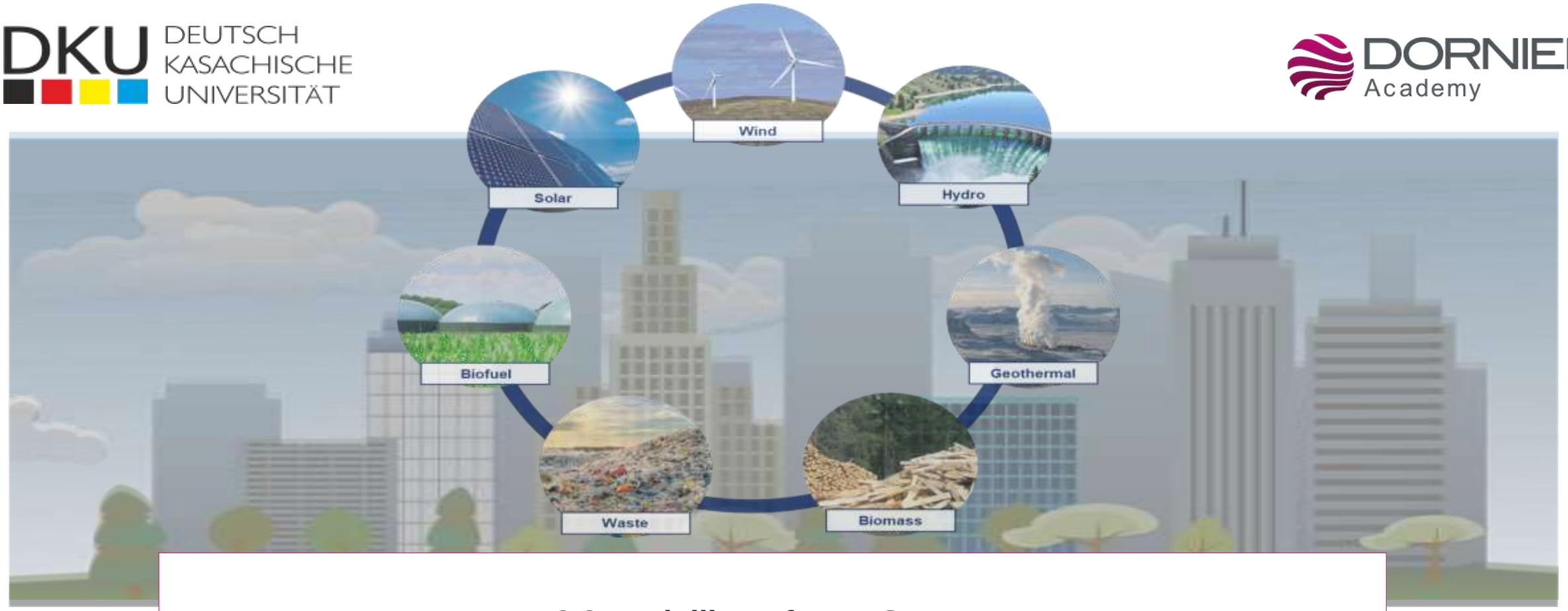


2.2 Modelling of Heat System

Lennart Larsson

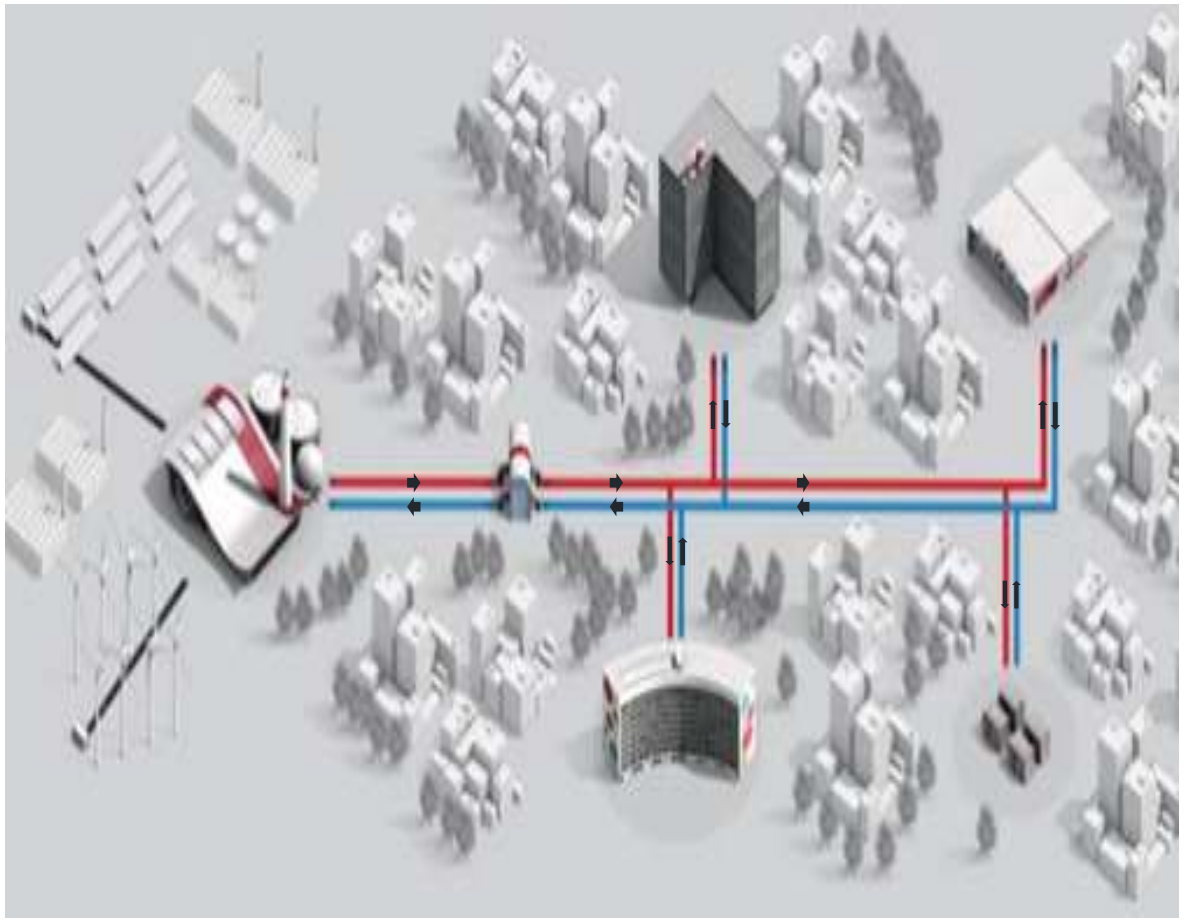
Modelling of Heat System

Introduction

- Last time we introduced and exemplified the work with:
  - Basic Least cost approach
  - More detailed simulation models

This time we should demonstrate:

- How to use detailed simulation models
- Necessary preparation of input to be used in the simulations
- Simulation of Production system utilisation for different scenarios
- Simulation of alternative scenarios influence on a DH company's future financial performance



Content of this session

- **Brief description of a production system utilization simulation model with its:**
  - **Basic principles**
  - **Necessary input**
  - **Output**
- **System Simulations - Demonstration**
- **Brief description of Financial simulations**
  - **Basic principles**
  - **Financial Input**
  - **Financial performance**
- **Financial simulation - Demonstration**
- **Discussion**
- **Results from discussion**

Production system utilisation simulation model

- Utilisation principles
  - Merit order
  - Stepwise simulation: External heat deliveries, Storage utilisation, Basic production simulation, Treatment of unavailabilities
- Demand forecast
  - Annual Energy
  - Annual maximum demand
  - Typical Annual Demand curve
- Production system
  - Installed capacities (heat and electricity)
  - Variable operation cost
  - Annual revision plan
  - Availability

Simulation steps

- Forecasted Daily demand
- External heat deliveries
- Utilize the storage
- Simulation of production system utilization
- Treatment of unavailability

External heat deliveries

- Original daily demand
- Reduce the daily demand with the external supply

=>

- Remaining demand to be covered by your own system

Storage utilisation

Day 1 - plan

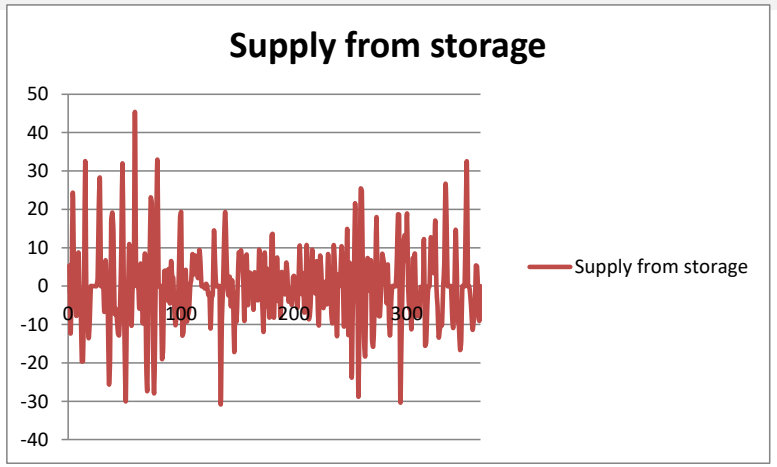
- 3 day demand forecast
- Preliminary plan 3-day average
- Stored energy is within the storage limits

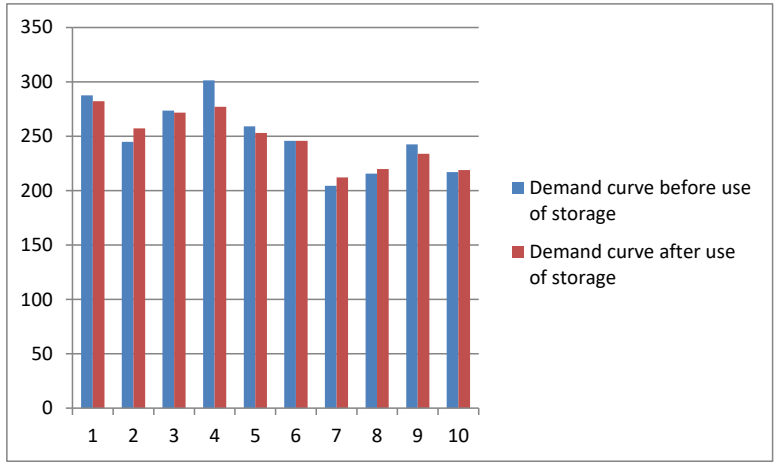
Day 2 plan

- Next day a new 3-day forecast

Result

- Storage 1200 MWh, 100 MW
- Peak reduced with 45 MW
- Valley increased with 30 MW



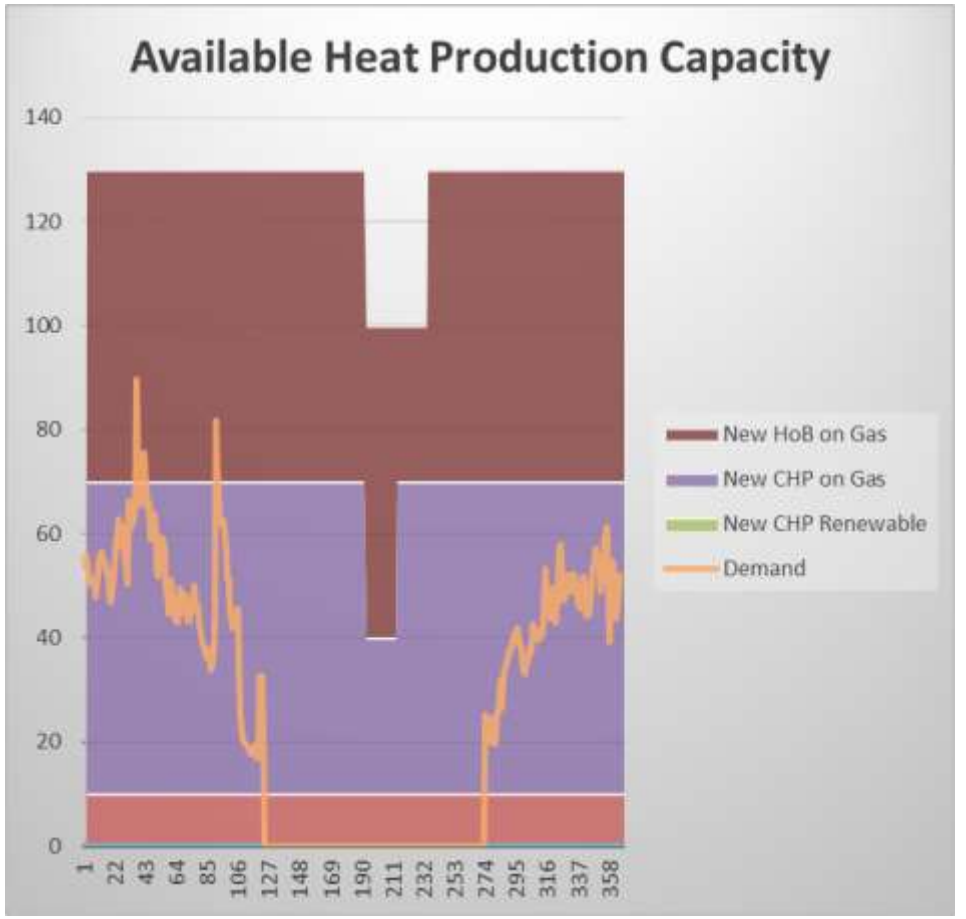


Daily production simulation

- Units in Merit order
- Assume 100% availability outside annual revision periods
- Check that units operate above their Minimum operational capacity
- Dependency of operation of another unit
- Base units starts only if they will operate more than 1 day
- Re-cooling possibilities

=>

- Final daily production and preliminary annual production



Treatment of Unavailability

- Daily simulation performed with 100% availability
- Annual energy for each unit reduced with the assumed degree of unplanned disturbances (unavailability)
  - CHP Ren -5
  - CHP Gas -4 + 5 (from CHP Ren)
  - HoB Gas +4
- Unavailabilities are assumed to be replaced by heat boilers of next step in merit order

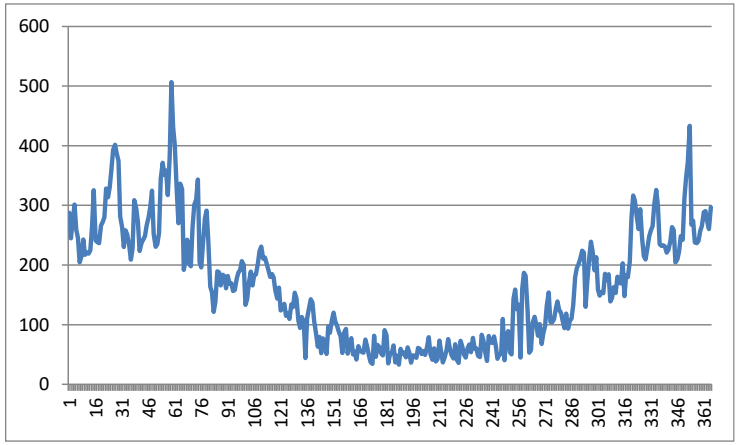
Production Unit	New CHP Renewable	New CHP on Gas	New HoB on Gas
Heat production base - no unavailabilities	*151*	*104*	*10*
Heat production final - no unavailabilities	151	104	10
Heat production final - including unavailabilities	146	105	14

Production system utilisation simulation model

–

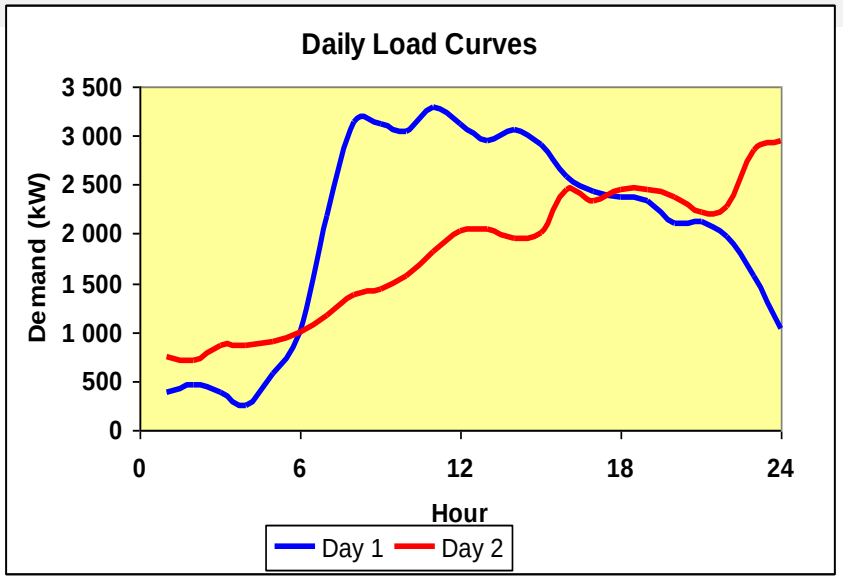
Input and input sheets

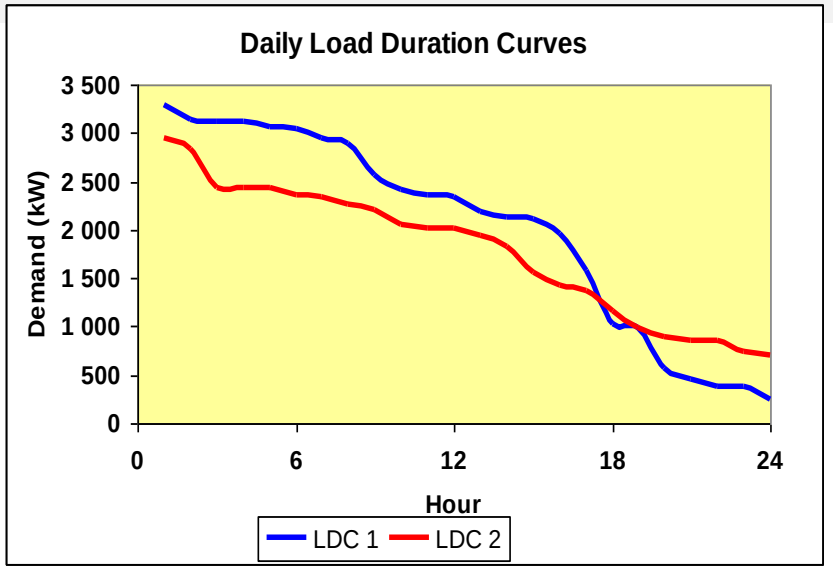
Demand Forecast

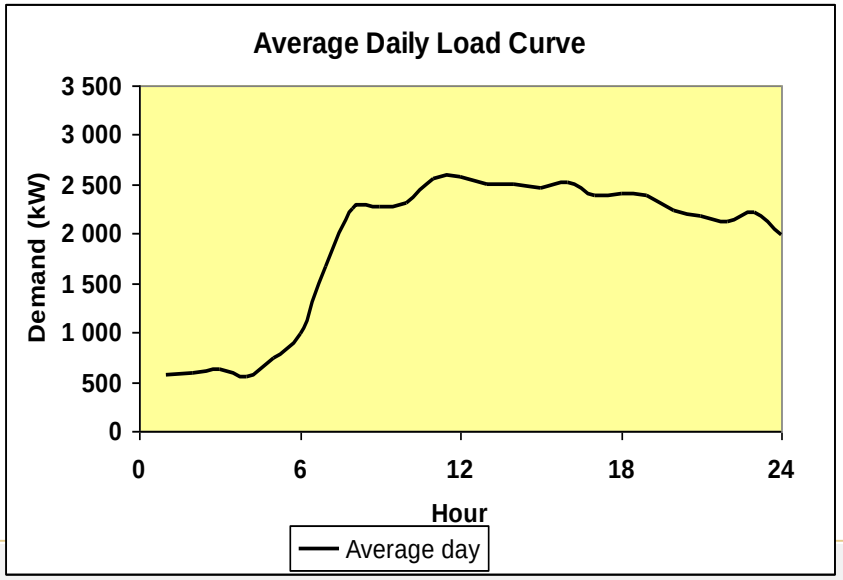


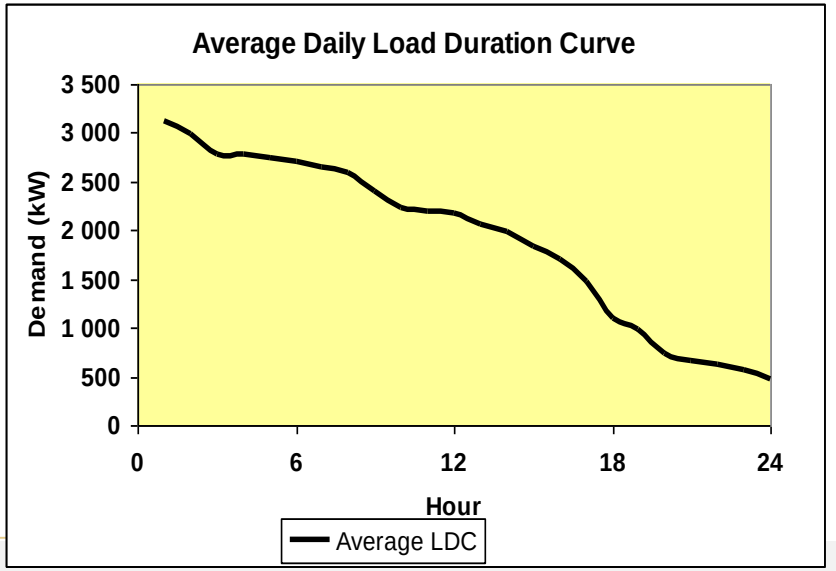
- Annual Energy in GWh (normal conditions)
- Annual maximum demand in MW (normal conditions)
- Annual Demand Curve
  - Use a curve with Typical daily average demands
  - Use the Same typical curve during the whole period
  - Adjust the typical curve to fit annual energy and the annual maximum demand for the actual year
- Choose if you want to analyze a normal, warm or cold year

General about load curves

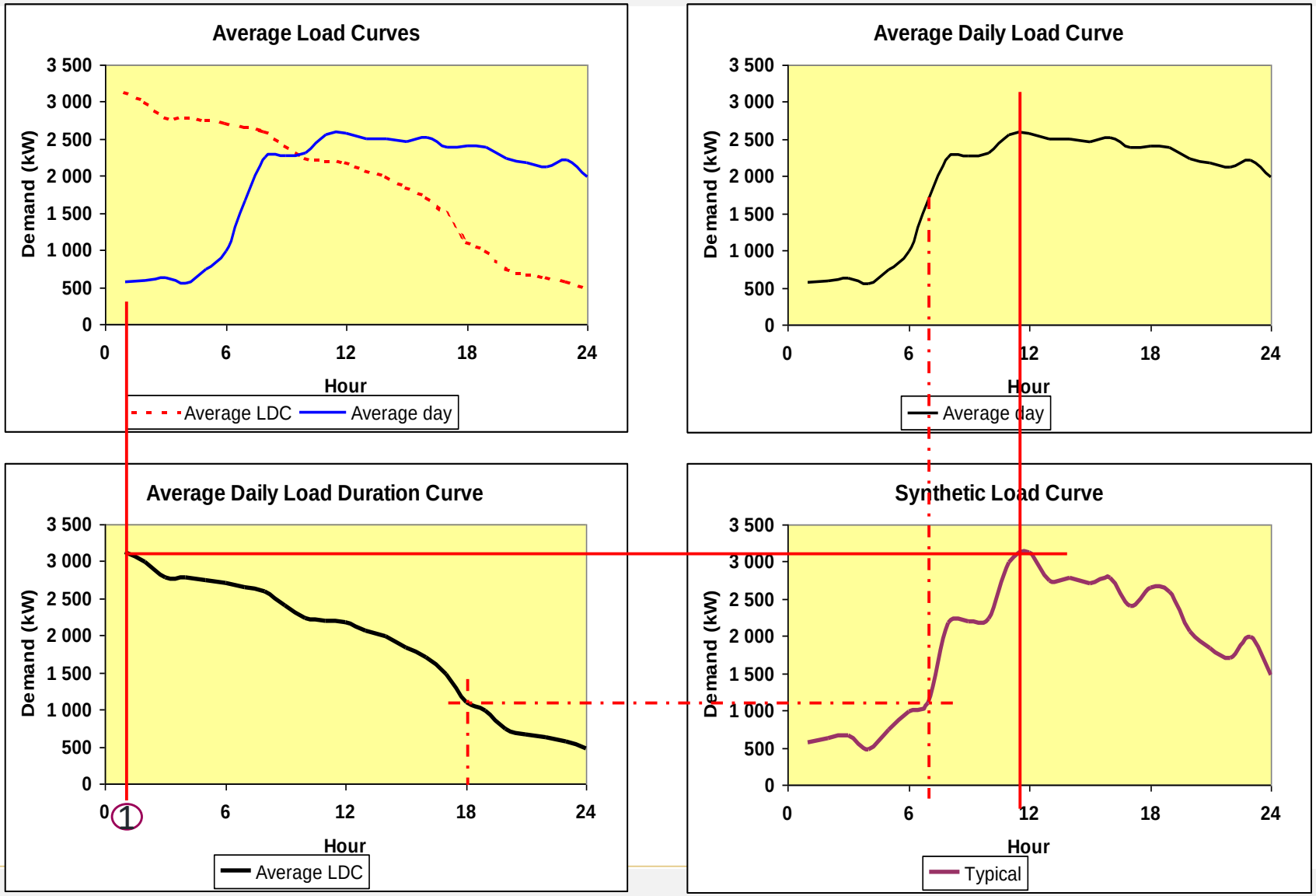








Creation of a Typical load curve



Input Demand and general

- Demand
  - Annual energy (GWh)
  - Annual Maximum daily average demand (MW)
  - Time series, maximum 40 years
- General
  - Name of the system or scenario

Company	Year	Annual Energy (GWh)	Annual Maximum Demand (MW)	Utilisation time (hours)
Shakhtinsk DH	2020	248	92	2680
Shakhtinsk DH	2021	254	94,66	2680
Shakhtinsk DH	2022	260	96,89	2680
Shakhtinsk DH	2023	266	99,11	2680
Shakhtinsk DH	2024	272	101,3	2680
Shakhtinsk DH	2025	278	103,6	2680
Shakhtinsk DH	2026	289	107,9	2680
Shakhtinsk DH	2027	301	112,3	2680
Shakhtinsk DH	2028	313	116,7	2680
Shakhtinsk DH	2029	324	121,1	2680
Shakhtinsk DH	2030	336	125,4	2680
Shakhtinsk DH	2031	336	125,4	2680
Shakhtinsk DH	2032	336	125,4	2680

Input Production system 1

- Locked types
  - External heat deliveries
  - Storage possibilities
- General types
  - Heat boilers
  - CHP
  - Flue gas condensor (FGC)
  - Heat pumps
- Operation conditions
  - Installed output capacities for Heat and electricity
  - Minimum operational load
  - Availability
  - Efficiency
  - Variable operation cost

Productions system input						
Unit		Surplus heat	Heat storage	New CHP Renewable	New CHP on Gas	CHP Boiler # 1
Installed Capacity	MW	0	10	0,0	60,0	0,0
Minimum operational capacity	%	0%	0%	0%	0%	0%
Installed electric output	MW			0	30	18
Availability	%			97%	97%	97%
Efficiency	%		100%	95%	95%	70%
Fuel cost	USD/MWh,br	0		10	9	6
Other variable cost	USD/MWh,br	0,1	0,1	20	20	20
Specific electricity consumption	MWh,el/MWh,br		0,010	0,035	0,020	0,035
Emissions 1 CO2	kg CO2/MWh,br			0	202	328
Emissions 2 Dust	kg dust/MWh,br					
Emissions 3 NOx	kg NOx/MWh,br					
Special 1 - dependence of unit before	(Yes=J / No=n)			n	n	n
Special 2 - Capacity can be reduced to keep next un	(Yes=J / No=n)			j	j	j
Special 3 - Cooling possibilities				*)		*)

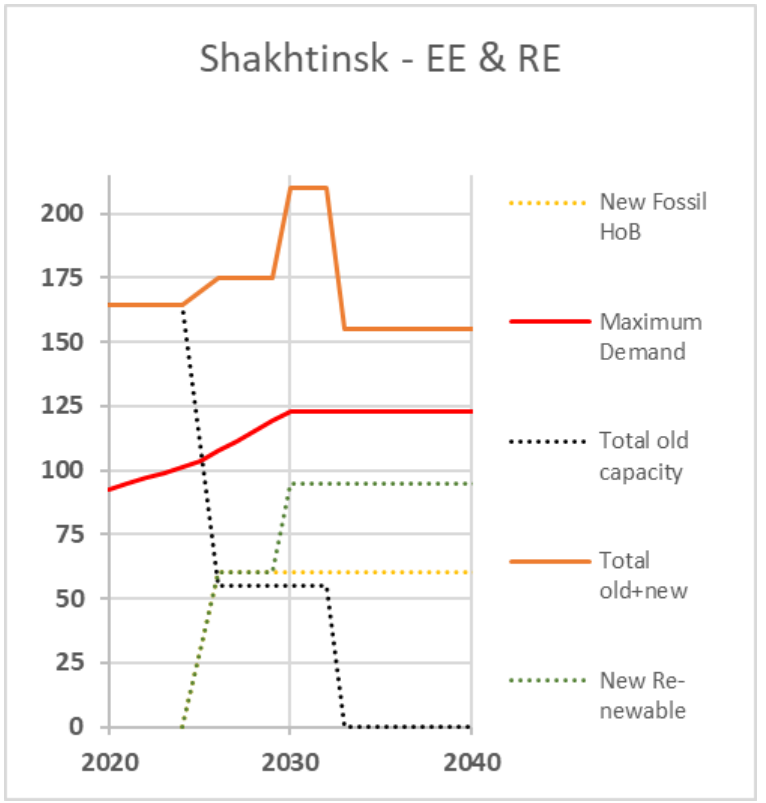
Input Production system 2

Annual revision plan

- Stop for whole weeks only
- 0 if fully available
- 1 if not available at all
- A proportion if only a proportion of the capacity is unavailable

	Surplus heat	Heat storage	CHP Boiler # 1	CHP Boiler # 2	CHP Boiler # 3
Week		Proportion of unavailabilty			
1			0,0	0,0	0,0
2			0,0	0,0	0,0
3			0,0	0,0	0,0
4			0,0	0,0	0,0
5			0,0	0,0	0,0
6			0,0	0,0	0,0
7			0,0	0,0	0,0
8			0,0	0,0	0,0
9			0,0	0,0	0,0
10			0,0	0,0	0,0
11			0,0	0,0	0,0
12			0,0	0,0	0,0
13			0,0	0,0	0,0
14			0,0	0,0	0,0
15			0,0	0,0	0,0
16			0,0	0,0	0,0
17			0,0	0,0	0,0
18			0,0	0,0	1,0
19			0,0	1,0	1,0
20			1,0	1,0	1,0
21			1,0	1,0	1,0
22			1,0	1,0	1,0
23			1,0	1,0	1,0
24			1,0	1,0	1,0
25			1,0	1,0	1,0
26			1,0	1,0	1,0
27			1,0	1,0	1,0
28			1,0	1,0	1,0
29			1,0	1,0	1,0
30			1,0	1,0	1,0
31			1,0	1,0	1,0
32			1,0	1,0	1,0

- System development plan

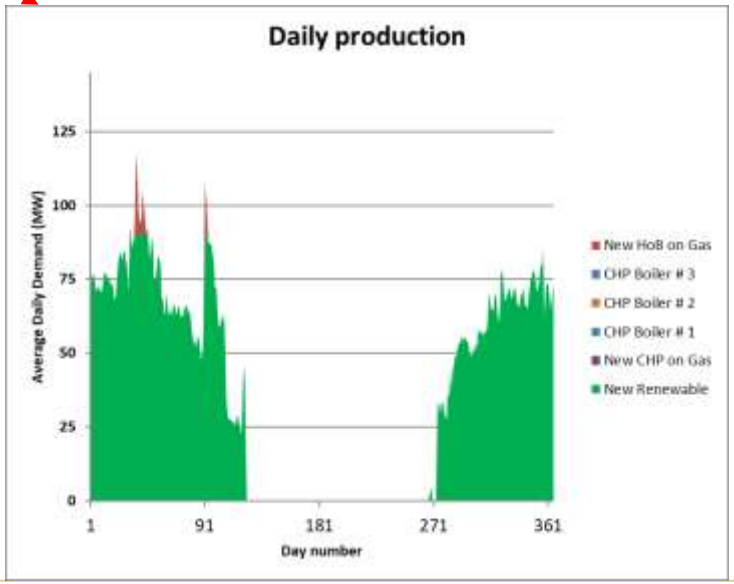


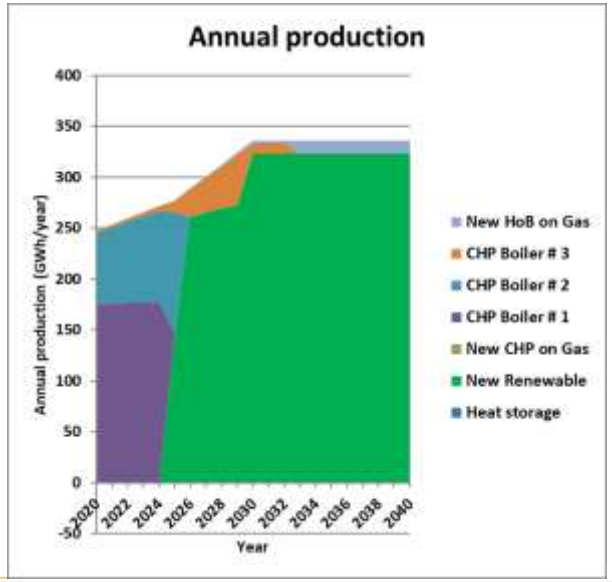
Output

- Annual figures for each unit or type of unit
- Daily generation final year for each unit or type of unit

Year	Annual production	Maximum demand	Surplus heat	Heat storage	New Renewable	New CHP on Gas	CHP Boiler # 1	CHP Boiler # 2	CHP Boiler # 3
2020	247,7	92,43	0,0	0,0	0,0	0,0	180,8	66,9	0,0
2021	253,7	94,66	0,0	0,0	0,0	0,0	181,3	72,4	0,0
2022	259,7	96,89	0,0	0,0	0,0	0,0	181,8	77,9	0,0
2023	265,6	99,11	0,0	0,0	0,0	0,0	182,2	83,5	0,0
2024	271,6	101,3	0,0	0,0	0,0	0,0	182,5	89,0	0,1
2025	277,6	103,6	0,0	0,0	151,6	0,0	0,0	119,1	6,9
2026	289,3	107,9	0,0	0,0	268,7	0,0	0,0	0,0	20,5

Shakhtinsk DH	Year	Annual produc	Maximum demand					
	2060	336,1 GWh	125,4 MW					
Production Unit	Surplus heat	Heat storage	New Renewable	New CHP on Gas	CHP Boiler # 1	CHP Boiler # 2	CHP Boiler # 3	New HoB on Gas
Heat production base - no unavailabilities	*0*	*0*	*333*	*0*	*0*	*0*	*0*	*3*
Heat production final - no unavailabilities	0	0	333	0	0	0	0	3
Heat production final - including unavailabilities	0	0	323	0	0	0	0	13
Electricity production final - including unavailabilities	0	0	0	0	0	0	0	0
Fuel consumption	0	0	340	0	0	0	0	14
Electricity consumption	0	0	12	0	0	0	0	0
CO2 emissions	0	0	0	0	0	0	0	2736
Operational time	0	1152	5208	0	0	0	0	360
Number of starts	0	25	3	0	0	0	0	4
Utilization time	0	-2	3698	0	0	0	0	55





Simulation model – Operation

1		Open the file
2		Save the file with a case specific name
3		Go to "Demand Curve"
		Add a typical Load Curve
4		Go to "Production curves"
		Sort U:AM after values in U in increasing numbers and the U:AM in falling order for values in V
5		Go to "Input"
		Fill general input in light yellow cells
6		Go to "Input Time series"
		Fill annual input in clear yellow cells
7		Go to "Input"
		Save the file
		Click on "40-years simulation"
		Go to "Output Time series" and see the annual results
8		Go to "Output Final year"
		See diagrams valid for the last year of the simulation

Demonstration example

Simulation 1

- Typical demand curve from Shakhtinsk
- Energy demand – 240 GWh/year, 2020-2060
- Existing system 3 units of 55 MW each to be retired at age of 60
- New capacity 4 units of 30 MW heat output each
  - 2 CHP on natural gas
  - 2 HoB on natural gas

Capacity check	2020	2030	2040
Normal Max demand	90	90	90
Dimensioning demand	100	100	100
Installed capacity	165	145	120
Biggest unit	55	55	30
Inst - Biggest - Max	20	0	0

Capacity check	2020	2030	2040
Normal Max demand	90	94	99
Dimensioning demand	100	105	111
Installed capacity	165	175	150
Biggest unit	55	55	30
Inst-Biggest-Max	20	26	21

Simulation 2

- As simulation 1 but
- One more HoB on Natural gas in 2040

Financial modelling

- Create a base scenario for:
  - Sales, Production and Investment
  - Price development for fuels
  - Development of other operational cost
- Simulate operation of the system
- Prepare a cash flow for operation of the company for the Base scenario several years ahead
  - Calculate the necessary heat price (or subsidies) to get a 0-result for the analysed period, taking all necessary actions into consideration
- Create alternative scenarios for the same period and do the same simulation as for the Base scenario
- Compare the results for the alternative scenarios with the base scenario

Example

- Base scenario including expansion and reduction of losses
- Energy Efficiency and Renewable scenario, same customers as in Base, savings on customer side, renewable fuels instead of fossil in units that replace old ones

1. Input from annual report
   - Current Income
   - Current Variable cost (volume dependent)
   - Current Fixed cost
2. Assumptions
   - Constant real prices on sales and purchases during the whole period
3. Simulations
   1. Necessary price to get 0-result for year 2019
   2. Necessary price to get 0-result for a 40-year period using 6% discount rate, taking into consideration necessary investments in accordance with the scenario used for the simulation (Base, Energy Efficiency&Renewable)
   3. Sensitivity analysis for variations in CO_2 trading price

Financial projections Example

Current situation – No CO_2 cost

		2019		Current average	2019 balanced	Price for 0-result
		Mtenge	(GWh)	tenge/kWh,heat	Mtenge	tenge/kWh,heat
Income	Sales	613	193,7	3,16	1663	8,59
	Total income	613				
Cost	Fuel	849,3	353,9		849,3	
	Other	813,7			813,7	
	Total	1663				
Annual Result		-1050			0	
Average fuel cost per sold heat unit			4,38	tenge/kWh,heat		

Current heat price has to be increased by:

- 39% to cover the fuel cost and by
- 172% to cover annual operational cost

Financial projections Example

Base 2020-2060, Long term price balance

	2020		2030	
Sales	193,7	GWh	346,0	GWh
Distribution losses	54,0	GWh	44,0	GWh
	22%	of prod 2020	10%	of prod 2020 adjusted with sales increase
Production	247,7	GWh	390,0	GWh
Boiler efficiency	70%		90%	
Fuel consumption	353,9	GWh	433,3	GWh
Investments in network				
Immediate actions	15	M$	5 years	
Continous reinv.	1	M$/year	from year 6	
New connections	50	M		
	MW		45 M$	30 / 60

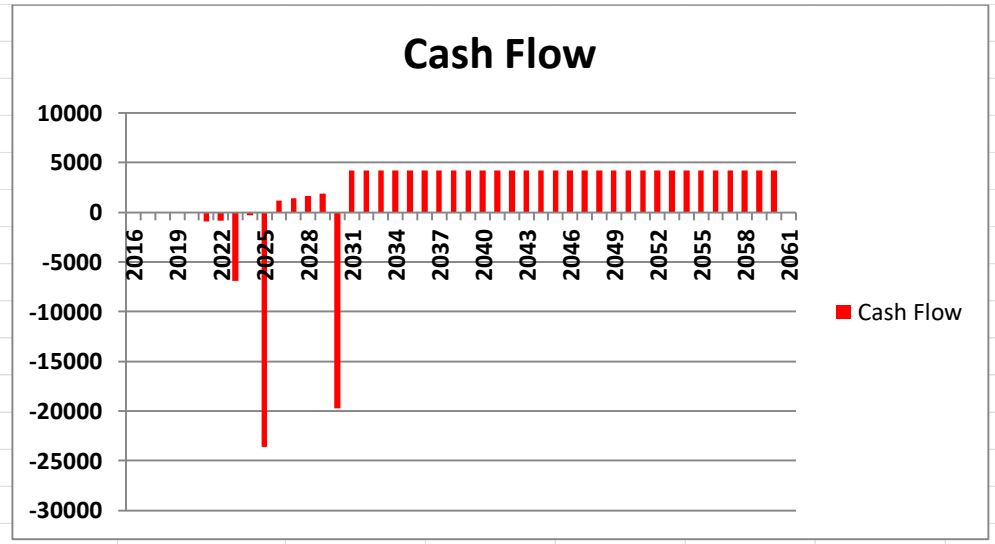
NPV January 1	2021
Total revenue	104 804
Total operational cost	-40 882
Operational result	63 922
Total investment	-63 922
Total project	0

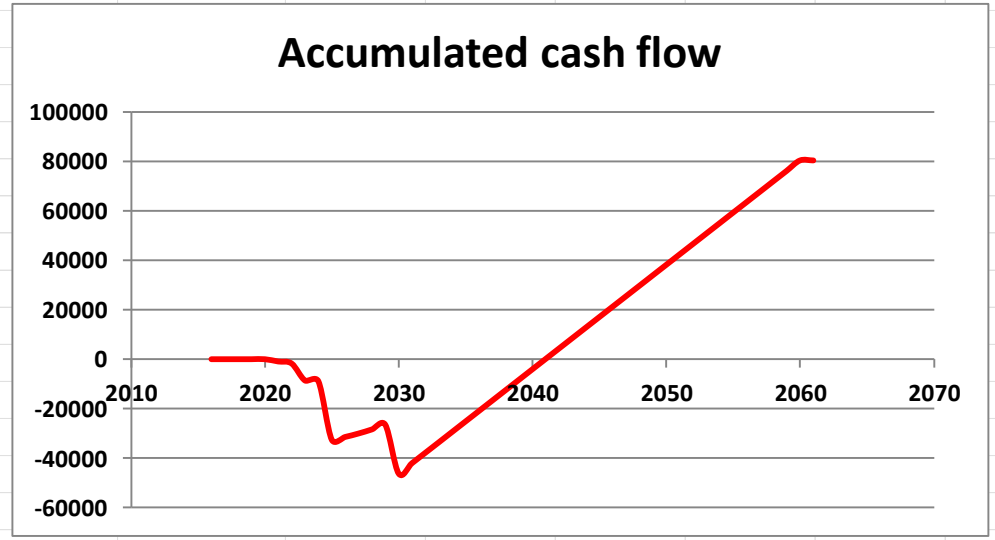
Net present value	**0**
Positive NPV year	**41**
Internal rate of return	**6,0%**

Price for 0-result 2020-2060

tenge/kWh,heat

21,29 (discount rate 6%)





Financial projections Example

Energy Efficiency & Renewable 2020-2060, Long term price balance

	2020	2030
Sales	193,7 GWh	298,0 GWh
Distribution losses	54,0 GWh	38,0 GWh
	22% of prod 2020	10% of prod 2020 adj with sales increase
Production	247,7 GWh	336,0 GWh
Boiler efficiency	70%	95%
Fuel consumption	353,9 GWh	353,7 GWh
Investments in network		
Immediate actions	15 M$	5 years
Continous reinv.	1 M$/year	from year 6
New connections	50 M$	10 years

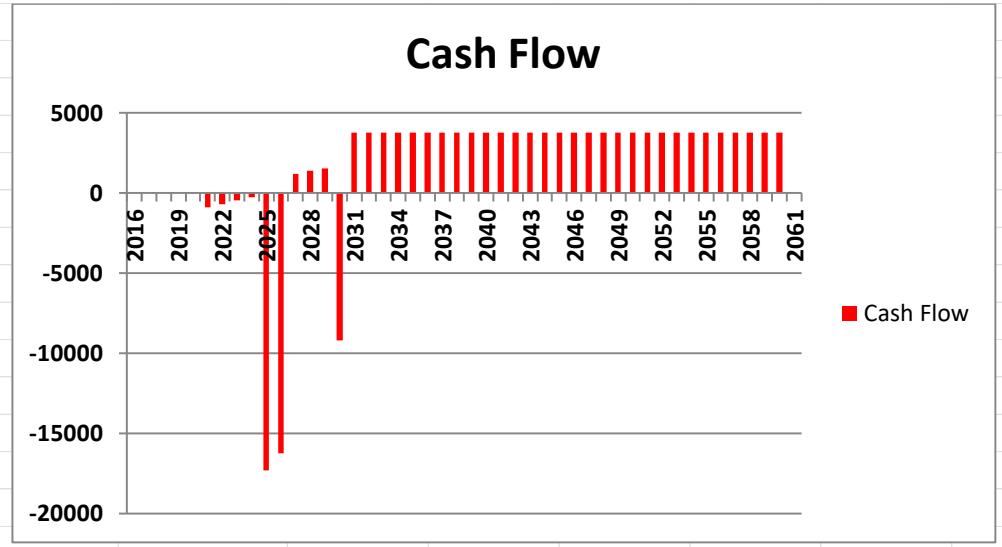
NPV January 1 production	2021
Investment in production	
Total revenue	98 391
Total operational cost	-38 542
Operational result	59 850
Total investment	-59 850
Total project	0

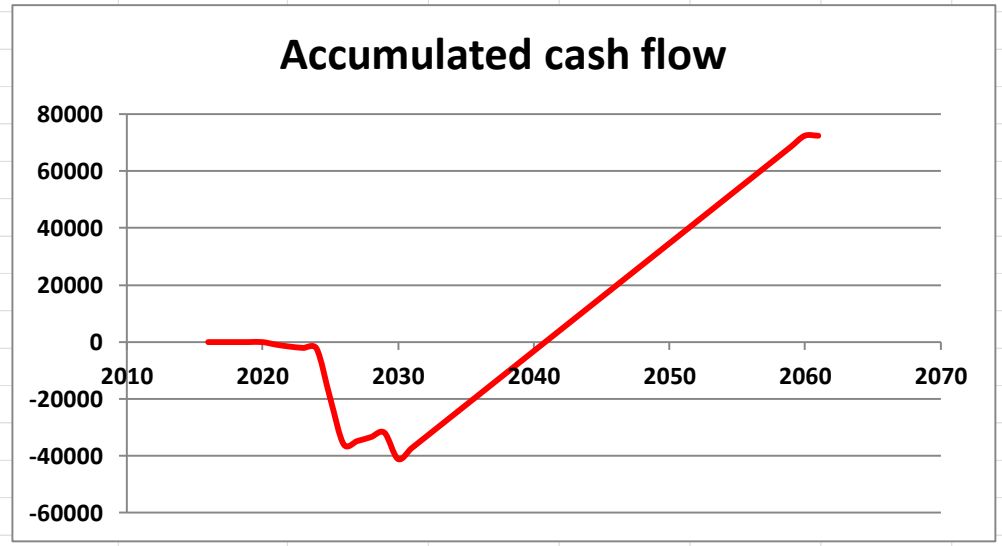
Net present value	0
Positive NPV year	39
Internal rate of return	6,0%
Pay back time (years)	20

Price for 0-result 2020-2030

tenge/kWh,heat

22,61 (discount rate 6%)





Financial projections Example

Sensitivity analysis

Current trading price

Kazakhstan	1 $/ton
Europé	22 $/ton (lowest since 2015)
WB forecast	75 $/ton (2030)

Lowest risk - Energy Efficiency and Renewable

Highest risk – Business as usual

Demonstration examples

1. Simulation 1 – Find necessary subsidies

   Current heat price

   O $/ton CO2 emissions

1. Simulation 2 – Find necessary price

   As simulation 1, but No Subsidies

1. Simulation 3 – Find necessary price

   As simulation 2, but European CO2 price (20 $/ton)

1. Simulation 4 – Find necessary price

   As simulation 2, but World Bank CO2 price forecast 2030 (80 $/ton)

Demonstration result

1. Simulation 1 – Necessary subsidies
2. Simulation 2 – Necessary price - No Subsidies
3. Simulation 3 – Necessary price - European CO2 price
4. Simulation 4 – Necessary price - World Bank CO2 price

	tenge/kWh	Mtenge
Simulation 1	3,16	5193
Simulation 2	20,0	0
Simulation 3	22,6	0
Simulation 4	30,6	0

Discussion

Requirements on operation simulation models:

- Details in description of units - Long term expansion vs Short term operation planning
- Flexibility – Long term expansion vs Short term operation planning

Current price level is not enough – What to do?

- Subsidies or heavy price increase – Long term / Short term

CO2 cost – What to expect for the DH system? - Now and in the future

- Current trading level is around 1 $/ton in Kazakhstan and 20$/ton in Europé and WB forecasts a level of 80 $/ton in 2030

Results from Discussion

Thank you for your Attention!

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