

Best Duurzaam All A3s

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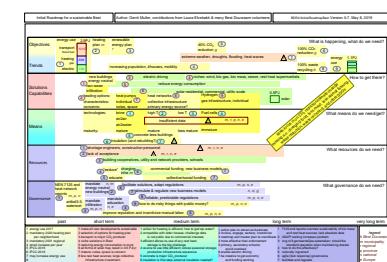
Abstract

This presentation bundles all A3s that we make for Best Duurzaam (Best Sustainable).

Distribution

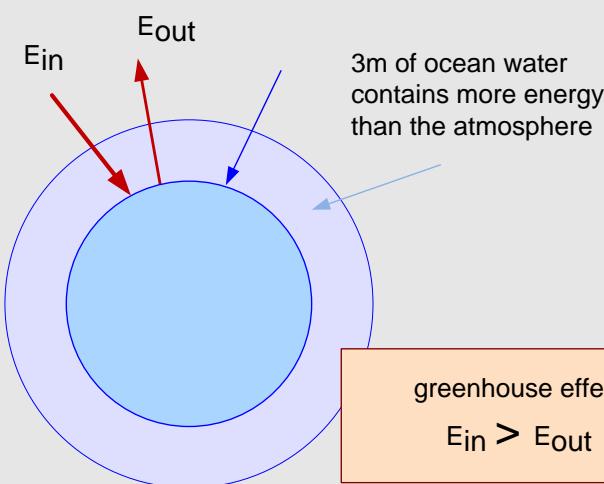
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1**CO₂ ppm****Global CO₂ levels**

CO₂ levels started to increase with the industrial revolution
The rate of change is very high on cosmic time scale

2**physics/nature of earth**

High CO₂ levels cause the greenhouse effect. Earth warms up because more energy from the sun comes in than the amount of energy that can escape the atmosphere

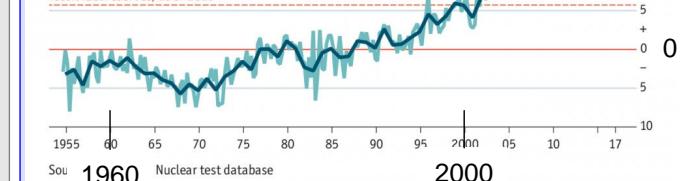
3**Global Ocean Heat Content Change**
in 10²¹ Joules (=10⁶ PJ; NL uses 3 PJ/yr)**In hot water**

Global ocean heat content, change relative to 1955-2010 average
0-700 metres, 10¹⁷ joules

— Yearly average — Three-month average

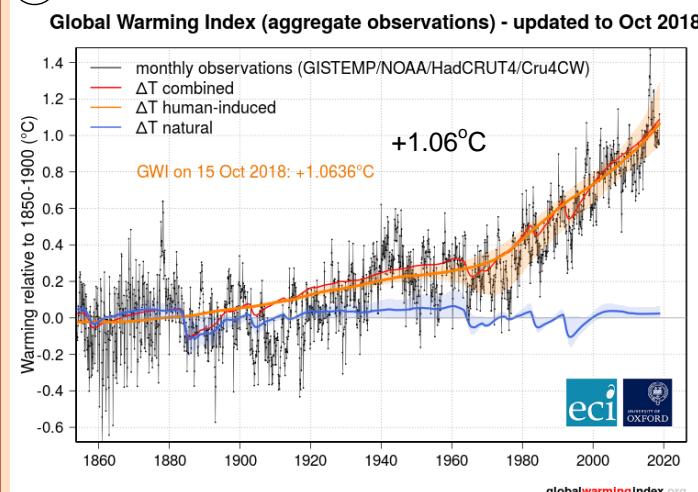
One billion times the energy of the atomic bombs used on Hiroshima and Nagasaki in 1945

Energy contained in the world's fossil fuel reserves, as of 2016

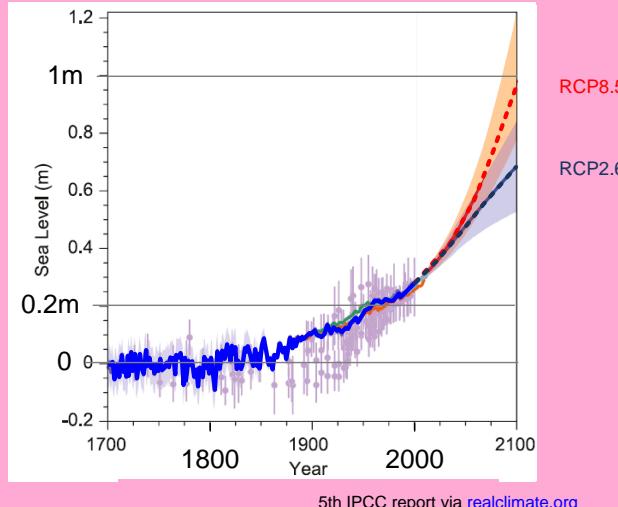


sources: NOAA; BP, Nuclear test database
<https://www.economist.com/graphic-detail/2018/03/12/the-temperature-of-the-ocean-is-rising>

The oceans act as buffer for accumulating energy surplus.
The amount of energy that oceans absorbed in past decades is huge

4**temperature on earth**

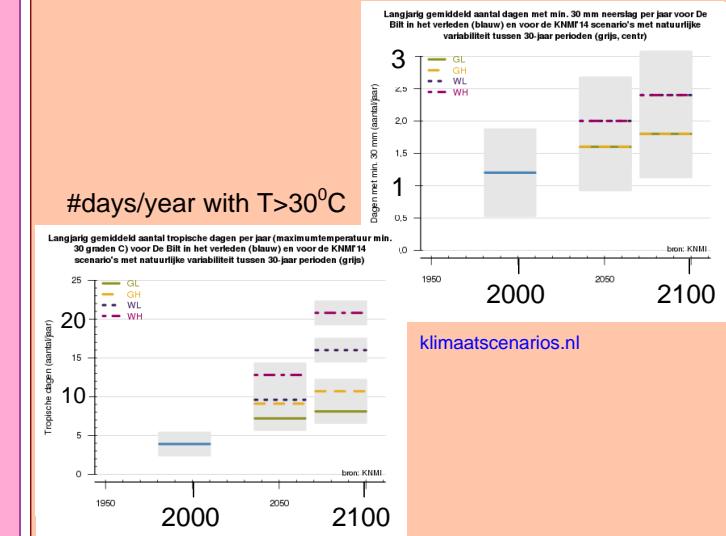
The average temperature on earth has been rising. This rise has accelerated since the 1960s. Local temperature changes vary a lot. The arctic areas have warmed much more

5**sea water level**

Combination of melting land ice and increasing sea water temperature will increase sea water level. In a few centuries this increase can be tens of meters

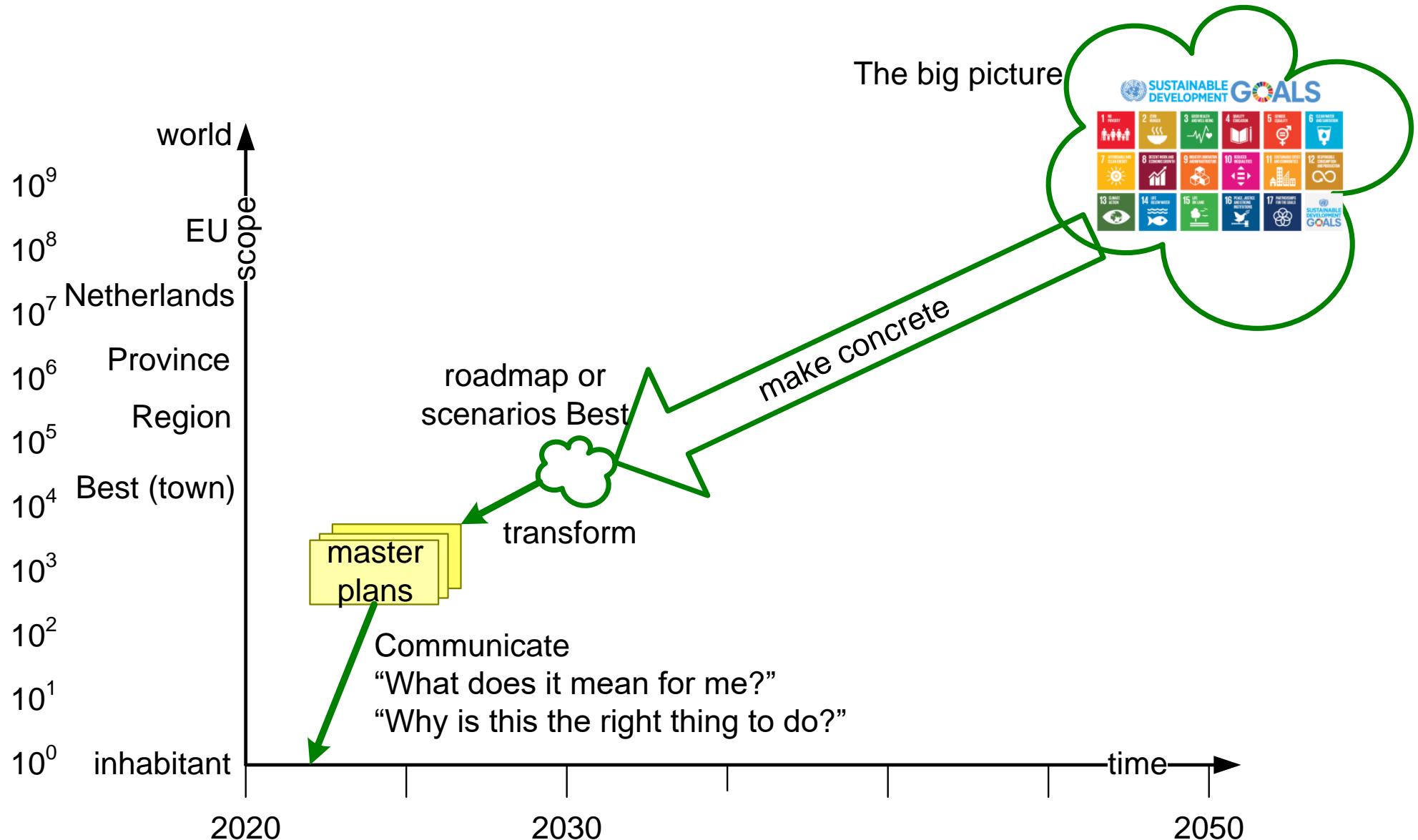
6**extreme weather**

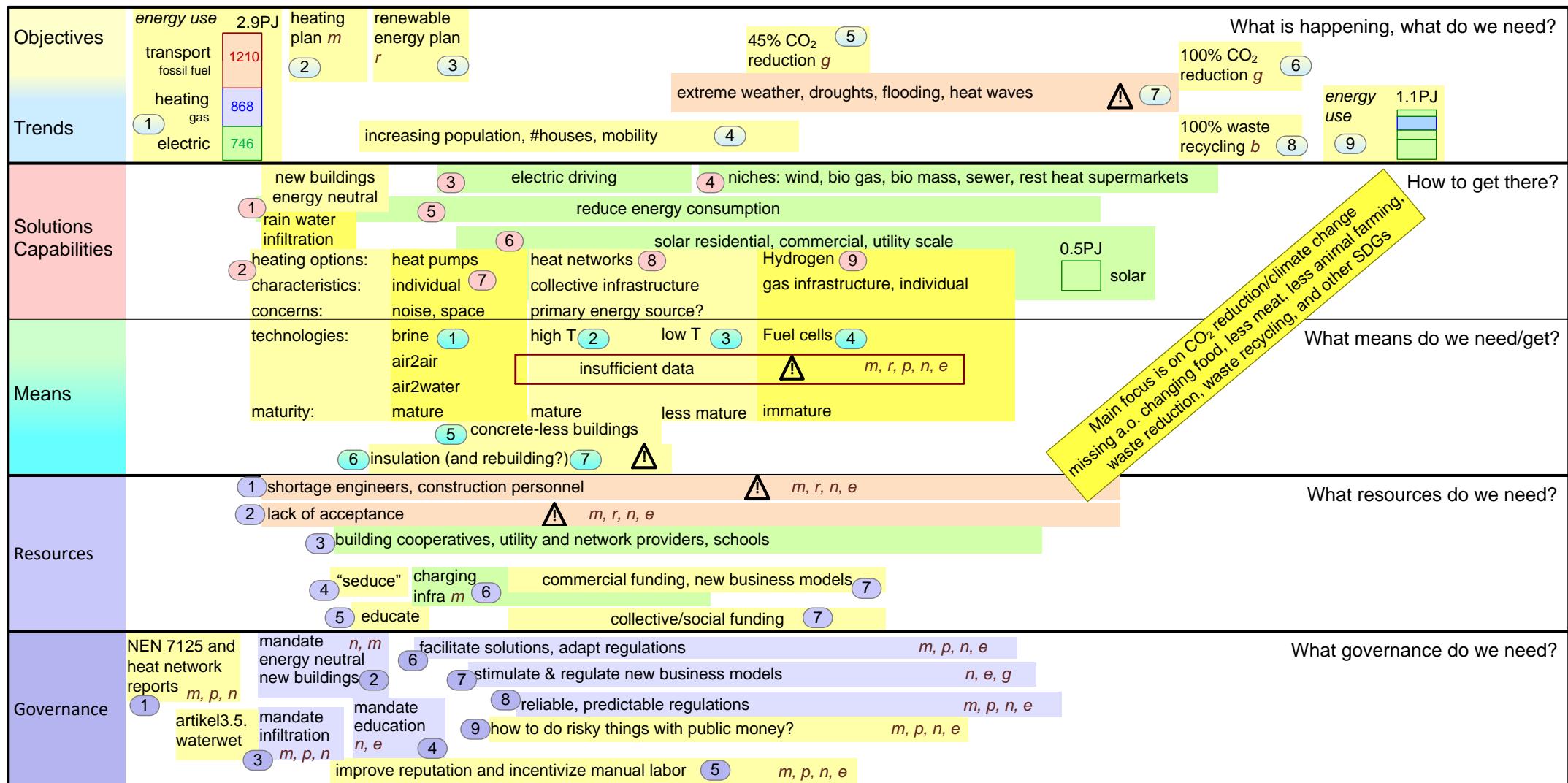
#days/year with >30mm rain



Oceans affect the local climates to a large degree. We can expect more extreme weather, e.g. droughts & tropical rain

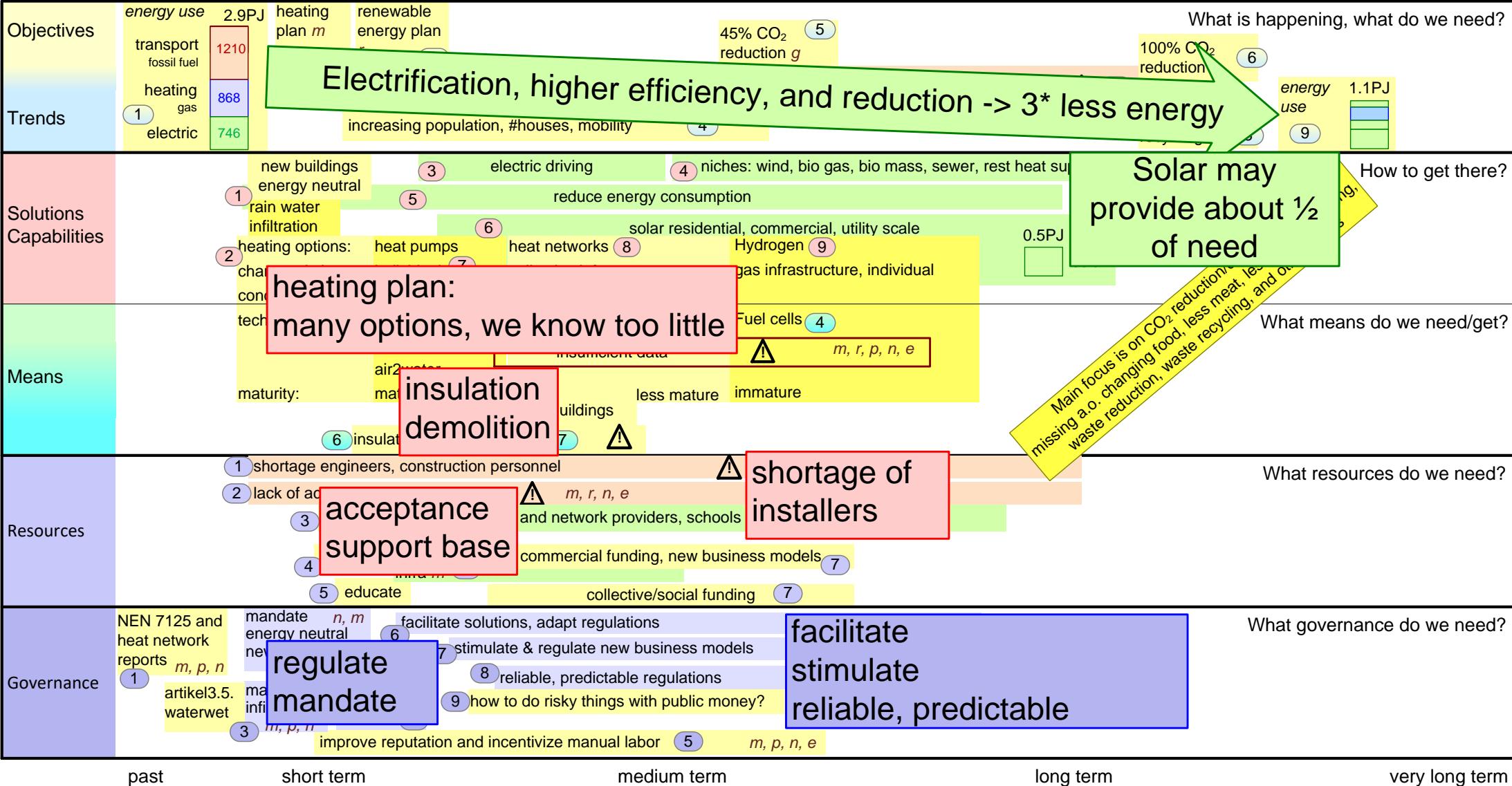
Transform Strategy into Individual Action



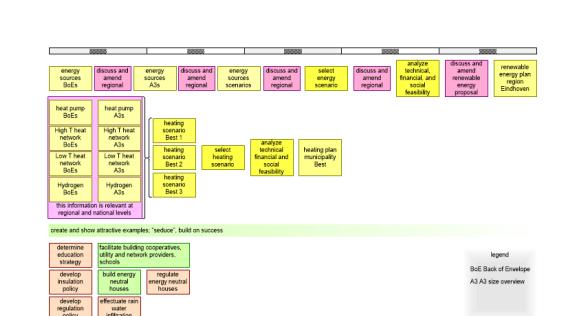
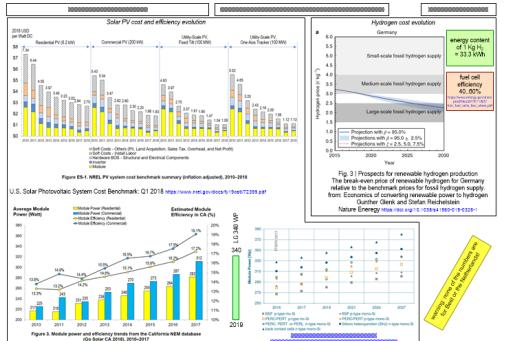
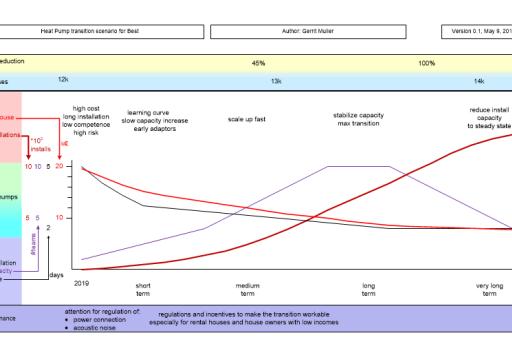
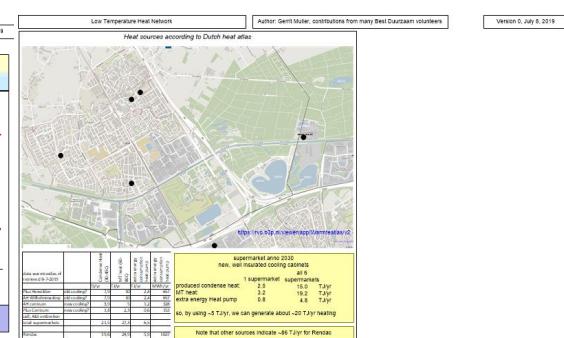
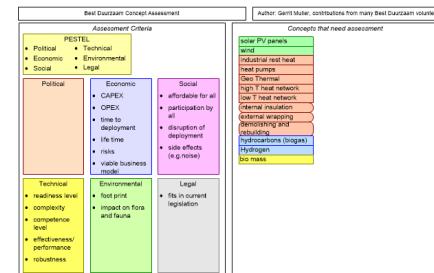
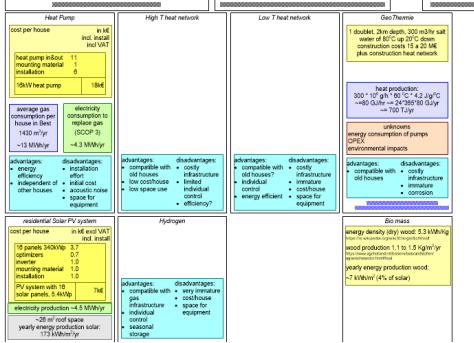
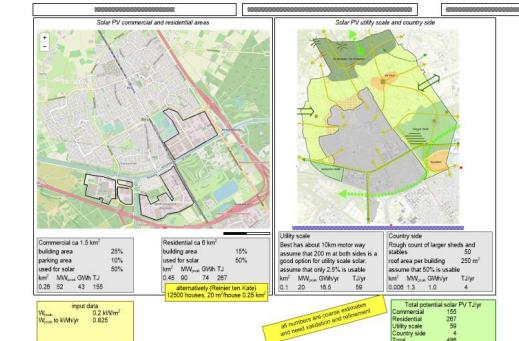
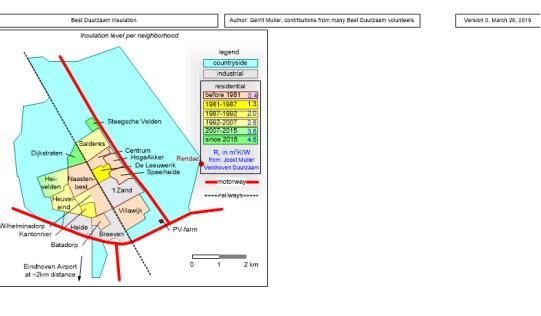
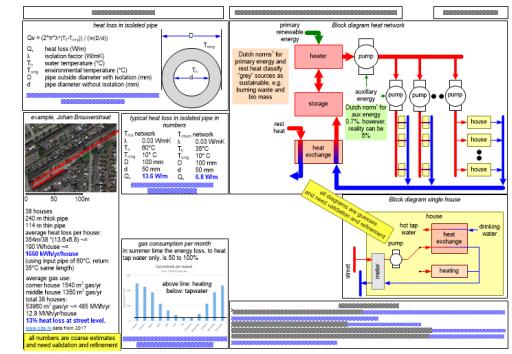
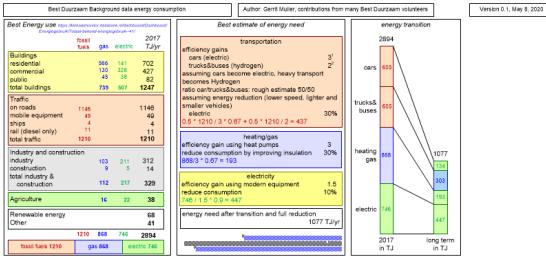
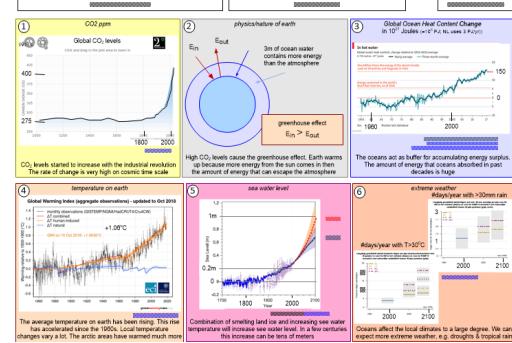


past short term medium term long term very long term

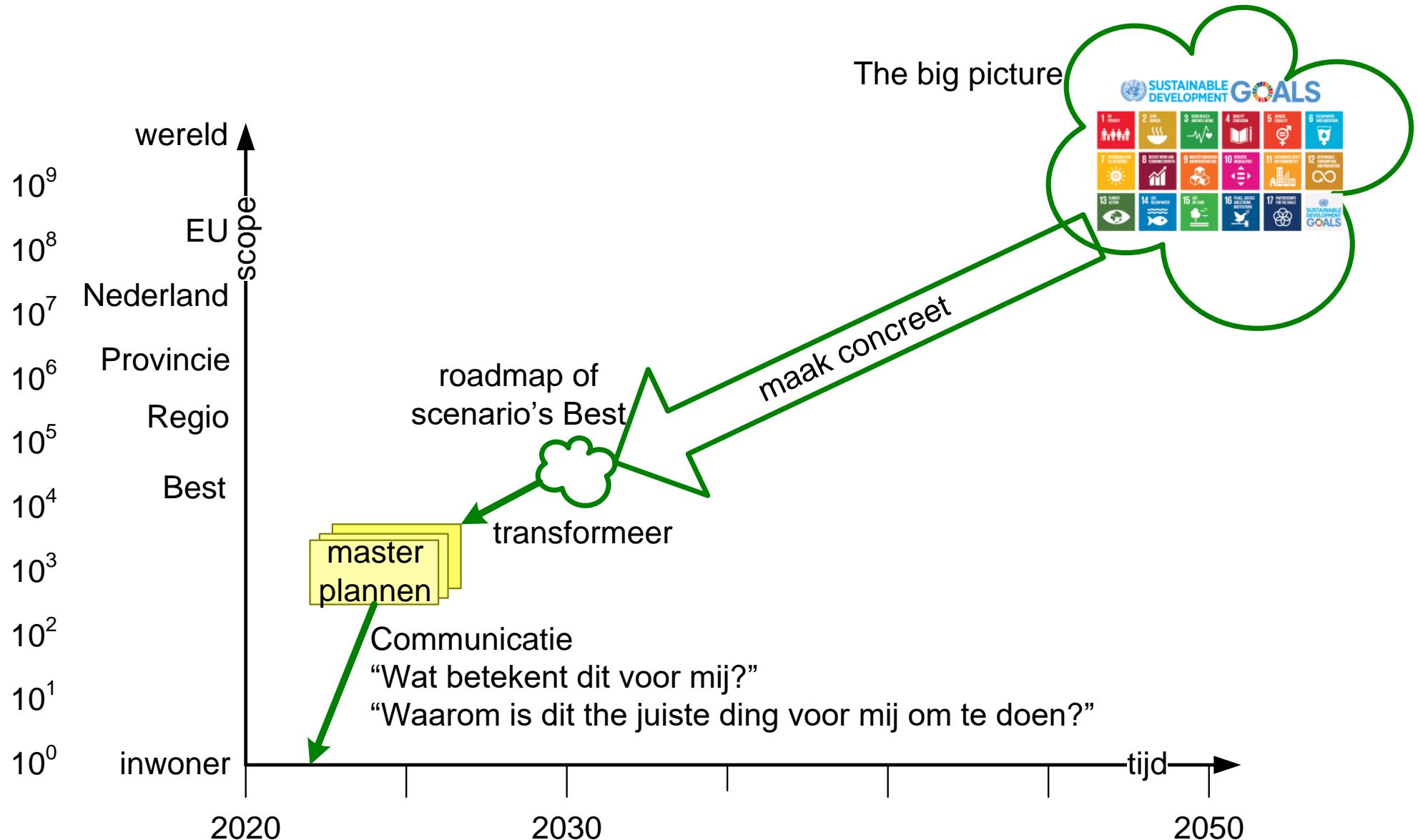
1 energy use 2017	1 make all new developments sustainable	1 air2air for heating is efficient; how to get tap water?	1 action plan to attract and educate	1 7125 and reports overrate sustainability of bio mass and rest heat sources; lack absolute data	legend <i>b</i> Best Duurzaam <i>m</i> municipality <i>r</i> regional <i>p</i> province <i>n</i> national <i>e</i> Europe <i>g</i> global
2 mandatory 2020 heating plan per neighborhood	2 selection of options for heating plan	2 compatible with older houses; challenge data is not public due to commercial interests	2 involve, engage, seduce, incentivize	2 ASAP! waiting increases problem	
3 mandatory 2021 regional	3 niche solutions in Best	3 efficient allows re-use of any rest heat; storage is the big challenge	3 roadmap and master plan to coordinate	3 vng.nl/3-gemeentelijke-watertaken; should be standard operation when maintaining streets	
4 small increase per year	5 reducing energy consumption is must	4 source to use little efficient; solves seasonal storage; production infrastructure expensive	4 more effective than enforcement	4 how to do this effectively?	
5 IPCC 2018	6 all forms of solar may result in 0.5 PJ/yr	5 concrete is major CO ₂ producer	5 primary, secondary schools; avoid overload	5 culturally ingrained	
6 IPCC 2018	7 mature; noise, space is concern	6 insulation is first step; external insulation needed?	6 enable electric driving	6 agile (fast response) governance	
7 may increase energy use	8 few rest heat sources; large collective infrastructure investment	7 when is rebuilding better (justified and acceptable)	7 be creative to get economy and funding working	7 facilitate and regulate	
8	9 long-term option; re-use gas infra			8 past pitfall; blocks investments	
9 energy use after full electrification and some reduction				9 major dilemma for 6, 7, and 8	

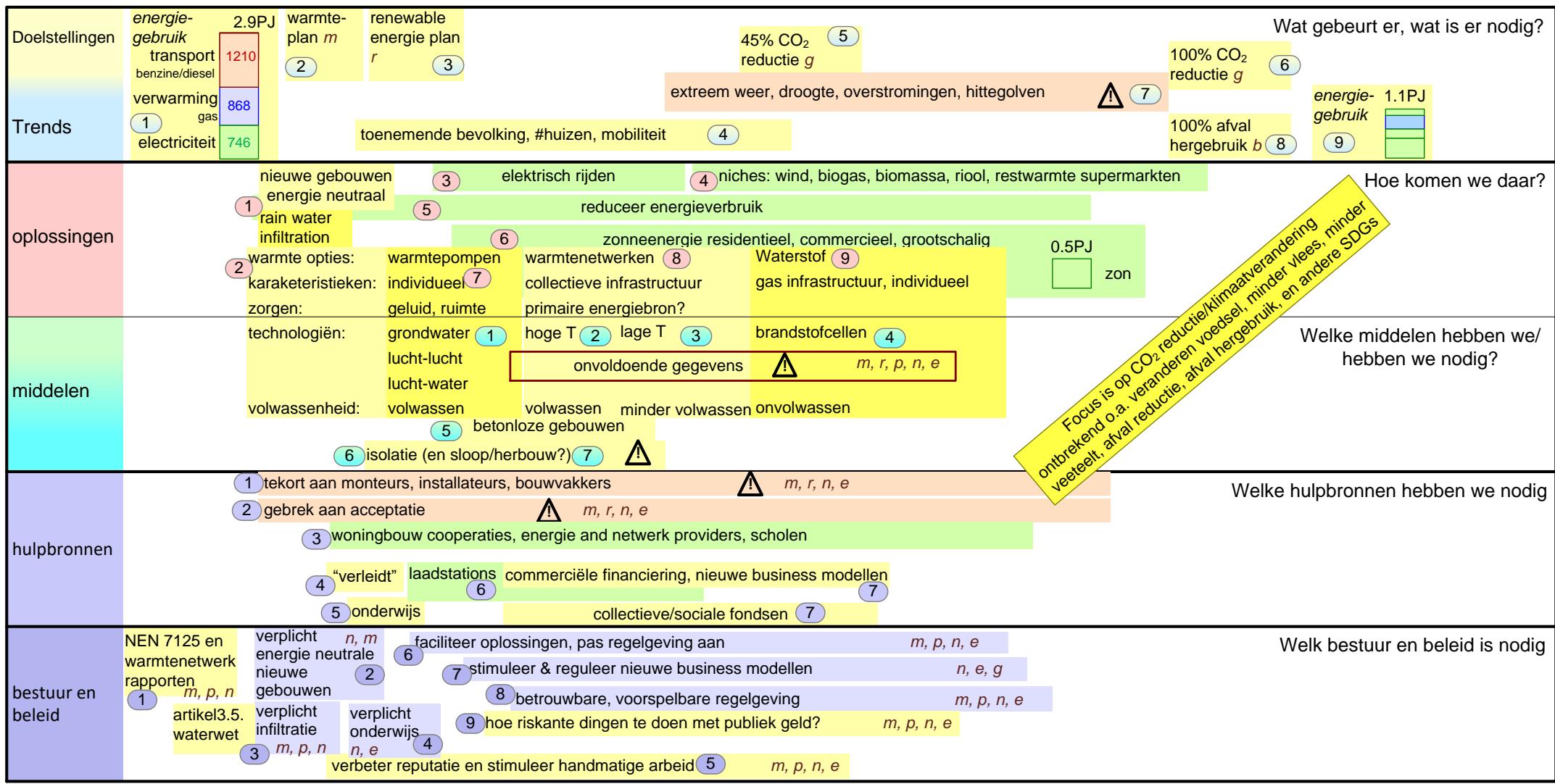


Best Duurzaam A3s to Support the Roadmap Creation



Transformeer Strategie in Individuele Actie





verleden

korte termijn

middellange termijn

lange termijn

zeer lange termijn

1 energiegebruik in 2017

2 verplicht 2020 warmteplan per wijk

3 verplicht 2021 regionaal

4 kleine toename per jaar

5 IPCC 2018

6 IPCC 2018

7 kan energieverbruik verhogen

8 9 energiegebruik na volledige elektrificatie en enige reductie

1 maak alle nieuw ontwikkelingen duurzaam

2 selecteer opties voor het warmteplan

3 transport is grootste CO₂ producent

4 niche oplossingen in Best

5 reduceren energiegebruik moet

6 alle vormen van samen leveren 0.5 TJ/yr

7 volwassen; zorgen zij geluid en ruimte

8 weinig restwarmtebronnen; grote collectieve infrastructuur investering

9 lange termijn optie; hergebruik gas infra

1 lucht-lucht voor verwarming is efficient; hoe krijgen we warmwater?

2 compatibel met oude huizen; uitdaging data is niet publiek door commerciële belangen

3 efficiënt maakt herbgebruik van restwarmte mogelijk; opslag is de grote uitdaging

4 weinig efficiënt van bron tot gebruik; oplossing voor seizoensvariatie; productie infrastructuur is duur

5 beton is grote CO₂ producent

6 isolatie is eerste stap; externe isolatie is nodig?

7 wanneer is herbouw beter (verantwoord&acceptabel)

1 aktieplan aantrekkelijkheid en onderwijs

2 betrek, verleid en stimuleer

3 roadmap en master plan voor coordinatie

4 dit is effectiever dan dwang

5 basis en middelbare scholen;

6 vermijd overdriven en overladen

7 voorwaarde voor elektrisch rijden

7 wees creatief om de economie en betaalbaarheid te bereiken

1 7125 overschat duurzaamheid van biomassa en restwarmtebronnen; gebrek aan absolute data

2 ASAPI wachten vergroot het probleem

3 vng.nl/3-gemeentelijke-watertaken; meteen meenemen bij standaardonderhoud van straten

4 hoe dit effectief te doen?

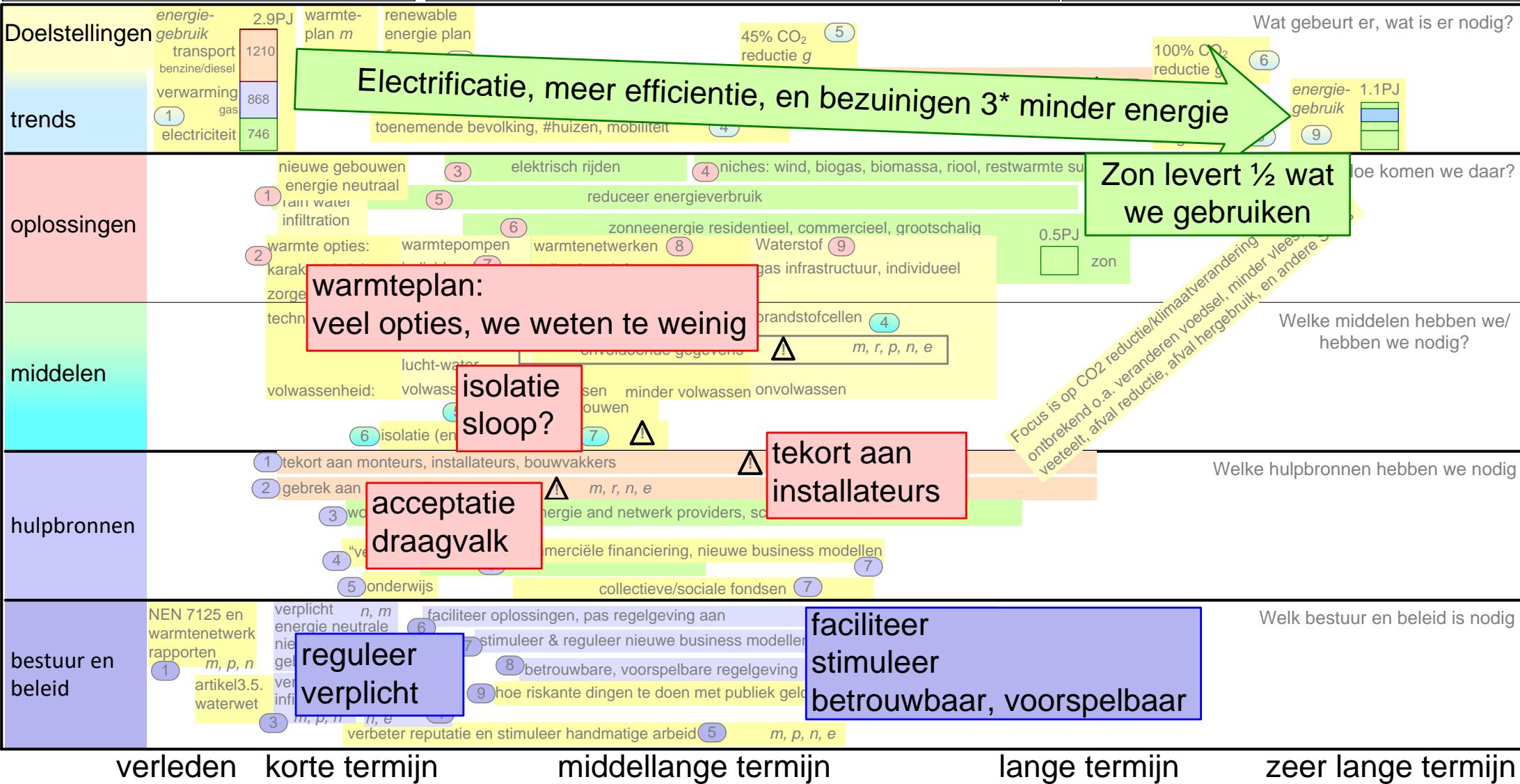
5 dit is cultureel verankerd

6 agile (snelle response) bestuur en beleid

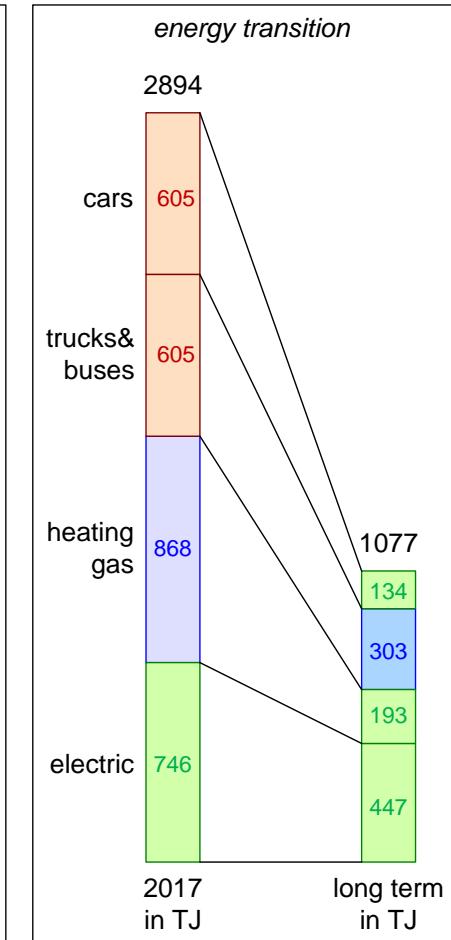
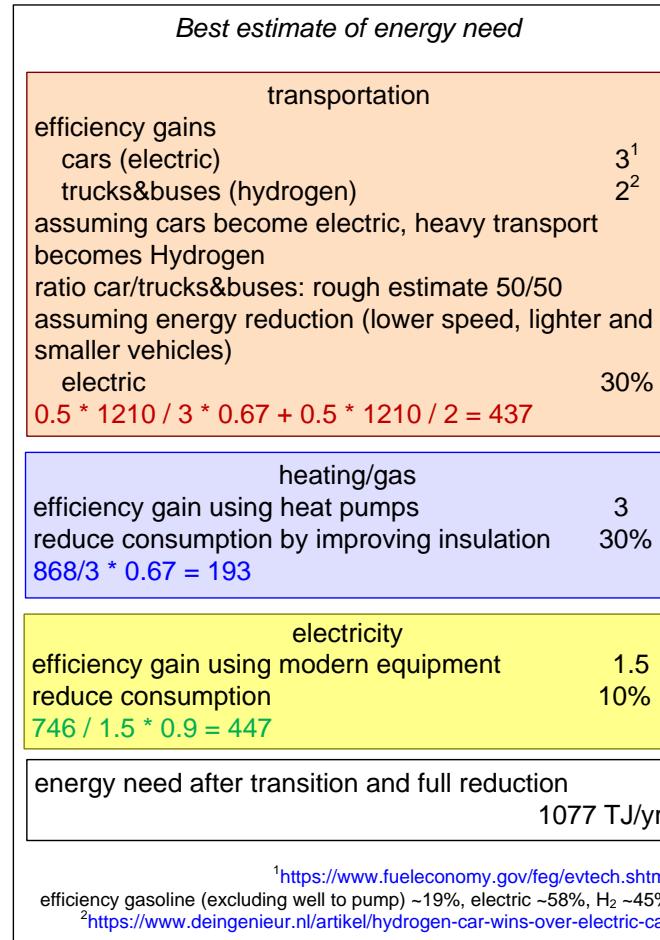
7 faciliteert en reguleert

8 valkuil uit verleden; dit blokkeert investeringen

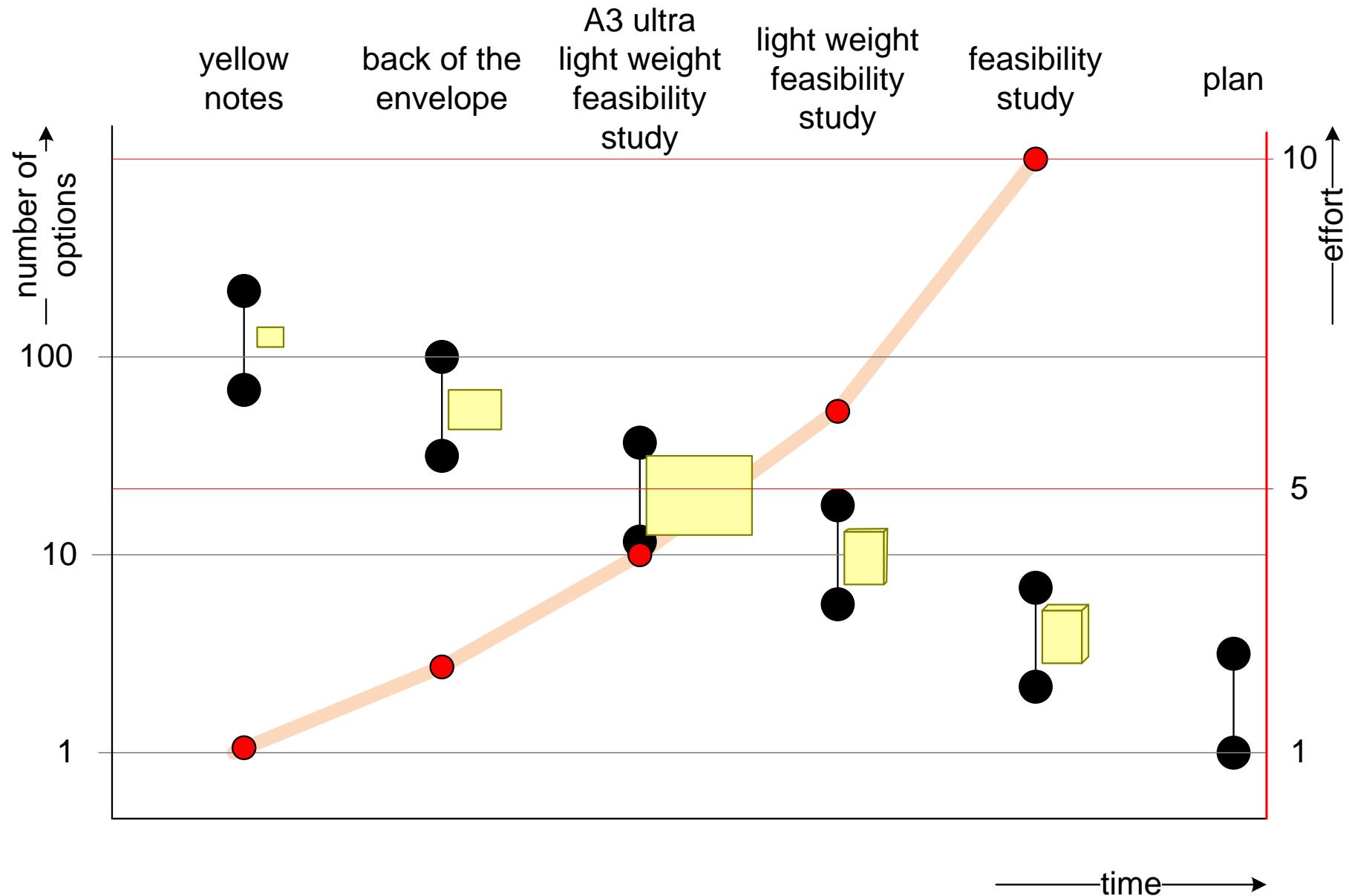
legend
b Best Duurzaam
m municipality
r regional
p province
n national
e Europe
g global

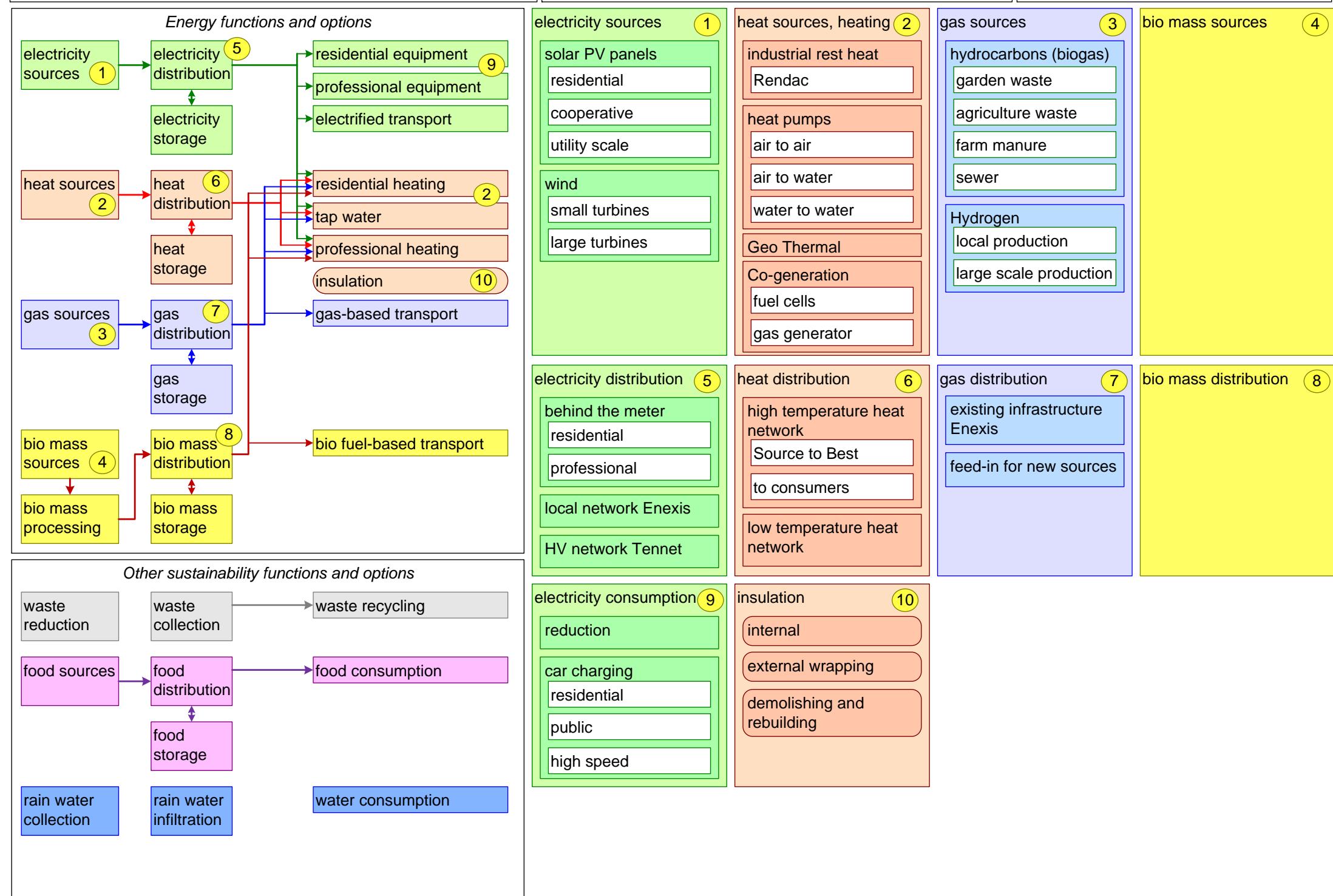


Best Energy use https://klimaatmonitor.databank.nl/dashboard/Dashboard/Energiegebruik/Totaal-bekend-energiegebruik--41/			
	fossil fuels	gas	electric
	2017 TJ/yr		
Buildings			
residential	566	141	702
commercial	130	328	427
public	45	38	82
total buildings	739	507	1247
Traffic			
on roads	1146		1146
mobile equipment	49		49
ships	4		4
rail (diesel only)	11		11
total traffic	1210		1210
Industry and construction			
industry	103	211	312
construction	9	5	14
total industry & construction	112	217	329
Agriculture	16	22	38
Renewable energy			68
Other			41
	1210	868	746
	2894		
fossil fuels	1210	gas 868	electric 746



Funnel from Ideas to Decisions





*Assessment Criteria***PESTEL**

- Political • Technical
- Economic • Environmental
- Social • Legal

Political**Economic**

- CAPEX
- OPEX
- time to deployment
- life time
- risks
- viable business model

Technical

- readiness level
- complexity
- competence level
- effectiveness/ performance
- robustness

Environmental

- foot print
- impact on flora and fauna

Social

- affordable for all
- participation by all
- disruption of deployment
- side effects (e.g.noise)

Legal

- fits in current legislation

Concepts that need assessment

- solar PV panels
- wind
- industrial rest heat
- heat pumps
- Geo Thermal
- high T heat network
- low T heat network
- internal insulation
- external wrapping
- demolishing and rebuilding
- hydrocarbons (biogas)
- Hydrogen
- bio mass

Heat Pump

cost per house	in k€ incl. install incl VAT
heat pump in&out	11
mounting material	1
installation	6
16kW heat pump	18k€

average gas consumption per house in Best	electricity consumption to replace gas (SCOP 3)
1430 m ³ /yr ~13 MWh/yr	~4.3 MWh/yr

advantages:	disadvantages:
<ul style="list-style-type: none"> • energy efficiency • independent of other houses 	<ul style="list-style-type: none"> • installation effort • initial cost • acoustic noise • space for equipment

*High T heat network**Low T heat network**GeoThermie*

1 doublet, 2km depth, 300 m³/hr salt water of 80°C up 20°C down construction costs 15 a 20 M€ plus construction heat network

heat production:
 $300 * 10^6 \text{ g/h} * 60^\circ\text{C} * 4.2 \text{ J/g}^\circ\text{C}$
 $\approx 80 \text{ GJ/hr} \approx 24 * 365 * 80 \text{ GJ/yr}$
 $\approx 700 \text{ TJ/yr}$

unknowns
energy consumption of pumps
OPEX
environmental impacts

advantages:	disadvantages:
<ul style="list-style-type: none"> • compatible with old houses • low cost/house • low space use 	<ul style="list-style-type: none"> • costly infrastructure • limited individual control • efficiency?

<https://www.nrc.nl/nieuws/2019/06/14/een-waterput-om-je-huis-te-verwarmen-a3963783>

residential Solar PV system

cost per house	in k€ excl VAT incl. install
16 panels 340kWp	3.7
optimizers	0.7
inverter	1.0
mounting material	1.0
installation	1.0
PV system with 16 solar panels, 5.4kWp	7k€

electricity production ~4.5 MWh/yr

~26 m² roof space
yearly energy production solar:
173 kWh/m²/yr

Hydrogen

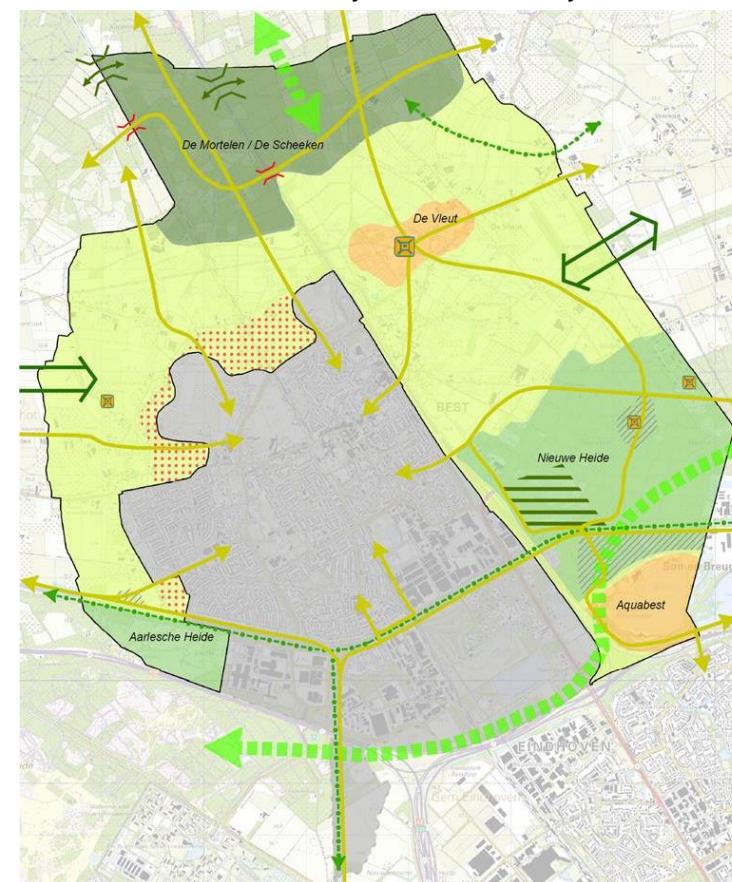
advantages:	disadvantages:
<ul style="list-style-type: none"> • compatible with gas infrastructure • individual control • seasonal storage 	<ul style="list-style-type: none"> • very immature • cost/house • space for equipment

Bio mass

energy density (dry) wood: 5.3 kWh/Kg
<https://nl.wikipedia.org/wiki/Energiedichtheid>

wood production 1.1 to 1.5 Kg/m²/yr
<https://www.agriholland.nl/dossiers/biobrandstoffen/agrarischesesector.html#hout>

yearly energy production wood:
~7 kWh/m² (4% of solar)

Solar PV commercial and residential areas*Solar PV utility scale and country side***Utility scale**

Best has about 10km motor way
assume that 200 m at both sides is a
good option for utility scale solar.
assume that only 2.5% is usable

km ²	MW _{peak}	GWh/yr	TJ/yr
0.1	20	16.5	59

Country side

Rough count of larger sheds and stables	50		
roof area per building	250 m ²		
assume that 50% is usable			
km ²	MW _{peak}	GWh/yr	TJ/yr
0.006	1.3	1.0	4

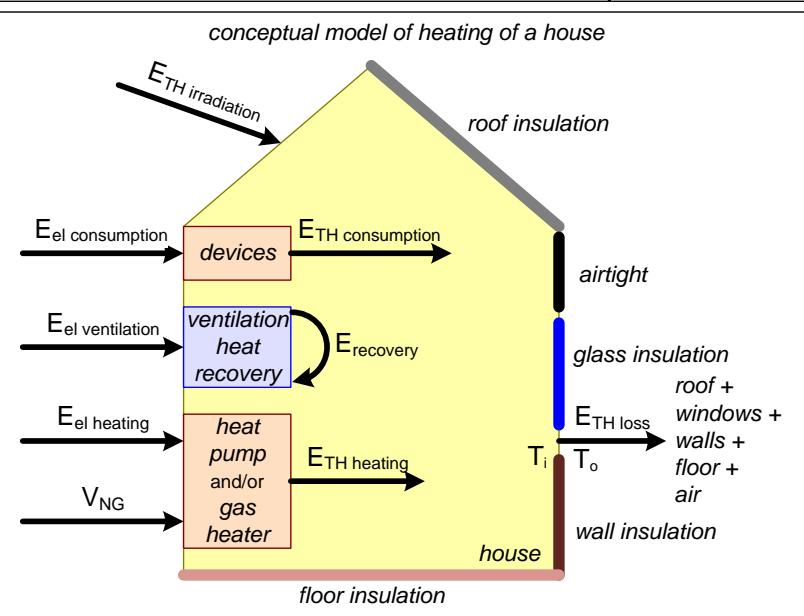
input data

W _{peak}	0.2 kW/m ²
W _{peak} to kWh/yr	0.825

all numbers are coarse estimates
and need validation and refinement

Total potential solar PV TJ/yr

Commercial	155
Residential	267
Utility scale	59
Country side	4
Total	486



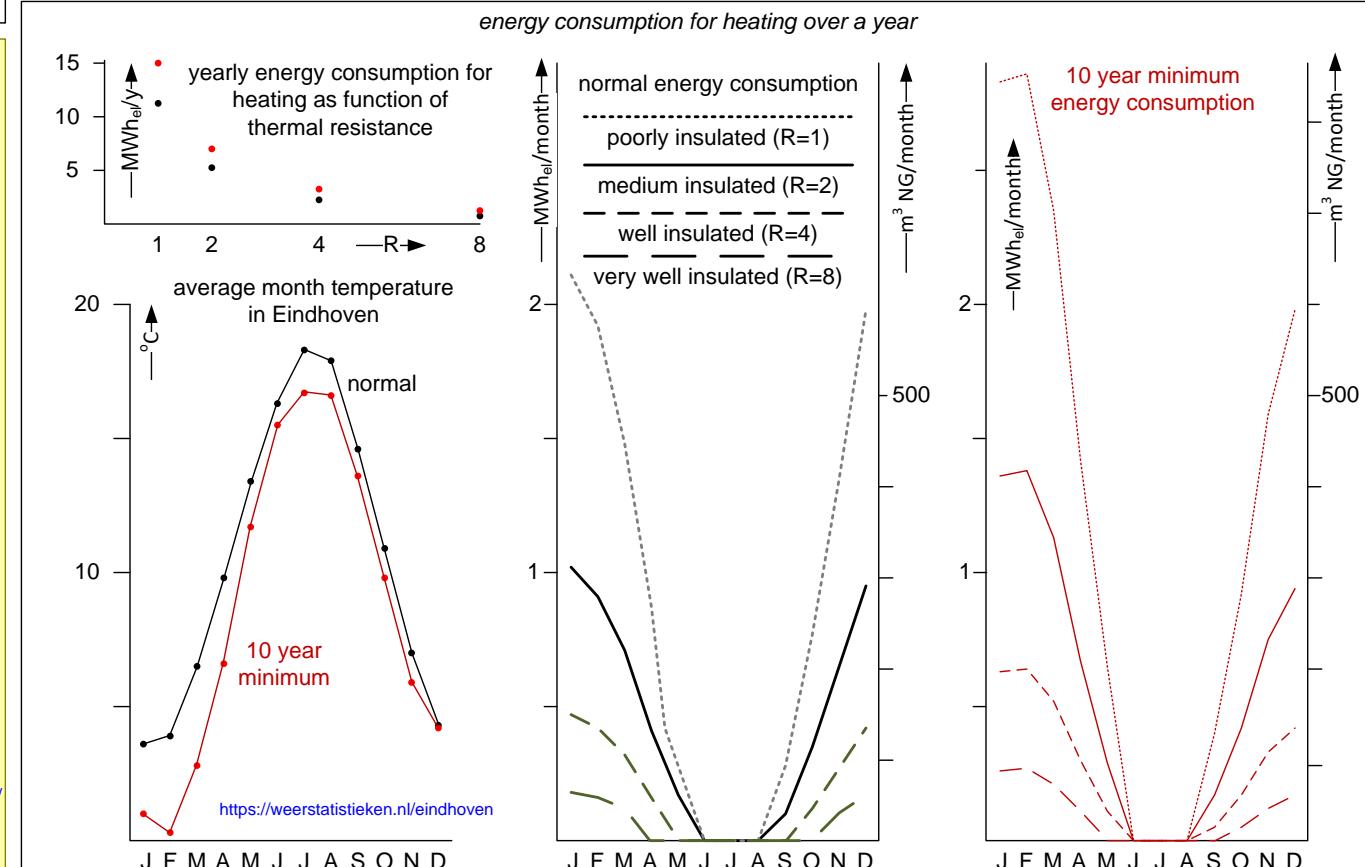
the related formulas

gas heater E_{TH} heating $\approx V_{NG} [m^3] * 10 \text{ kWh}$
heat pump E_{TH} heating $= \text{COP}(T_o) * E_{el}$ heating
 $\text{COP}(T_o) = c_a * T_o + c_b$
 E_{TH} consumption $= C_{th} * E_{el}$ consumption
 $\Delta T = T_i - T_o$
 E_{TH} heating $= E_{TH}$ loss - E_{TH} consumption
 E_{TH} loss $= C_{loss} * \Delta T * t$

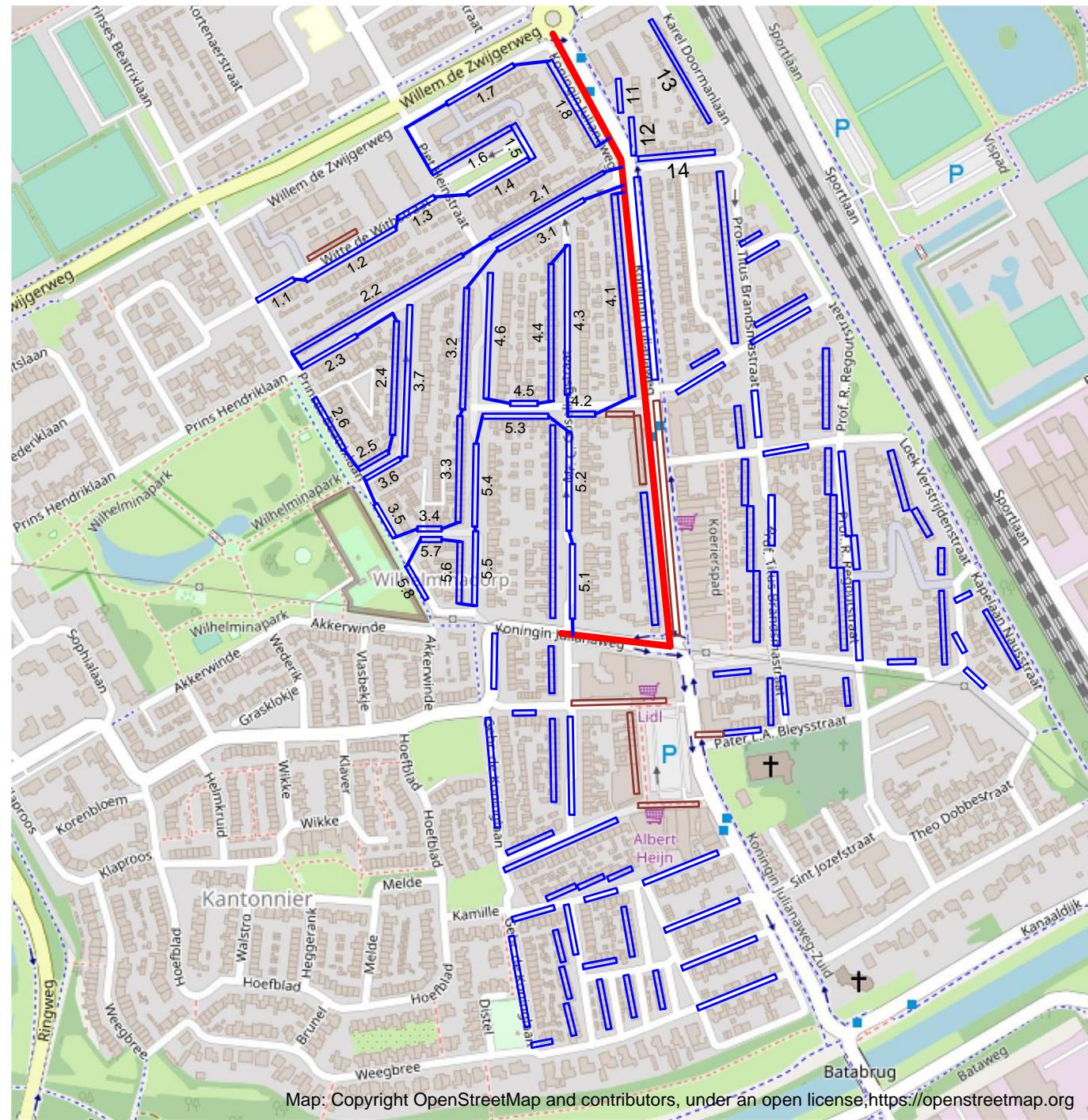
insulation thermal resistance		
material	λ W/mK	R_{5cm} m ² K/W
PUR (wall)	0.023	2.2
PUR (roof)	0.028	1.8
glass wool	0.035	1.43
wood	0.18	0.28
concrete/stone	1.5	0.03
glass	U	R _{glass}
single	5.8	0.18
double	2.8	0.33
double HR++	1.1	0.83
triple HR++	0.5	1.6
poor insulation R ≈ 1		
• e.g. 3 cm glass wool; • build before 1987		
medium insulation R ≈ 2		
• e.g. 6 cm glass wool; • 1987-2007		
well insulated, R ≈ 4		
• e.g. 10 cm PUR; • 2007-present		
very well insulated, R ≈ 8		
• e.g. 20 cm PUR • not mandatory yet		
https://bouw-energie.be/nl-be/bereken/r-waarde-isolatie		
https://glassterstelhermans.nl/isolatiewaarde-glas/		

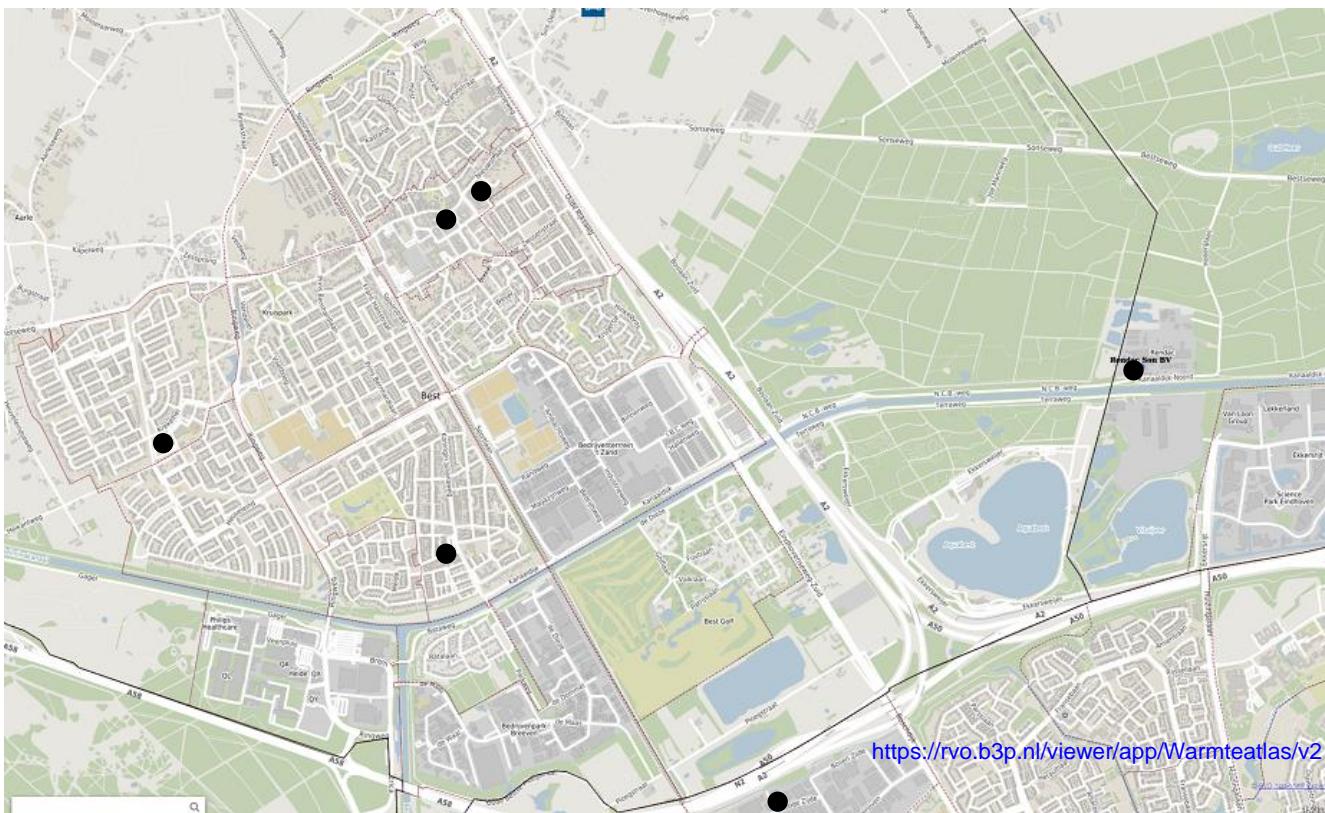
estimating C_{loss} for a medium isolated house based on data of Gerrit's house

January 2021	month [MWh]	E_{el} total = 1.56
	hour [kWh]	E_{el} total = 2.09
		E_{el} consumption = 0.3
		E_{el} heating = 1.44
		E_{TH} heating = 3.63
		$C_{loss} = 0.244$ kWh _{TH} °C ⁻¹ hr ⁻¹



section	total houses	total thick pipe (m)	total thin pipe (m)	energy for heating and tapwater MWh/yr	total loss/yr/ house MWh/yr	loss as percentage
1.total	48	677	249	1053	1,99	16%
2.total	38	689	258	1093	1,97	15%
3.total	40	685	249	1049	2,01	16%
4.total	31	728	276	1171	1,95	15%
5.total	35	609	255	1062	1,82	15%
total	192	3388	1287	5428		



Heat sources according to Dutch heat atlas

data warmteatlas.nl retrieved 8-7-2019		Condense Heat (30-45C)	MT heat (60-80C)	extra energy consumption heat pump	extra energy consumption heat pump
		TJ/yr	TJ/yr	TJ/yr	MWh/yr
Plus Heivelden	old cooling?	7,9	10	2,4	657
AH Wilhelminadorp	old cooling?	7,9	10	2,4	657
AH centrum	new cooling?	3,9	5	1,2	328
Plus Centrum	new cooling?	1,8	2,3	0,6	153
Lidl, Aldi ontbreken					
total supermarkets		21,5	27,3	6,5	
Rendac		19,6	24,9	5,9	1637

supermarket anno 2030
new, well insulated cooling cabinets

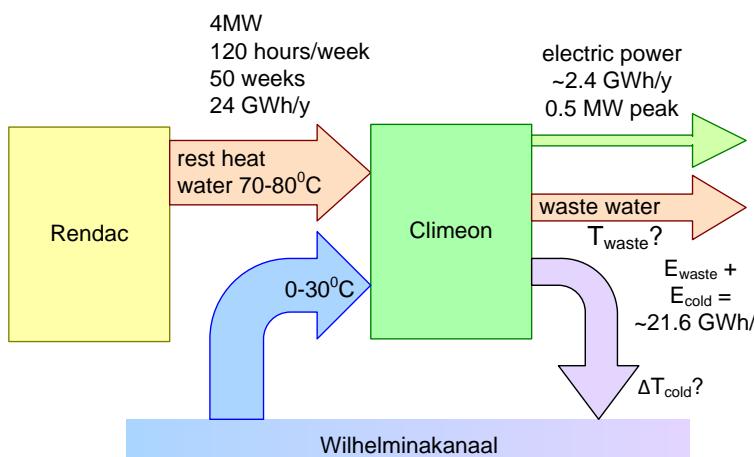
all 6
1 supermarket supermarkets

produced condense heat:	2.5	15.0	TJ/yr
MT heat:	3.2	19.2	TJ/yr
extra energy Heat pump	0.8	4.8	TJ/yr

so, by using ~5 TJ/yr, we can generate about ~20 TJ/yr heating

Note that other sources indicate ~86 TJ/yr for Rendac

1 System level block diagram

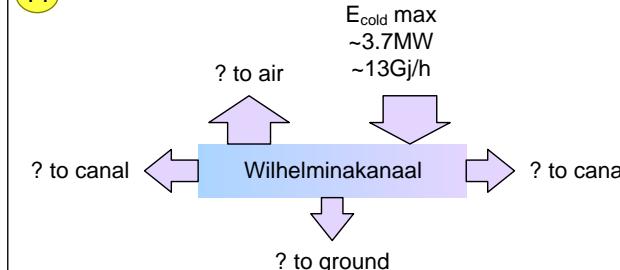


10 Assumptions, limitations

ignored:

- Operational cost
- effect of climate change (higher temperatures)
- warming up of Wilhelminakanaal
- energy use of auxiliary systems
- potential subsidies

11 Where does the heat go that flows back into the canal?



Explanations

This A3 explores how the Climeon system may transform rest heat into electricity at Rendac in Son. Purpose is to understand this option and to find out what questions we need to ask. Feedback is welcome. Blame Gerrit for mistakes.

- 1 provides a high level block diagram of the concept
- How does the rest heat leave the system? How much is hot waste water, how much is the cold water warmed up?

2 the efficiency of the Climeon system depends on t_{hot} and t_{cold}

3 the P_{out} also depends on t_{hot} and t_{cold}

4 We need the efficiency and P_{out} @ $t_{hot} = 70.80^{\circ}\text{C}$ as function of t_{cold} between 0 and 30°C , we derived a linear relation from 2 and 3

5 KNMI.nl provides the temperature per month for the regio Eindhoven we assume that the water temperature follows the air temperature

6 Combining 4 and 5, with the data from 1 gives the energy per month

7 cumulating all months in 6 gives the produced electric energy per year

8 we use 4 to calculate the required #modules at worst case conditions, which is when $t_{cold} = 30^{\circ}\text{C}$; it also shows E_{month} @ 30°C

9 cost = #modules * cost/module + installation cost
income per year = $E_{year} * price_{kWh}$
ROI = cost / income per year

10 we have simplified a lot, here are some limitations

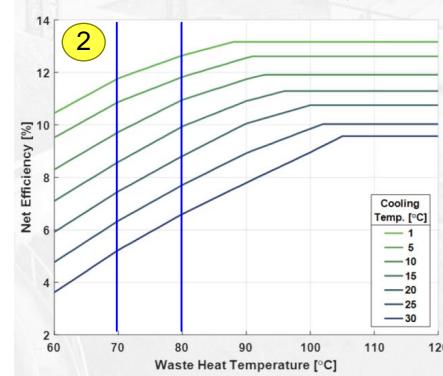
11 warming up of the canal has a big impact on environment and efficiency of the solution. Where does all the remaining heat go?

12 to get a feel for the impact, we estimate how much a stretch of 100m of the canal gets warmer per hour or per day, if all rest heat stays in the that part of the canal.

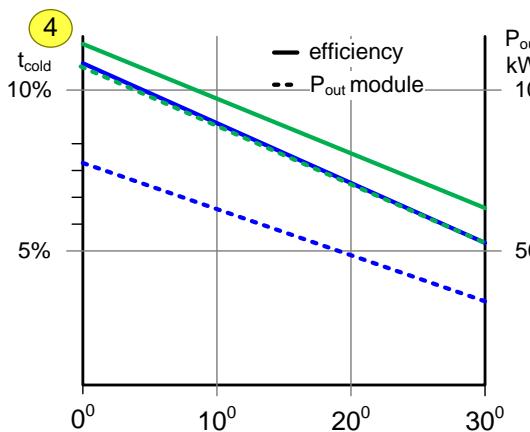
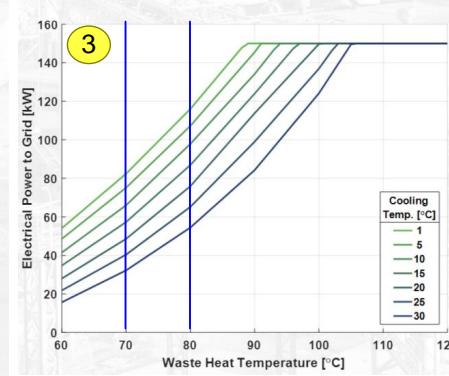
13 shows the impact of canal water that is 3°C warmer than the average air temperature

Climeon data from <https://climeon.com/wp-content/uploads/2017/04/Climeon-Tech-Product-Sheet.pdf>

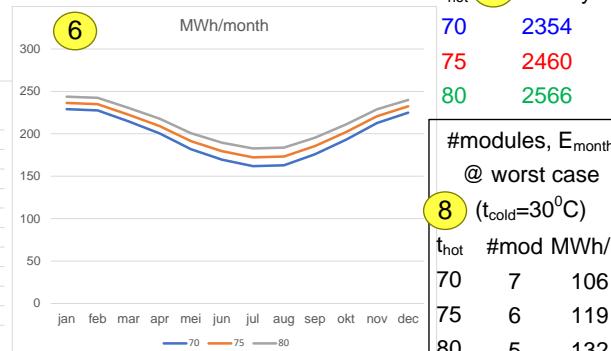
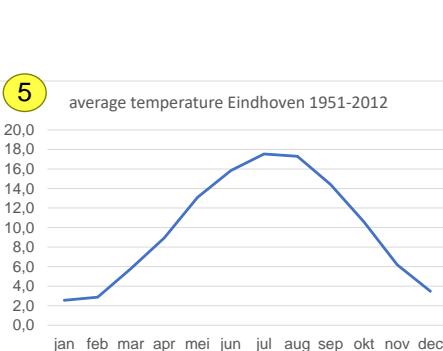
NET EFFICIENCY @ 40 l/s hot volume flow, 150 kW module



OUTPUT @ 40 l/s hot volume flow, 150 kW module



Electricity production in Eindhoven area

7 t_{hot} MWh/y

70 2354

75 2460

80 2566

#modules, E_{month} @ worst case t_{hot} #mod MWh/m

70 7 106

75 6 119

80 5 132

income k€/y

ROI years

70 2750 118 23.3

75 2400 123 19.5

80 2050 128 16.0

9 Cost and Income

Cost/module 350 k€

install cost (wild guess GM) 300 k€

electricity price 0.05€/kWh

What if t_{cold} is 3 degrees warmer?

13 income k€/y ROI years

70 2193 109 25.2

75 2306 115 20.9

80 2402 120 17.1

this stretch of the channel would heat 0.8 K /hour if no heat escape or 20°C/day

It is crucial to understand how the heat dissipates via the waste water, or from the canal to air, the rest of the canal, and the ground.

1 provides a high level block diagram of the concept

How does the rest heat leave the system? How much is hot waste water, how much is the cold water warmed up?

2 the efficiency of the Climeon system depends on t_{hot} and t_{cold}

3 the P_{out} also depends on t_{hot} and t_{cold}

4 We need the efficiency and P_{out} @ $t_{hot} = 70.80^{\circ}\text{C}$ as function of t_{cold} between 0 and 30°C , we derived a linear relation from 2 and 3

5 KNMI.nl provides the temperature per month for the regio Eindhoven we assume that the water temperature follows the air temperature

6 Combining 4 and 5, with the data from 1 gives the energy per month

7 cumulating all months in 6 gives the produced electric energy per year

8 we use 4 to calculate the required #modules at worst case conditions, which is when $t_{cold} = 30^{\circ}\text{C}$; it also shows E_{month} @ 30°C

9 cost = #modules * cost/module + installation cost
income per year = $E_{year} * price_{kWh}$
ROI = cost / income per year

10 we have simplified a lot, here are some limitations

11 warming up of the canal has a big impact on environment and efficiency of the solution. Where does all the remaining heat go?

12 to get a feel for the impact, we estimate how much a stretch of 100m of the canal gets warmer per hour or per day, if all rest heat stays in the that part of the canal.

13 shows the impact of canal water that is 3°C warmer than the average air temperature

12 Estimate of warming of canal water



$$V_{water} = 100 * 20 * 2 = 4000 \text{ m}^3$$

$$m_{water} = V_{water} * 1000 \text{ kg/m}^3$$

$$C_{water} = 4.2 \text{ J/gK}$$

$$E_{in} = 3.7 \text{ MW/h} * 3600 = 13.3 \text{ GJ}$$

$$\Delta T = P_{in} / m_{water} * C_{water}$$

$$= 13.3 * 10^9 / 4 * 10^9 * 4.2$$

$$\approx 0.8 \text{ K}$$

major technical questions:

- what is a good heat pump source
 - brine (at what depth?)
 - air conventional
 - air PVT
- what rest heat sources and how to utilize?

major technical issues

- acoustic noise heat pumps
- electric grid capacity; winter peak load
- grid resilience

major legislation issues

- allow wrapping with neighboring houses
- regulations promoting stone
- regulations for shared heat pumps
- regulations for “vereniging van eigenaren”
- supply guarantees

**social acceptance is
the major challenge**

*social economic needs*

- home owner consultancy that makes a home specific integral feasible plan that contractors can execute

social economic drivers

- comfort
- healthy inner climate
- financial incentives (prevent backfiring, e.g. just satisfying checkmarks)

social economic goals

- sustainable behavior and life style
- ownership from individuals
- inclusive engagement

social economic issues

- transition cost for home owners without own equity
- cooperative solutions (e.g. brine heat pumps, rest heat)
- system life time of intermediate steps
- installation capacity
- system life time of intermediate steps
- installation capacity

conclusions

- insulation has highest priority for existing houses
 - “in-house” from poor to medium
 - “wrapping” externally from medium to well for new houses
 - mandate R=8
 - stimulate wood i.s.o. stone and concrete
 - add ventilation heat recovery
 - long-term transition to electrical heat pumps
 - long-term heat air i.s.o. water
 - heat networks only 5th generation as niche for rest heat

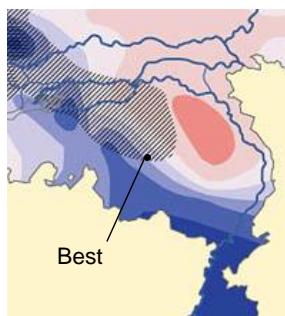
geothermal in Brabant

geothermal gradient in the Netherlands: 30 °C/km

this is low enthalpy geothermal heat

depth temp¹ Cost of drilling²

10 m	10 °C	
1 km	40 °C	1 M€
2 km	70 °C	5.5 M€
3 km	100 °C	14 M€



Temperatuur in °C

95 - 100	75 - 80
90 - 95	70 - 75
85 - 90	65 - 70
80 - 85	60 - 65

//// Hoofd-Bontzandsteen Subgroep

¹ <https://www.geologievannederland.nl/ondergrond/afzettingen-en-delfstoffen/aardwarmte>² <https://edepot.wur.nl/5772>*geothermal formulas,
technical and economic*

$$E_{th} = \Delta T * V * c_{water} * t_{duration}$$

$$c_{water} = 4.2 \text{ kJ Kg}^{-1} \text{ °C}^{-1}$$

$$\Delta T = T_{source} - T_{injected}$$

$$cost_{gas}(t) = p_{gas} * V * t$$

$$cost_{geo}(t) = CAPEX_{geo} + cost_{el}(t) + OPEX(t)$$

$$cost_{el}(t) = p_{el} * E_{el} * t$$

$$benefit(t) = cost_{gas}(t) - cost_{geo}(t)$$

$$ROI: benefit(t_{ROI}) = 0$$

concerns

- what is the environmental impact of drilling, penetrating geological layers, and extracting this amount of heat?
- detailed knowledge about geological layers is missing, resulting in drilling and exploration risks.
- brine water may contain sand and other polluting particles, increasing OPEX, decreasing reliability
- Best may lack the proper sandstone layer

conclusions

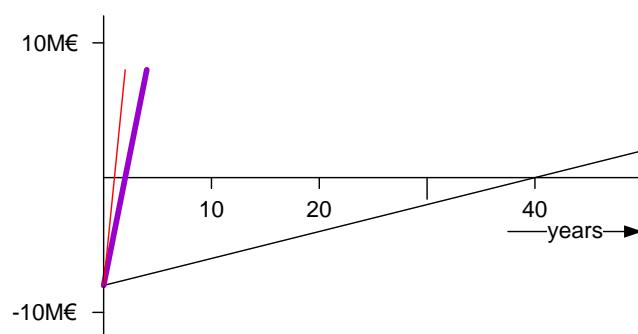
geothermal with current gas prices is obvious for agriculture

geothermal for residential heating is more challenging, because:

- needs high source temperature (=expensive)
 - requires costly heat network
 - heat network losses at high temperatures
 - mostly needed in winter months
- only relevant for high density buildings?

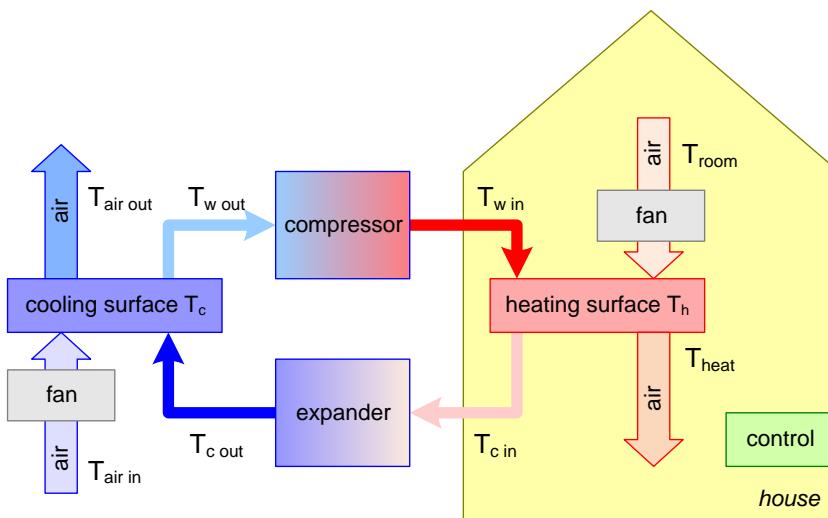
Example Case van den Bosch <https://edepot.wur.nl/5772>application: heating green houses
location: Bleiswijk, the Netherlands

depth:	per hour	per year	p _{gas} €/m ³	cost _{gas} M€/year	ROI year
	1700 m		0.1	0.4	40
temperature _{source} :	60 °C		1	4	2.2
temperature _{injected} :	30 °C		2	8	1.1
volume:	150	12000 m ³			
heat production:	5	40000 MWh _{th}			
electricity consumption:	275 kWh	2200 MWh			
COP:	18				
gas equivalent		4 * 10 ⁶ m ³			

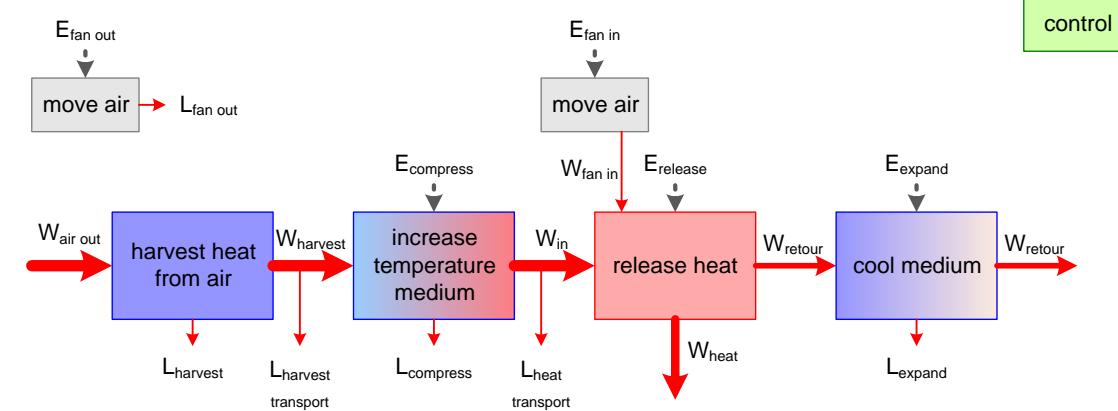
*more links (thanks to Harry Brugman)*

- https://www.youtube.com/watch?v=b_WaeH3undI
- <https://www.geothermie.nl/index.php/nl/geothermie-aardwarmte/wat-is-geothermie/22-geothermie/wat-is-geothermie/66-glastrinbouw>
- <https://www.triaswestland.nl/project/de-proefboring>
- <https://www.youtube.com/watch?v=2Yx00PHDtaQ>

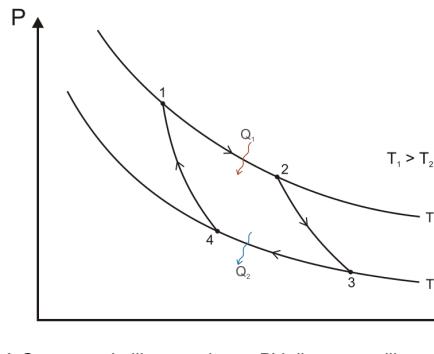
conceptual model of an air-air heat pump



functional model of an air-air heat pump



ideal thermodynamics model



A Carnot cycle illustrated on a PV diagram to illustrate the work done. 1-to-2 (isothermal expansion), 2-to-3 (isentropic expansion), 3-to-4 (isothermal compression), 4-to-1 (isentropic compression).

https://en.wikipedia.org/wiki/Carnot_cycle#/media/File:Carnot_cycle_p-V_diagram.svg
https://en.wikipedia.org/wiki/Carnot_cycle
https://en.wikipedia.org/wiki/Rankine_cycle

A Carnot cycle assumes that the temperature increase and decrease of the heat and cold reservoirs is insignificant; that is not the case for air-to-air or air-to-water heat pumps. For engines a Rankine cycle is more realistic.

in formulas

$$\eta_{ideal} = 1 - T_c / T_h$$

$$COP_{ideal} = T_h / (T_h - T_c) = W_{heat} / E_{hp}$$

<https://courses.lumenlearning.com/atd-austincc-physics1/chapter/15-5-applications-of-thermodynamics-heat-pumps-and-refrigerators/>

E_{hp} = the thermodynamic energy that we need to add during the cycle $\sim E_{compress}$

$$E_{hp} = W_{heat} / COP_{ideal}$$

E_{extra} = all energy that we need to add to really make the cycle work, e.g. for the fans, pumps, and controls. We also add energy to compensate for all losses.

E_{in} = the total electric energy going into the heat pump

$$E_{in} = E_{hp} + E_{extra}$$

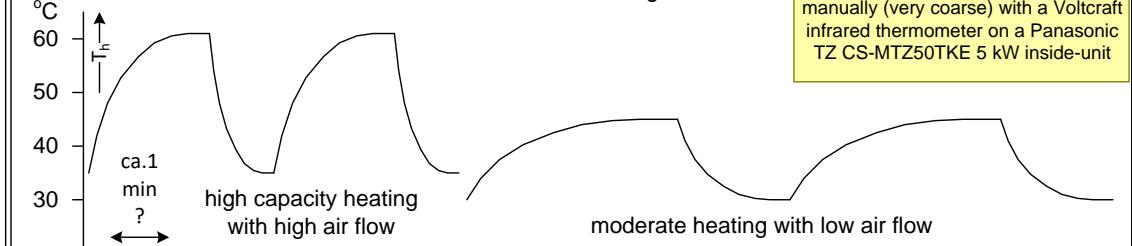
W_{heat} = the energy actually heating the house

W_{air} = the energy harvested from the air

$$W_{air} = W_{heat} - E_{in}$$

$$COP_{real} = W_{heat} / (E_{hp} + E_{extra})$$

measurements of heating surface



$$COP_{flyer} = 5$$

$$@T_c = 7^\circ\text{C} (308\text{K}), T_h = 35^\circ\text{C} (=280\text{K})$$

assuming

$$W_{heat} = 5\text{kW}$$

gives

$$COP_{ideal} = 308 / 28 = 11$$

$$E_{hp} = 5 / 11 \sim 0.45\text{kW}$$

$$E_{in} = 1\text{kW}$$

$$E_{extra} = 1 - 0.45 \sim 0.55\text{kW}$$

$$W_{air} = 4\text{kW}$$

other use cases assume E_{extra} constant

quantified exploration

flyer

$$@T_c = 7^\circ\text{C}$$

$$T_h = 35^\circ\text{C}$$

$$COP = 5$$

$$\begin{matrix} E_{hp} & 0.45\text{kW} \\ E_{extra} & 0.55\text{kW} \end{matrix}$$

$$\begin{matrix} W_{air} & 4.5\text{kW} \\ E_{extra} & 0.55\text{kW} \end{matrix}$$

$$\begin{matrix} W_{air} & 3.25\text{kW} \\ W_{heat} & 5\text{kW} \end{matrix}$$

cold

$$@T_c = -20^\circ\text{C}$$

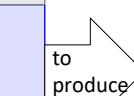
$$T_h = 60^\circ\text{C}$$

$$COP = 2.86$$

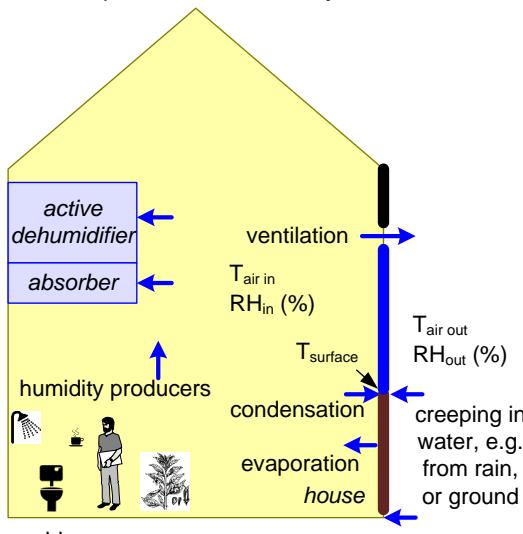
$$\begin{matrix} E_{hp} & 1.2\text{kW} \\ E_{extra} & 0.55\text{kW} \end{matrix}$$

$$\begin{matrix} W_{air} & 0.71\text{kW} \\ E_{extra} & 0.55\text{kW} \end{matrix}$$

$$\begin{matrix} W_{air} & 3.75\text{kW} \\ W_{heat} & 5\text{kW} \end{matrix}$$



conceptual model of humidity flow of a house



problem:
condensation of water may cause **rot** and **mold**,
which is a **threat** for **human health** and the house

some examples of undesired condensation

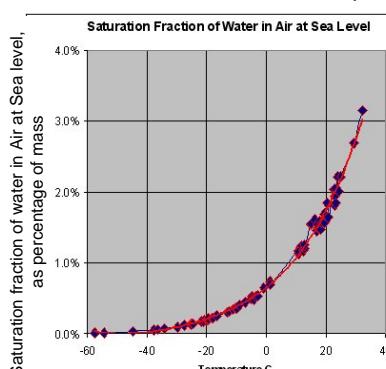


Example of frozen condensed water in an unheated room with an old double glass window



Example of condensed water in a bath room at 7°C, -17°C outside with an old double glass window

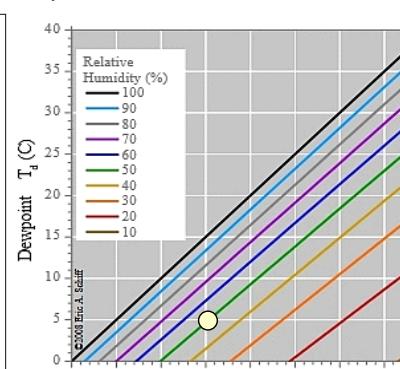
Dew point temperature



https://en.wikipedia.org/wiki/Dew_point#/media/File:Dewpoint.jpg

https://en.wikipedia.org/wiki/Dew_point

<https://www.joostdevree.nl/shtm1s/dauwpunt.shtml>

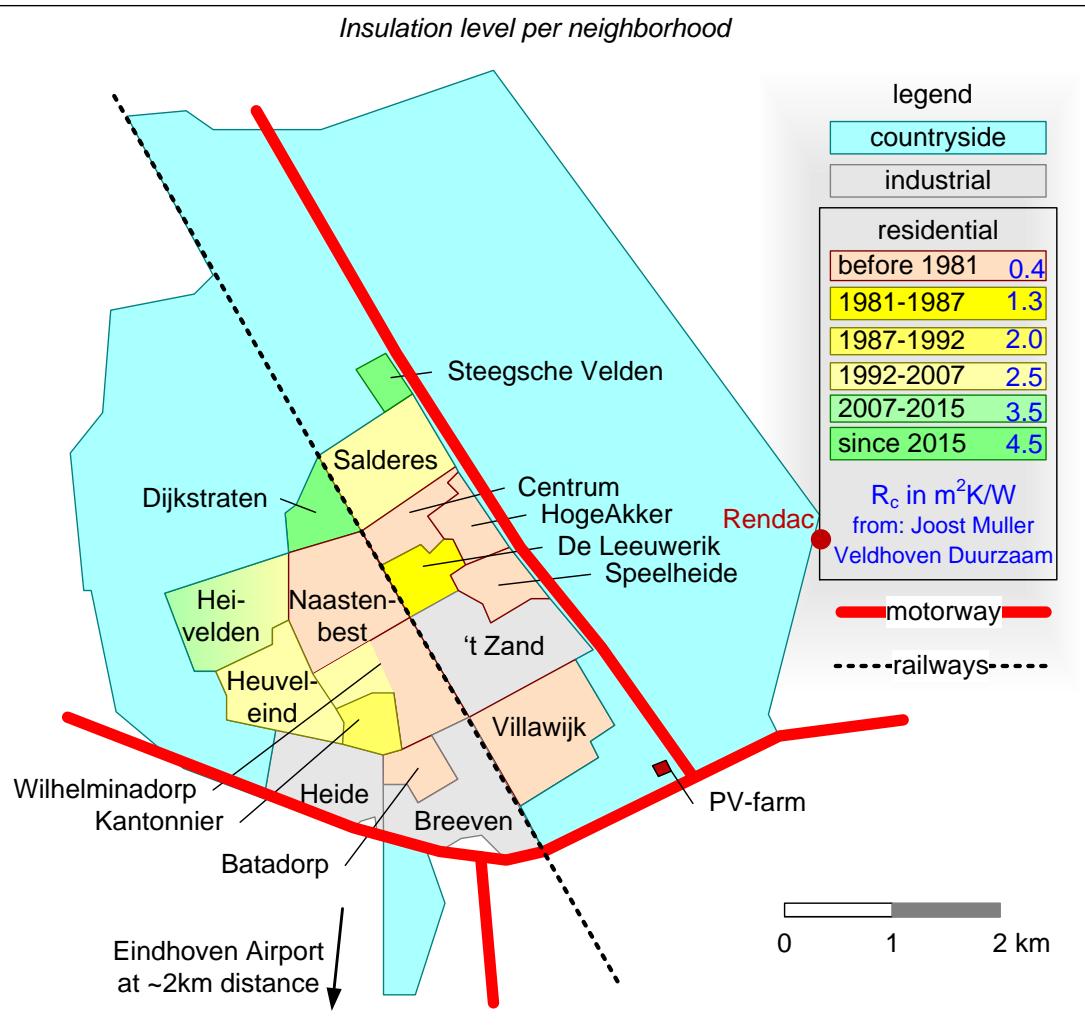


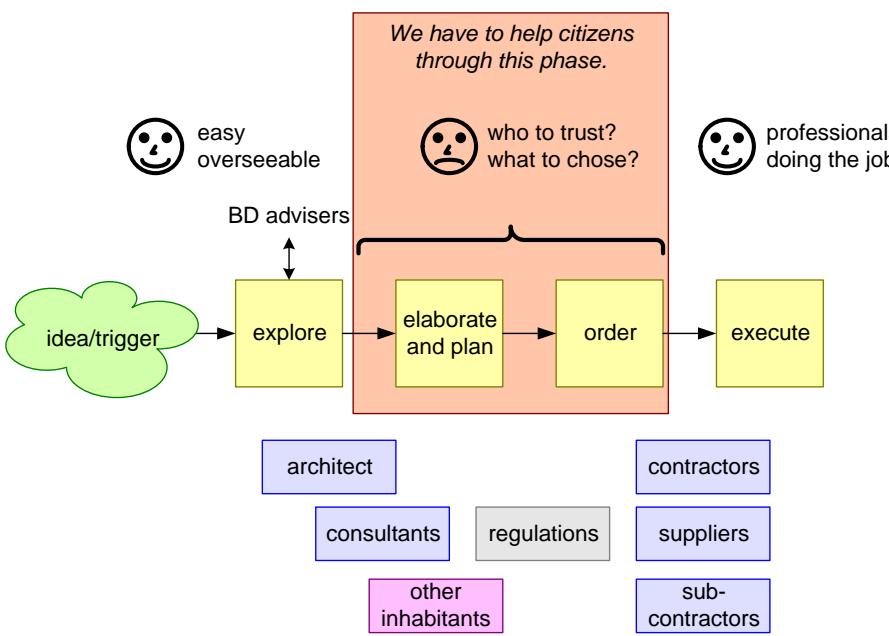
https://en.wikipedia.org/wiki/Dew_point#/media/File:Dewpoint-RH.svg

at $T_{\text{air in}} = 15^{\circ}\text{C}$, $\text{RH}_{\text{in}} = 50\%$, $T_{\text{dew}} \sim 5^{\circ}\text{C}$
if $T_{\text{surface}} < T_{\text{dew}}$, then water will condense on the surface.
In this case, when $T_{\text{surface}} < 5^{\circ}\text{C}$ we will get condense

Potential measures to prevent condensation:

- Insulate all cold spots, so that they stay above T_{dew}
This is the most fundamental solution
Insulation must be at the **outside** to prevent hidden condensation between insulation and cold surface
- Lower relative humidity
- close off open water (toilet, sinks, etc)
- use an active dehumidifier
This will increase the energy consumption somewhat
- use a passive dehumidifier
This requires regular human maintenance
- ventilate
This will increase the energy consumption for heating somewhat
- Increase $T_{\text{air in}}$
This will increase the energy consumption for heating significantly
- Do this very local only
reducing the required additional energy

Insulation level per neighborhood

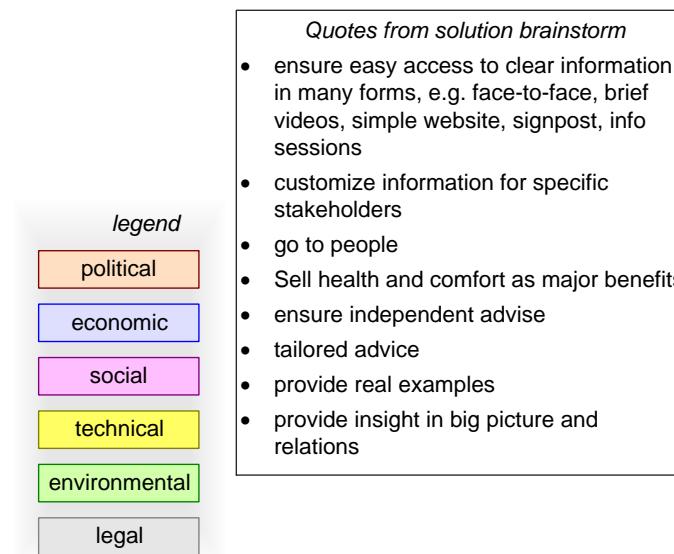
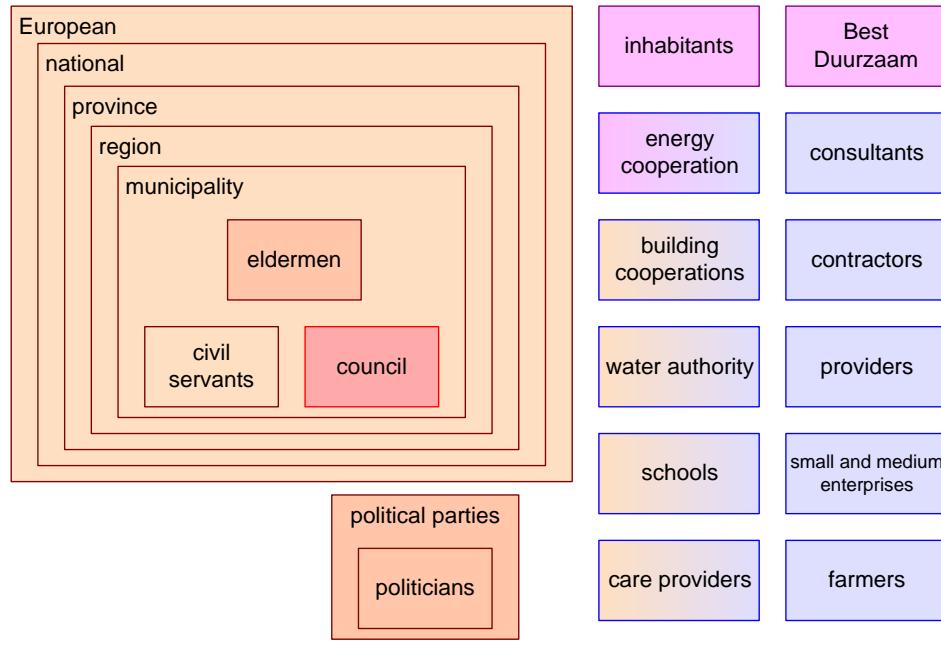
The threshold to come to action for citizens*Variations between citizens*

citizen type	what motivates and helps them
Anneke: bad house high gas price	lack of knowledge needs unburdening house is unfit for change
Reinier: BD volunteer house 1990	needs unburdening house is unfit for change
60+ couple detached house double income	reduce inheritance tax when improving sustainability
25-30 yr couple new house	concrete stepwise plan good neighbor reference show examples
50 yr mother, 2 teenagers limited money	concrete stepwise plan reliable information success story showing benefits suitable business model low cooperation thresholds inform and support
40-50 yr couple >= 2 studying kids	concrete stepwise plan reliable information good neighbor reference success story showing benefits suitable business model inform and support
Young, 20< studying	??unreadable concrete stepwise plan success story showing benefits focus on community recruit via cooperation

Concluding questions and comments

- How to increase the scale while maintaining trust?
- Help individuals with tailored advise, sufficiently complete
- One person directing ("regie") the execution.
- Relation between municipality, politicians, and civil servants
- How to translate this in "ready-to-go" advise for the municipality?
- Organize an energy market (e.g. as Udenhout)

- Quotes from obstacle brainstorm
- it's not worth it to me anymore
- what is the financial benefit for me?
- my home is not fit for sustainability improvements
- where do I start
- shirking planning and execution
- I have other things on my mind now
- It will lower my comfort
- Advise isn't independent
- unknown is unloved
- Building cooperation tax blocks insulation
- Now I must do something
- Overload (of what can and must)
- Mind set change required
- too many options
- too much information
- lack of trust in technology
- (lack of) trust in the municipality
- lack of trust in contractors
- lack of insight and understanding
- lack of money
- defeatism
- waiting for external factor, e.g. advise from municipality

sustainability stakeholder field

CO₂ footprint for typical Dutch family (2021)

family of 2.2 persons	Kg CO ₂ /yr	%
clothing and "stuff"	6500	33
residential energy	3700	19
transportation land	2300	12
transportation air	1400	7
food and drinks	4200	21
miscellaneous	1700	8
total	19800	

<https://www.milieuentaal.nl/klimaat-en-aarde/klimaatverandering/wat-is-je-co2-voetafdruk/>

Transpot cost containers Shanghai-Rotterdam

modus	Cost[\$]	time[days]	distance[km]	Kg CO ₂
ship	4000	35..55	20.000	757
train	8000	15..28	11.000	125
plane	32000	5..8	9.000	49.500

[NRC Handelsblad ZATERDAG 16 APRIL 2022, CarbonCare.org](https://www.nrc.nl/nieuws/2022/04/16/zaterdag-16-april-2022-carbon-care.org)

food and drinks Kg CO₂/Kg

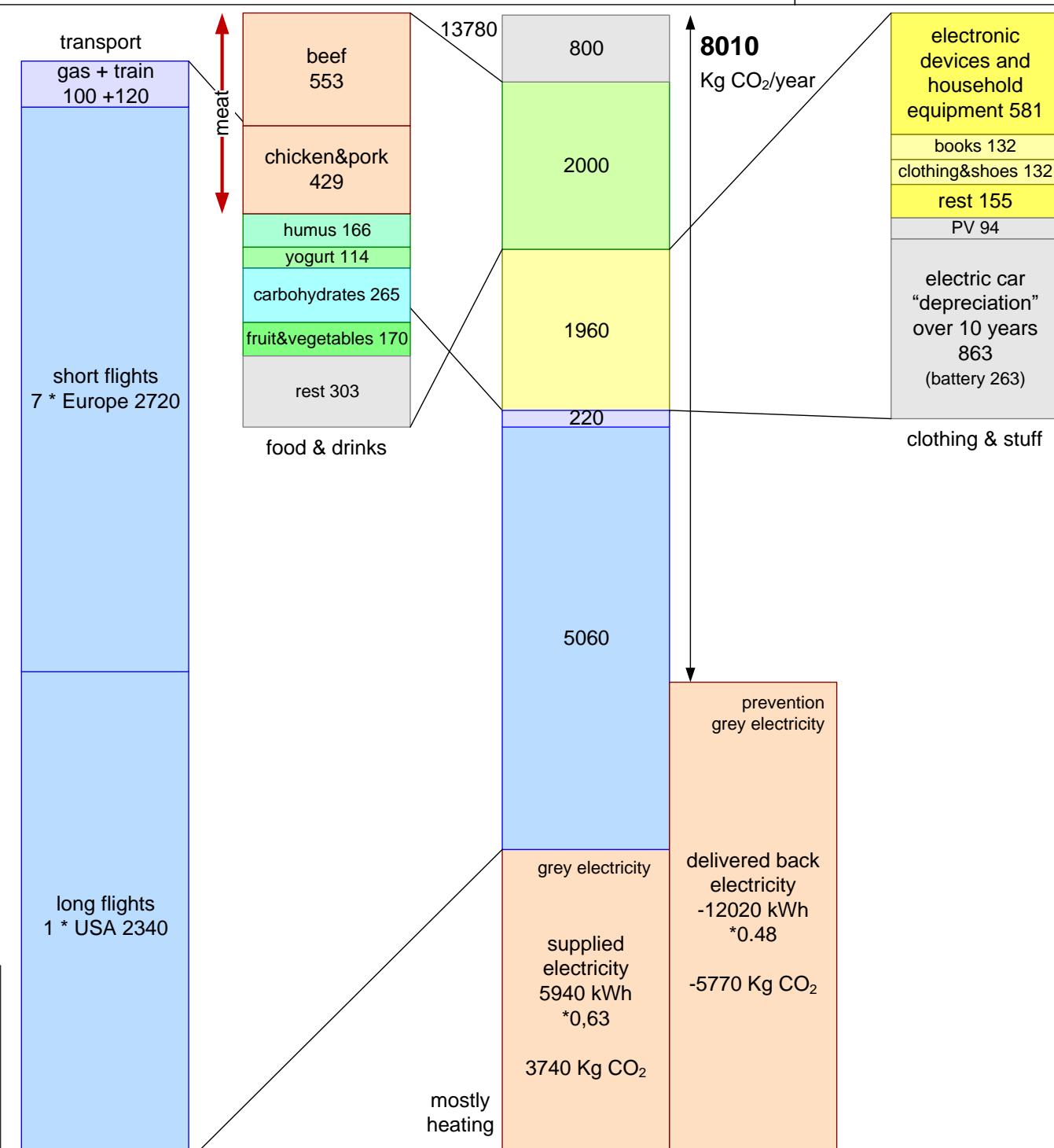
butter	sandwich filling	9.25	potatoes	carbohydrates	0.18
cheese	sandwich filling	12	bread	carbohydrates	1.2
Humus	sandwich filling	6.4	rice	carbohydrates	1.8
peanut butter	sandwich filling	8	wheat flour	carbohydrates	0.9
salad	sandwich filling	6	pasta	carbohydrates	1.5
wine	drinks	2	musli	carbohydrates	1.7
tea	drinks	0.16	cake	luxury	3
coffee	drinks	0.3	kidney beans	legumes	1.5
Vegetarian sausage	protein	4.3	chickpeas	legumes	6.2
tofu	protein	3.2	mayonnaise	sauce	5
vegetarian slice	protein	3.3	beef	meat	26.6
vegetables	fruit, vegetables	0.37	pork	meat	7.4
grapes	fruit, vegetables	1.1	chicken	meat	6.5
mandarine	fruit, vegetables	0.47	fish	meat	6
pear	fruit, vegetables	0.6	yogurt	dairy	2.2

CO₂ emission data Kg CO₂/Kg

production textile	13.6	small car (Citroën C1)	6000
transport textile	1.4	medium car (Mondeo)	17000
paperback	2	large car (Landrover)	35000
shoes/pair	4	PV panel (1.7*1m ²)	31
laptop/piece	250	Kg CO ₂ /kWh	
AA battery	0.1	Li-ion battery	73
household equipment	300		

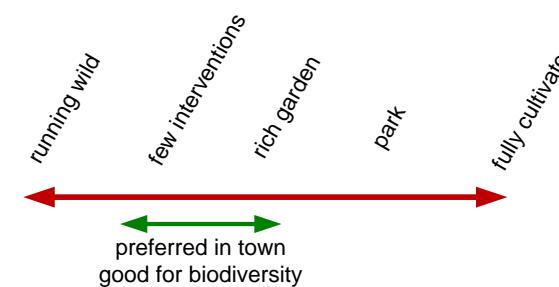
Sources

- <https://www.milieuentaal.nl/klimaat-en-aarde/klimaatverandering/wat-is-je-co2-voetafdruk/>
- <https://www.rivm.nl/sites/default/files/2021-02/Database%20milieubelasting%20voedingsmiddelen%20Beveiligd.pdf>
- <https://ce.nl/publicaties/milieuprofiel-van-stroomaanbod-in-nederland/>
- <https://vandebron.nl/blog/co2-compensatie-hoezo-eigenlijk>
- <https://www.robeco.com/en/insights/2020/02/short-haul-flights-are-the-worst-offenders-for-co2.html>
- <https://www.textilia.nl/220-gram-textiel-geeft-footprint-van-11-kilo-co2/>
- <https://nl-nl.albirds.eu/pages/albirds-adidas-futurecraft-collaboration>
- <https://phys.org/news/2011-04-factory-energy.html>
- https://www.apple.com/environment/pdf/products/notebooks/14-inch_MacBook_Pro_PER_Oct2021.pdf
- <https://pdf.scienceidrectassets.com/306234/1-s2.0-S2351978920X00072/1-s2.0-S2351978920307794/main.pdf>
- <https://www.penguin.co.uk/articles/2019/jul/sos-climate-change-things-you-can-do-daily-life-home.html>
- <https://mobly.be/nl/wiki/co2-uitstoot-auto-berekenen>



Quotes from problem exploration

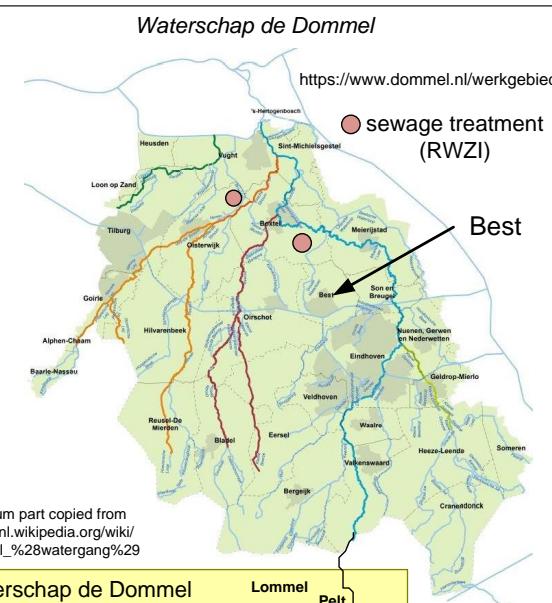
- dehydration
- reduction of number of (wild) animals, plants
- reduction of insects
- exotic species threaten/supplant native species
- reduction of species threaten other related species (chain reaction)
- areas are fragmented and disconnected
- gras areas
- pollution and exhaustion of soil
- pollution of water and air
- poisons and pesticides
- climate change
- crisis
- garden and borer srunning wild not accepted by all citizens
- reissuance from inhabitants against change

Spectrum from running wild to fully cultivated*Concluding questions and comments*

- Municipality has many different interests
- It may outsource maintenance
- select limited areas for ground bound solar

Quotes from solution brainstorm

- develop new neighborhoods for biodiversity
- Municipality should define framework and provide direction
- varied planting new neighborhoods
- small gardens in favor of collective parks
- connect green areas in town and countryside
- less tiles and pavement
- get rainwater into the ground rather than sewer
- high density building to save more area for nature
- low density building to allow (connected) nature between houses
- influence municipality for more varied borders
- maintenance with focus on biodiversity
- maintenance by citizens
- employers providing pubic transport card to employees (e.g. Decathlon)
- visible biodiversity at primary schools
- education and communication
- free rain barrels, insect hotels
- vouchers for various plants



Waterschap de Dommel Lommel Pelt Peer Houthalen-Helchteren

(https://www.dommel.nl/_flysystem/media/folder-feiten-cijfers-wdd-digitaal.pdf)

cleaned wastewater: $0.1 \times 10^9 \text{ m}^3/\text{year}$

water consumption per person: $43.8 \text{ m}^3/\text{year}$

900,000 inhabitants

water consumption: $0.039 \times 10^9 \text{ m}^3/\text{year}$

Background information

Brabant Waterland; Book with background information:
https://www.brabant.nl/_/media/1fb7de40c9fb447386438923d82af8d6.pdf

Brabant

average extraction of ground water per year

- for agriculture normal years: $70 \times 10^6 \text{ m}^3$
- for agriculture in dry years: $100 \text{ to } 200 \times 10^6 \text{ m}^3$
- for drinking water and industry: $240 \times 10^6 \text{ m}^3$

extraction of ground water during droughts per day:

- for agriculture: $2.0 \times 10^6 \text{ m}^3$
- for drinking water and industry: $0.66 \times 10^6 \text{ m}^3$ (p75)

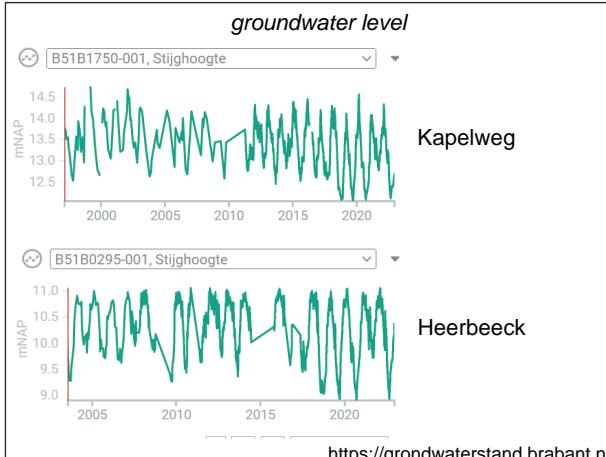
Water inlets

Brabant's brooks and streams can be filled through

- the canals
- water treatment systems (p77)

who pays what: <https://www.dommel.nl/tarieven>

visualizations of Brabant Water: <https://www.brabantinricht.nl/toestand-natuur-water-en-milieu/water/>



At this moment, the minimum rising height gets lower over time, however it seems to recover still during the wet season.

The lower minimum may be problematic for biodiversity, for instance when fens and shallow pools and lakes dry up during spring or summer.

- Problem exploration**
- precipitation
- decrease in summer
 - increase in winter
 - increase of probability of intense downpours
 - increase of droughts
 - many roofs and streets discharge in sewer
- water quality
- chemical pollution
 - biodiversity
- clean water consumption
- increase due to growing population

- Consequence exploration**
- precipitation
- buffer water for use during droughts
 - sufficient buffers to prevent flooding
 - redirect water to land rather than sewer
- water quality
- lower chemical emissions
 - extend water treatment systems
 - adapt to facilitate biodiversity
- clean water consumption
- reduce individual consumption
 - use "grey" water where feasible

precipitation Eindhoven average over 10 years													
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC year													
1994	66	38	62	48	43	70	68	65	64	60	63	82	730
1995	74	46	66	42	46	62	67	57	68	60	59	81	727
1996	62	51	59	37	45	59	67	63	66	58	63	74	705
1997	59	56	52	39	49	60	61	62	63	54	57	76	687
1998	52	50	49	46	45	72	51	62	71	64	62	73	698
1999	60	52	48	42	52	72	52	70	71	59	65	78	721
2000	60	51	52	44	57	69	63	69	72	65	68	77	745
2001	59	56	60	47	56	66	71	73	83	68	63	78	780
2002	65	56	46	57	65	73	66	81	65	62	82	82	784
2003	64	54	59	49	59	65	69	66	72	67	63	77	773
2004	66	67	53	47	59	63	81	68	66	65	66	72	774
2005	58	67	48	50	57	61	89	71	62	66	71	71	771
2006	58	72	53	54	60	61	88	69	60	67	69	73	786
2007	70	70	56	50	61	60	95	70	63	66	72	75	808
2008	71	74	56	46	64	51	100	73	51	56	69	72	784
2009	66	73	55	47	59	51	102	69	48	61	78	67	776
2010	65	70	55	44	58	47	95	78	51	57	80	67	768
2011	65	70	48	39	59	51	90	85	39	58	74	72	750
2012	68	60	46	41	62	56	93	84	43	59	68	75	754
2013	65	63	47	38	60	57	88	84	49	61	72	72	757
2014	60	61	45	35	66	56	89	90	48	63	68	75	756
2015	64	57	48	30	66	54	84	94	52	64	68	75	755
2016	72	57	47	32	64	71	85	85	53	60	69	70	766
2017	66	55	47	34	57	65	85	84	55	62	70	73	754
2018	70	52	46	39	58	60	75	83	54	60	68	81	745
2019	71	51	49	36	59	62	69	82	58	61	61	82	743
2020	71	60	49	35	53	72	69	72	54	62	55	83	736
2021	74	59	53	38	58	75	70	66	54	65	58	74	745
2022	68	67	52	34	55	77	60	61	60	61	60	69	723

source: ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE
https://cdn.knmi.nl/knmi/map/page/klimatologie/gegevens/maandgegevens/mndgeg_370_rh24.txt

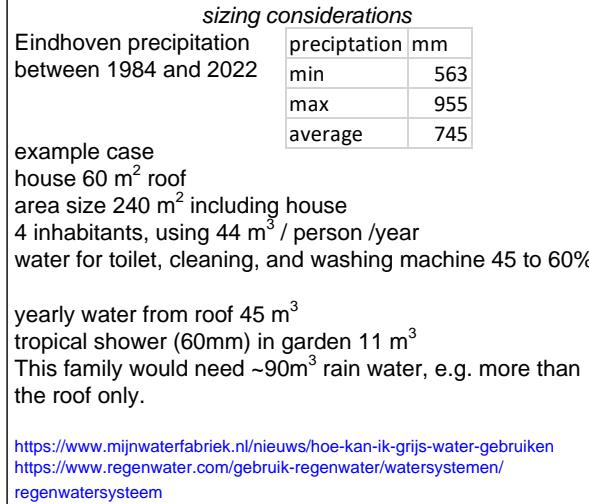
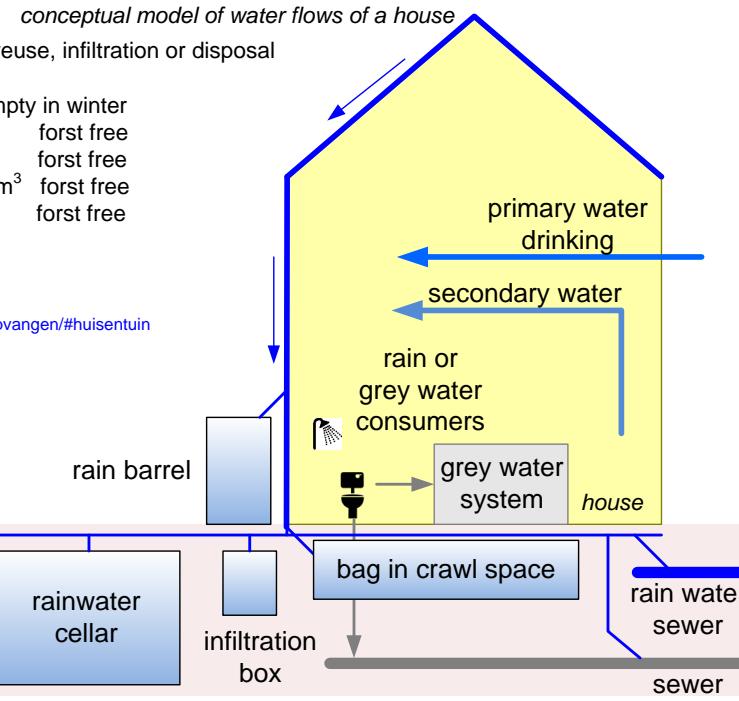
Quotes from solution brainstorm

-

Concluding questions and comments

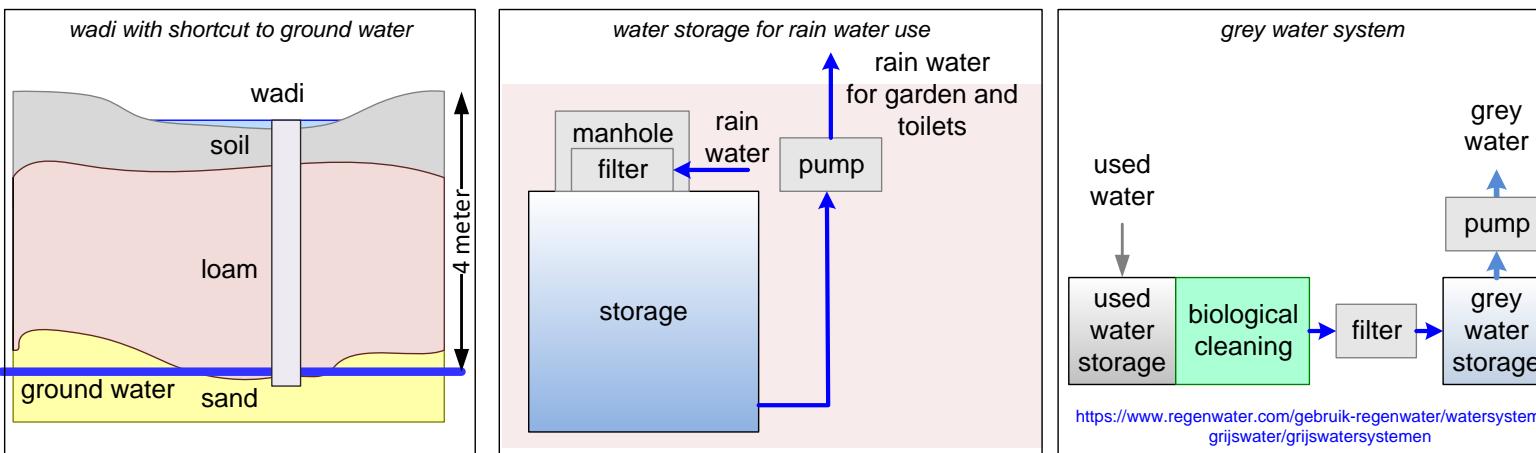
-

yearly precipitation Eindhoven 1985-2022	
precipitation mm	
min	563
max	955
average	745



aantekeningen 6-11-2023

- druppelslang
- Gemeente: stedelijk waterplan
- Industrieterrein afkoppelen (grote daken, veel water)
- bij stroomstoring backup nodig voor toiletten



context

- 80 houses, old, large, barely insulated
 - country side
- envisioned future:
- large storage tank
 - heated during summer
 - used during winter
 - low temperature heat network to houses
 - solar panels for electricity and heating

historic data

yearly energy consumption per large old house

$$E_{\text{electricity past}} = 3550 \text{ kWh}$$

$$V_{\text{gas heating}} = 3636 \text{ m}^3$$

$$V_{\text{gas hot water}} = 288 \text{ m}^3$$

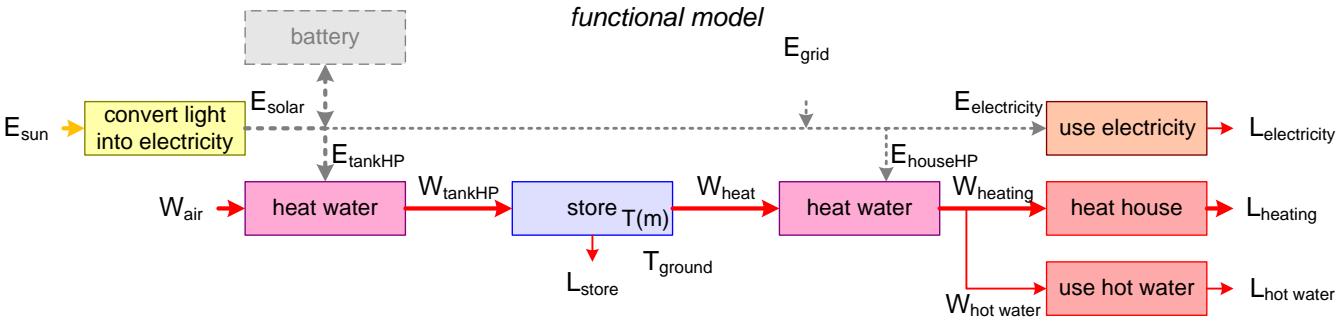
$$C_{\text{gas}} = 9 \text{ kWh/m}^3$$

$$C_{\text{solar}} = 0,913 \text{ kWh/W}_{\text{peak}}$$

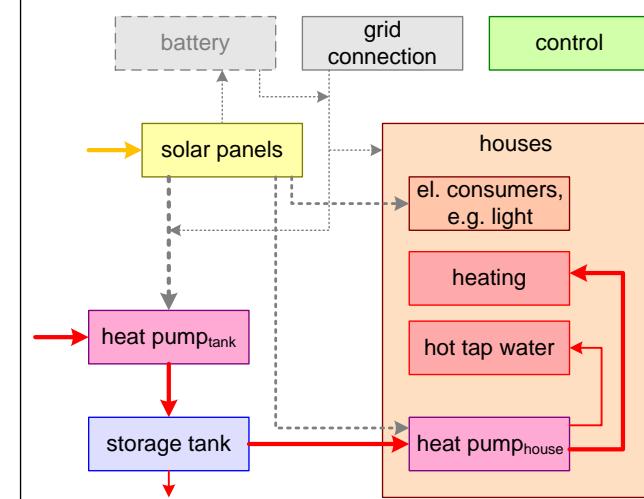
capacity factor = 11%

<https://www.linkedin.com/pulse/waarom-we-moeten-en-kunnen-stoppen-met-het-van-hans-schneider/>

functional model



energy system



in formulas

$$E_{\text{electricity}} = E_{\text{electricity past}}$$

$$W_{\text{heating}} = V_{\text{gas heating}} * C_{\text{gas}}$$

$$W_{\text{hot water}} = V_{\text{gas hot water}} * C_{\text{gas}}$$

$$E_{\text{solar}} = W_{\text{peak}} * C_{\text{solar}}$$

$$W_{\text{heat}} = (W_{\text{heating}} + W_{\text{hot water}}) - E_{\text{houseHP}}$$

$$E_{\text{houseHP}} = (W_{\text{heating}} + W_{\text{hot water}}) / COP_{\text{houseHP}}$$

$$E_{\text{tankHP}} = E_{\text{solar}} + E_{\text{grid}} - E_{\text{electricity}} - E_{\text{houseHP}}$$

$$E_{\text{grid}} = \text{energy in winter when solar is too low}$$

$$W_{\text{tankHP}} = E_{\text{tankHP}} * COP_{\text{tankHP}}$$

$$L_{\text{store}} = \sum_{\text{jan..dec}} A * h_{\text{month}} * \Delta T / R$$

$$R = d / \lambda \approx d / 0.03 ; h_{\text{month}} = 720 \text{ hrs}$$

$$\Delta T = T(\text{month}) - T_{\text{ground}}$$

$$L_{\text{electricity}} = E_{\text{electricity}}, L_{\text{heating}} = W_{\text{heating}}$$

$$L_{\text{hot water}} = W_{\text{hot water}}$$

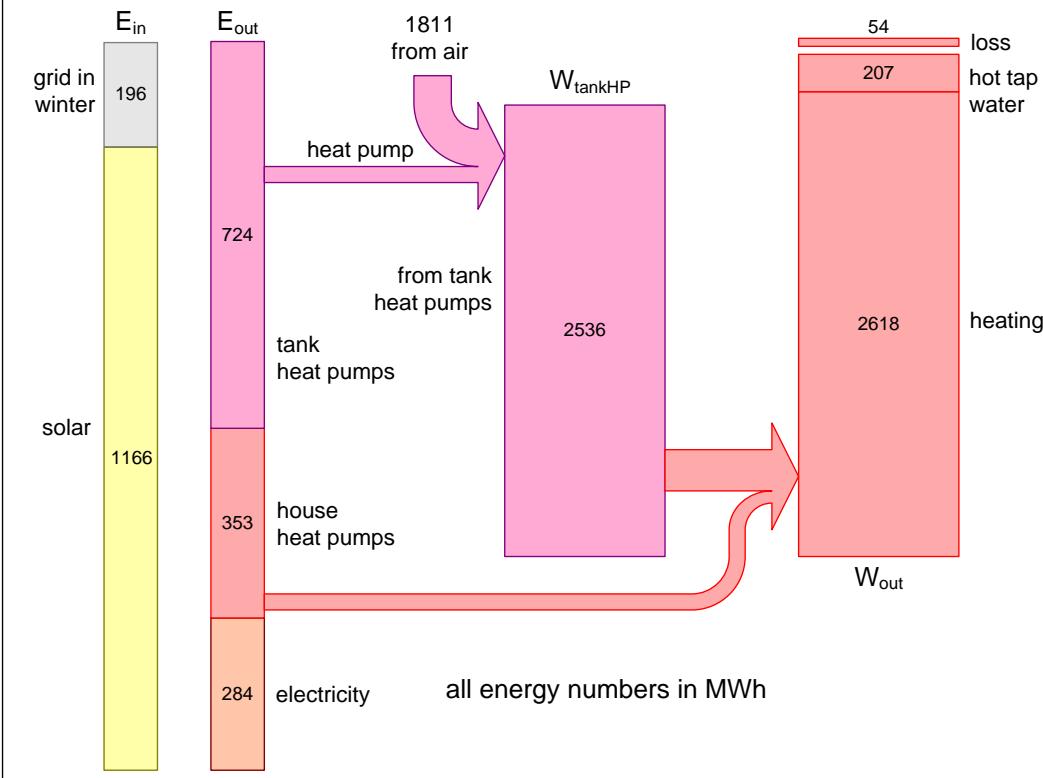
base case scenario

80 * 74 m² solar panels
35 kWh/m²
345 Wp, 1*1.6m, 2019

tank: 65 * 65 * 20m³
insulation: 1m
 $\lambda \approx 0.03 \text{ W/m}^\circ\text{C}$
 $R \approx 33 \text{ m}^2 \text{ }^\circ\text{C} / \text{W}$
 $T_{\min} = 14 \text{ }^\circ\text{C}$
 $T_{\max} = 34 \text{ }^\circ\text{C}$

COP_{tankHP} = 3.5
COP_{houseHP} = 8

n_{houses} = 80



design parameters

solar panels W_{peak} n _{panels} or A orientation $\rightarrow E_{\text{solar}}$	storage tank h, b, l T_{\min}, T_{\max} $\rightarrow E_{\text{tank}}$ $d_{\text{insulation}}, \lambda_{\text{insulation}}$ $\rightarrow E_{\text{loss}}$	E_{battery} W_{peak}
heat pump _{tank} source W_{peak} COP _{tank}	E_{electric} E_{heating} $E_{\text{hot tap water}}$ COP _{heat pump house} n _{houses}	

Assessment Criteria

PESTEL

- Political
 - Technical
 - Environmental
 - Legal

Political

- social acceptance
- fit with regional and national politics
- reputation risk

Economic

- CAPEX
- OPEX
- time to deployment
- life time
- risks
- viable business model

Social

- affordable for all
- participation by all
- disruption of deployment
- side effects (e.g. noise)

Technical

- readiness level
- complexity
- competence level
- effectiveness/ performance
- robustness

Environmental

- foot print
- impact on flora and fauna

Legal

- fits in current legislation

Concepts that need assessment

solar

PV panel type TEc

heat collectors TEc

trackers TEc

inverters TEc

payment Ec

governance, owner PEcSL

location PSEn

battery

type TEc

location PSEn

electric network

measuring Ec

payment Ec

governance, owner PEcSL

tank heat pump

type TEc

source TEc

location PSEn

storage tank

insulation TEc

shape TEc

construction TEc

location PSEn

heat network

type TEc

measuring Ec

payment Ec

governance, owner PEcSL

in-house heat equipment

heat pump type TEc

local tank TEc

control

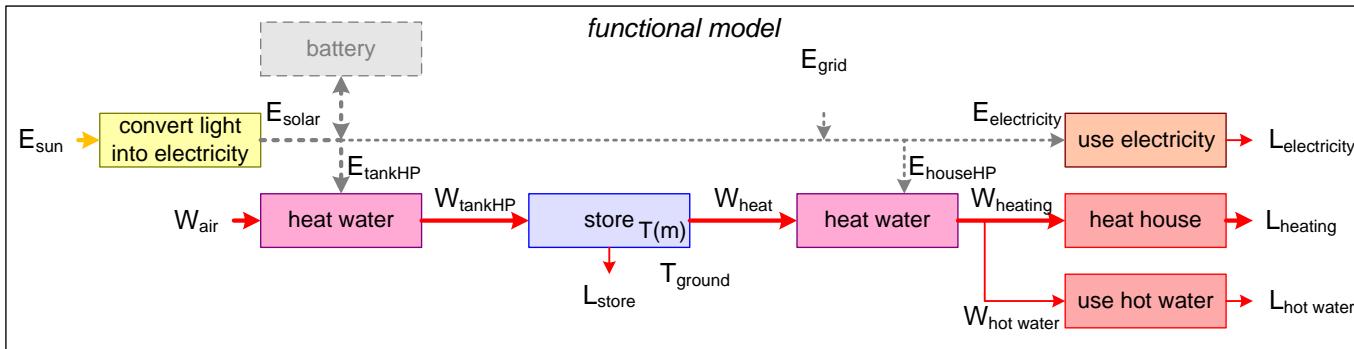
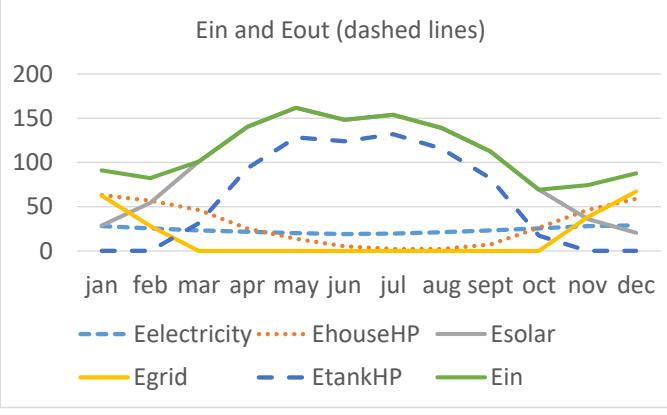
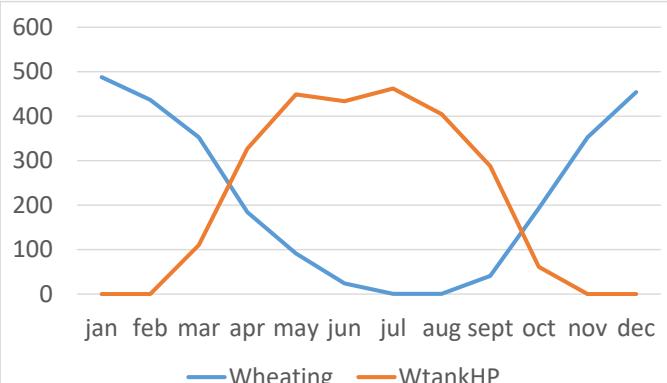
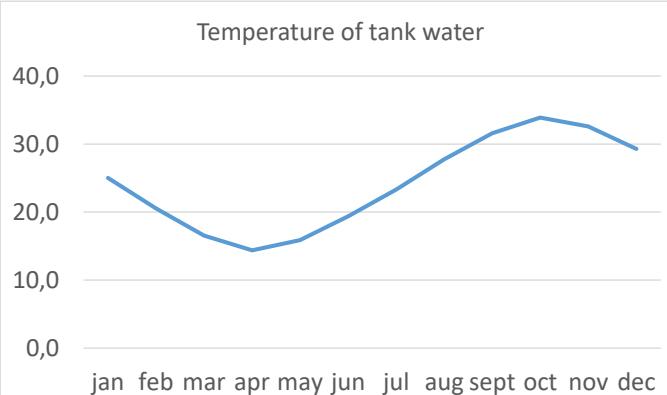
energy management TEc

handling extremes TEc

maintenance TEc



graphical representation of monthly dynamics



formulas for monthly dynamics

$$DT(m+1) = DT_{supplied}(m) - DT_{loss}(m) - DT_{used}(m)$$

$$DT_{supplied}(m) = E_{tankHP}(m) / V / C_{water}$$

$$DT_{loss}(m) = W_{loss}(m) / V / C_{water}$$

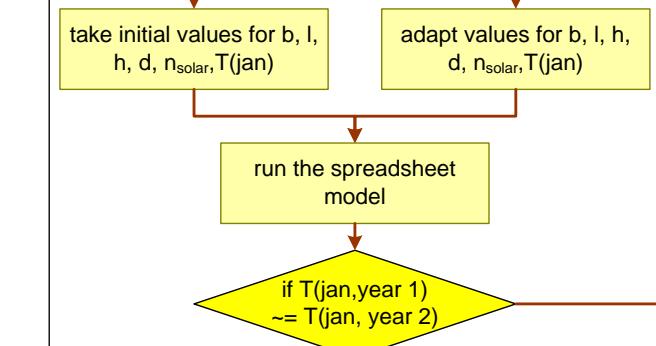
$$DT_{used}(m) = (W_{heating}(m) + W_{hot\ water}(m) - E_{houseHP}(m)) / V / C_{water}$$

$$C_{water} = 1,17 \text{ kWh/m}^3/\text{°C}$$

$$V = b * l * h$$

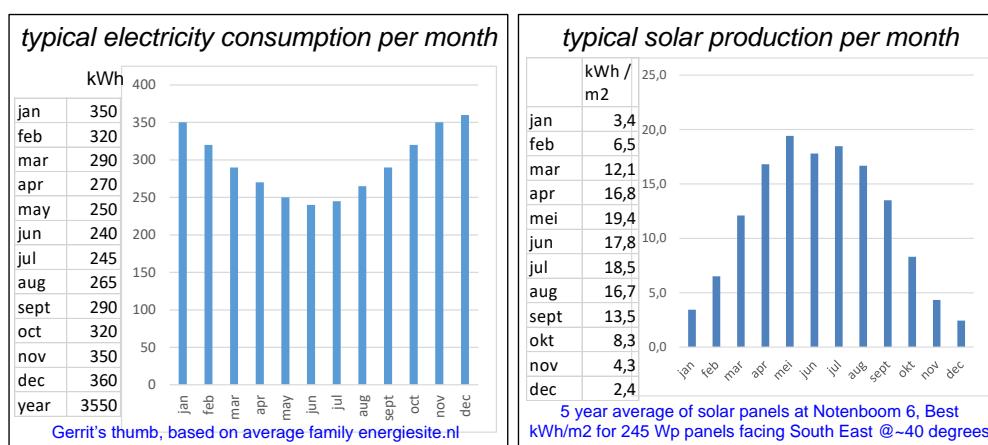
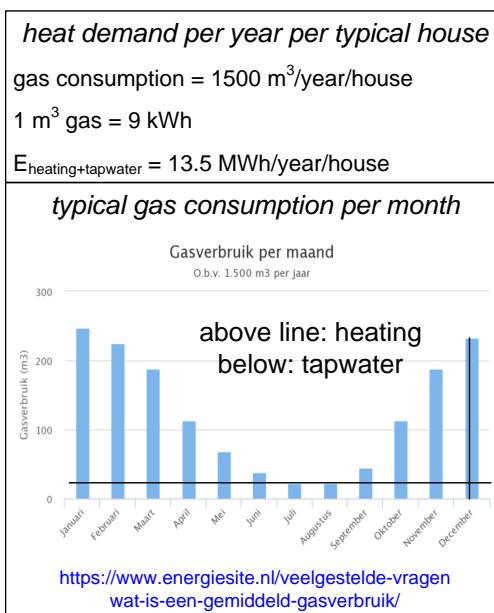
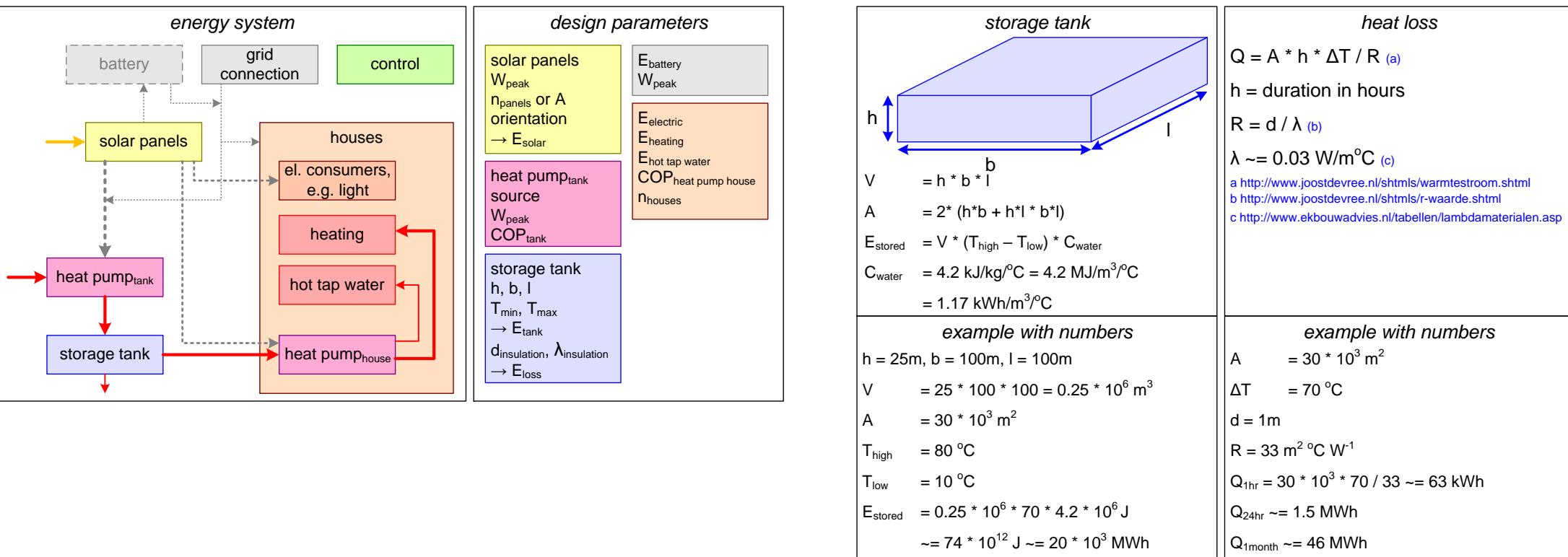
$W_{heating}(m)$, $W_{hot\ water}(m)$, $E_{electricity}(m)$, $E_{zon}(m)$ use historic data

simulation workflow



the core part of the spreadsheet

	m3	MWh	m3	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	oC	MWh	°C	°C	°C	°C	DT	
jan	1920	17	54178	488	505	28	63	29	62	0	91	510	0	25,0	5	0,0	4,4	0,0	-4,5
feb	1920	17	48558	437	454	26	57	54	28	0	82	458	0	20,5	3	0,0	4,0	0,0	-4,0
mar	1920	17	39193	353	370	23	46	101	0	31	101	372	110	16,5	2	0,0	3,2	1,1	-2,2
apr	1920	17	20463	184	201	22	25	140	0	93	140	203	327	14,4	2	0,0	1,8	3,3	1,5
may	1920	17	10161	91	109	20	14	162	0	128	162	111	449	15,9	2	0,0	1,0	4,5	3,5
jun	1920	17	2669	24	41	19	5	148	0	124	148	44	434	19,4	3	0,0	0,4	4,3	3,9
Jul	1920	17	46	0	18	20	2	154	0	132	154	22	462	23,3	4	0,0	0,2	4,6	4,4
aug	1920	17	46	0	18	21	2	139	0	116	139	23	405	27,7	6	0,1	0,2	4,0	3,8
sept	1920	17	4542	41	58	23	7	113	0	82	113	65	287	31,6	7	0,1	0,5	2,9	2,3
oct	1920	17	21399	193	210	26	26	69	0	17	69	217	61	33,9	7	0,1	1,8	0,6	-1,3
nov	1920	17	39193	353	370	28	46	36	38	0	74	377	0	32,6	7	0,1	3,2	0,0	-3,3
dec	1920	17	50431	454	471	29	59	20	67	0	88	477	0	29,3	6	0,1	4,1	0,0	-4,2
jan	1920	17	54178	488	505	28	63	29	62	0	91	510	0	25,1	5	0,0	4,4	0,0	-4,5
feb	1920	17	48558	437	454	26	57	54	28	0	82	458	0	20,6	3	0,0	4,0	0,0	-4,0
mar	1920	17	39193	353	370	23	46	101	0	31	101	372	110	16,6	2	0,0	3,2	1,1	-2,2
apr	1920	17	20463	184	201	22	25	140	0	93	140	203	327	14,5	2	0,0	1,8	3,3	1,5
may	1920	17	10161	91	109	20	14	162	0	128	162	111	449	15,9	2	0,0	1,0	4,5	3,5
jun	1920	17	2669	24	41	19	5	148	0	124	148	44	434	19,5	3	0,0	0,4	4,3	3,9
Jul	1920	17	46	0	18	20	2	154	0	132	154	22	462	23,4	4	0,0	0,2	4,6	4,4
aug	1920	17	46	0	18	21	2	139	0	116	139	23	405	27,8	6	0,1	0,2	4,0	3,8
sept	1920	17	4542	41	58	23	7	113	0	82	113	65	287	31,7	7	0,1	0,5	2,9	2,3
oct	1920	17	21399	193	210	26	26	69	0	17	69	217	61	34,0	7	0,1	1,8	0,6	-1,3
nov	1920	17	39193	353	370	28	46	36	38	0	74	377	0	32,7	7	0,1	3,2	0,0	-3,3
dec	1920	17	50431	454	471	29	59	20	67	0	88	477	0	29,4	6	0,1	4,1	0,0	-4,2
year	1	23040	207	290880	2618	2825	284	353	1166	196	724	1362	2880	2536	54				
	2	23040	207	290880	2618	2825	284	353	1166	196	724	1362	2880	2536	54				



2 bad insulation scenario

- 0.1m insulation i.s.o. 1m consequences
- $W_{loss} = 561\text{MWh}$ i.s.o. 54 MWh
- $80 * 84\text{ m}^2$ solar panels i.s.o. $80 * 72\text{ m}^2$

3 low tank temperature scenario

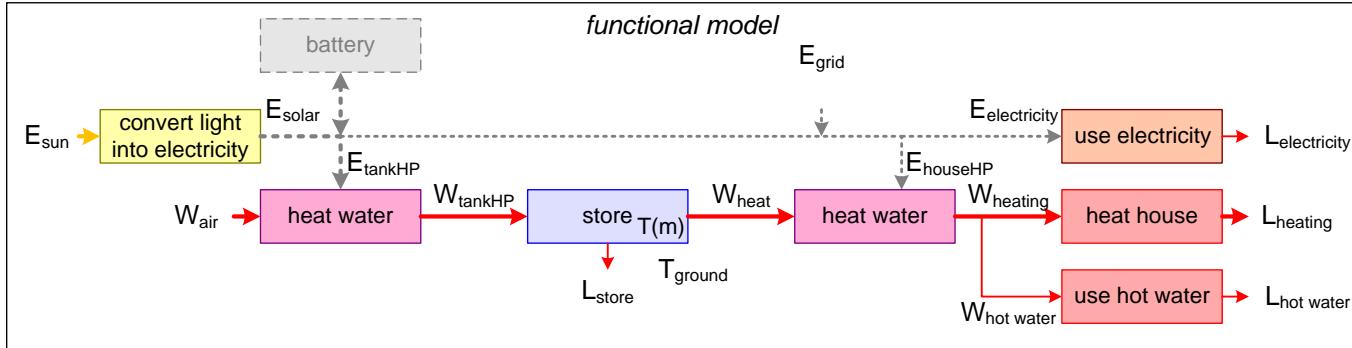
- $T_{min} = 8^\circ\text{C}$, $T_{max} = 25^\circ\text{C}$ i.s.o. $14..34^\circ\text{C}$ consequences
- $b, l = 72\text{ m}$ i.s.o. 65 m
- less loss in pipes of heat network (not modeled)

4 medium size tank scenario

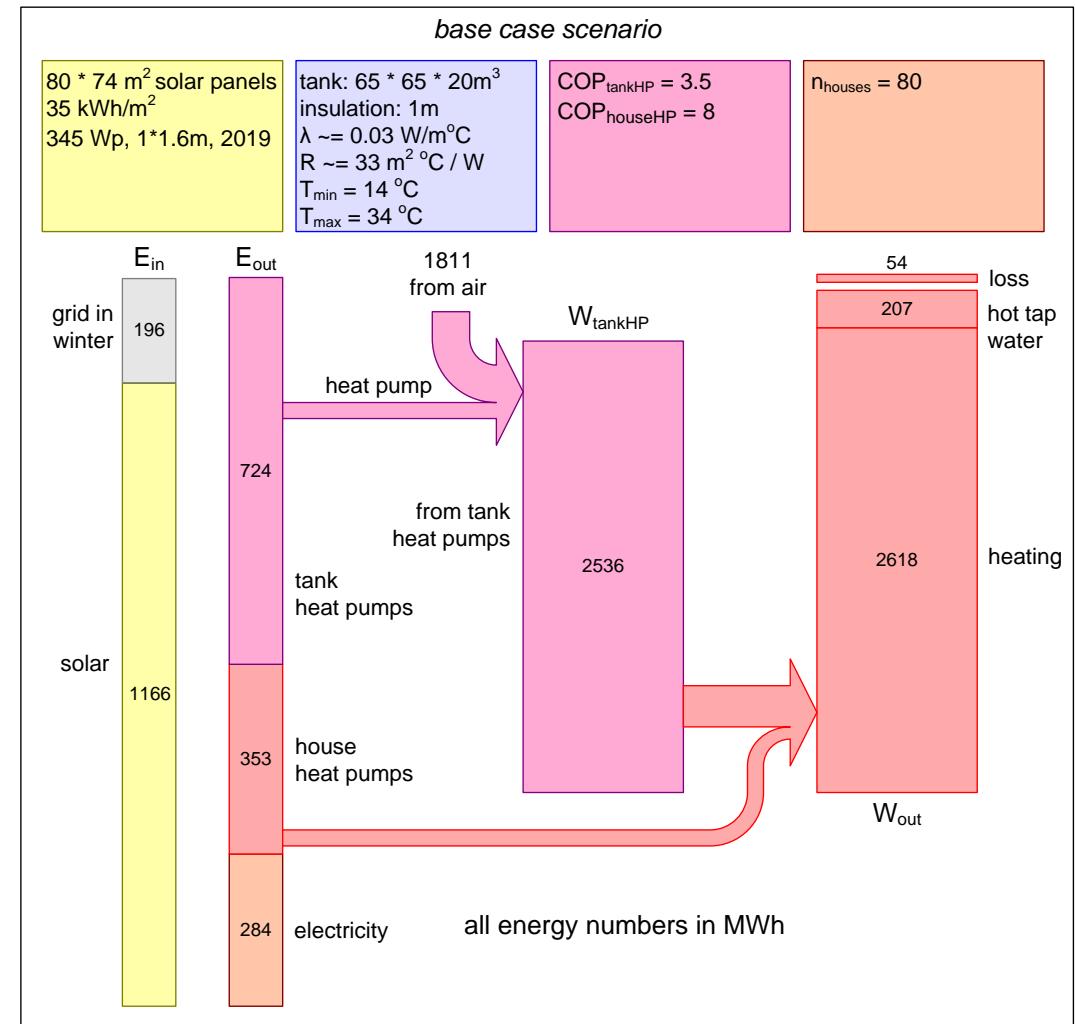
- $b, l = 59\text{ m}$ i.s.o. 65 m consequences
- $T_{min} = 12^\circ\text{C}$, $T_{max} = 36^\circ\text{C}$ i.s.o. $14..34^\circ\text{C}$
- less capacity for extreme winters

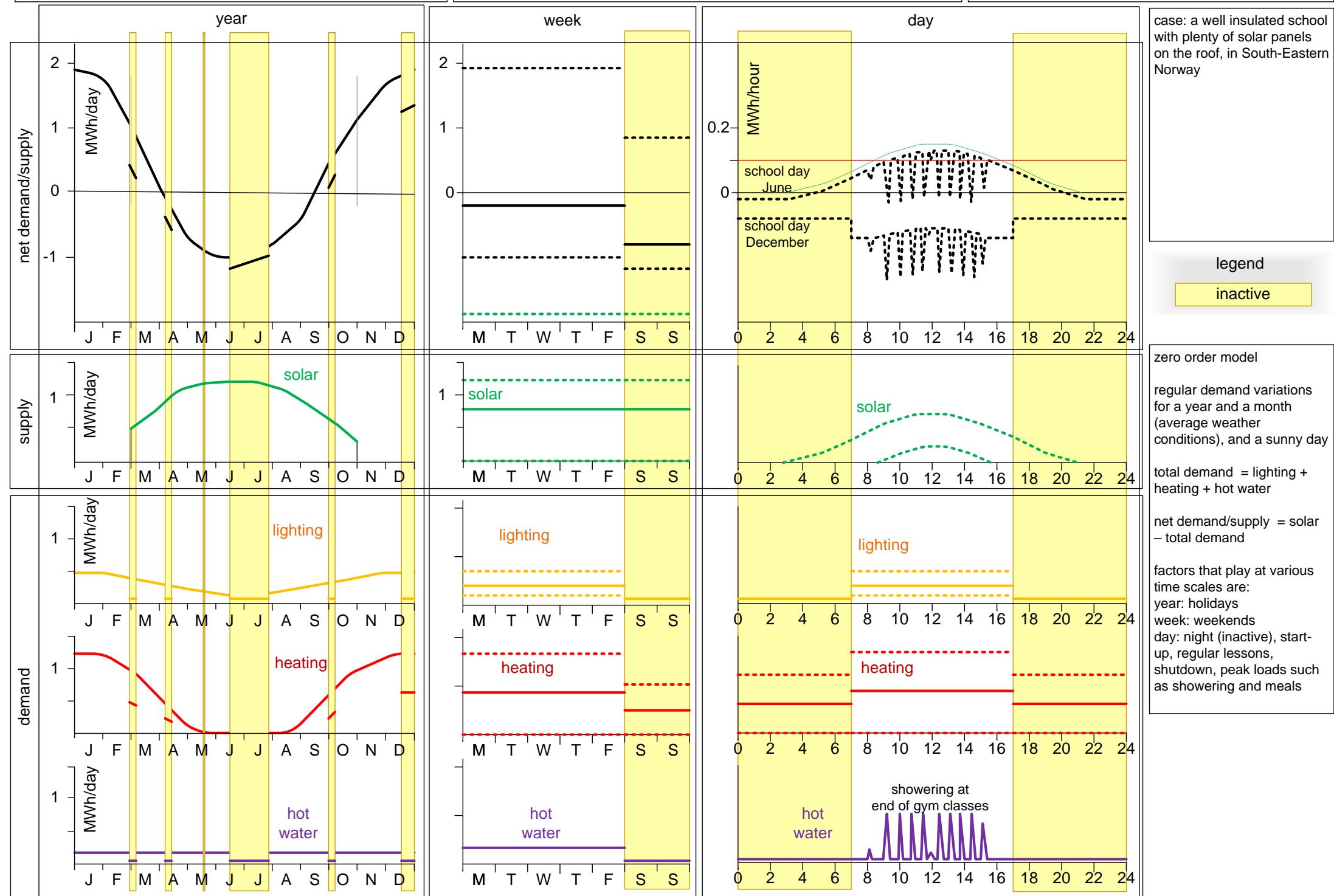
5 small tank scenario

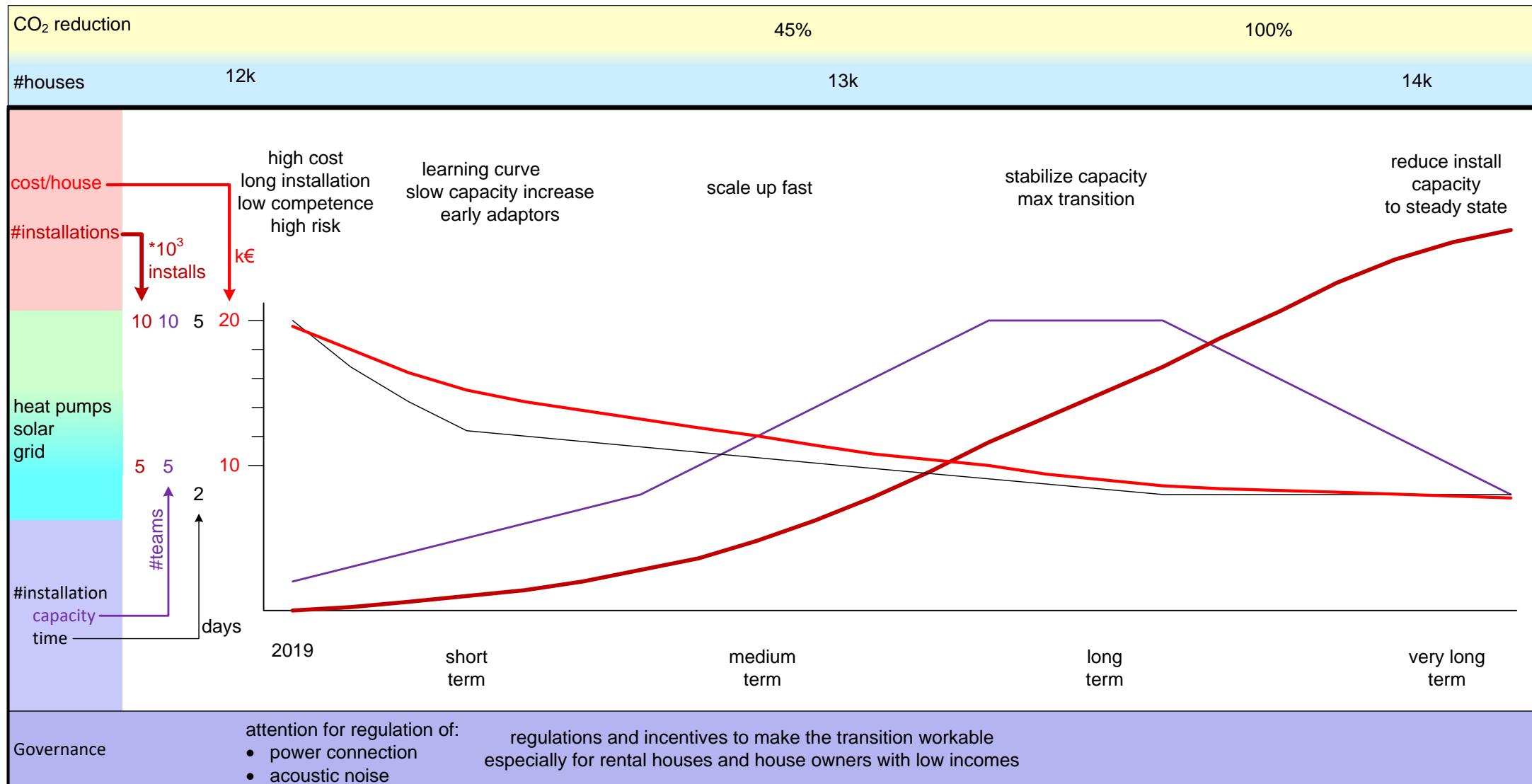
- $b, l = 51\text{ m}$ i.s.o. 65 m consequences
- $T_{min} = 10^\circ\text{C}$, $T_{max} = 43^\circ\text{C}$ i.s.o. $14..34^\circ\text{C}$
- less capacity for extreme winters



scenarios		1	2	3	4	5
Oct 17, 09:21		base case	bad insulation	low temp	medium tank	small tank
T start January		25	25	17	25	28
T high		40	40	30	40	45
T low		10	10	5	10	15
desired capacity	MWh	3000	3000	3000	2400	1800
d	m	1	0,1	1	1	1
solar area per house	m²	74	84	74	74	74
h	m	20	20	20	20	20
old large house/average house		3	3	3	3	3
#houses per block		80	80	80	80	80
Electricity	MWh	284	284	284	284	284
EhouseHeatPumps	MWh	353	353	353	353	353
Esolar	MWh	1166	1323	1166	1166	1166
Egrid	MWh	196	177	196	196	196
EtankHeatumps	MWh	724	863	724	724	724
Wheating	MWh	2618	2618	2618	2618	2618
WhotWater	MWh	207	207	207	207	207
Wloss	MWh	54	561	31	45	42
WfromHeatPumps	MWh	2536	3021	2536	2536	2536
WfromAir	MWh	1811	2158	1811	1811	1811
TminActual	oC	14	14	8	12	10
TmaxActual	oC	34	35	25	36	43
DTjan	oC	0,1	-0,1	0,3	0,2	0,4
b, l	m	65	65	72	59	51







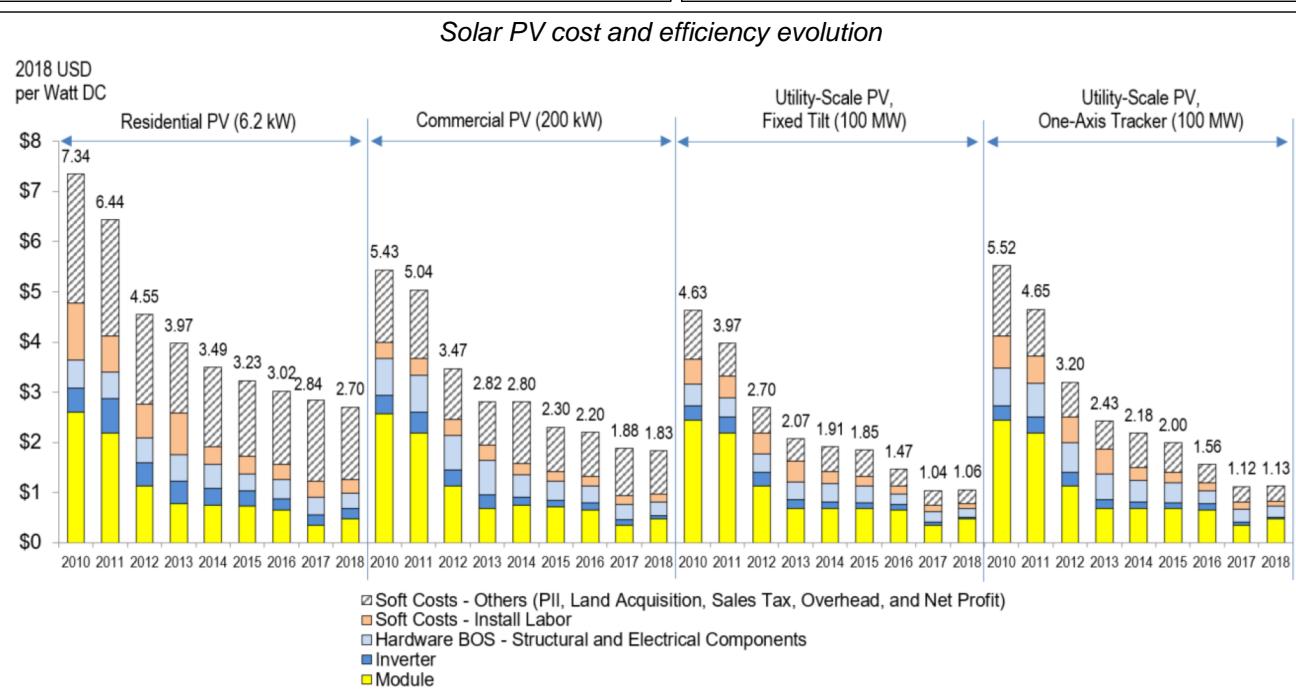


Figure ES-1. NREL PV system cost benchmark summary (inflation adjusted), 2010–2018

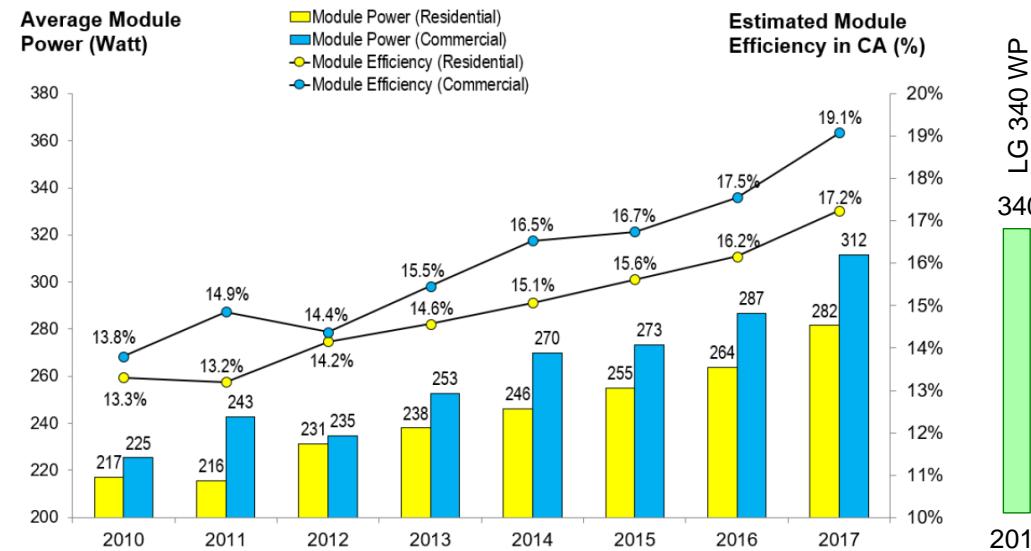
U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018 <https://www.nrel.gov/docs/fy19osti/72399.pdf>

Figure 3. Module power and efficiency trends from the California NEM database (Go Solar CA 2018), 2010–2017

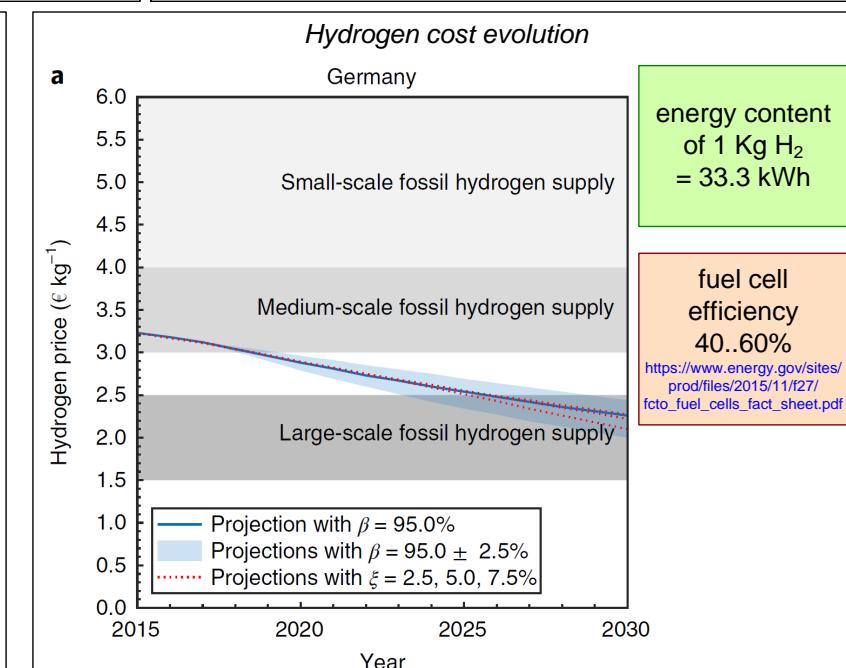
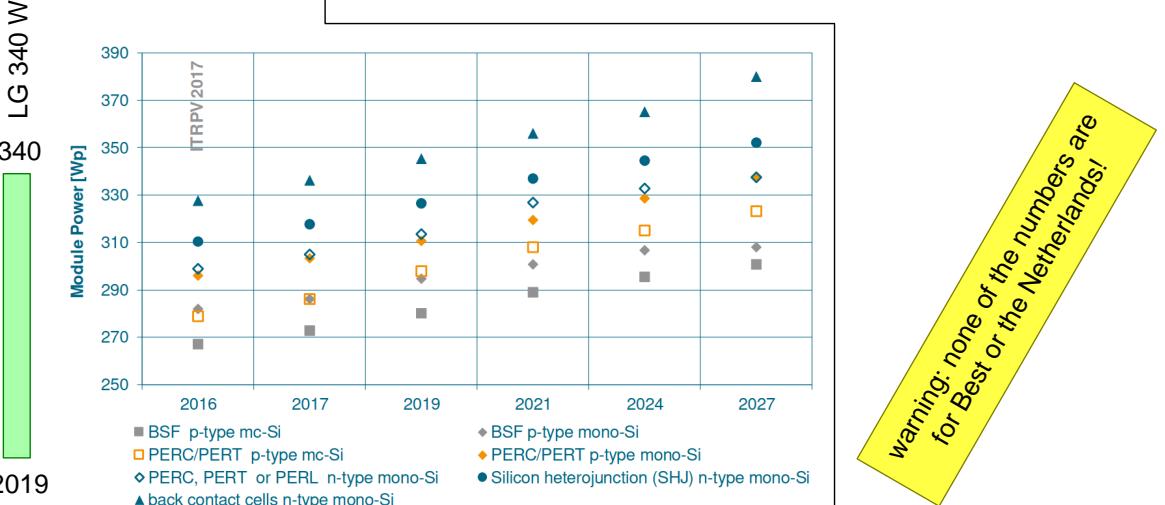


Fig. 3 | Prospects for renewable hydrogen production
The break-even price of renewable hydrogen for Germany relative to the benchmark prices for fossil hydrogen supply.
from: Economics of converting renewable power to hydrogen
Gunther Glenk and Stefan Reichelstein
Nature Energy <https://doi.org/10.1038/s41560-019-0326-1>



warning: none of the numbers are for Best or the Netherlands!

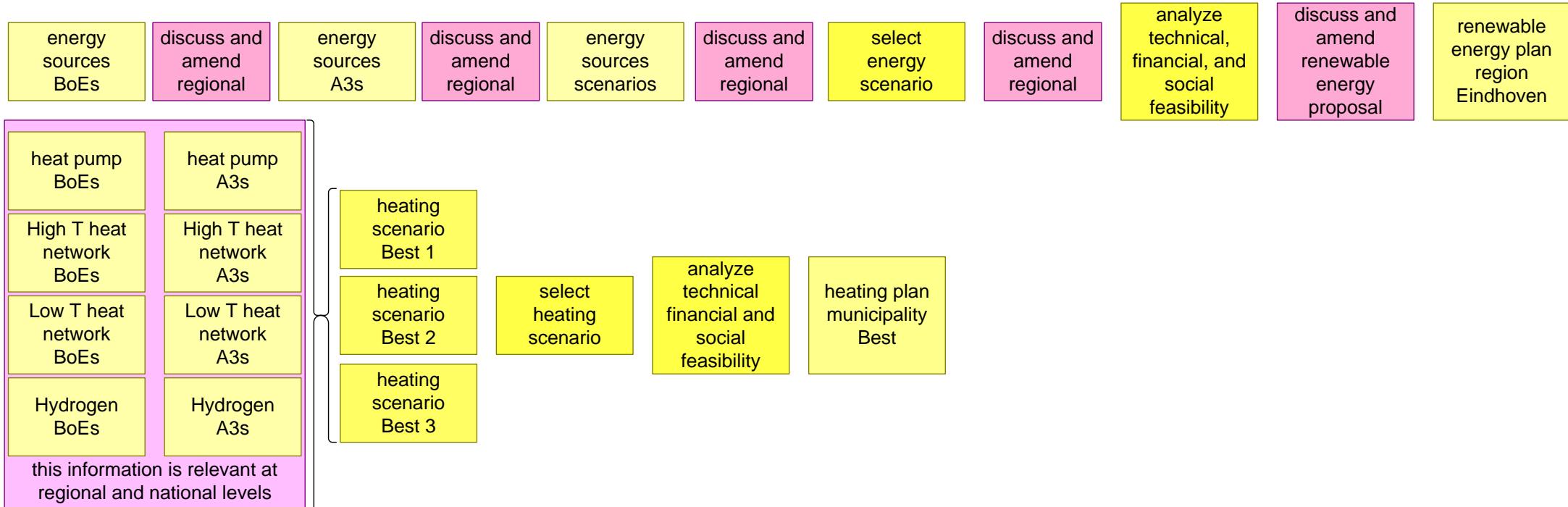
H2 2019

H1 2020

H2 2020

H1 2021

H2 2021



create and show attractive examples; "seduce", build on success

