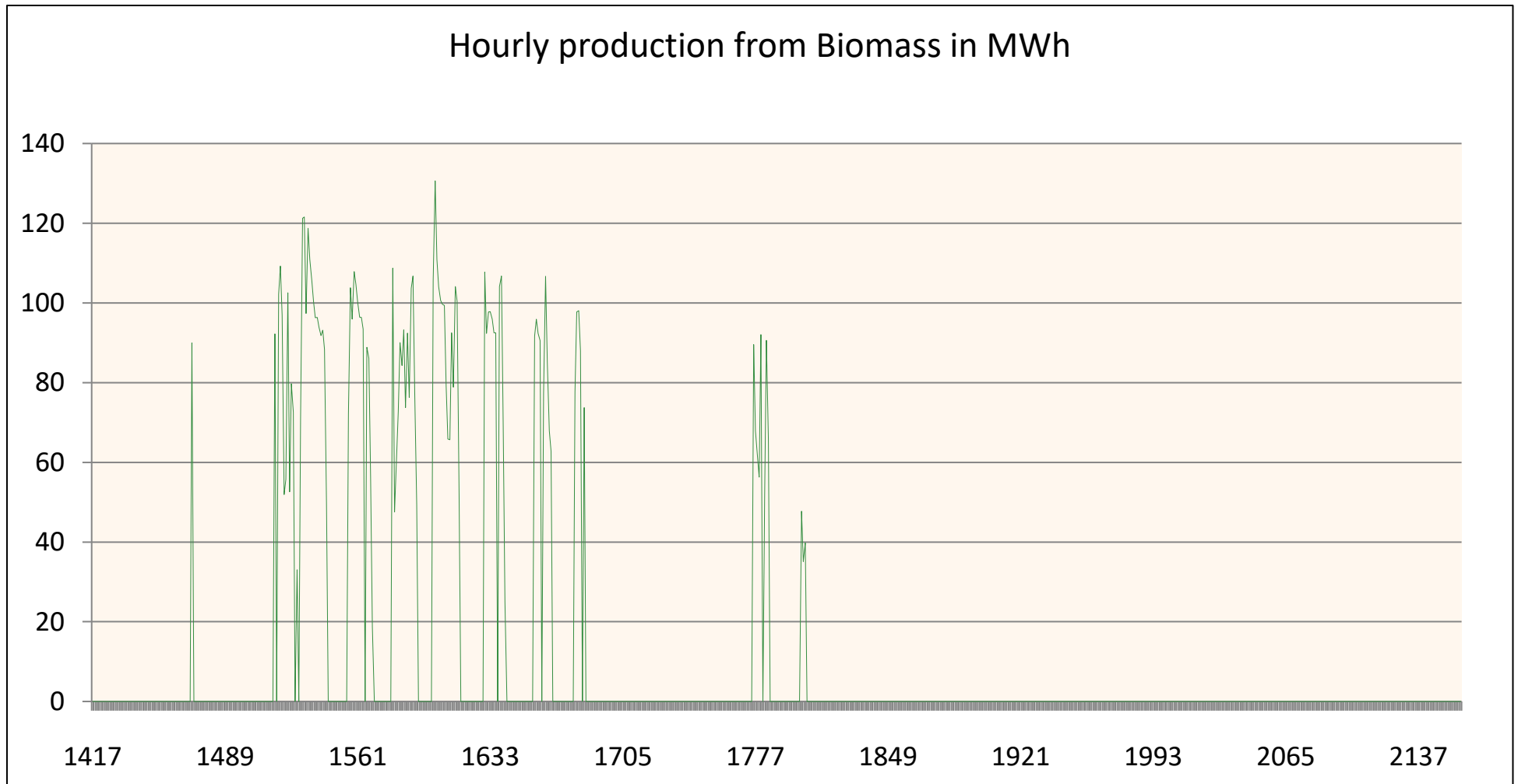


Storage filling level in March

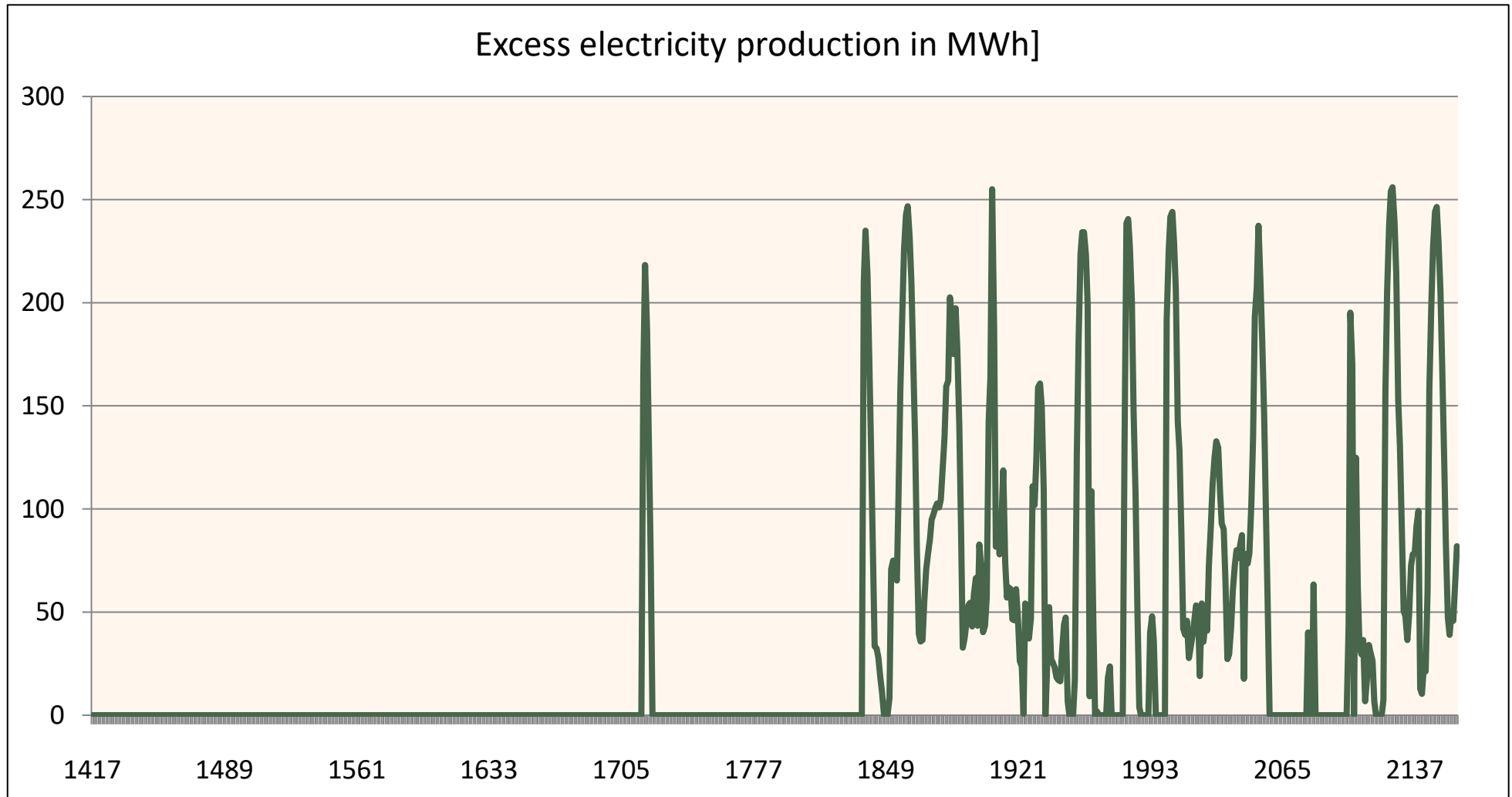


Use of biomass in March to match the load not met by wind, PV or pump storage

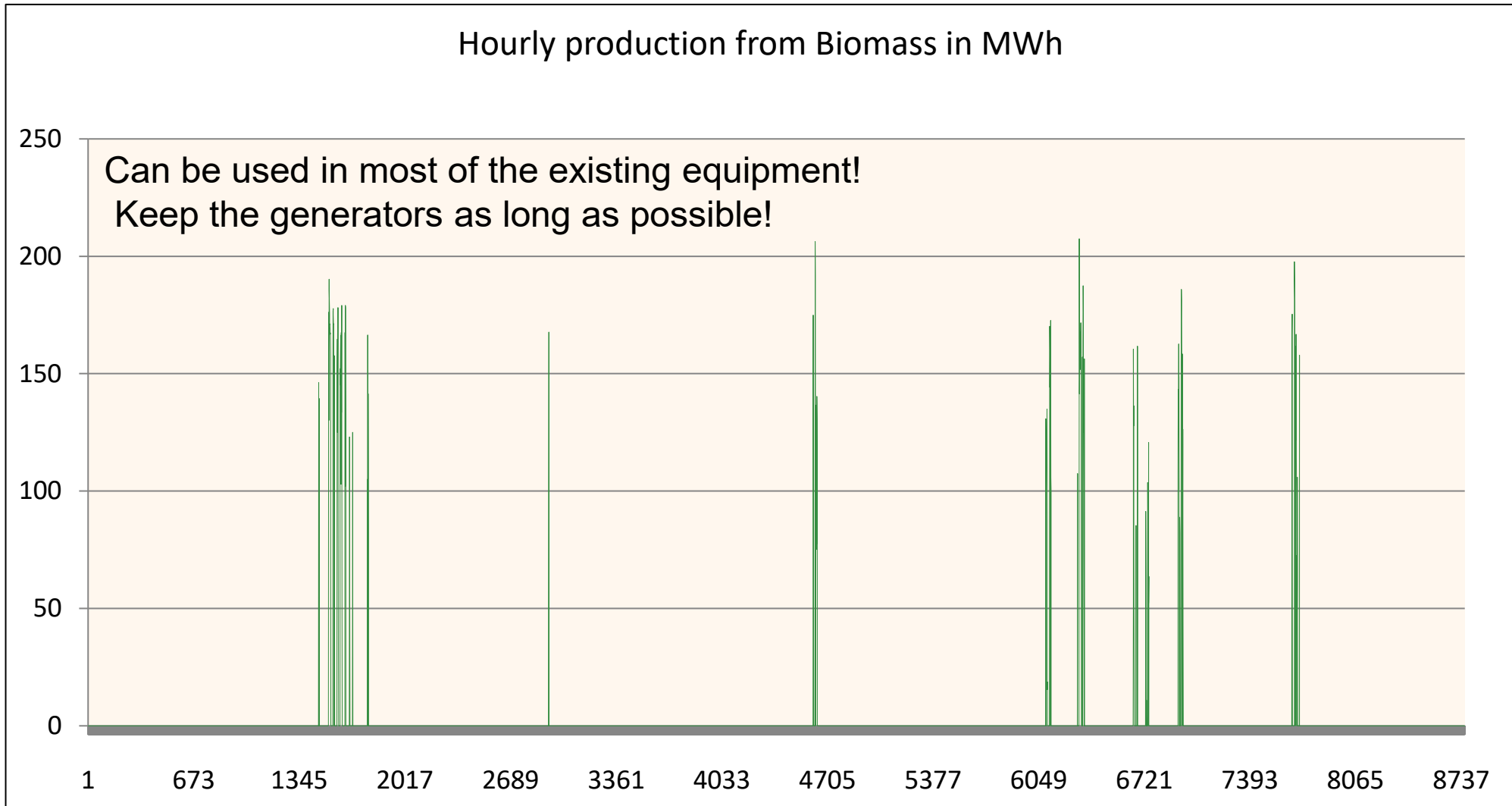
Hourly production from Biomass in MWh



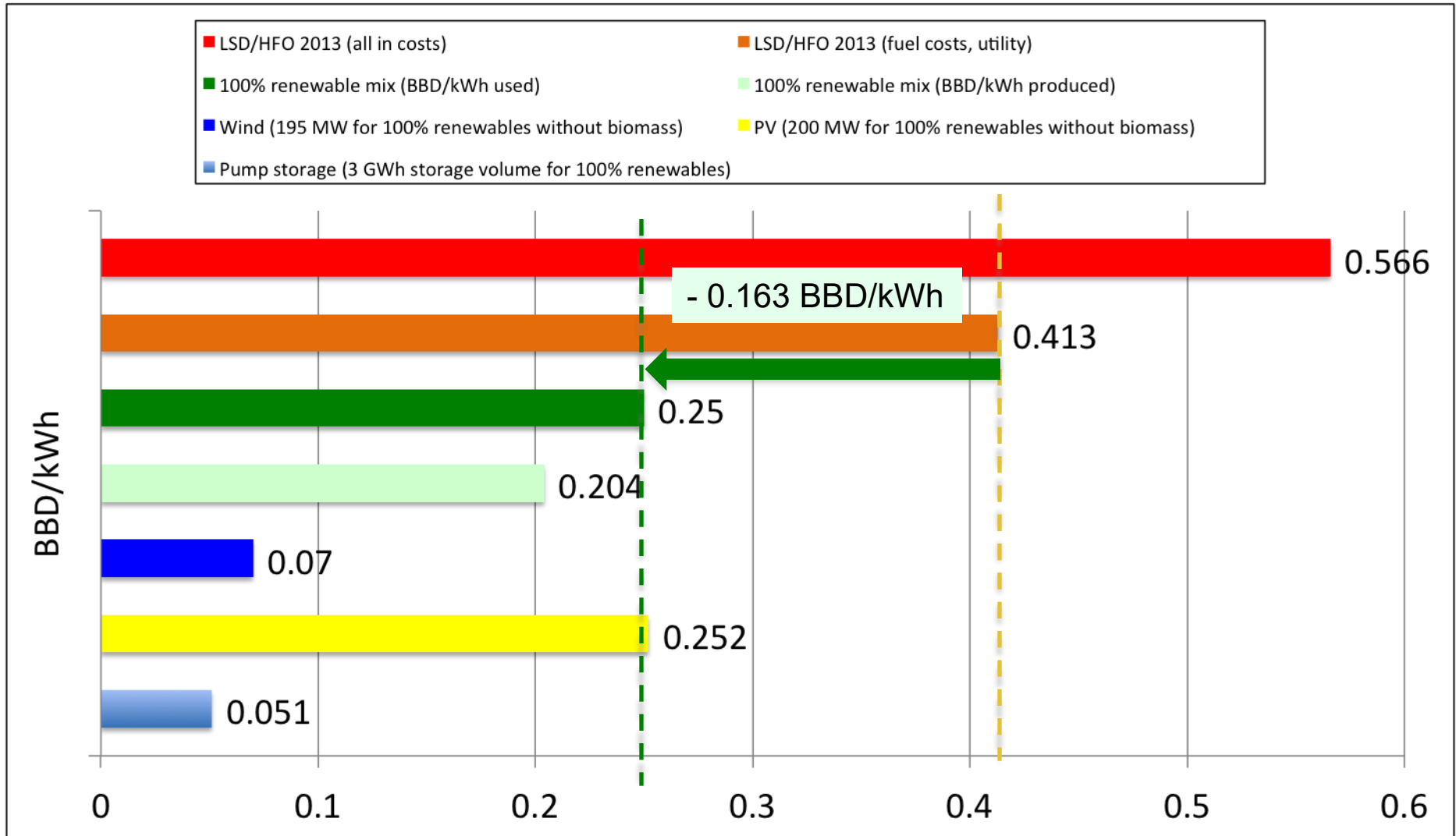
Power overproduction in March from wind and PV



Use of 25 GWh of biomass during the year (about 5 000 t of biodiesel per year)



Electricity costs for 100% renewable Barbados (25 GWh biomass, 3 GWh storage)



- **A 100% renewable power supply for Barbados is no problem**
- **Electricity bill lowered by 175 Million BBD/a**
- **Diesel import savings of about 375 Million BBD/a**
- **Net import reduction per year - 300 Million BBD/a**
- **Net tax increase per year + 104 Million BBD/a**

Conclusions

- 100% renewable power for Barbados is a bargain
- It can reduce Barbados' power costs by about 40%
- A 100% renewable energy strategy can boost Barbados' economy
- Barbados' tax income will significantly increase
- The drain of hard currency will stop

A look beyond

- It is possible to additionally supply even all cars on Barbados with 100% renewable electricity
- It can reduce fuel bills by about 35%
- Save another 250 to 300 Million BBD in fuel imports per year
- Reduce total imports by another 200 - 250 Million BBD/a
- and give the economy an additional boost!

The 100% renewable power system for Barbados including an all electrical car fleet

376 MW PV



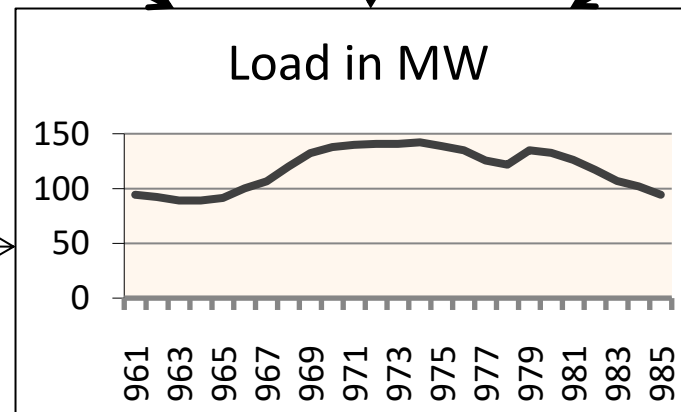
3 GWh PSH



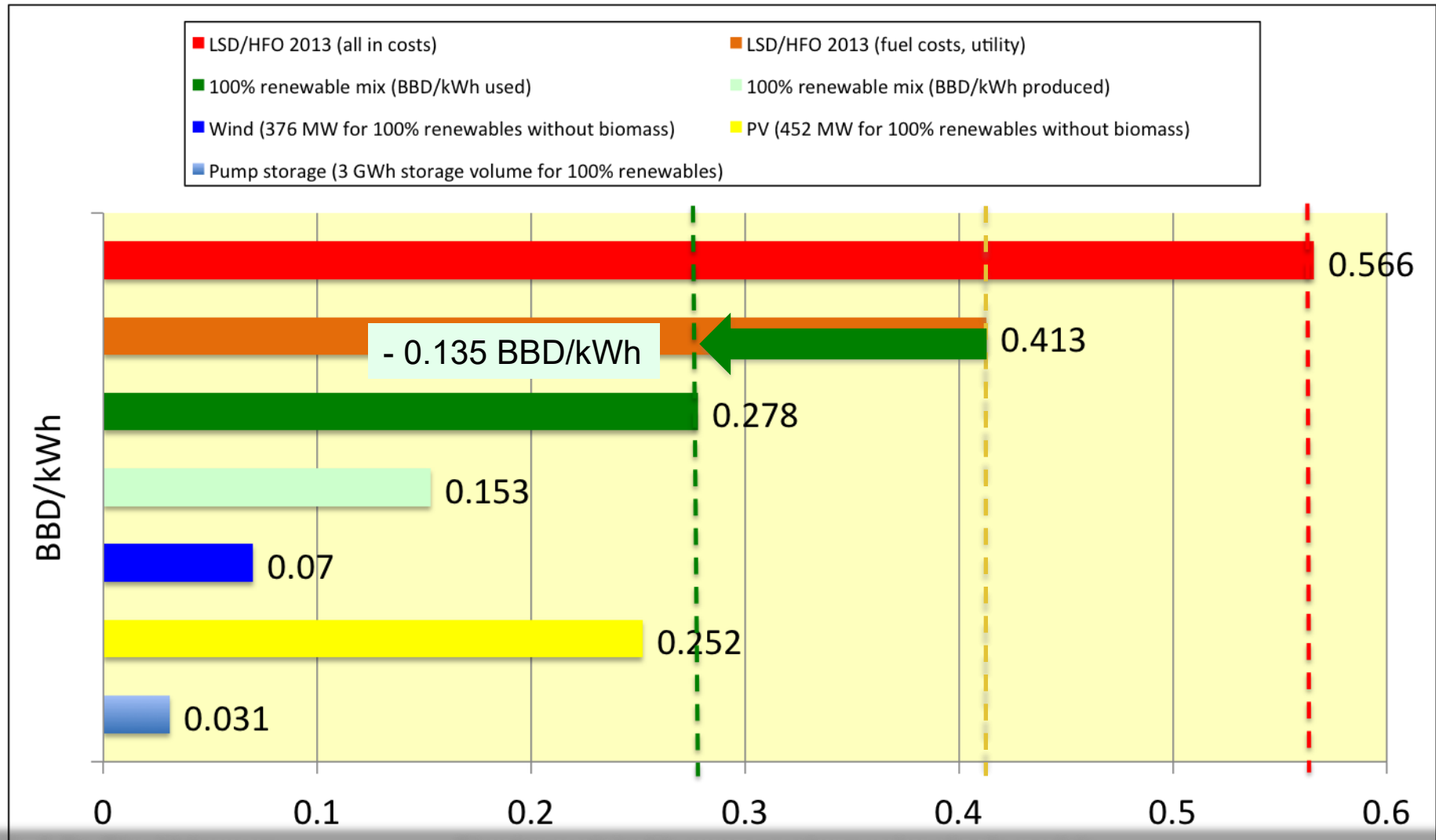
452 MW wind

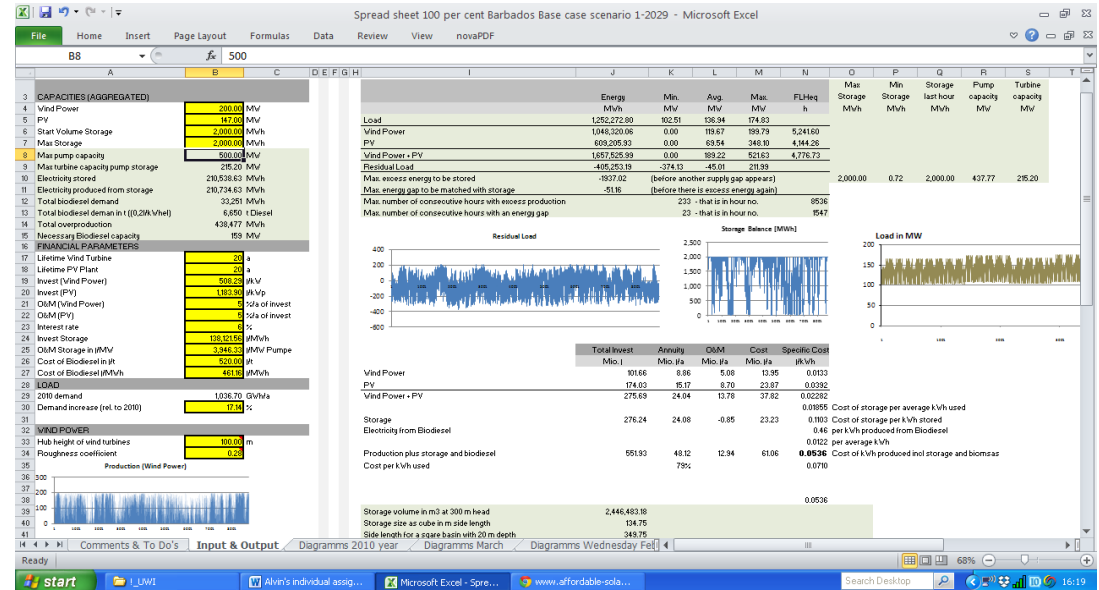


25 GWh biomass



Electricity costs for 100% renewable Barbados (25 GWh biomass, 3 GWh storage, el. cars)





BUILDING YOUR OWN ENERGY MODEL

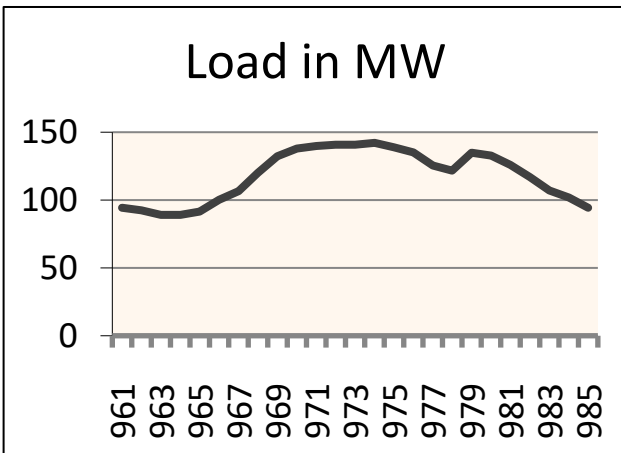


Moving towards a sustainable world

Building your own 100% renewable energy supply model

- Each participant can build a basic power supply model for an island system based on hourly demand, wind and solar data (until the next training session)
- The model should include demand, wind, PV, biomass, conventional (diesel based electricity) power production and storage
- It should also include a possibility to include the additional demand for e-mobility
- It needs to include a calculation of the energy costs as well
- The model should be able to run a given test-scenario

Basic model structure (hourly calculation)



1.

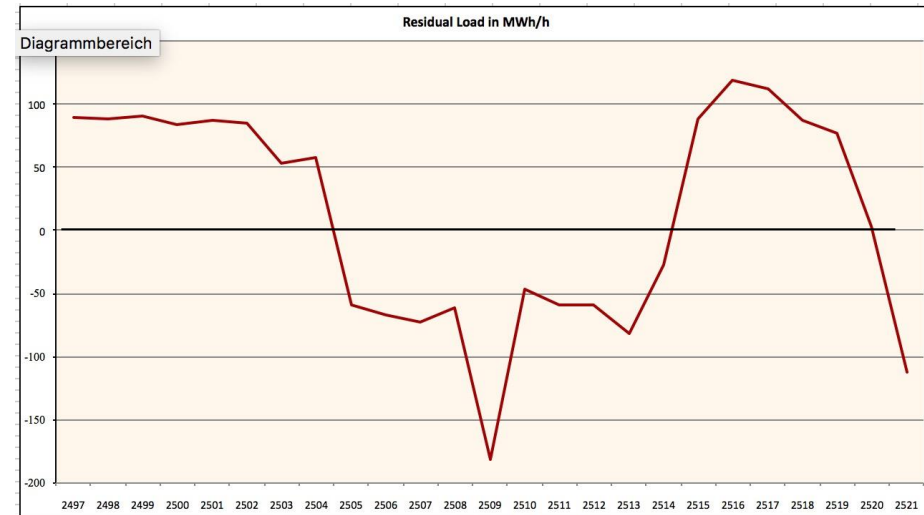
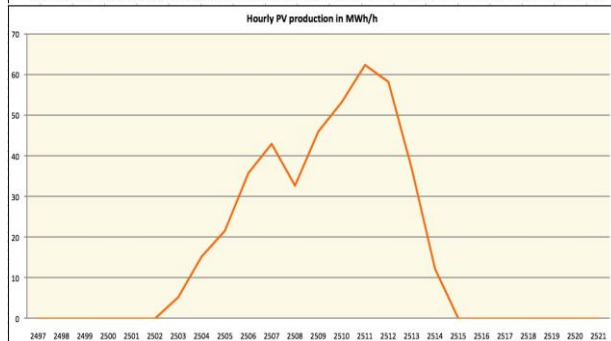
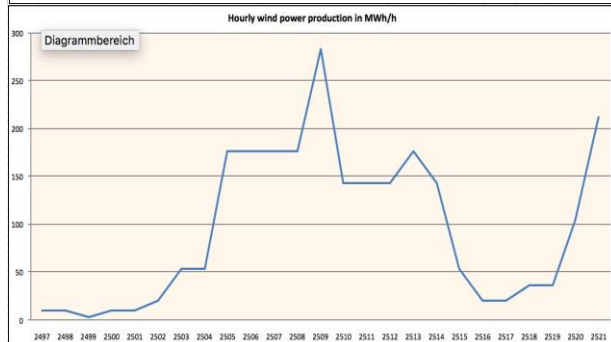
Basic model structure (hourly calculation)

1.



$$\text{Load} - \text{wind} - \text{PV} = \text{Residual load}$$

2.



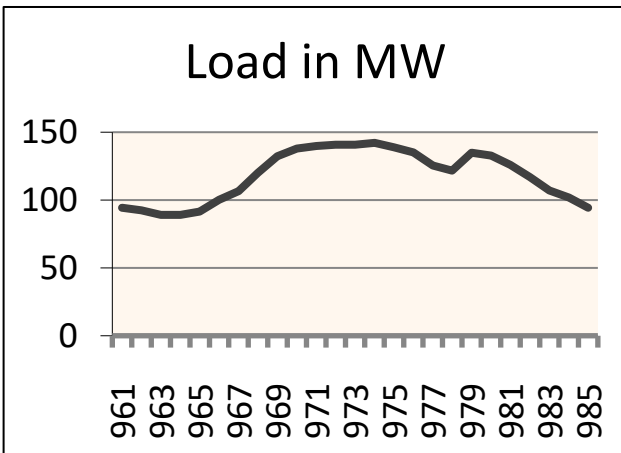
Basic model structure (hourly calculation)



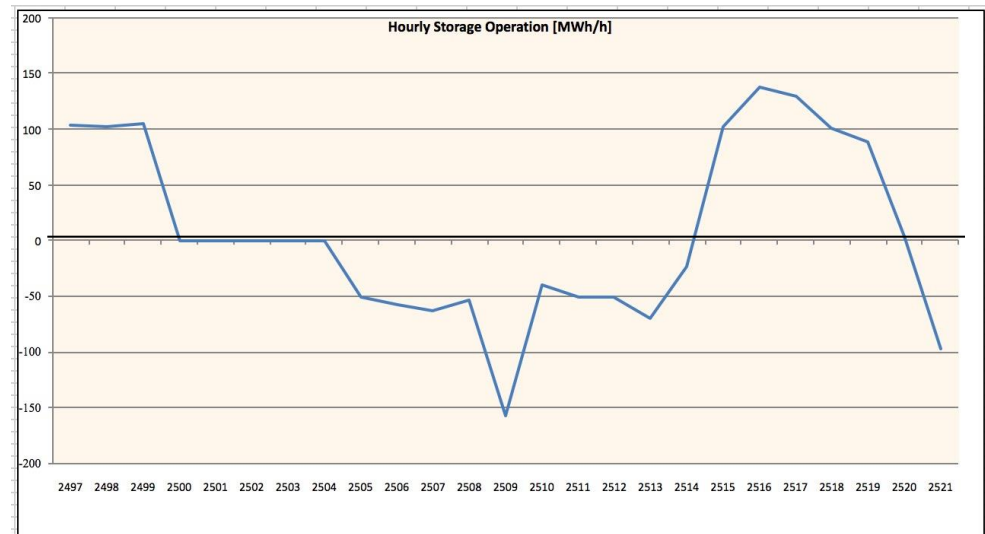
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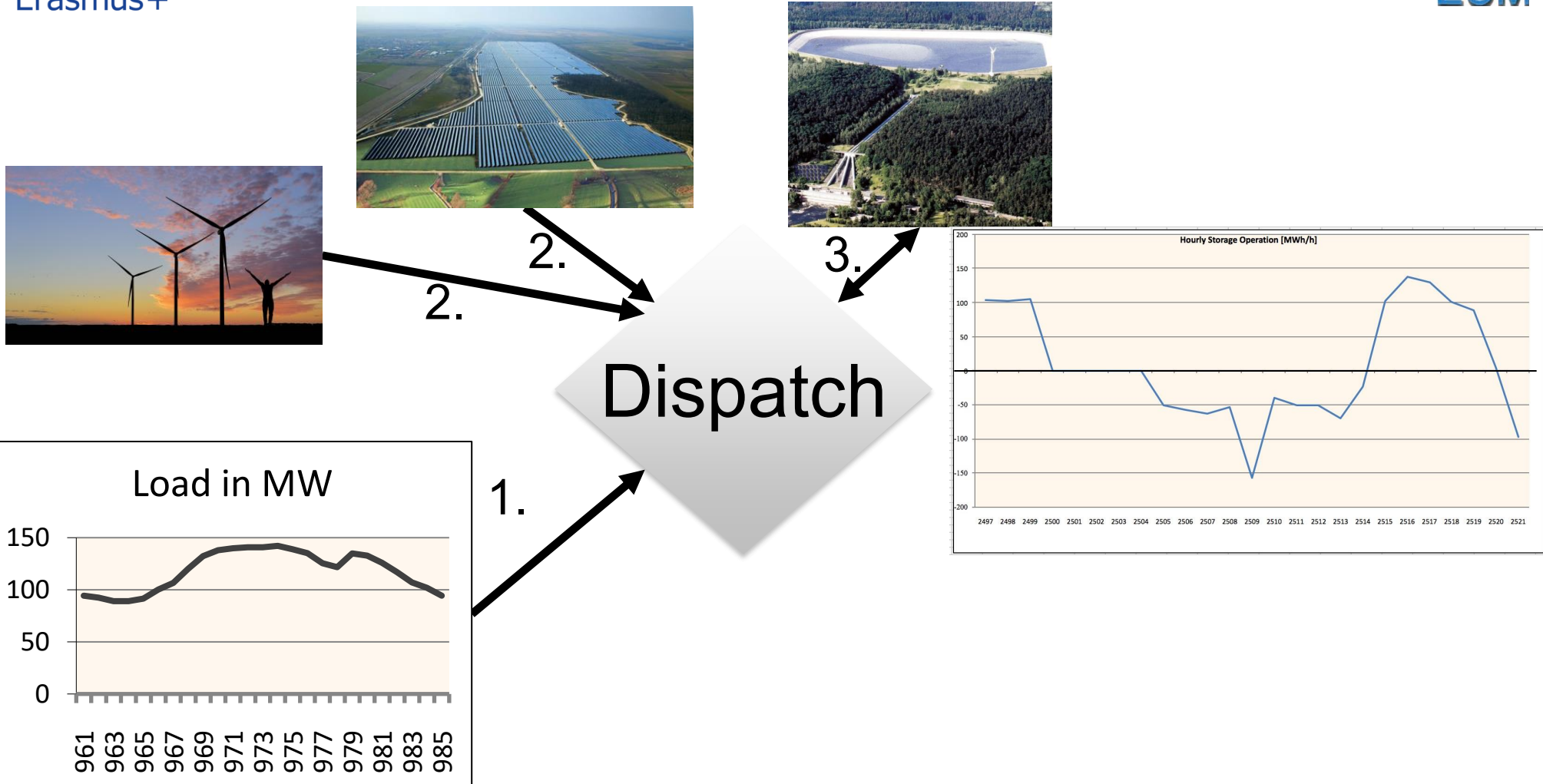
3.



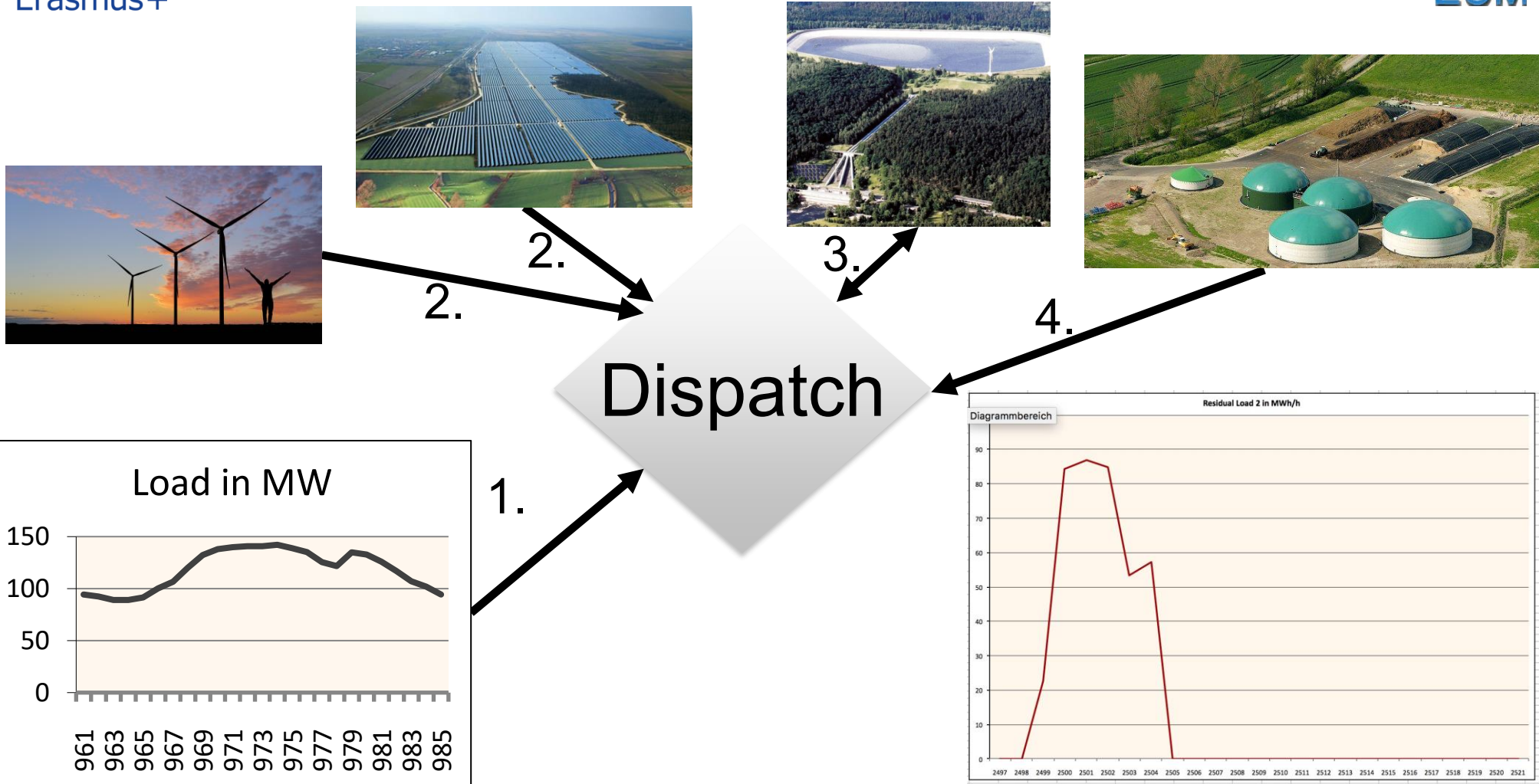
1.



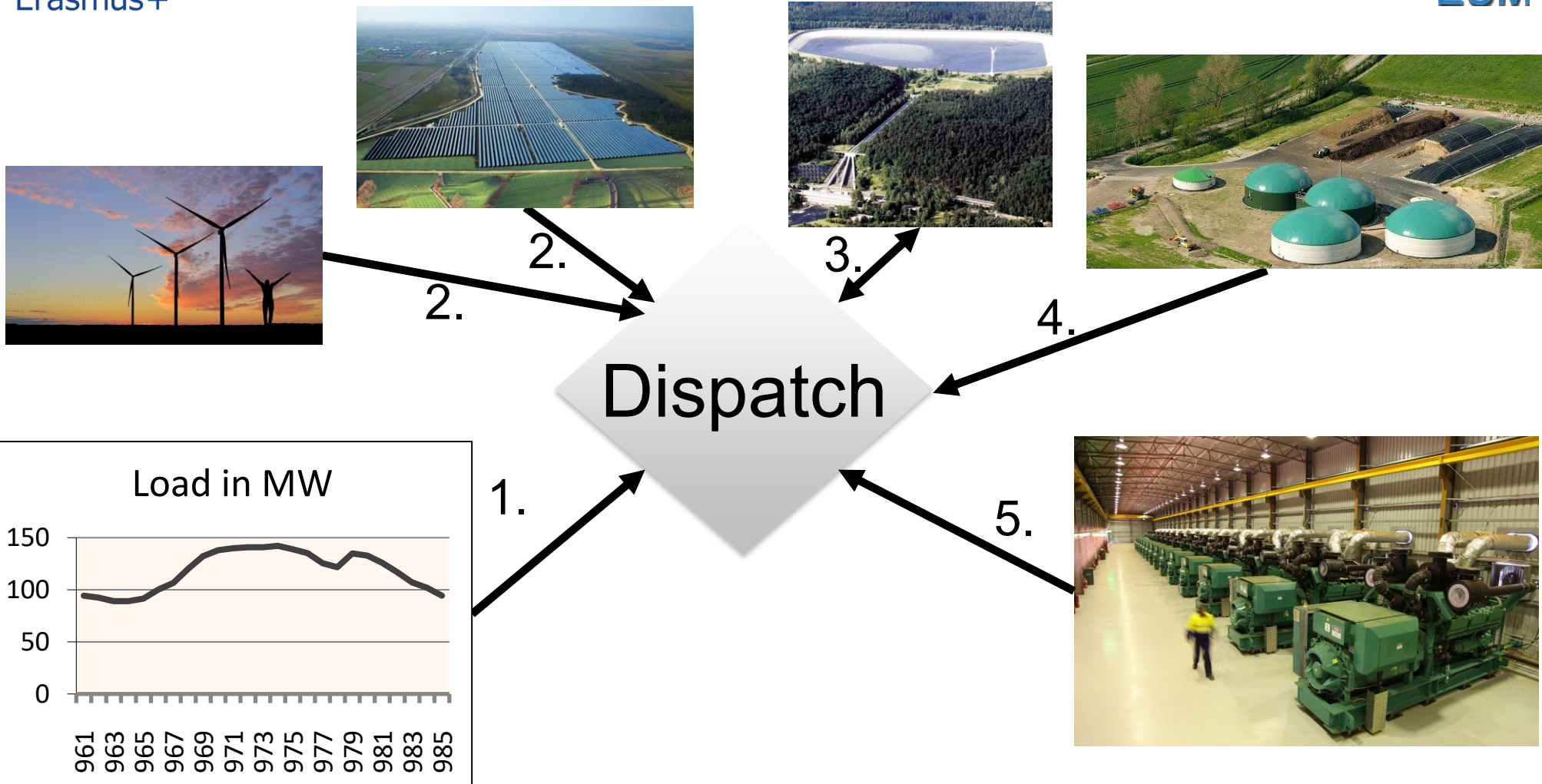
Basic model structure (hourly calculation)



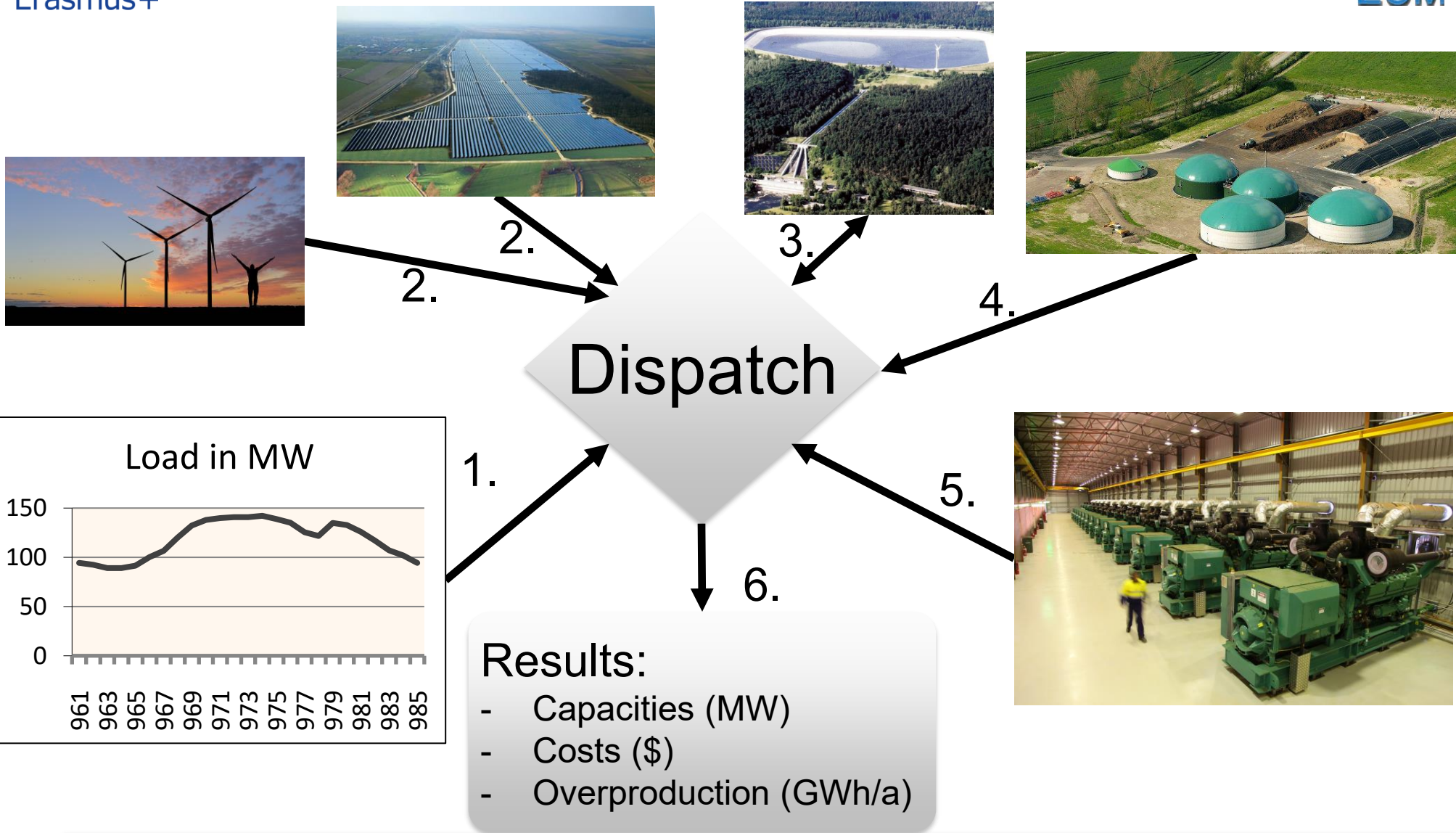
Basic model structure (hourly calculation)



Basic model structure (hourly calculation)



Basic model structure (hourly calculation)



Basic model calculations

$$\text{Residual load}_t = \text{load}_t - \text{PV}_t - \text{wind}_t$$



Residual load_t = $\text{load}_t - \text{PV}_t - \text{wind}_t$

Case 1: Wind and solar are not enough to cover the load

If $\text{Residual load}_t > 0$, and $\text{storage}_t > \text{residual load}$,

then $\text{storage}_{(t+1)} = \text{storage}_t - \text{Residual load}_t$

And $\text{Residual load}_{t_2} = 0$

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If $\text{Residual load}_t > 0$, and $\text{storage}_t < \text{residual load}_t$,
then **Residual load 2_t** = $\text{Residual load}_t - \text{storage}_t$,
 $\text{Storage}_{(t+1)} = 0$,
and **Biomass Prod_t** = **Residual load 2_t** (or conventional production = Residual load 2) (we need dispatchable production to cover the rest of the demand)





Residual load_t = $\text{load}_t - \text{PV}_t - \text{wind}_t$

Case 2: Wind and solar production are higher than demand

If $\text{Residual load}_t < 0$, and $\text{storage maximum} - \text{storage}_t \geq \text{residual load}_t$
then $\text{storage}_{(t+1)} = \text{storage}_t + \text{residual load}_t$

All excess production fits into the storage!



Residual load_t = $\text{load}_t - \text{PV}_t - \text{wind}_t$

Case 2: Wind and solar production are higher than demand

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All excess production fits into the storage!

If $\text{Residual load}_t < 0$, and $\text{storage maximum} - \text{storage}_t < \text{residual load}_t$
then
down regulated power_t = $\text{residual load}_t - (\text{storage maximum} - \text{storage}_t)$

Basic model calculations



Residual load_t = $\text{load}_t - \text{PV}_t - \text{wind}_t$

If $\text{Residual load}_t > 0$, and $\text{storage}_t > \text{residual load}_t$,
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then

$\text{down regulated power}_t = \text{residual load}_t - (\text{storage maximum} - \text{storage}_t)$

Basic model calculations

$$R1_t = L_t - PV_t - Wind_t$$

If $R1_t > 0$, and $S_t > R1_t$, 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 $S_{max} - S_t \geq R1_t$ then $S_{(t+1)} = S_t + R1_t$

If $R1_t < 0$, and $S_{max} - S_t < R1_t$, then $DRP_t = R1_t - (S_{max} - S_t)$



Basic modules of the model:

Input module

- Data to be entered into the input module:
 - Scenario assumptions
 - How much wind capacity is installed
 - How much PV capacity is installed
 - How much storage volume is installed
 - Head of pump storage in m
 - Initial filling level of the storage
 - Hub height of wind turbines
 - Shear factor for wind
 - Efficiency of PV systems
 - Efficiency of storage ...
 - Cost assumptions

Model input for Barbados

Capacities installed

CAPACITIES (AGGREGATED)	Wind year	2 012
Wind Power	230	MW
PV	205	MW
Solid Biomass Capacity installed	0.0	MW
Geothermal Capacity installed	0	MW
Waste to Energy Combustion	0	MW
Run of River Hydropower	0	MW
Biogas to Power Capacity installed	0.0	MW el
Waste to Energy Gasification installed	0.0	MW el
Start Volume Storage	1 000	MWh
Max Storage	3 000	MWh
Storage efficiency (one way)	0.866	

Model input for Barbados

Financial parameters 1

FINANCIAL PARAMETERS

Lifetime Wind Turbine	20	a
Lifetime PV Plant	20	a
Lifetime Solid Biomass Plant	25	a
Lifetime Geothermal Power Plant	25	a
Lifetime Solid Waste to Energy Plant	25	a
Lifetime Run of River Hydropower	50	a
Lifetime Biogas to Power Capacity	20	a
Lifetime Waste to Energy Gasification	15	a
Biodiesel generator	25	a
Lifetime Pump Storage Hydro Plant	50	a
Lifetime Gasstorage (gas field)	50	a

Model input for Barbados

Financial parameters 2

Investment cost Wind Power	1 050.00	€/kW
Investment cost solar PV	1 500.00	€/kWp
Investment cost Solid Biomass Plant	8 418.84	€/kW
Investment cost Geothermal Plant	5 000.00	€/kW
Investment cost Solid Waste to Energy Plant	4 000.00	€/kW
Investment cost Run of River Hydropower	5 000.00	€/kW
Investment cost Biogas to Power	2 500.00	€/kW
Investment cost Waste to Energy Gasification	10 523.55	€/kW
Investment Biodiesel generator	2 500.00	€/kWh
Investment cost Pump Storage Hydro Plant	120 000.00	€/MWh
Investment cost Gas storage (old gas field)	100	€/MWh gas

Model input for Barbados

Financial parameters 3

Operation and Maintenance cost (O&M) Wind Power	5	%/a of invest
O&M (PV)	5	%/a of invest
O&M Solid Biomass Power Plant	10	%/a of invest
O&M Geothermal Power Plant	5	%/a of invest
O&M Solid Waste to Energy Plant	5	%/a of invest
O&M Run of River Hydropower	3	%/a of invest
O&M Biogas to Power	5	%/a of invest
O&M Waste to Energy Gasification	10	%/a of invest
O&M Biodiesel Generator	5	%/a of invest
O&M Pump Storage Hydro Plant	4 000.00	€/MW Pumpe
O&M Gasstorage	1	%/a of invest

Model input for Barbados

Technical parameters 1

LOAD

2010 demand	1 065 964 GWh/a
Demand increase (rel. to 2010)	0.00 %

Wind power technical parameters

Hub height of wind turbines	66.00 m
Roughness coefficient	0.20
Wind year (high=2012, low=2011)	
Average wind speed 2012	6.74 m/sec
Average wind speed 2011	5.57 m/sec

PV technical parameters

Annual irradiation on horizontal	2 024.69 kWh/m ²
Module Peak Capacity	127.50 Wp
Area Requirement	8.00 m ² /kWp
Module Area	1.02 m ²
Specific annual production	2 065.18 kWh/kWp

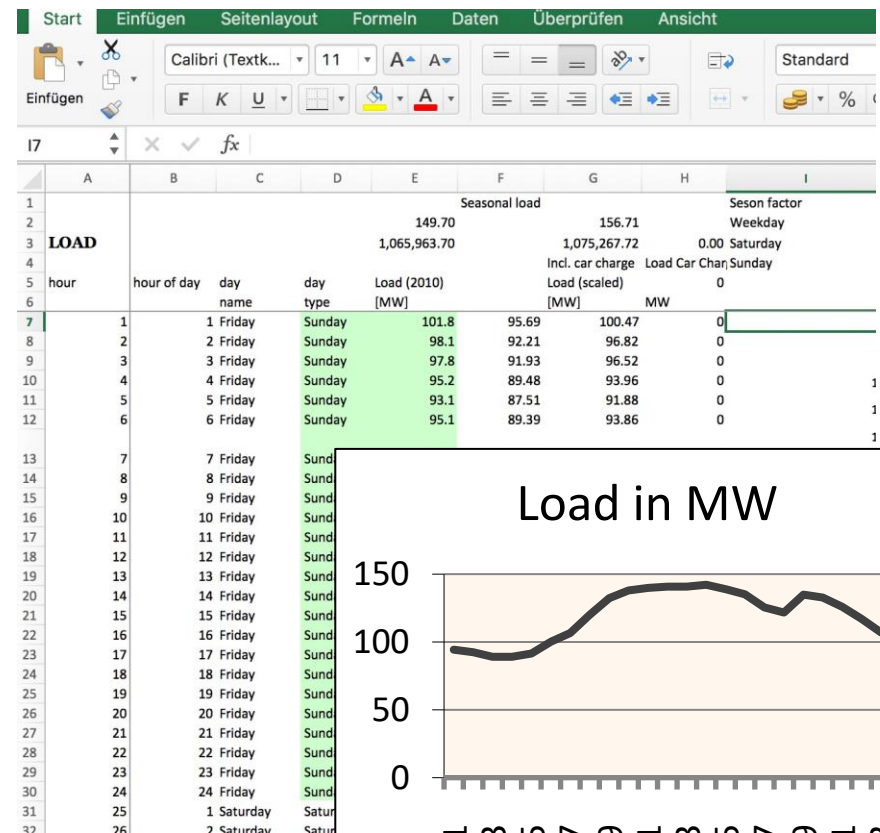
Pump storage hydro plant technical parameters

Head in m	300.00 m
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Basic modules of the model: Demand module

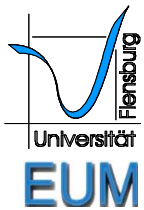
Data and calculations in the demand module:

- **Hourly power demand for an entire year**
- Possibly a substructure of the power demand
 - Air conditioning
 - dispatchable loads
 - **e-vehicle charging cycles**
 - Lighting demand
 - Cooking demand
 - Typical household demand
 - Typical hotel demand (seasonality)



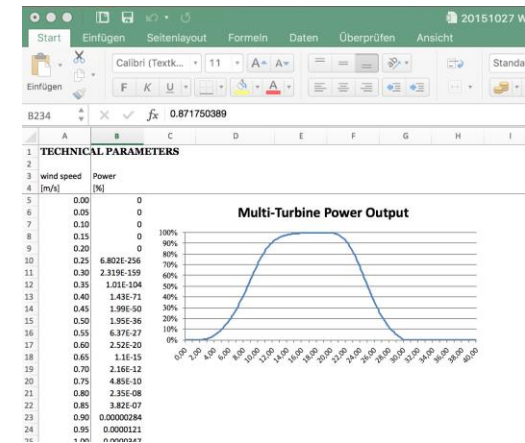


Basic modules of the model: Wind module



Data and calculations in the wind module

- Power curve for wind turbine(s) (Supplied by Prof. Hohmeyer)
- Hourly wind speeds for at least one site and year (airport?)
- Height of measurements, roughness class of site
- Hub height of average turbine
- Recalculation algorithm for wind speed at hub height (shear factor) (Supplied by Prof. Hohmeyer) ($v_1 = v_2 * (Z_1/Z_2)^n$)
- cost of wind turbine investment and operation
- Life time of investment
- Result: Hourly wind power production per MW installed



Basic modules of the model:

Wind module

Recalculation algorithm for wind speed at hub height (shear coefficient)

$$V_1 = V_2 * (Z_1/Z_2)^n$$

- V_1 : wind speed at hub height
- V_2 : wind speed at measuring height (10m)
- Z_1 : hub height
- Z_2 : measuring height
- n : shear coefficient

Table 1: Wind shear coefficient of various terrains [3].

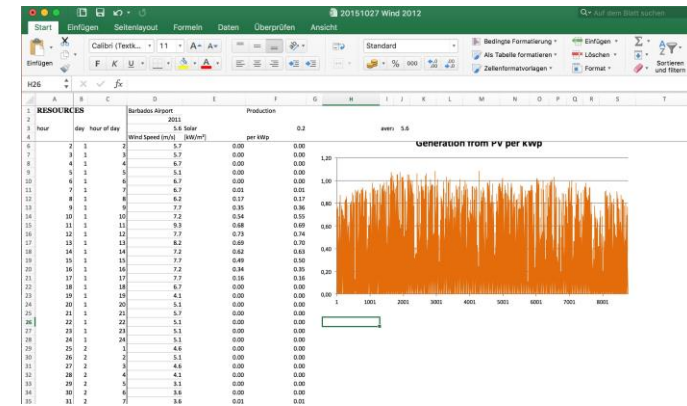
Terrain type	
Lake, ocean, and smooth-hard ground	0.1
Foot-high grass on level ground	0.15
Tall crops, hedges, and shrubs	0.2
Wooded country with many trees	0.25
Small town with some trees and shrubs	0.3
City area with tall buildings	0.4



Basic modules of the model: PV module

Data and calculations in the PV module:

- System efficiency data
- Hourly solar radiation data
- Calculation algorithm for output per kW of installed power
- cost of PV system for investment and operation
- Life time of investment
- Result: Hourly solar power production per MW installed





Basic modules of the model: PV calculation

$\text{output}_t \text{ (kWh/kW}_p\text{)} =$

$\text{irradiation}_t * \text{module area per kW}_p * \text{module capacity at 1 kW irradiation}_t$
 $\text{(m}^2\text{/kW}_p\text{)} \quad \quad \quad \text{(kW/kW}_p\text{)}$

Example: output in hour 13 of the year

$$0.35 \text{ kWh/m}^2 * 8 \text{ m}^2\text{/kW}_p * 0.1275 \text{ kW/kW}_p = 0.357 \text{ kWh/kW}_p$$

if 195 MW are installed this is going to produce

$$0.357 * 195 \text{ MW} = 69.62 \text{ MWh/h}$$

in hour 13 of the year



Hourly wind and solar data can be obtained from NOAA

www7.ncdc.noaa.gov

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)
U.S. Department of Commerce

National Climatic Data Center
U.S. Department of Commerce

DOC > NOAA > NESDIS > NCDC

Search Field: Search NCDC

Land-Based Data / NNDC CDO / Product Search / Help

NNDC CLIMATE DATA ONLINE

Accessing data selection screen for
Surface Data Hourly Global (DS3505)

The Global Surface Hourly database, with data from as early as 1901, is now online, with the full period of record. We also have an [FTP access](#) for the entire archive; along with [CD/DVD products](#). We highly encourage FTP access for large volume data requests.

Simplified: this system allows for very easy selection of data for a station or multiple stations, for user-selected time period. The elements provided include precipitation, temperature, dewpoint, winds, visibility, cloud cover, pressure, and present weather (as available for each station) on an [easy-to-read, printable form](#) plus a [delimited file](#).

Continue With SIMPLIFIED Options

Advanced: this system allows for selection of data for a station or multiple stations, for user-selected time period. In contrast to the simplified system, the user selects the elements of interest (eg, snow depth, relative humidity). The output and documentation are dynamically generated based on the elements selected. Output formats include [ASCII](#) and Comma-separated text files which are ideal for use in a spreadsheet.

Continue With ADVANCED Options

Previous Page

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<https://www7.ncdc.noaa.gov/CDO/cdopoemain.cmd>
Downloaded Mon May 08 06:40:14 EDT 2017
Production Version
If you have questions or comments, please contact our [support team](#).

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)
U.S. Department of Commerce

National Climatic Data Center
U.S. Department of Commerce

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NNDC CLIMATE DATA ONLINE

Surface Data Hourly Global (DS3505)

Retrieve data for:

- ☒ Worldwide
- ☐ Geographic Region None Selected
- ☐ Country United States
- ☐ Station Range (IDs): to

Continue Previous Page Clear Selections

Data Documentation

☒	Data format documentation (complete dataset, PDF)
☒	Space delimited data sample, without station names
☒	Space delimited documentation sample, without station names
☒	Space delimited data sample, with station names
☒	Space delimited documentation sample, with station names
☒	Webform data sample
☒	Webform and Text file documentation sample
☒	Station list (may take several minutes to load)
☒	Data Issues

Data and pricing (if applicable) details at the [CDO Help Page](#)

Privacy Policy USA.gov Disclaimer

<https://www7.ncdc.noaa.gov/CDO/cdopoemain.cmd?datasetabbv=DS3505&countryabbv=&georegionabbv=&resolution=40>

Basic modules of the model:

Storage module

Data and calculations in the storage module:

- Efficiency of storage technology
- Installed capacity
 - pumps in MW
 - generators in MW
 - Storage volume in MWh
- Cost of storage
 - Investment (per volume and per installed capacity)
 - operation and maintenance
 - Life time of investment
- Result: Hourly storage operation per MW installed

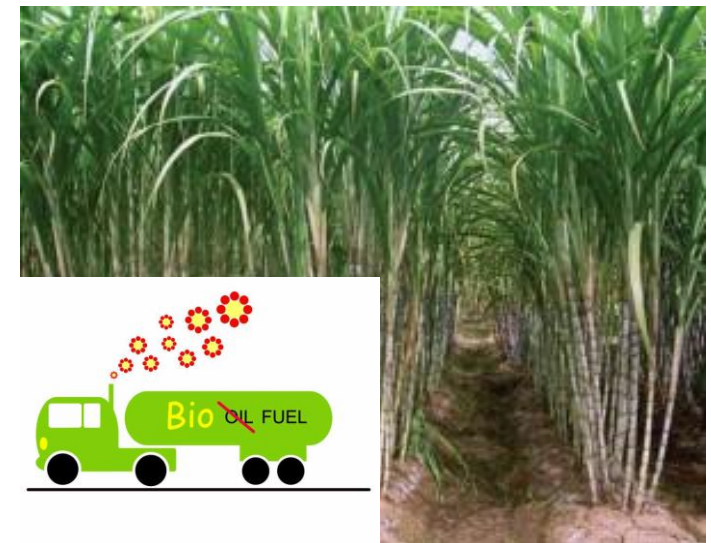


Basic modules of the model:

Biomass module

Data and calculations in the (liquid) biomass module:

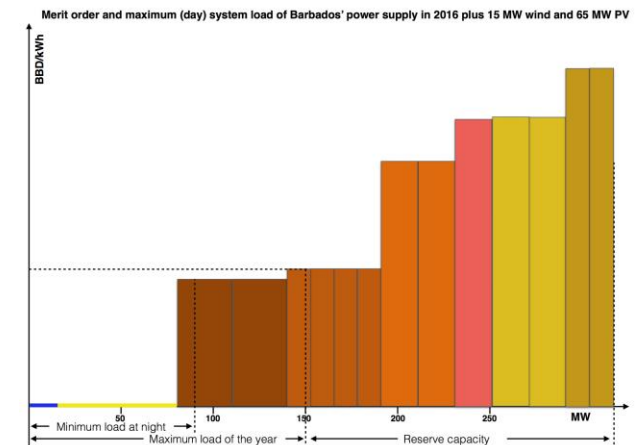
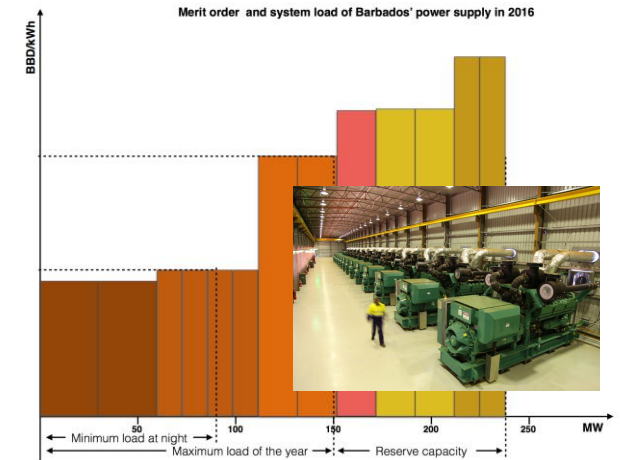
- System efficiency data
- Cost of electricity from liquid biomass (investment and operation)
- Take investment as given by conversion of existing conventional diesel generators and turbines
- Result: Hourly biomass production per MW installed



Basic modules of the model: Conventional power module

Data and calculations of the module:

- Capacities and fuel of each unit
- Fuel costs for different conventional units
- O&M costs for different conventional units
- Results:
 - Variable costs per MWh for every conventional unit
 - Time required for cold start
 - Merit order of conventional modules





Basic modules of the model: Dispatch module

- Calculate wind and PV production for every hour
- Subtract from load to calculate residual load
- Take difference from storage or add to storage, if production is higher than demand
- If taking from storage take care of storage efficiency
- Keep track of filling level of storage
- If storage is full and you are overproducing, keep track of the power which is overproduced
- If storage is empty use biomass to supply the residual load, as biomass is available
- If there is no more biomass use conventional units to cover the remaining load
- Keep track of all production and costs for the entire year

Hour	Load	Solar Biomass	Geothermal Power	Waste to Energy	Wind Power	PV	Biomass-02	Biomass	Residual Load 1	Residual Load 2	Hourly Storage Potential
1	100.47	0.00	0.00	0.00	176.34	0.00	0.00	0.00	-75.88	0.00	63.71
2	96.82	0.00	0.00	0.00	203.94	0.00	0.00	0.00	-107.12	0.00	170.70
3	96.32	0.00	0.00	0.00	201.94	0.00	0.00	0.00	-105.62	0.00	170.36
4	93.96	0.00	0.00	0.00	242.40	0.00	0.00	0.00	-148.44	0.00	128.55
5	91.88	0.00	0.00	0.00	282.79	0.00	0.00	0.00	-191.00	0.00	87.66
6	93.86	0.00	0.00	0.00	265.33	0.00	0.00	0.00	-171.48	0.00	148.50
7	92.87	0.00	0.00	0.00	276.24	1.02	0.00	0.00	-84.49	0.00	73.27
8	104.81	0.00	0.00	0.00	265.33	17.34	0.00	0.00	-177.86	0.00	154.03
9	116.06	0.00	0.00	0.00	265.33	35.70	0.00	0.00	-184.97	0.00	160.39
10	121.49	0.00	0.00	0.00	176.34	51.08	0.00	0.00	-105.56	0.00	85.20
11	123.96	0.00	0.00	0.00	203.94	69.36	0.00	0.00	-239.34	0.00	207.27
12	123.27	0.00	0.00	0.00	242.40	74.46	0.00	0.00	-193.59	0.00	187.66
13	123.07	0.00	0.00	0.00	282.89	79.38	0.00	0.00	-230.90	0.00	199.44
14	123.09	0.00	0.00	0.00	211.43	63.24	0.00	0.00	-133.58	0.00	132.48
15	120.01	0.00	0.00	0.00	182.44	49.98	0.00	0.00	-122.41	0.00	201.28
16	127.84	0.00	0.00	0.00	201.94	34.68	0.00	0.00	-222.97	0.00	282.70
17	114.78	0.00	0.00	0.00	242.40	35.32	0.00	0.00	-145.94	0.00	144.65
18	113.77	0.00	0.00	0.00	382.44	0.00	0.00	0.00	-268.67	0.00	163.86
19	105.87	0.00	0.00	0.00	282.79	0.00	0.00	0.00	-176.92	0.00	131.92
20	129.88	0.00	0.00	0.00	308.70	0.00	0.00	0.00	-178.82	0.00	155.03
21	124.75	0.00	0.00	0.00	242.40	0.00	0.00	0.00	-117.65	0.00	102.89
22	116.85	0.00	0.00	0.00	265.33	0.00	0.00	0.00	-148.48	0.00	128.59
23	111.91	0.00	0.00	0.00	211.43	0.00	0.00	0.00	-99.52	0.00	85.32
24	108.29	0.00	0.00	0.00	265.33	0.00	0.00	0.00	-157.04	0.00	137.73
25	103.47	0.00	0.00	0.00	282.89	0.00	0.00	0.00	-179.42	0.00	158.86
26	96.82	0.00	0.00	0.00	211.43	0.00	0.00	0.00	-114.61	0.00	99.25
27	96.32	0.00	0.00	0.00	211.43	0.00	0.00	0.00	-114.91	0.00	99.51

Basic model structure (hourly calculation)

Hour	Load								
1	Hourly load curve								
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
..									
....									
8760									

Basic model structure (hourly calculation)

Hour	Load	PV							
	Hourly load curve	-							
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
..									
....									
8760									

Basic model structure (hourly calculation)

Hour	Load	PV	Wind						
	Hourly load curve	-	-						
1									
2									
3									
4									
5									
6									
7									
8									
..									
....									
8760									

Basic model structure (hourly calculation)

Hour	Load	PV	Wind	Solid Biomass					
	Hourly load curve	-	-	-					
1									
2									
3									
4									
5									
6									
7									
8									
..									
....									
8760									

Basic model structure (hourly calculation)

Hour	Load	PV	Wind	Solid Biomass	Residual Load 1 (R1)				
	Hourly load curve	-	-	-	=				
1									
2									
3									
4									
5									
6									
7									
8									
..									
....									
8760									

Basic model structure (hourly calculation)

Hour	Load	PV	Wind	Solid Biomass	Residual Load 1 (R1)	Storage t-1			
	Hourly load curve	-	-	-	=	>/< R1			
1									
2									
3									
4									
5									
6									
7									
8									
..									
....									
8760									

Basic model structure (hourly calculation)

Hour	Load	PV	Wind	Solid Biomass	Residual Load 1 (R1)	Storage t-1	Storage t		
	Hourly load curve	-	-	-	=	>/< R1	$S_{t-1} + / - R1$		
1									
2									
3									
4									
5									
6									
7									
8									
..									
....									
8760									

Basic model structure (hourly calculation)

Hour	Load	PV	Wind	Solid Biomass	Residual Load 1 (R1)	Storage t-1	Storage t	Residual Load 2 (R2)	
	Hourly load curve	-	-	-	=	$>/< R1$	$S_{t-1} +/ - R1$	$R2 = R1 +/ - S_t$	
1									
2									
3									
4									
5									
6									
7									
8									
..									
....									
8760									

Basic model structure (hourly calculation)

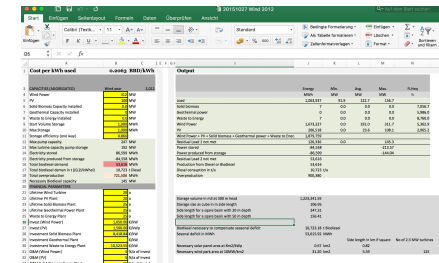
Hour	Load	PV	Wind	Solid Biomass	Residual Load 1 (R1)	Storage t-1	Storage t	Residual Load 2 (R2)	Back-up
	Hourly load curve	-	-	-	=	$>/< R1$	$S_{t-1} +/ - R1$	$R2 = R1 +/ - S_t$	$= R2$
1									
2									
3									
4									
5									
6									
7									
8									
..									
....									
8760									



Basic modules of the model: Results module

Give aggregated results for the entire year:

- production from each resource (in GWh)
- used maximum capacities for wind, PV, biomass, storage (pumps, generators, volume), conventional generators (in MW (MWh for storage volume))
- total production (in GWh)
- total supply (in GWh)
- costs for each resource (in million €)
- total cost for all production (in million €)
- average cost per kWh produced (in €/kWh)
- average cost per kWh supplied to final demand (in €/kWh)



Model output for Barbados

Summary of results

Summary of results		
Cost per kWh used	0.2500	BBD/kWh
Max pump capacity	277.3	MW
Max turbine capacity pump storage	194.9	MW
Electricity stored	-142 623	MWh
Electricity produced from storage	122 571	MWh
Power generation capacity for Biogas Power	0.0	MW
Power generation capacity for Waste to Energy	0.0	MW
Biogas storage volume required	0.0	MWh gas
Syngas storage volume required	0.0	MWh gas
Biogas storage volume required at ambient pressure	0.0	
Syngas storage volume required at ambient pressure	0.0	m3
Necessary Biodiesel capacity	143.8	MW
Total biodiesel demand	24 747	MWh
Total biodiesel demand in t ((0,2l/kWhel)	4 949	t Diesel
Total overproduction power	487 624	MWh
Total overproduction gas	0	MWh gas

Panel for quick change and response

CAPACITIES (AGGREGATED)	Wind year	2 012
Wind Power	230	MW
PV	205	MW
Solid Biomass Capacity installed	0.0	MW
Geothermal Capacity installed	0	MW
Waste to Energy Combustion	0	MW
Run of River Hydropower	0	MW
Biogas to Power Capacity installed	0.0	MW el
Waste to Energy Gasification installed	0.0	MW el
Start Volume Storage	1 000	MWh
Max Storage	3 000	MWh
Storage efficiency (one way)	0.866	
Summary of results		
Cost per kWh used	0.2500	BBD/kWh
Max pump capacity	277.3	MW
Max turbine capacity pump storage	194.9	MW
Electricity stored	-142 623	MWh
Electricity produced from storage	122 571	MWh
Power generation capacity for Biogas Power	0.0	MW
Power generation capacity for Waste to Energy	0.0	MW
Biogas storage volume required	0.0	MWh gas
Syngas storage volume required	0.0	MWh gas
Biogas storage volume required at ambient pressure	0.0	
Syngas storage volume required at ambient pressure	0.0	m3
Necessary Biodiesel capacity	143.8	MW
Total biodiesel demand	24 747	MWh
Total biodiesel demand in t ((0,2l/kWhel)	4 949	t Diesel
Total overproduction power	487 624	MWh
Total overproduction gas	0	MWh gas

Model output for Barbados

Costs by technology

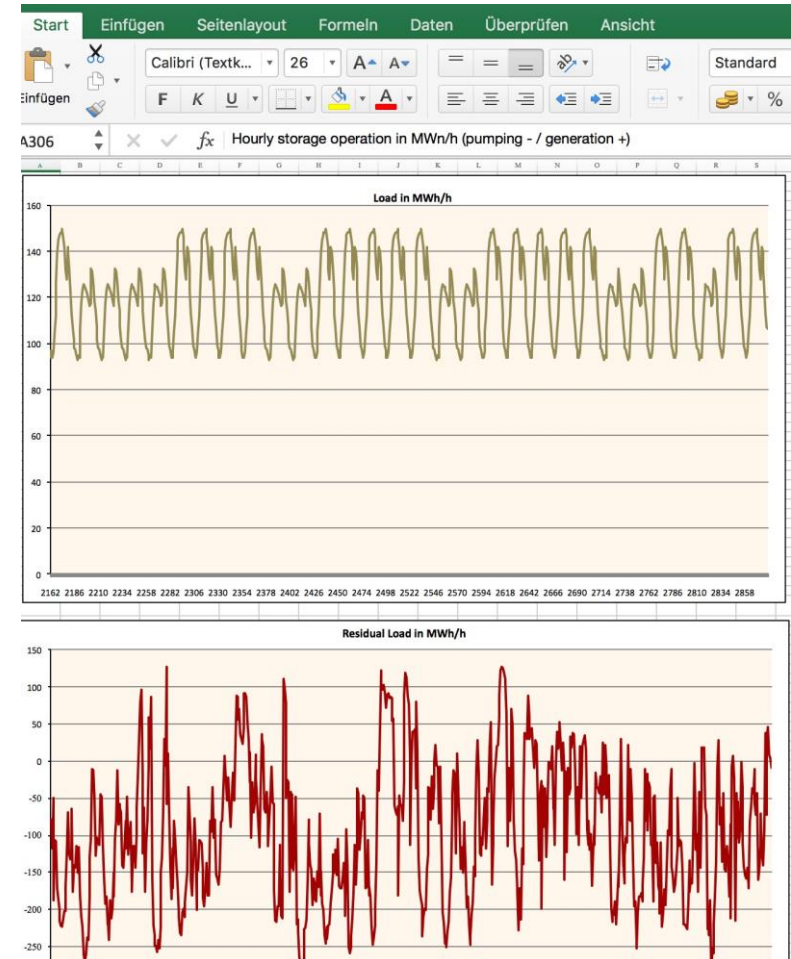
Cost analysis in BBD	Total Invest Mio. BBD	Annuity Mio. BBD/a	O&M Mio.BBD€/a	Cost Mio. BBD/a	Specific Cost BBD/kWh	Share of total cost BBD/kWh
Wind Power	611.96	53.35	30.60	83.95	0.07	0.08
PV	779.21	67.93	38.96	106.89	0.25	0.10
Solid biomass	0.00	0.00	0.00	0.00	#DIV/0!	0.00
Geothermal power	0.00	0.00	0.00	0.00	#DIV/0!	0.00
Waste to Energy (solid)	0.00	0.00	0.00	0.00	#DIV/0!	0.00
Run of River Hydropower	0.00	0.00	0.00	0.00	#DIV/0!	0.00
Biogas to Power	0.00	0.00	0.00	0.00	0.00	0.00
Waste to Energy Gasification (syngas)	0.00	0.00	0.00	0.00	0.00	0.00
Cost of electricity production from Wind + PV + Solid biomass + Geothermal + R o R Hydro + Biogas to Power + Waste to Syngas	1 391.17	121.29	69.56	190.85	0.12	0.18
Pump storage hydro	912.24	57.88	2.81	60.69	0.50	0.06
Gas storage for biogas	0.00	0.00	0.00	0.00	#DIV/0!	0.00
Gas storage for syngas	0.00	0.00	0.00	0.00	#DIV/0!	0.00
Total cost of storage	912.24	57.88	2.81	60.69	0.00	0.06
Cost of electricity from biodiesel in BBD/kWh	0.00	0.00	0.00	12.54	0.51	0.01
Production plus storage and biodiesel	2 303.41	179.16	72.37	264.08	0.00	0.25
Other power system costs in BBD/kWh (BL&P 2013)						0.153
Total power costs in BBD/kWh						0.40

Basic modules of the model:

Graphics module

Graphs of the model results:

- demand
- wind power production
- PV production
- storage operation
- biomass energy production
- conventional power production
- excess energy production
- daily graphs
- monthly graphs
- annual graphs



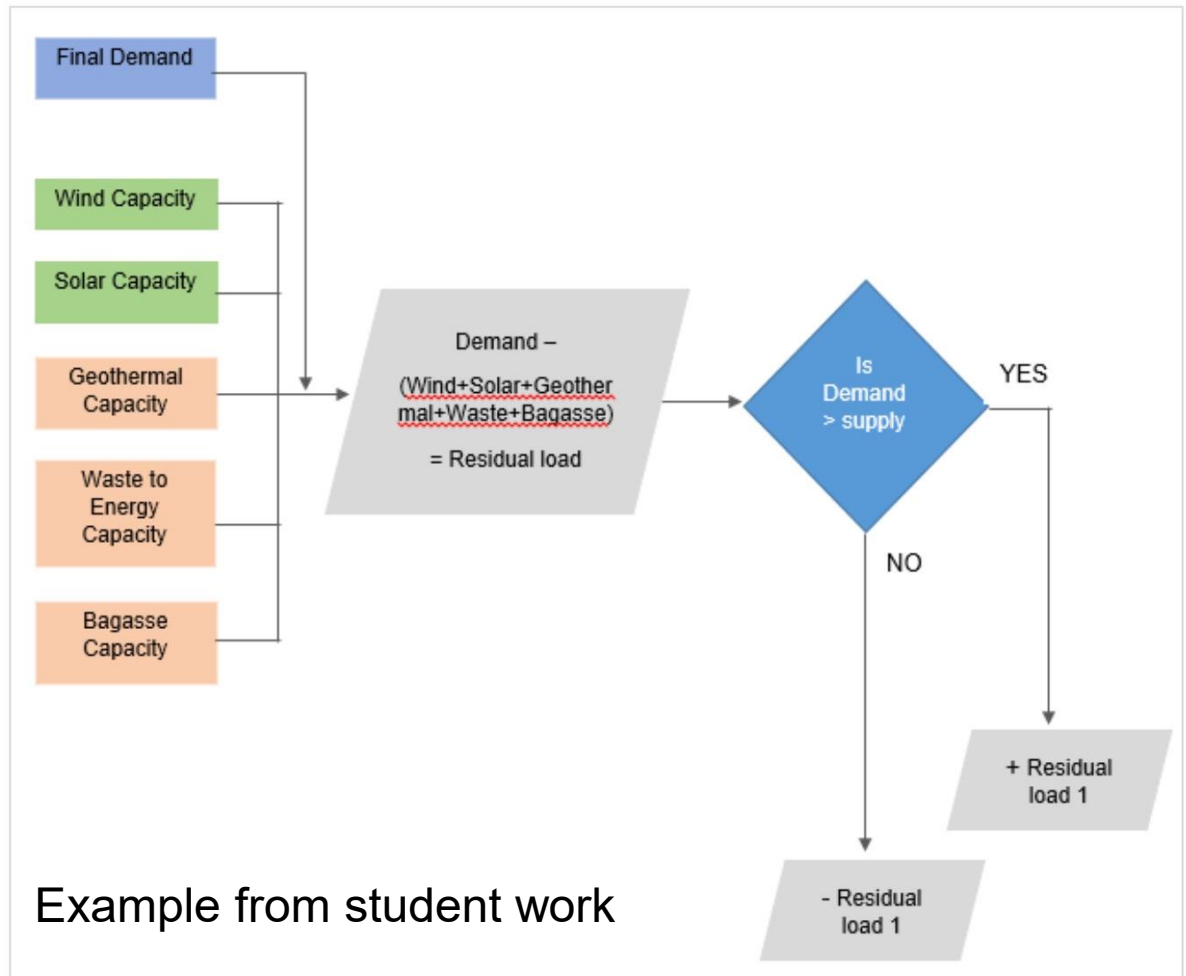
Tasks till Thursday

1. We form two groups
2. Every group gets a copy of the model for Barbados
3. Task A: Use the model to test the impact of varying the model inputs for (try to keep biodiesel at 5,000t/a) and note the results:
 1. Wind capacity (-100 MW))
 2. PV capacity (-150 MW)
 3. Storage capacity (500 MWh)
 4. What happens to the cost per kWh? (Keep biodiesel to 5000 t/a)
 5. Try to find the lowest cost combination of wind, PV and storage capacity (with no more than 5,000 t/a of biodiesel)
 6. What happens to the overproduction (in each case)?
 7. Try to vary other parameters (investment costs (-10%), interest rate (10%), height of wind turbine (120m), roughness (0.1))

Cost per kWh used	0.2396	BBD/kWh
Capacities (AGGREGATED)	Wind year	2022
Wind Power	241	MW
PV	251	MW
Solid Biomass Capacity installed	0.12	MW
Geothermal Capacity installed	0	MW
Waste to Energy installed	0.13	MW
Start Volume Storage	1,000	MWh
Max Storage	1,000	MWh
Storage efficiency (one way)	0.855	
Max pumped capacity	277	MW
Max turbine capacity pump storage	193	MW
Electricity stored	236,451	MWh
Electricity produced from storage	-123,364	MWh
Total biofuel demand	25,048	MWh
Total biofuel demand in 1 (0.25\$/kWh)	0.009	12\$/MWh
Total overproduction	517,363	MWh
Necessary Biodiesel capacity	146	MW

Tasks till Thursday

4. Task B: Develop your own logical structure of how your group wants to structure your spreadsheet model

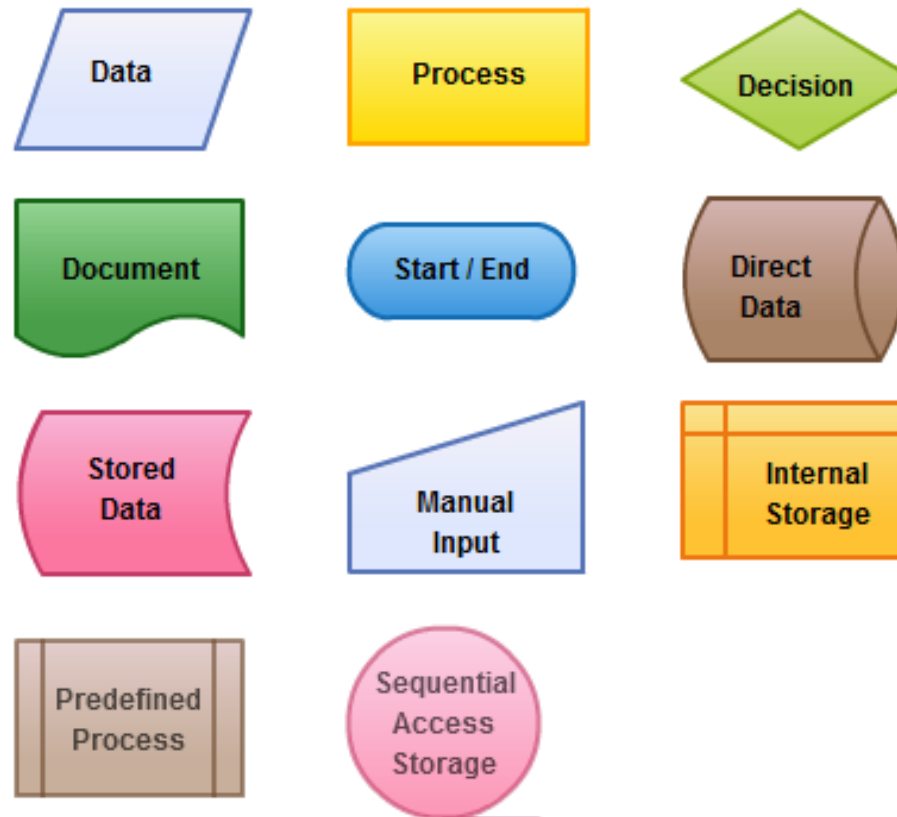


Basics of logical flow charting

Main symbols used

Basic flow chart symbols:

- Start/End
- Data input
- Manual input
- Direct data
- Stored data
- Process
- Decision
- Internal storage

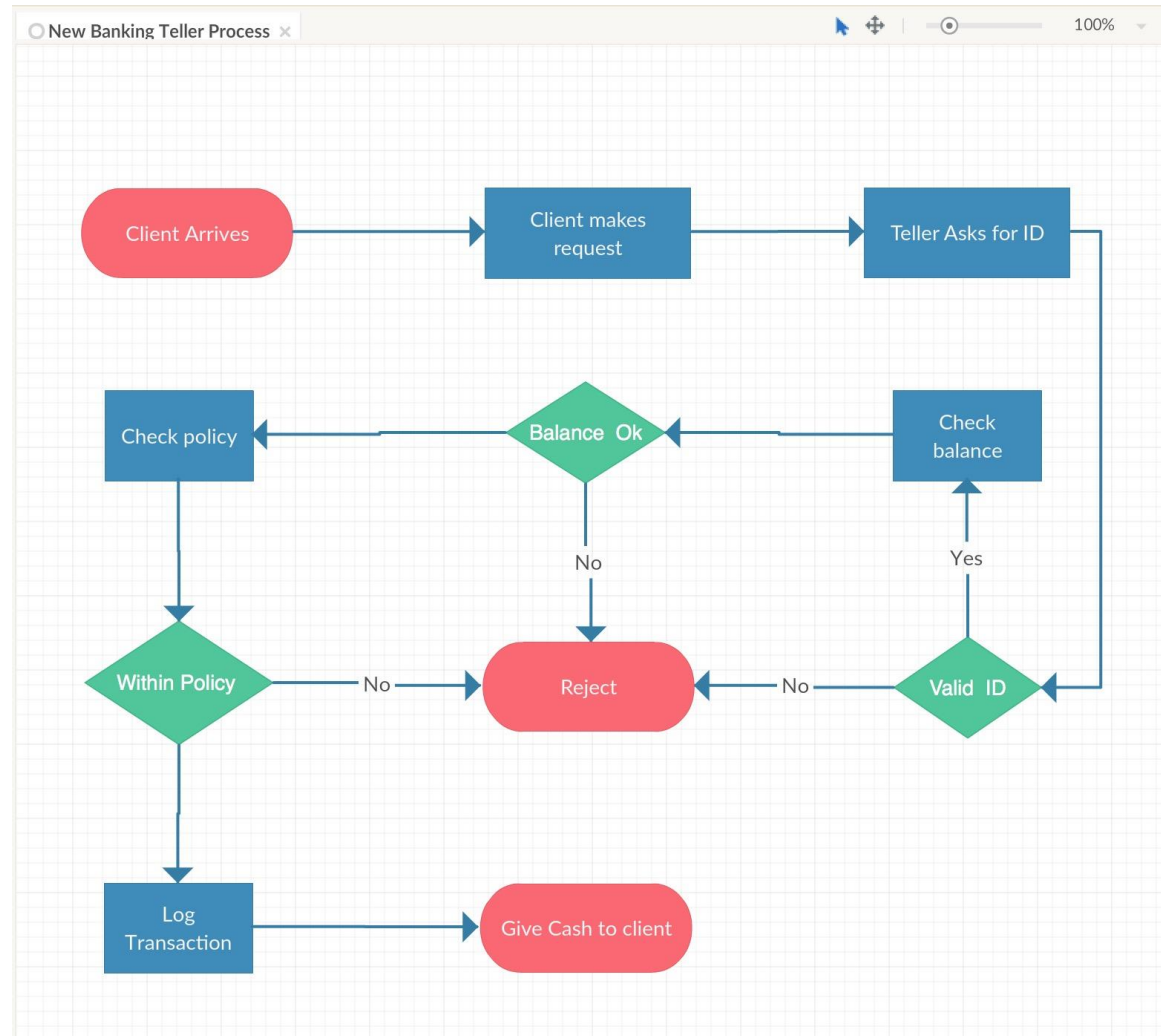


[online diagramming & design]  .com

Basics of logical flow charting: Example flow chart

Simple
example:

Banking
Teller
Process
(Can we
give money
to this
client?)





Task C: until the next training session

Task C:

Develop **your own** spread sheet model!
(until the next training session)

You may use the hourly data (wind, PV, load) from the model you were given.



Time for questions