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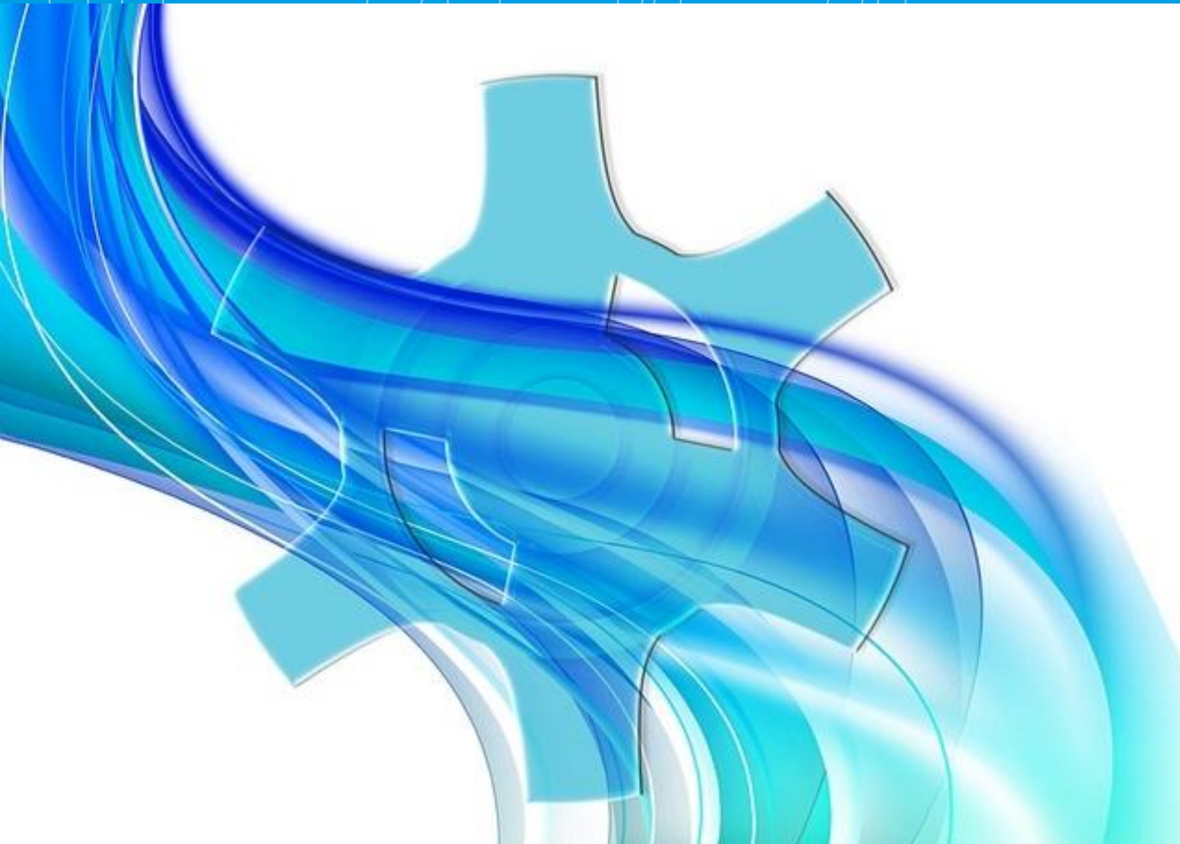

District heat with Small Modular Reactors (SMR)

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Tomi J. Lindroos

Preface

This presentation summarizes findings from a VTT's study of Small Modular Reactors (SMRs) conducted during the 2017. The PARIS project (Potential of Advanced Reactors for Industry and Society) was an internal project where we mapped different reactor types, their possible applications, and modelling requirements. The work is planned to continue with the most promising applications during the 2018.

Contents

1. Introduction to Small Modular Reactors
   - What? When? Where they can be used?

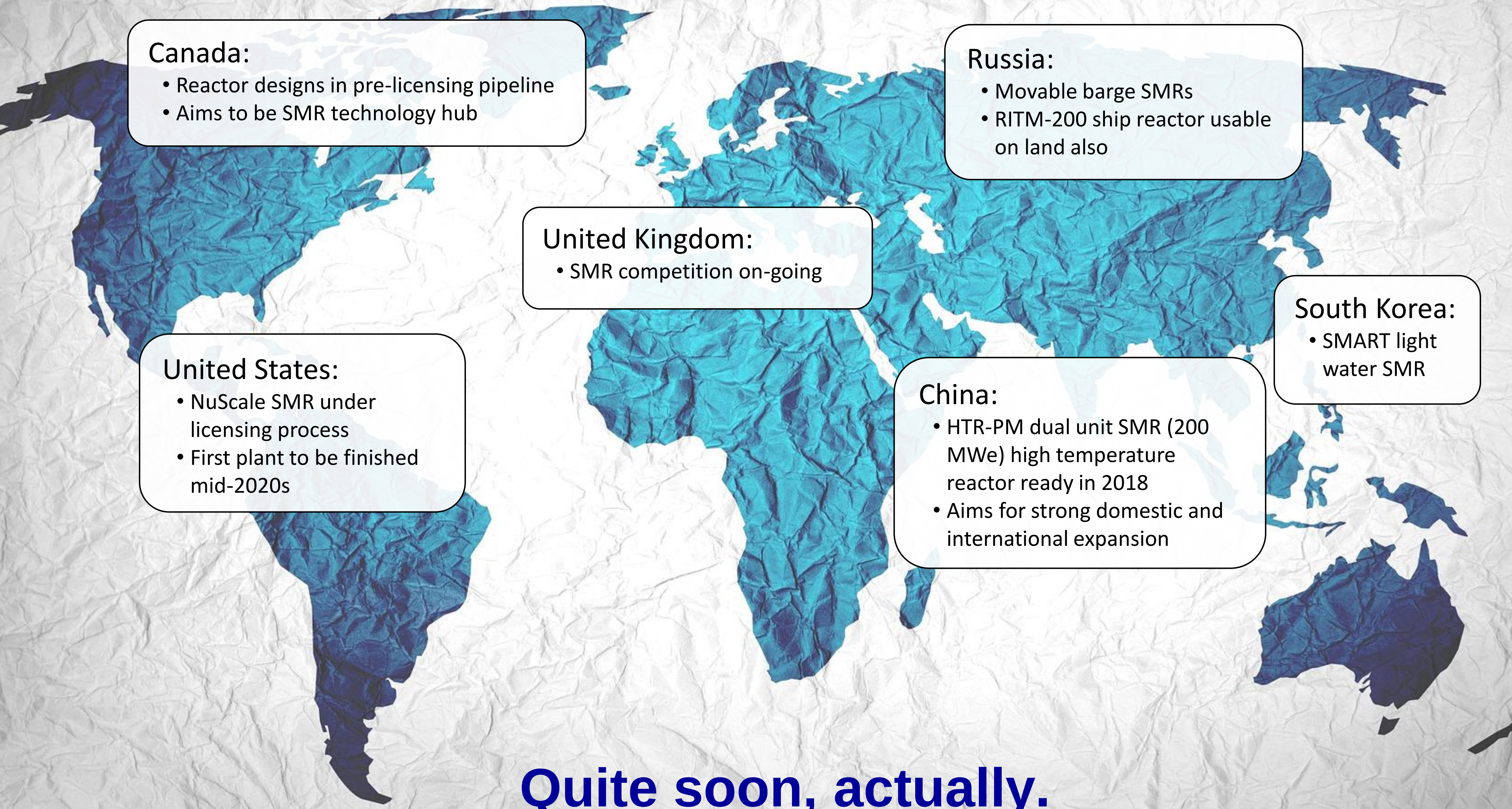
2. District heat with SMRs; Case study 2030
   - Feasibility study with preliminary cost estimates

1. Introduction to Small Modular Reactors (SMR)
   - Small nuclear reactors with fast construction time.
   - First already built, many other concepts following soon.
   - Can replace fossil fuels in district heat production and in industry steam production.

What are SMRs?

- **Small**
  - From ten to few hundreds of megawatts (MW) instead of gigawatt-scale reactors
  - New appliances for smaller users
- **Modular**
  - Standardized product
  - Can install multiple reactor modules for larger demands
  - Major components factory-produced instead of constructed on site
- **Reactors**
  - Nuclear reactors
  - Wide variety of proposed designs

When can we get SMRs?



Quite soon, actually.

Small modular reactors can be used for electricity production…

- Faster construction
- Lower per unit costs
- Suitable for small grids and users
- Grid support function
- More units mean better supply chain

… but they can also produce heat for industry and district heating

From low temperature to high temperature applications

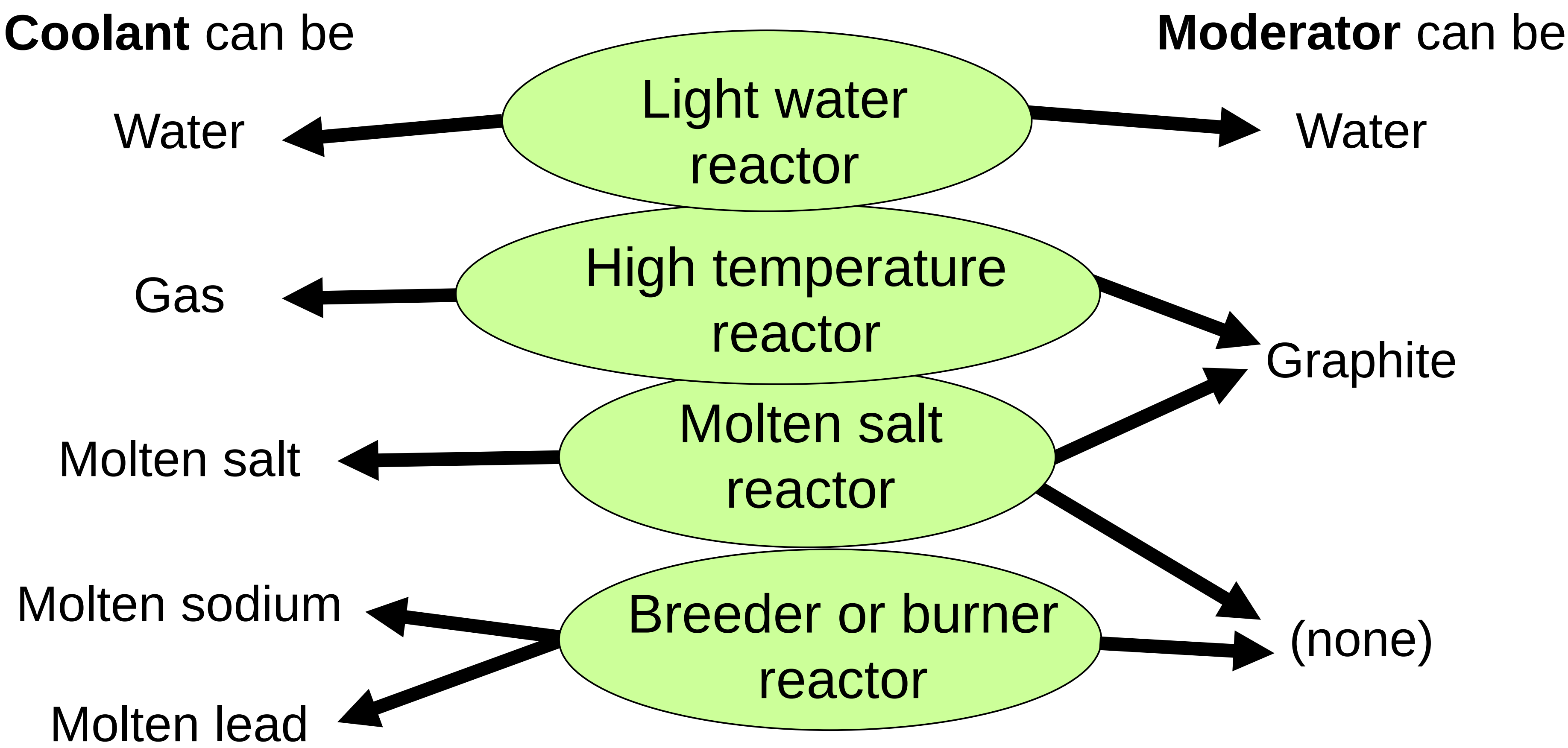
- District heating
- Bioindustry
- Refineries
- Desalination
- Catalytic processes
- Synthetic fuels
- Hydrogen production

Various non-electric applications for nuclear have been done before

- Steam supplied to paper mill by a research reactor in Halden, Norway
- District heating with nuclear power
- Seawater desalination with nuclear power
- Nuclear powered ships

Many ways to split the atom:

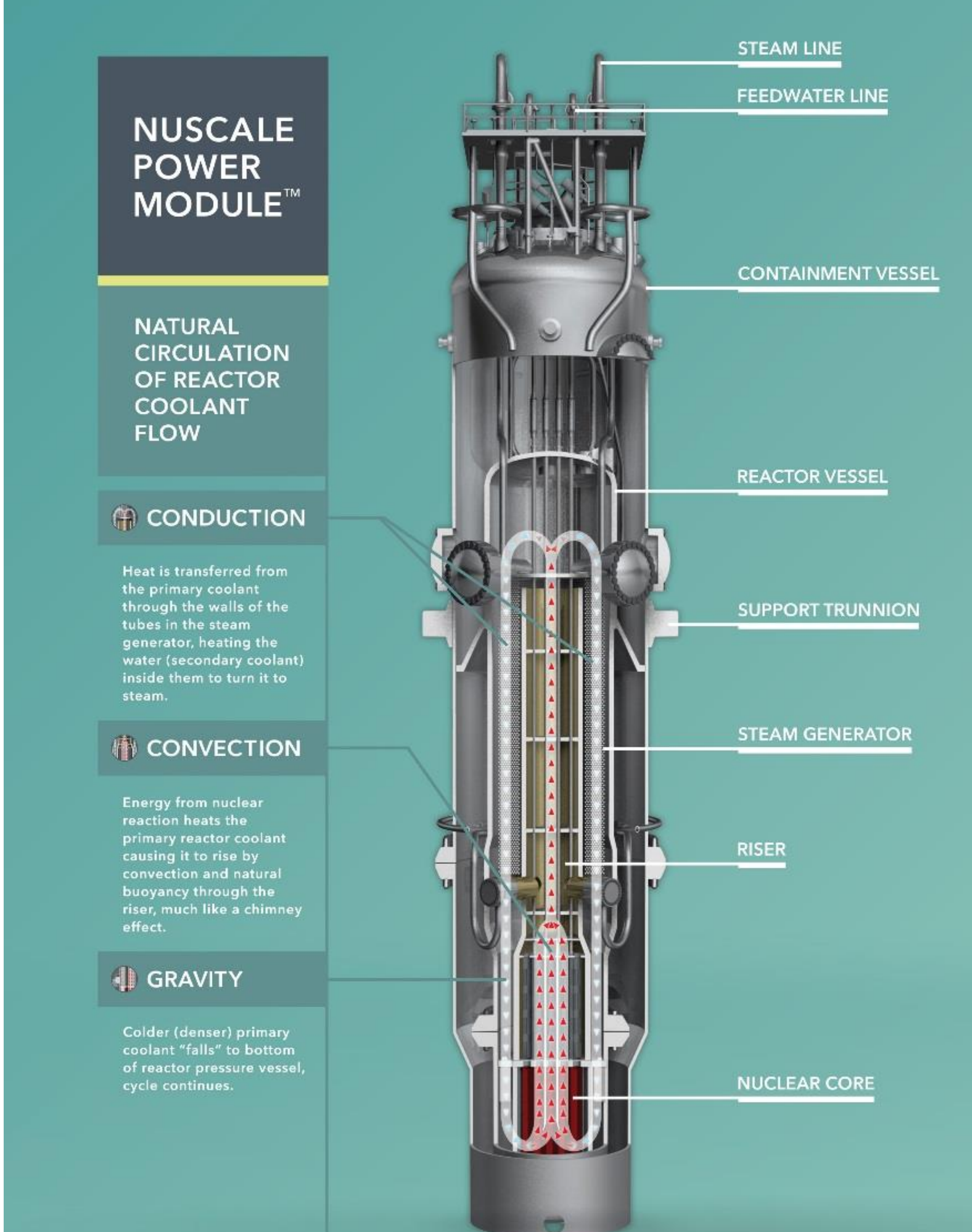
- In order to produce power in a nuclear reactor, you need two things in addition to uranium:



NuScale

- Factory produced reactor modules
  - 160 MWth Light Water Reactor
- 50 MWe turbine for each reactor
  - Also utilization of heat
  - Exit steam max 300 °C
- 1-12 module facility
- Under licensing in USA
  - First power plant planned to be finished mid-2020s

- Preliminary techno-economic case studies on feasibility to district heating



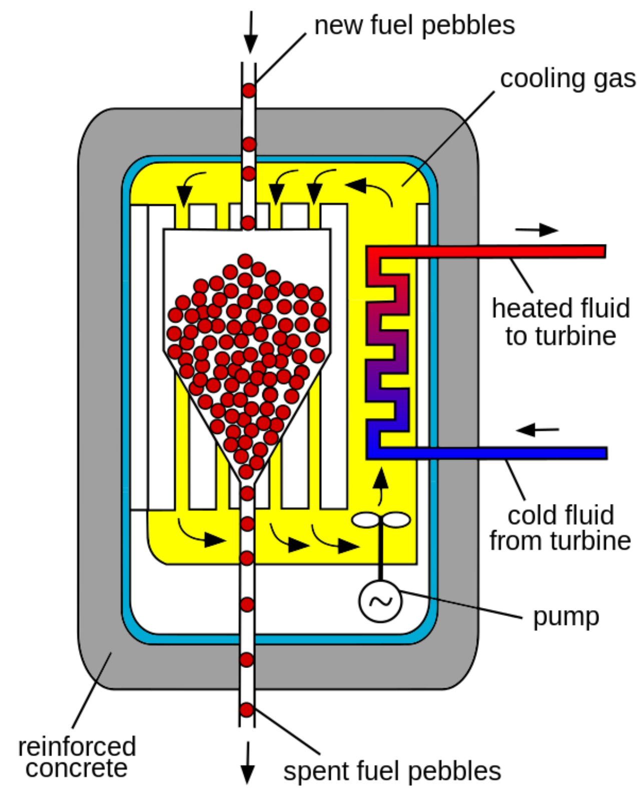
Source: free to use wikimedia figure
https://commons.wikimedia.org/wiki/File:Diagram_of_a_NuScale_reactor.jpg

HTR-PM

High Temperature Reactor – Pebble bed Modular

- Gas cooled pebble bed reactor
  - Technology initially developed in Germany
- Demonstration reactor should be connected to grid in China next year
  - Reactor outlet T 750 °C
  - Secondary circuit steam at 565 °C
  - 250 MWth per reactor
  - Dual reactor driving one 200 MWe turbine
- 2018 start of construction for second phase
  - 3 x dual reactors for 600 MWe turbine
- Feasibility study on petrochemistry application with Saudi-Arabia, collaboration with Indonesia, Poland…

Pebble Bed Reactor scheme



IEA Energy Technology Perspectives 2017:

"Nuclear energy is also a low-carbon source of heat and can play a relevant role in decarbonising other parts of the energy system where heat is being consumed, e.g. district heating, seawater desalination, industrial production processes and fuel synthesis."

"On-board nuclear energy storage and power generation could be a clean and relatively cheap solution to decarbonise shipping."

2. District heat with SMRs; Case study

- Modelled a Finnish city's district heat grid at 2030
- With and without NuScale SMR
- One NuScale unit could fit in to the modelled district heating system with 10 to 20 years payback time depending on final price and operation costs

Assumed DH production structure at 2030

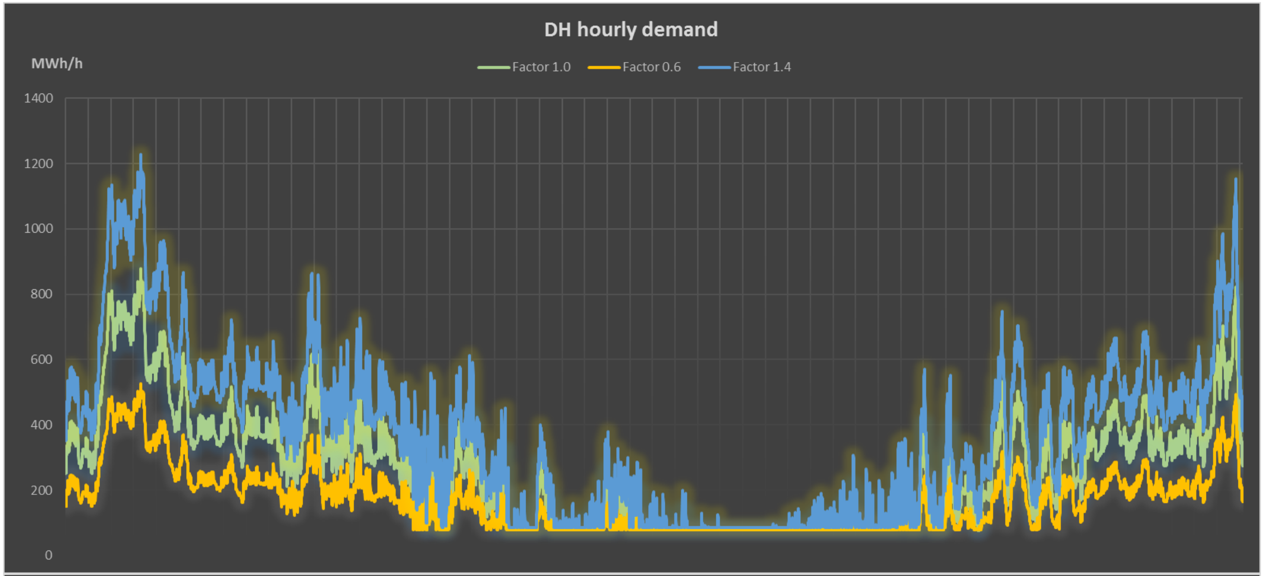
DH production unit	Code	DH capacity	ELC capacity	OM *	Minimum load	Total efficiency	Start-up cost
Scenario 1: NuScale DH	NuScale DH	152 MW	-	5.6 €/MWh**	40%	81%	-
Scenario 2: NuScale CHP	NuScale CHP	94 MW	35 MW	8.9 €/MWh**	40%	94%	-
Scenario 3: no NuScale							
Natural gas combined cycle CHP	NGCC	214 MW	234 MW	0.7 €/MWh	50%	90%	11700 €
Biomass steam turbine CHP	BioCHP	156 MW	74 MW	1.8 €/MWh	25%	88%	4500 €
Gas turbine + waste heat CHP	GtCHP	76 MW	42 MW	0.4 €/MWh	40%	90%	2100 €
Heat pump	HP	40 MW	-	-	-	400% ***	-
Biomass heat plant	BioDH	80 MW	-	2.1 €/MWh	-	90%	-
Natural gas heat plant	GasDH	580 MW	-	0.8 €/MWh	-	90%	-

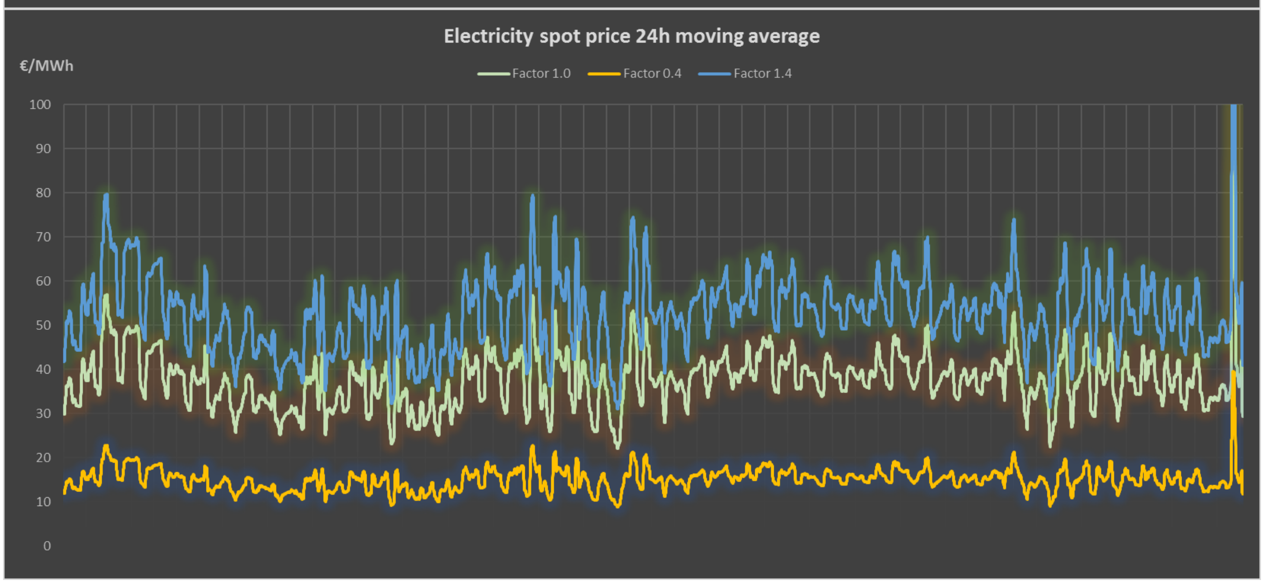
in all 3 scenarios

Assumptions based on public sources to correspond to the scale of Espoo CHP network as per in the earlier work reported in http://www.vtt.fi/inf/julkaisut/muut/2016/VTT-R-01173-16.pdf (section 2.4)

* OM cost per produced DH
** Includes fuel cost
*** COP value 4.0

Assumed DH consumption and electricity spot price





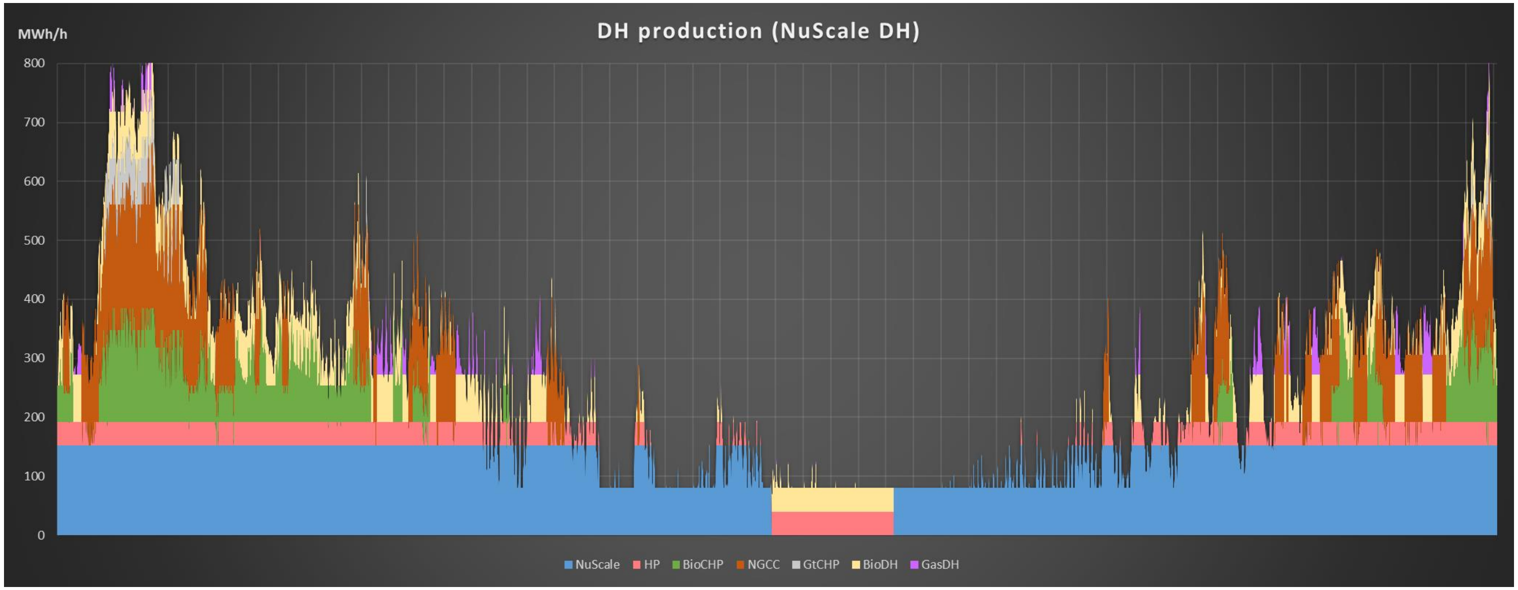
Other assumptions	
Emission permit price	20 €/ton
Natural gas price	27 €/MWh
Biomass price	35 €/MWh
Heat tax - CHP (gas)	12.1 €/MWh
Heat tax - boiler (gas)	17.4 €/MWh
Grid cost (HP)	35 €/MWh

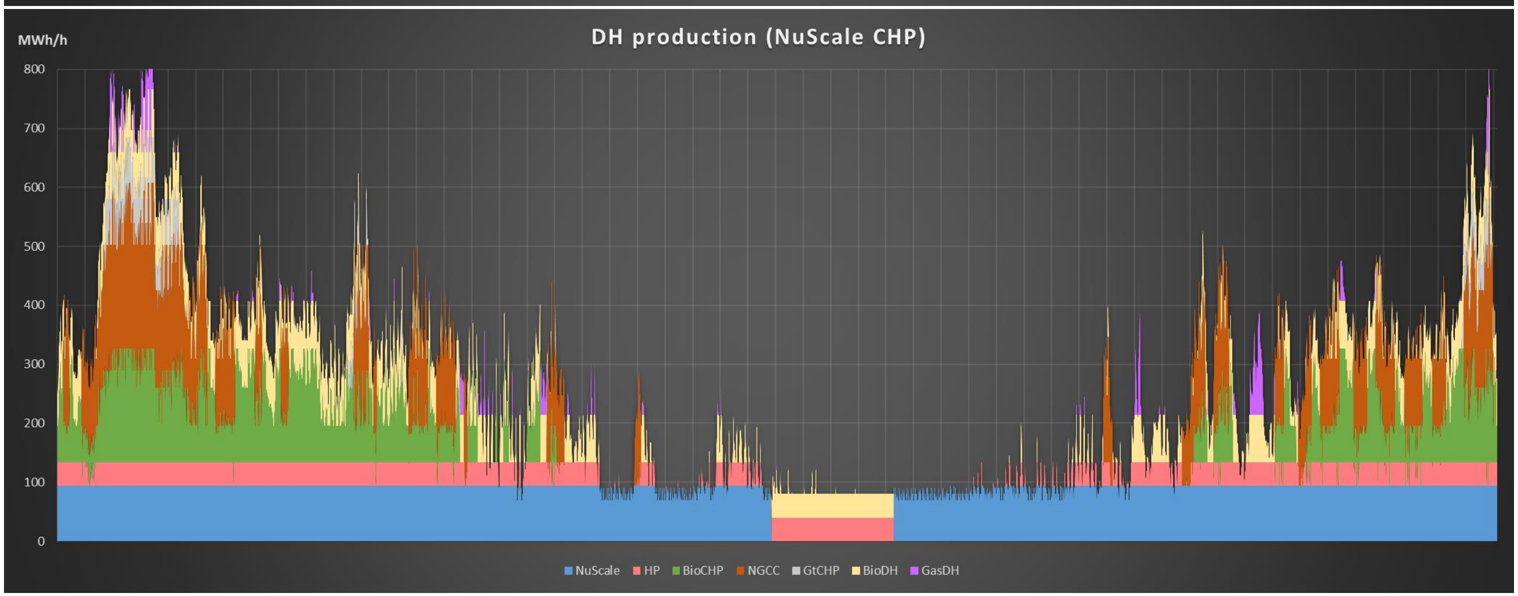
Minimum heat load of 80MW models hot water consumption.

Average electricity spot price ranges from 15 €/MWh (factor 0.4) to 52 €/MWh (factor 1.4).

Assumptions based on public sources as per earlier work reported in http://www.vtt.fi/inf/julkaisut/muut/2016/VTT-R-01173-16.pdf

DH production



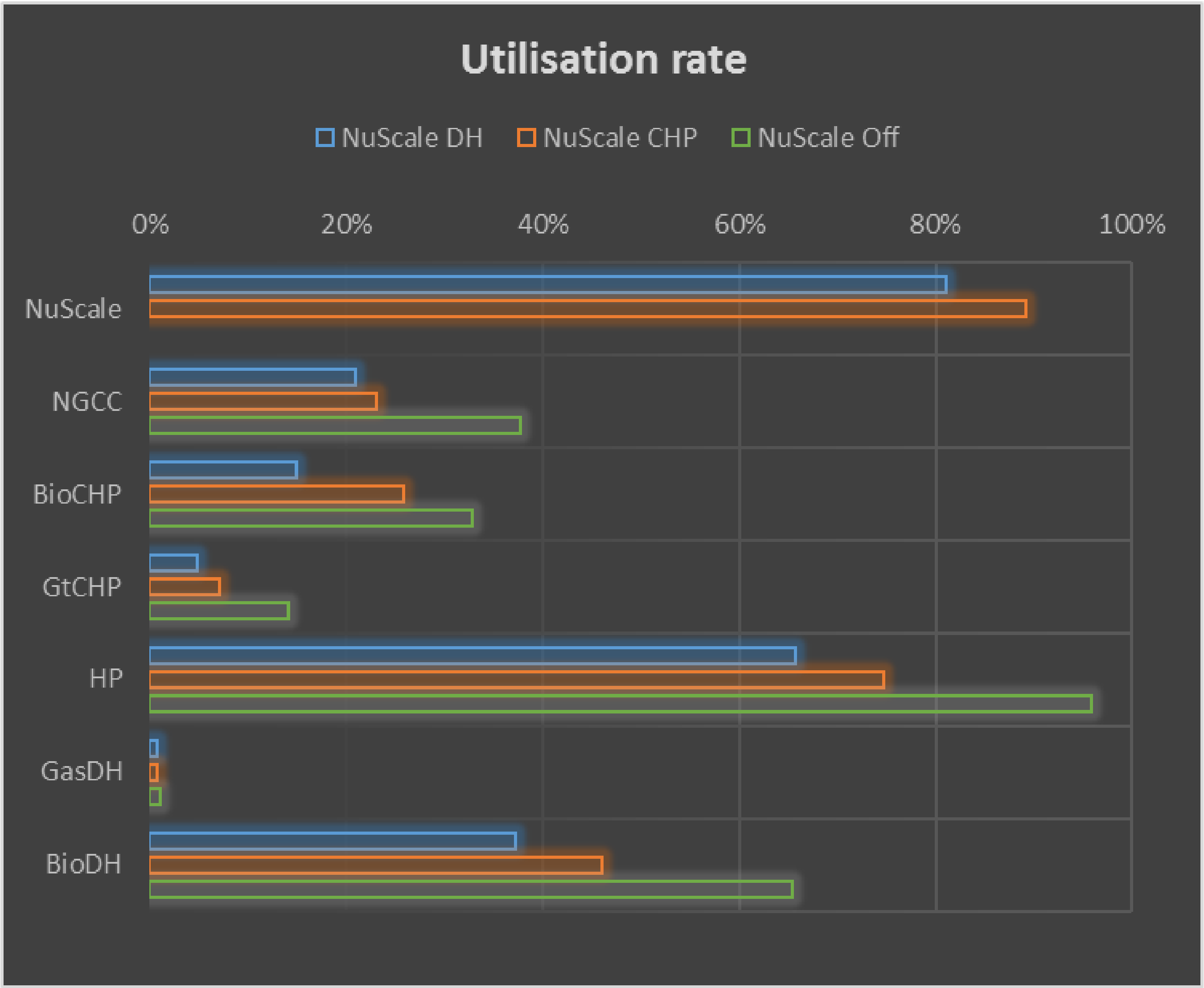


NGCC and BioCHP have summer maintenance shut-outs.

Heat plants (bio and gas) have no limits in terms of flexibility or minimum load.

Small heat storage (50 MWh) is used in the model to represent storage properties of DH pipeline.

Utilisation rates

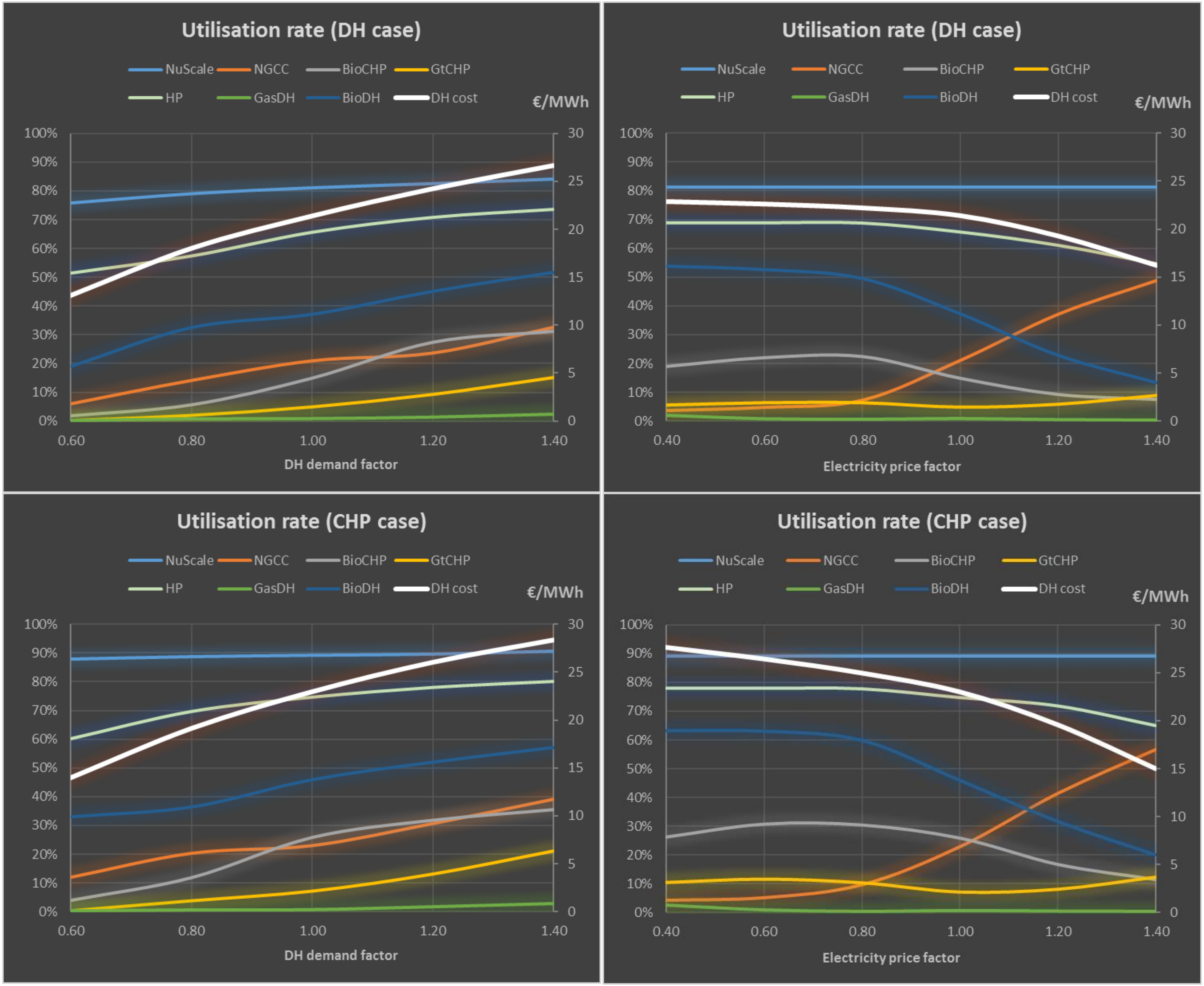


Role of natural gas fired power plants decreases in NuScale scenarios.

Heat pump utilisation remains in high level due to high efficiency.

Even with high level base load supply by NuScale high utilisation of biomass fired heat plant is required.

Utilisation rate of DH production units

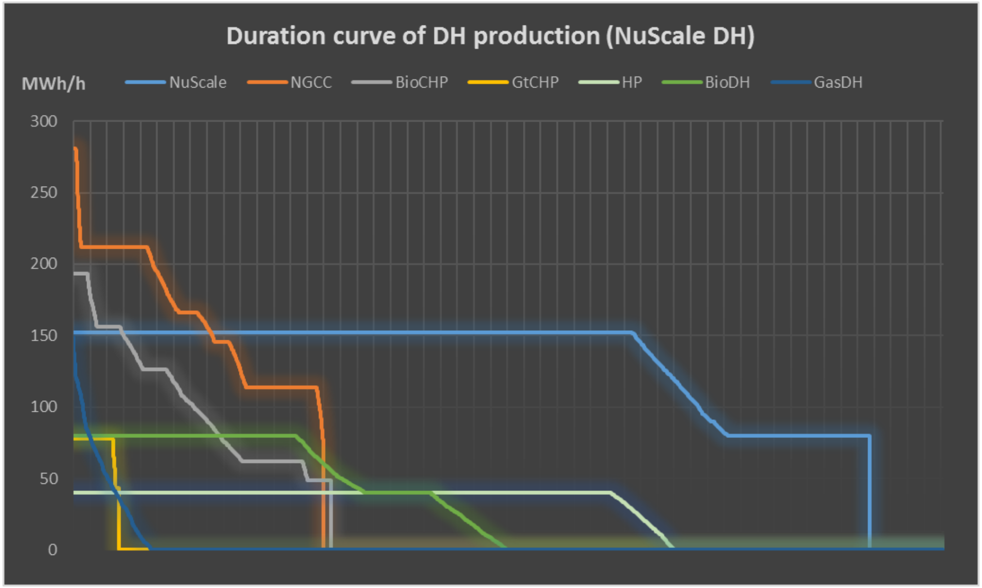


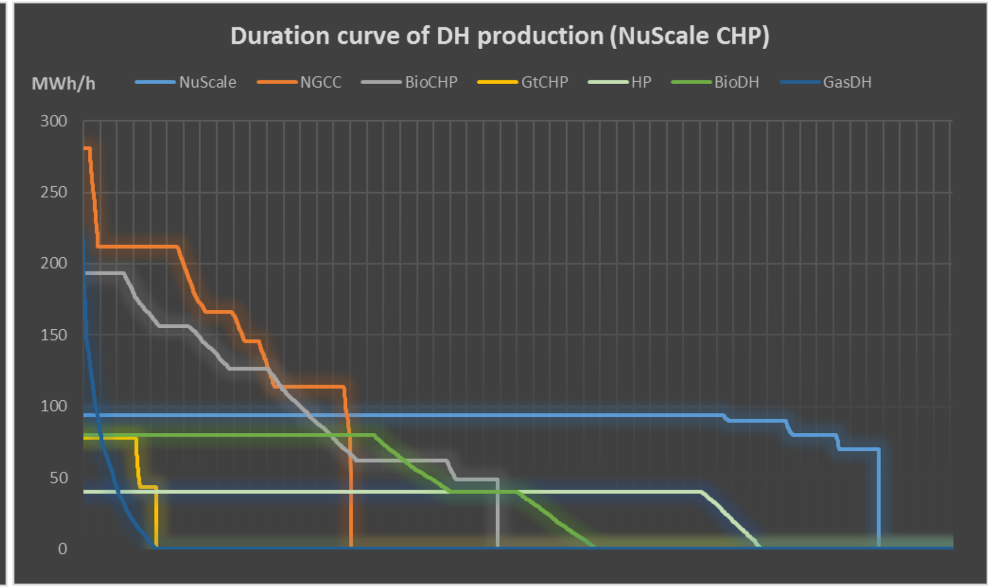
Utilisation rate of NuScale is not sensitive to DH demand or electricity price.

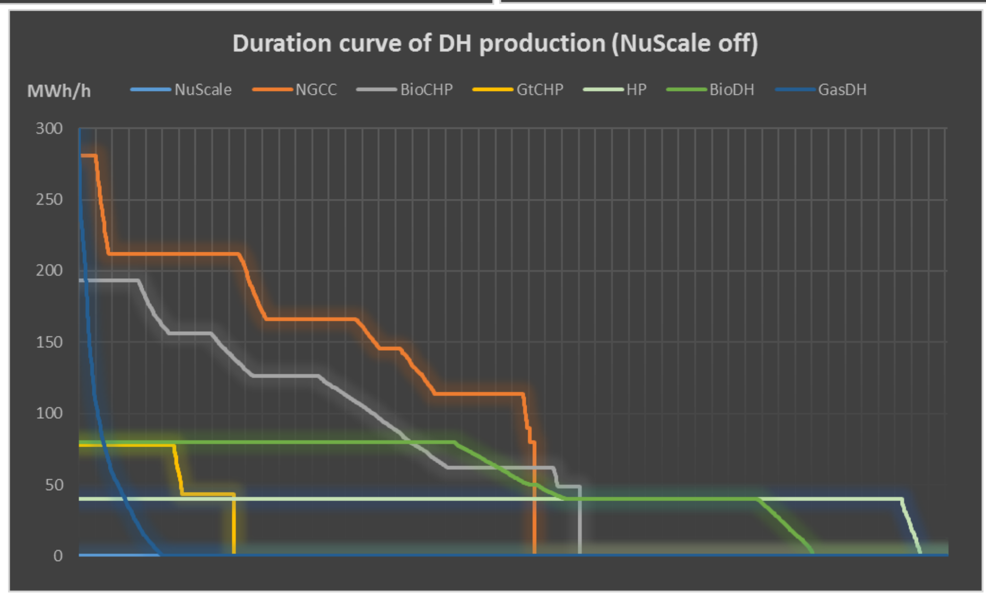
DH demand and electricity price variation affects strongly average DH production cost.

High electricity prices are necessity for higher NGCC operation.

Duration curves of DH production



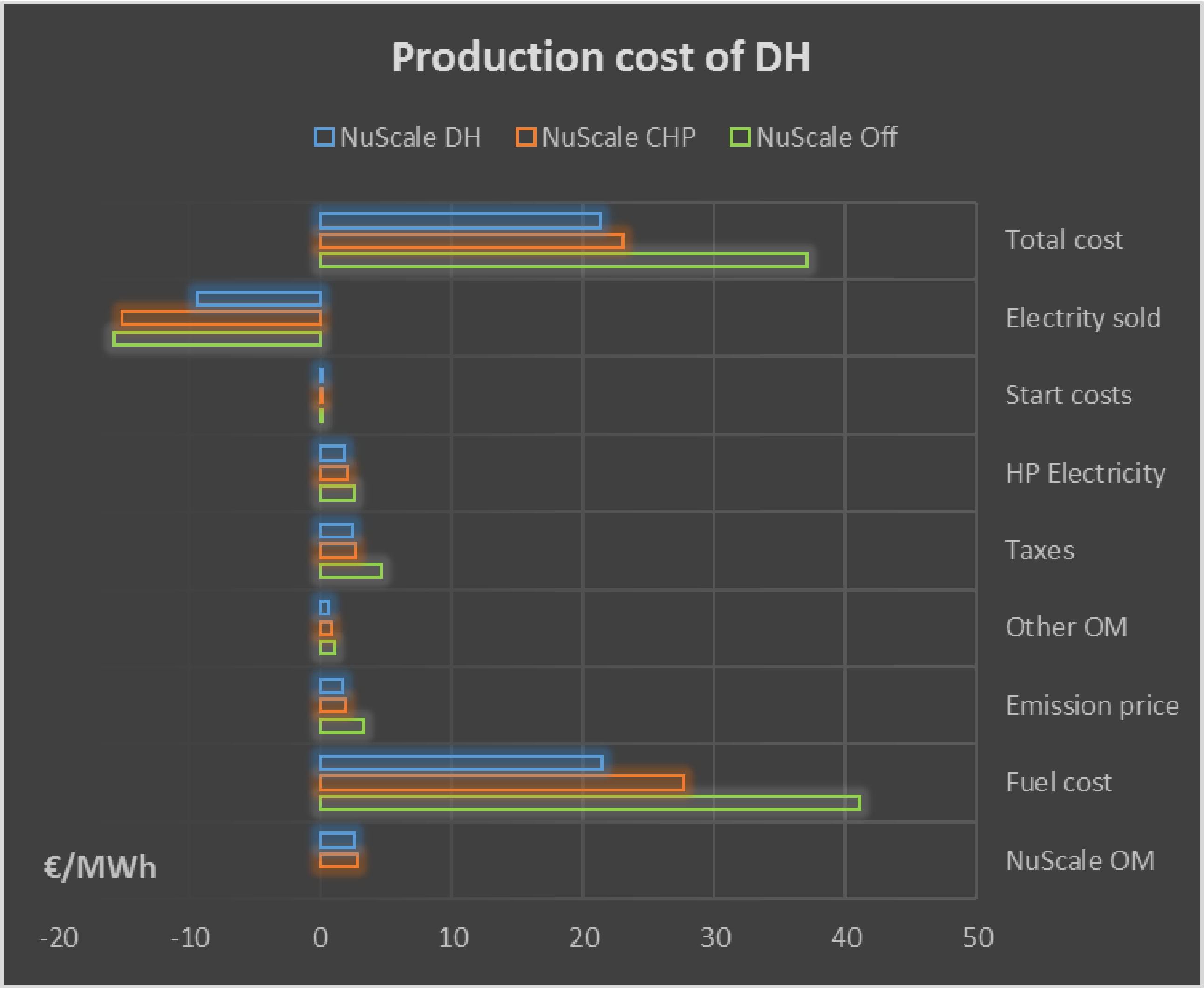




In DH mode NuScale operates at low load during summer due to high DH capacity, whereas in CHP mode capacity is more compatible with DH load.

Number of peak load hours of biomass fired heat plant relatively high.

Production cost of DH

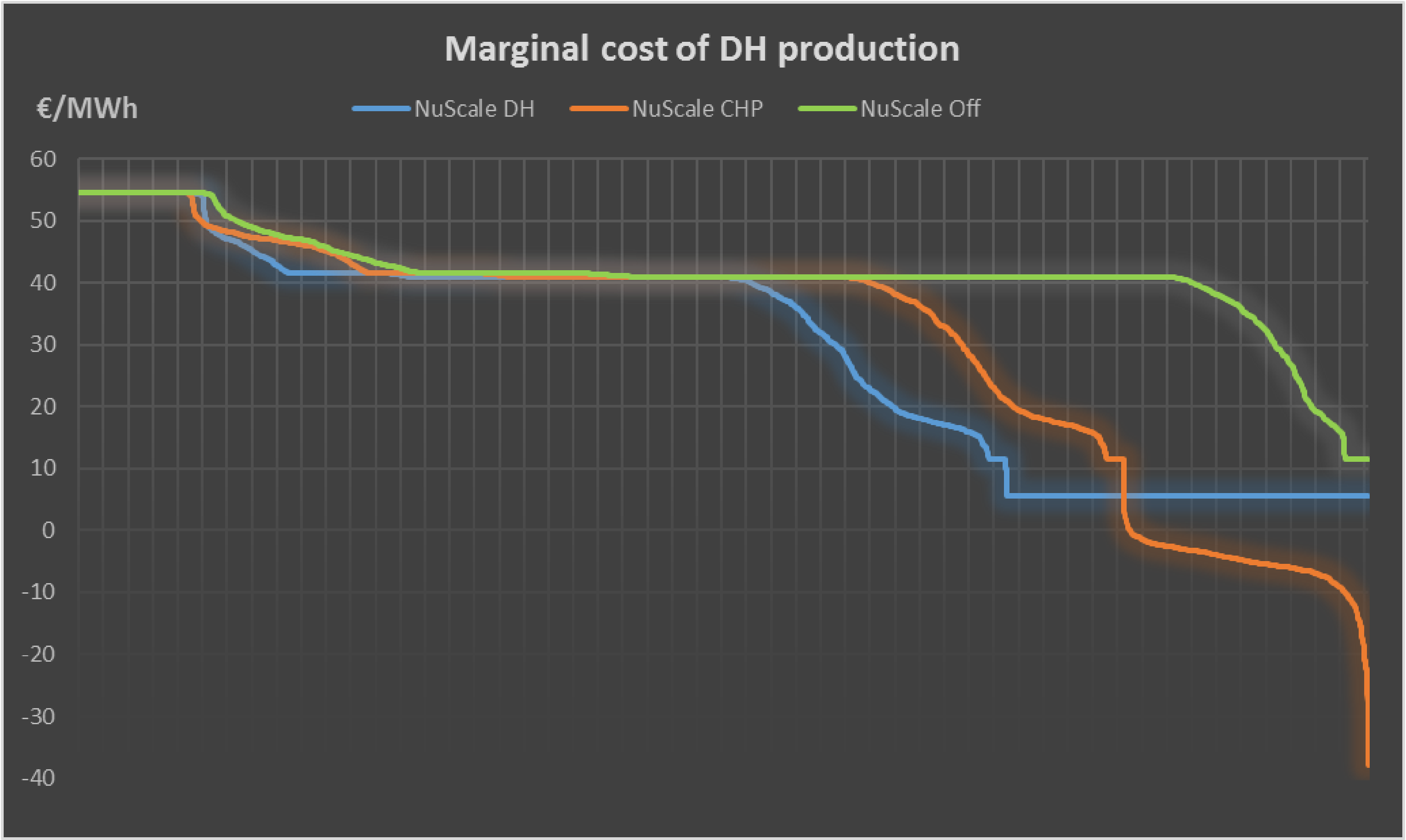


Production cost of DH in NuScale scenarios is 58-62% of BAU scenario.

Fuel cost and electricity trading affect most production cost.

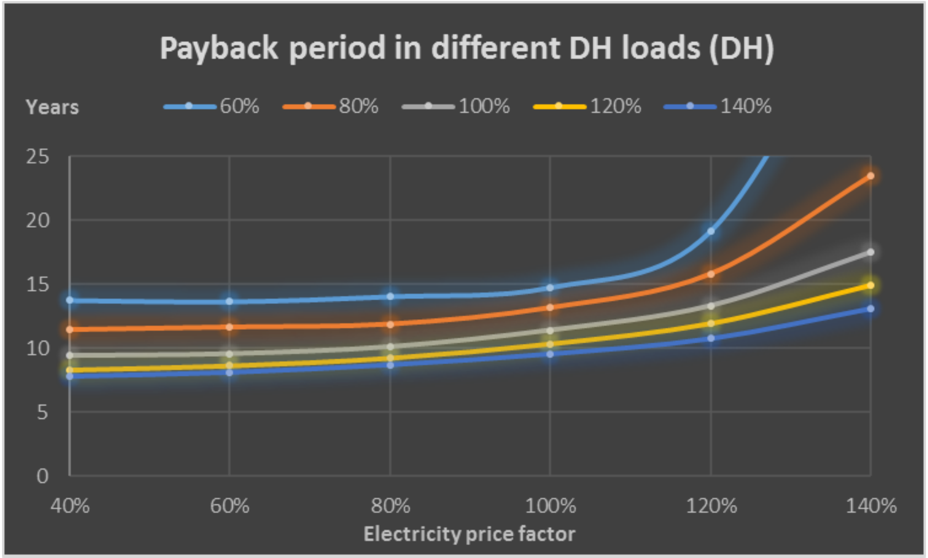
Taxes are low since natural gas fired untis are operated at relatively low level.

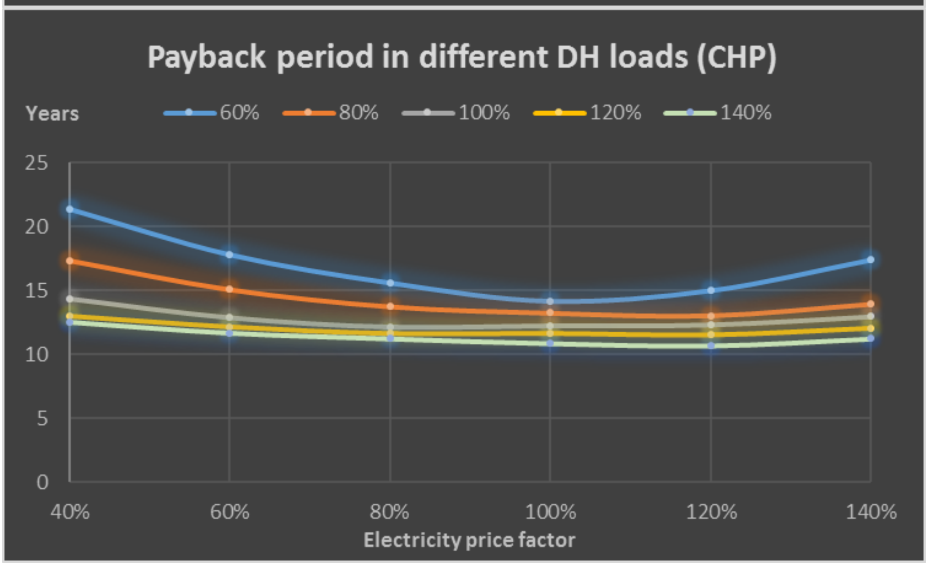
Marginal cost of DH production

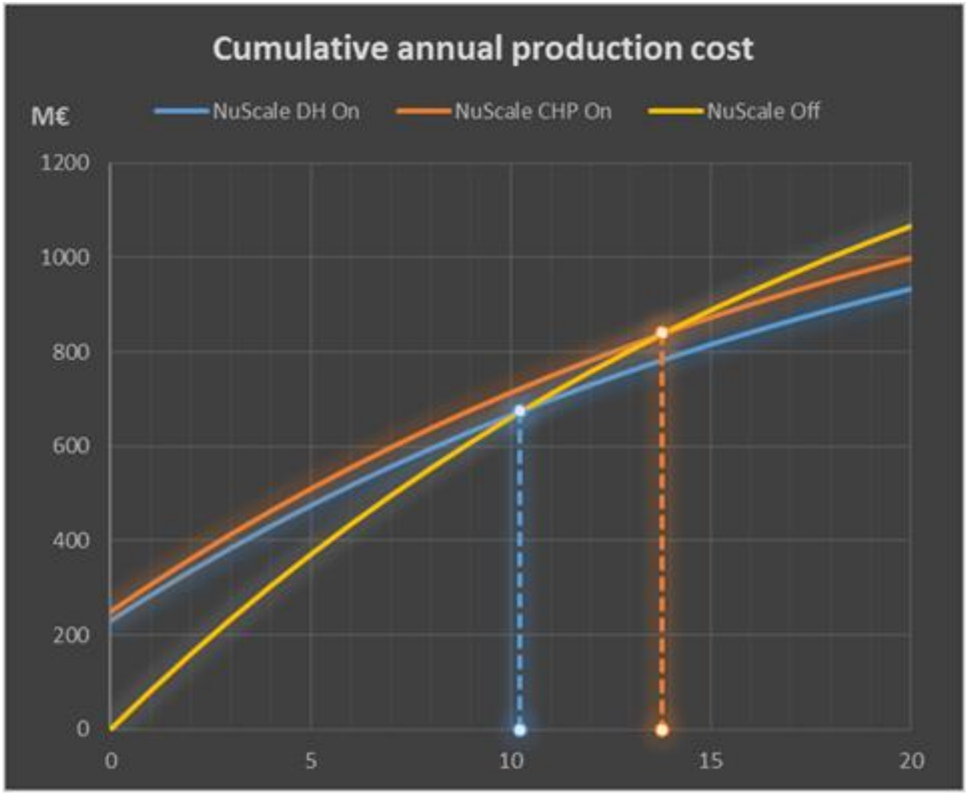


Marginal cost in NuScale CHP scenario is negative during summer hours due to sold nuclear electricity.

Investment payback period



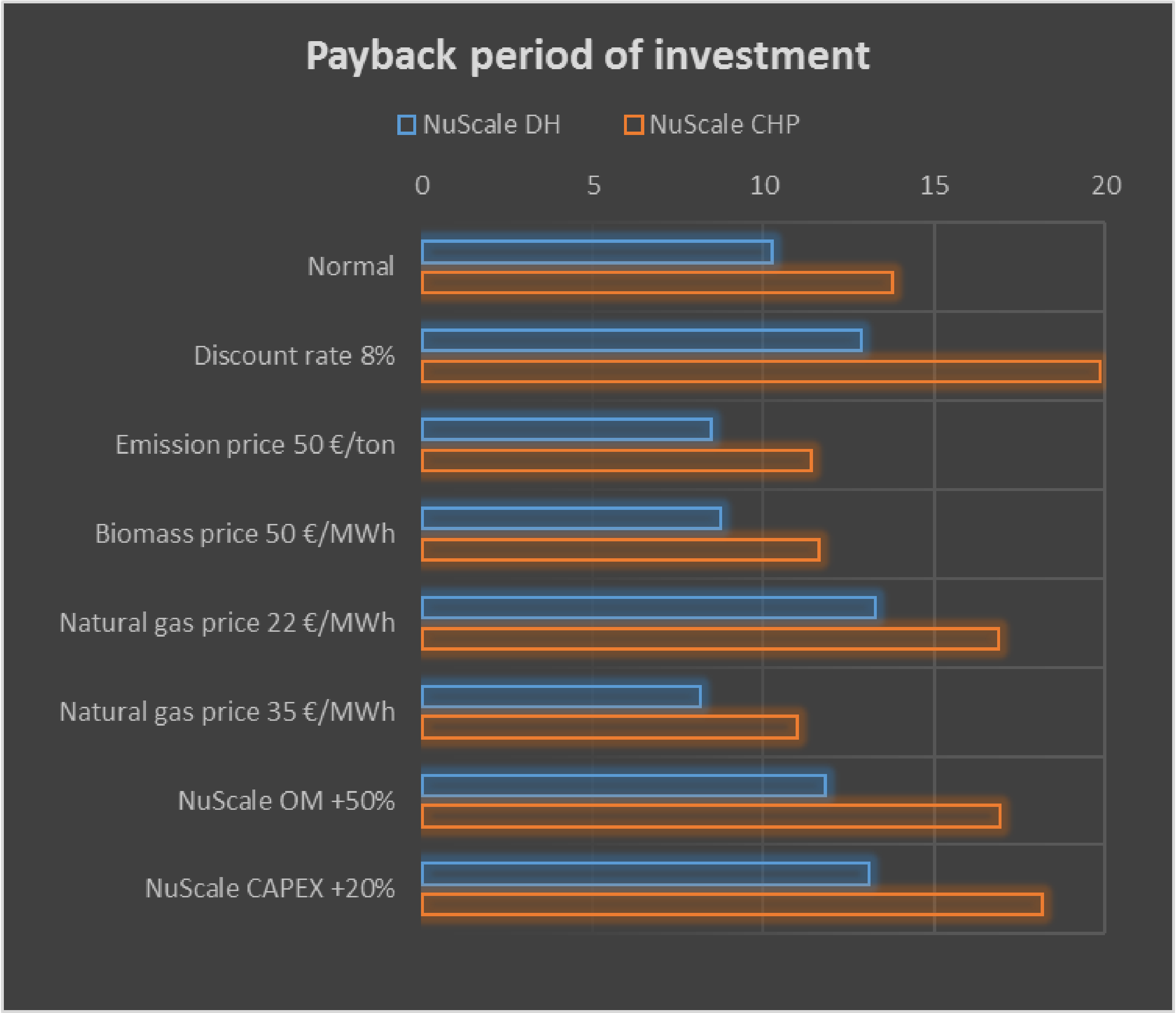




Discount rate of 5% is used.

Fixed OM cost of 0.043 M€/MW is used for NuScale in annual costs.

Sensitivity of investment



Licensing costs are assumed to be part of the CAPEX

Small Modular Reactors (SMR)

* Are small nuclear reactors with fast construction time.
* First have been already built and many other concepts will follow soon.
* Can replace fossil fuels in district heat production and in industry steam production for both high and low temperature heat.

One NuScale SMR unit would fit to the model district heating system with high utilization ratio. The estimated payback time would be from 10 to 20 years depending on assumed costs and prices.