# Best Duurzaam Roadmap A3s

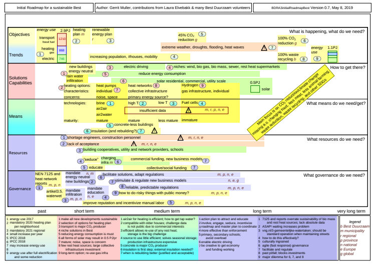
by *Gerrit Muller* USN-SE
e-mail: gaudisite@gmail.com
www.gaudisite.nl

## Abstract

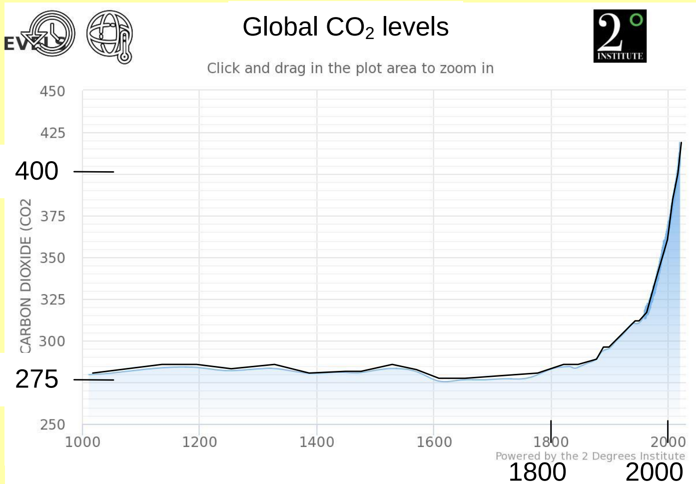
The roadmap for Best Duurzaam needs supporting A3s to explain and elaborate various options for Sustainability, such as energy harvesting, generation, storage, and distribution. This presentation is the collection of supporting A3s.



March 26, 2023
status: preliminary draft
version: 0.7



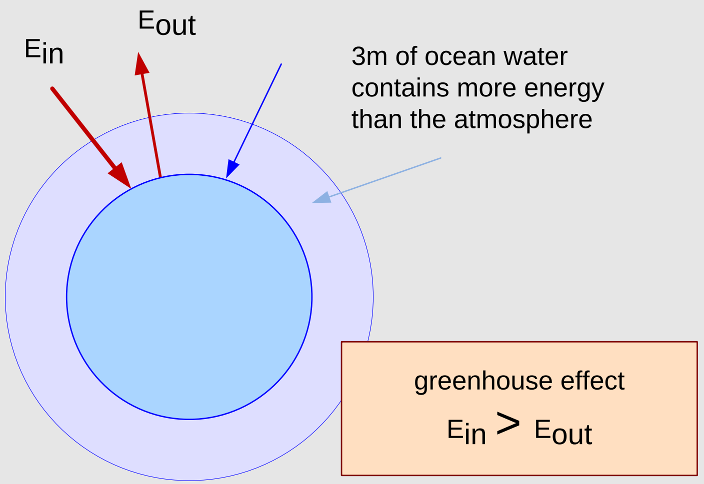
## 1 *CO2 ppm*




CO2levels.org

$CO_2$ levels started to increase with the industrial revolution
The rate of change is very high on cosmic time scale

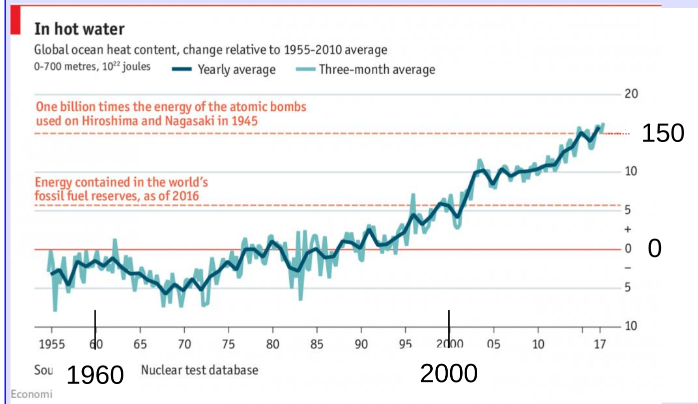
## 2 *physics/nature of earth*




High $CO_2$ levels cause the greenhouse effect. Earth warms up because more energy from the sun comes in then the amount of energy that can escape the atmosphere

## 3 *Global Ocean Heat Content* ***Change***

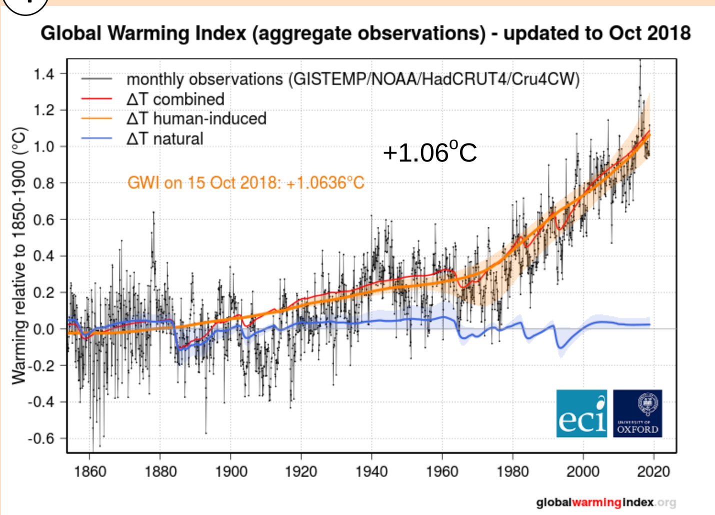
in $10^{21}$ Joules (=$10^6$ PJ; NL uses 3 PJ/yr))




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

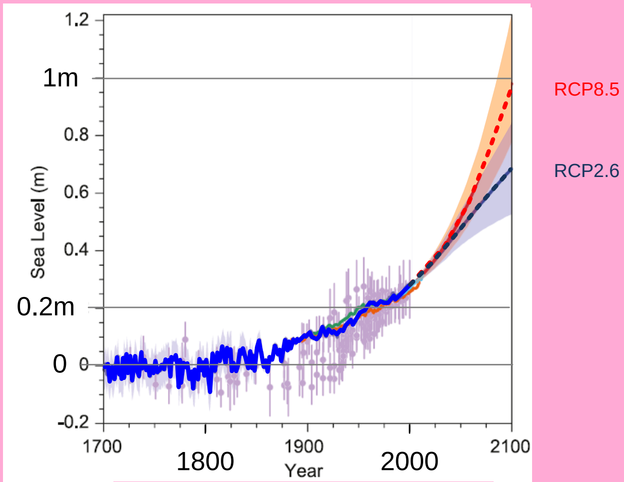
## 4 *temperature on earth*




globalwarmingindex.org

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*

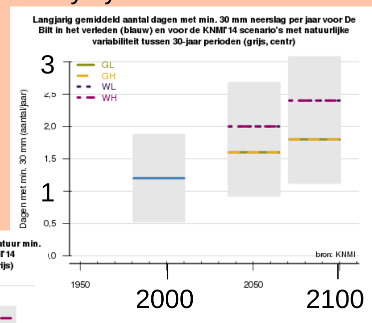



5th IPCC report via realclimate.org

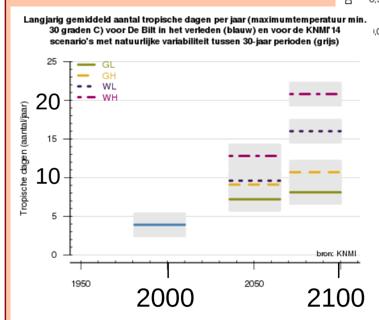
Combination of smelting land ice and increasing see water temperature will increase see water level. In a few centuries this increase can be tens of meters

## 6 *extreme weather*

#days/year with >30mm rain



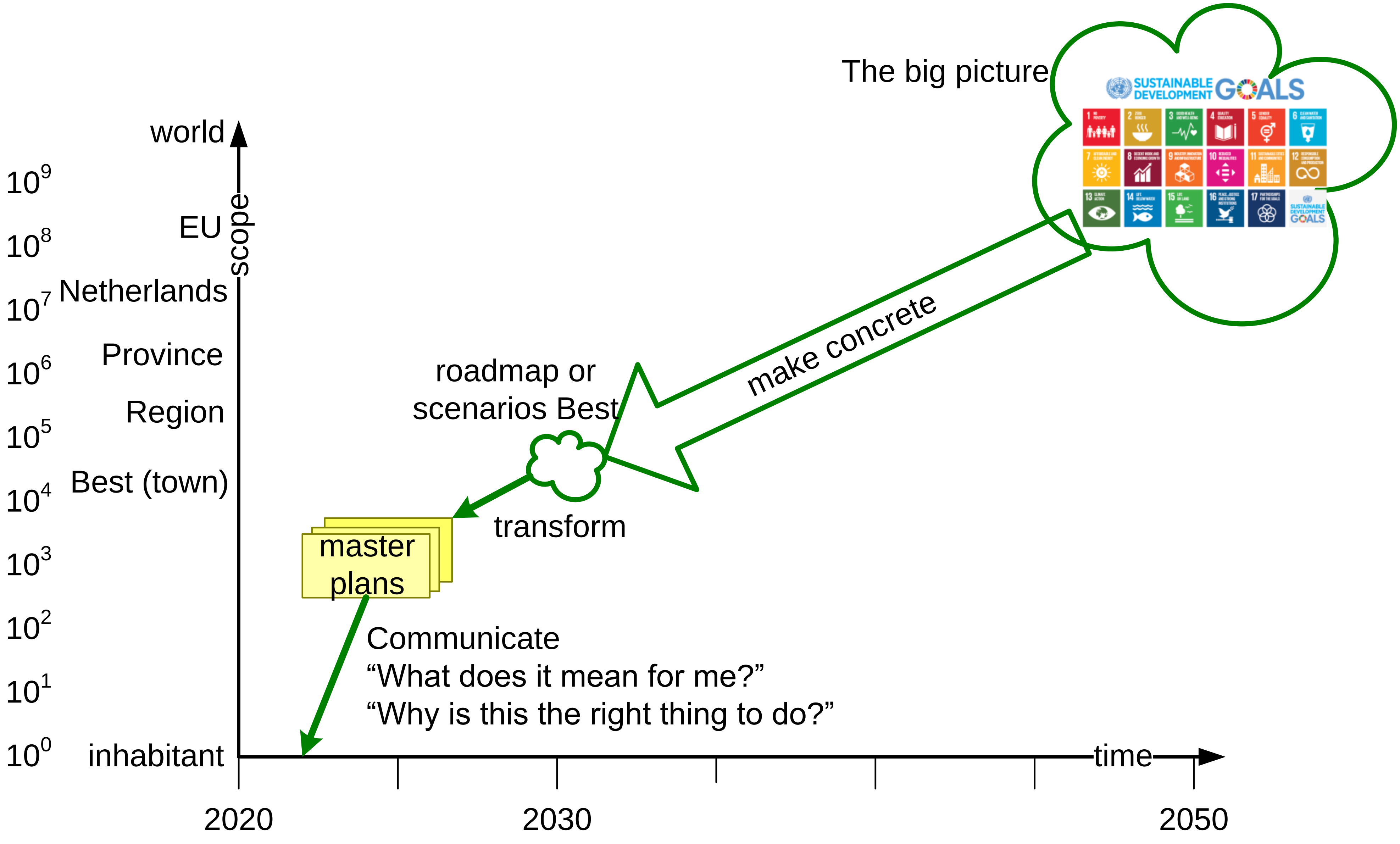

#days/year with T>30°C




klimaatscenarios.nl

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



| Best Duurzaam Background data energy consumption | Author: Gerrit Muller, contributions from many Best Duurzaam volunteers | BDRA3backgroundData. Version 0.1, May 8, 2020 |
|---|---|---|

*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** |
|---|---|---|

*Best estimate of energy need*

**transportation**

efficiency gains
- cars (electric) 3[1]
- trucks&buses (hydrogen) 2[2]

assuming cars become electric, heavy transport becomes Hydrogen

ratio car/trucks&buses: rough estimate 50/50

assuming energy reduction (lower speed, lighter and smaller vehicles)
- electric 30%

0.5 * 1210 / 3 * 0.67 + 0.5 * 1210 / 2 = 437

**heating/gas**

efficiency gain using heat pumps 3

reduce consumption by improving insulation 30%

868/3 * 0.67 = 193

**electricity**

efficiency gain using modern equipment 1.5

reduce consumption 10%

746 / 1.5 * 0.9 = 447

energy need after transition and full reduction

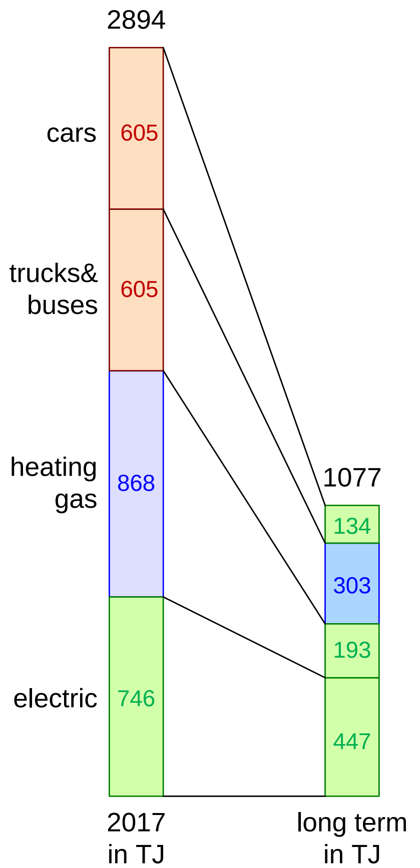
1077 TJ/yr

[1] https://www.fueleconomy.gov/feg/evtech.shtml

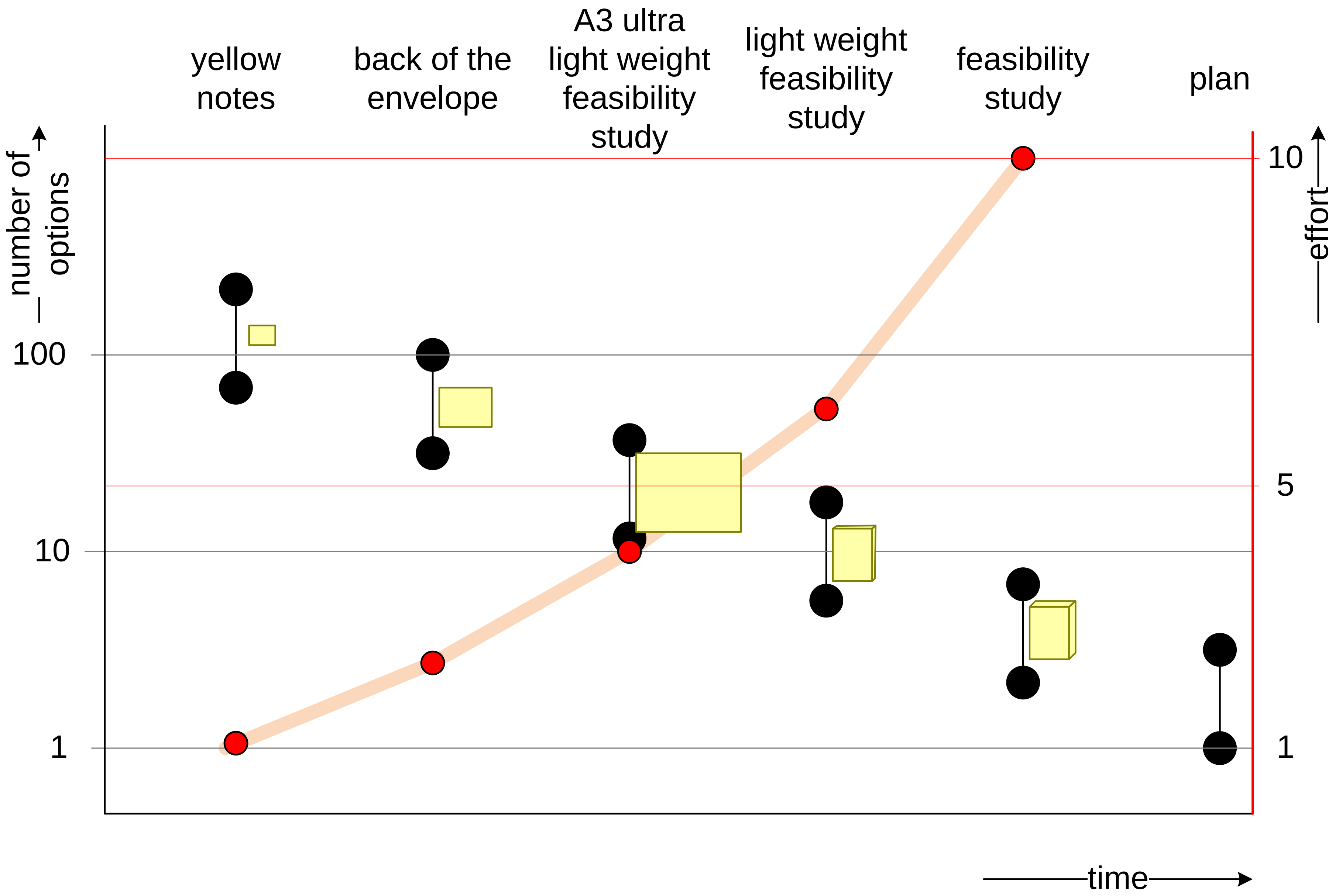
efficiency gasoline (excluding well to pump) ~19%, electric ~58%, $H_2$ ~45%

[2] https://www.deingenieur.nl/artikel/hydrogen-car-wins-over-electric-car

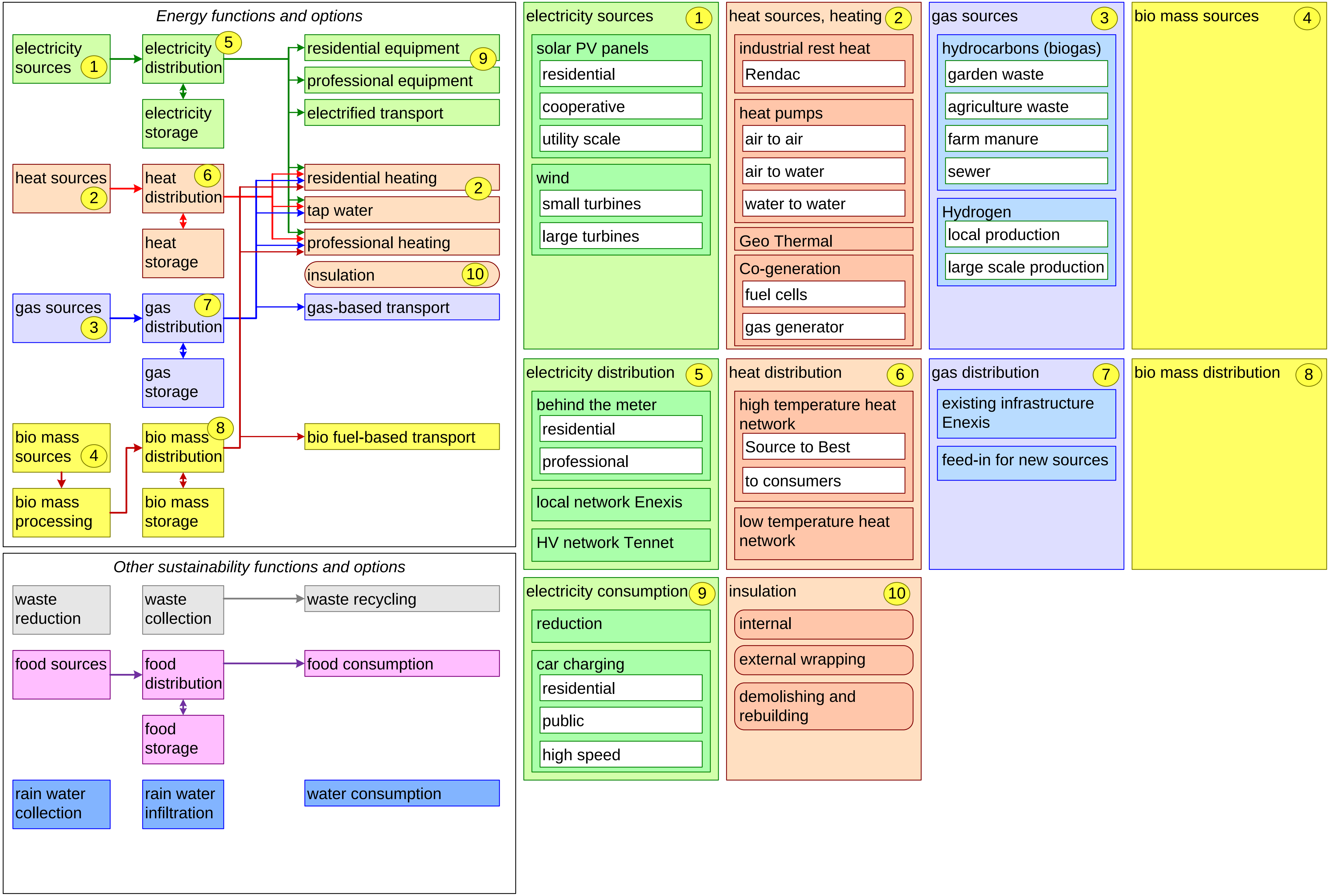
*energy transition*



# Funnel from Ideas to Decisions



Best Duurzaam Roadmap Options | Author: Gerrit Muller, contributions from many Best Duurzaam volunteers | BDRA3roadmapOptions Version 0, March 24, 2019



*Assessment Criteria*

**PESTEL**

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

**Political**

**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 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

1430 $m^3$/yr

~13 MWh/yr

electricity consumption to replace gas

(SCOP 3)

~4.3 MWh/yr

advantages:
- energy efficiency
- independent of other houses

disadvantages:
- installation effort
- initial cost
- acoustic noise
- space for equipment

## *High T heat network*

advantages:
- compatible with old houses
- low cost/house
- low space use

disadvantages:
- costly infrastructure
- limited individual control
- efficiency?

## *Low T heat network*

advantages:
- compatible with old houses?
- individual control
- energy efficient

disadvantages:
- costly infrastructure
- immature
- cost/house
- space for equipment

## *GeoThermie*

1 doublet, 2km depth, 300 m3/hr salt water of 80$^0$C up 20$^0$C down
construction costs 15 a 20 M€
plus construction heat network

heat production:
300 * $10^6$ g/h * 60 $^0$C * 4.2 J/g/$^0$C
~=80 GJ/hr ~= 24*365*80 GJ/yr
~= 700 TJ/yr

unknowns
energy consumption of pumps
OPEX
environmental impacts

advantages:
- compatible with old houses

disadvantages:
- costly infrastructure
- immature
- corrosion

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 $m^2$ roof space
yearly energy production solar:
173 kWh/$m^2$/yr

## *Hydrogen*

advantages:
- compatible with gas infrastructure
- individual control
- seasonal storage

disadvantages:
- very immature
- cost/house
- space for equipment

## *Bio mass*

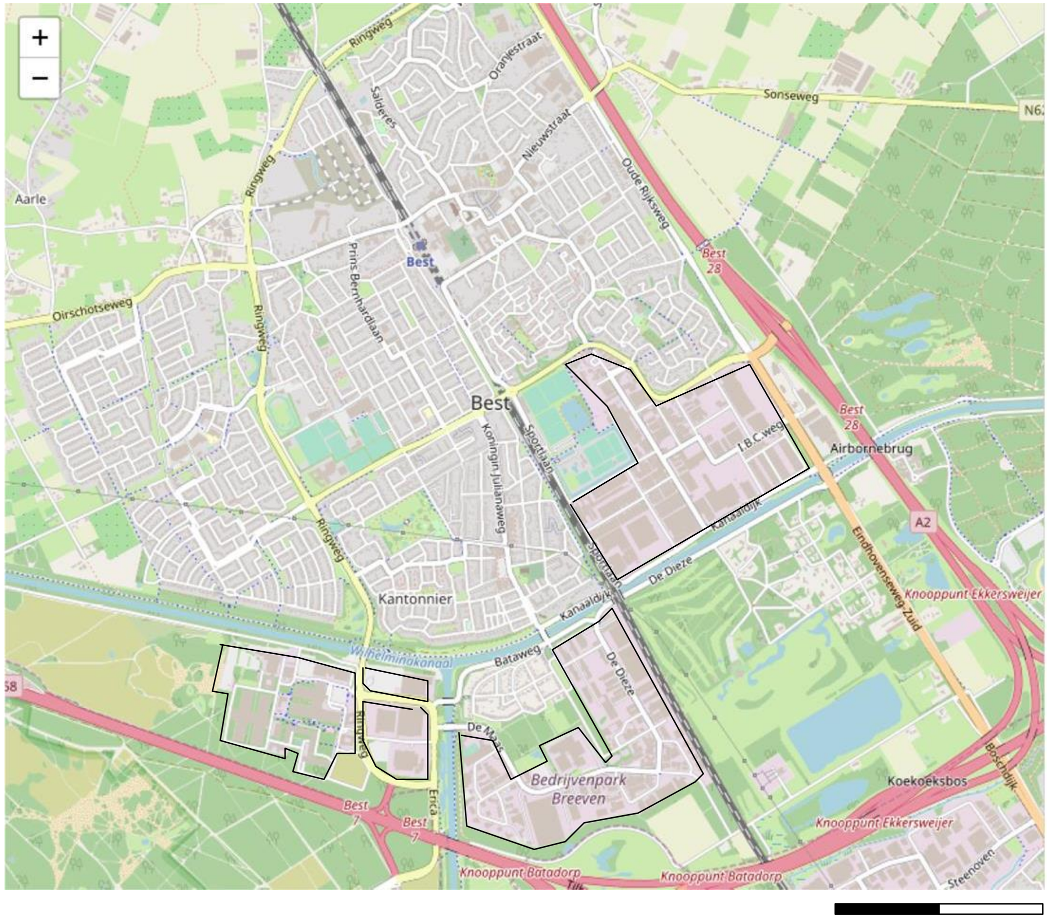
energy density (dry) wood: 5.3 kWh/Kg
https://nl.wikipedia.org/wiki/Energiedichtheid

wood production 1.1 to 1.5 Kg/$m^2$/yr
https://www.agriholland.nl/dossiers/biobrandstoffen/agrarischesector.html#hout

yearly energy production wood:

~7 kWh/$m^2$ (4% of solar)

*Solar PV commercial and residential areas*




Commercial ca 1.5 km$^2$

| | |
|---|---|
| building area | 25% |
| parking area | 10% |
| used for solar | 50% |

| km$^2$ | MW$_{peak}$ | GWh | TJ |
|---|---|---|---|
| 0.26 | 52 | 43 | 155 |

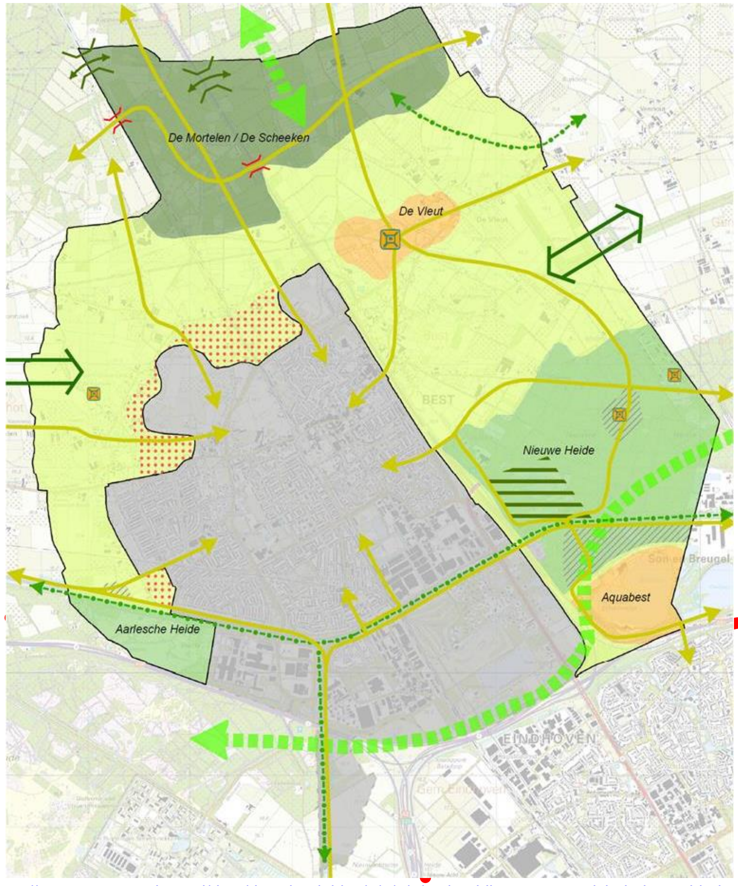
Residential ca 6 km$^2$

| | |
|---|---|
| building area | 15% |
| used for solar | 50% |

| km$^2$ | MW$_{peak}$ | GWh | TJ |
|---|---|---|---|
| 0.45 | 90 | 74 | 267 |

alternatively (Reinier ten Kate)
12500 houses, 20 m$^2$/house 0.25 km$^2$

*Solar PV utility scale and country side*




https://www.gemeentebest.nl/data/downloadables/5/8/6/7/verbeelding-structuurvisie-buitengebied.pdf

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

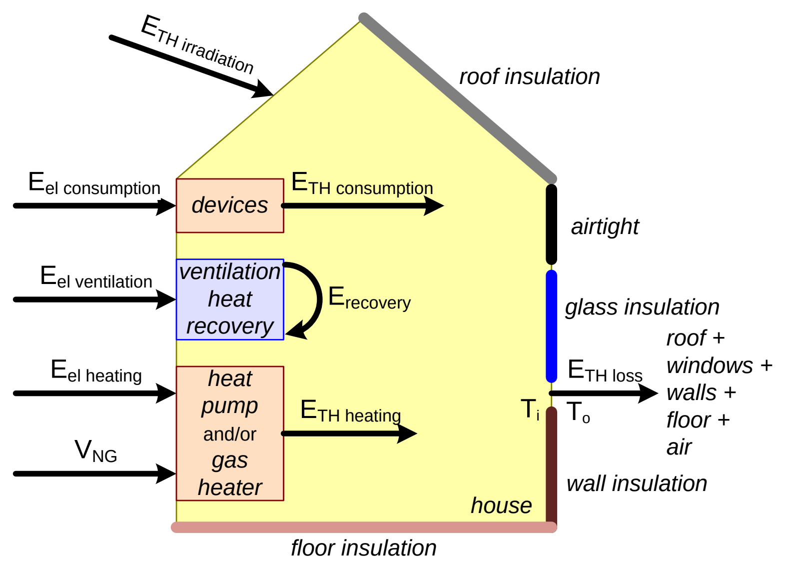
| | |
|---|---|
| W$_{peak}$ | 0,2 kW/m$^2$ |
| W$_{peak}$ to kWh/yr | 0.825 |

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 |

*conceptual model of heating of a house*




*the related formulas*

gas heater $E_{TH\ heating}$ ~= $V_{NG}$ [m3] * 10 kWh

heat pump $E_{TH\ heating} = COP(T_o) * E_{el\ heating}$

$COP(T_o) = c_a * T_o + c_b$

$E_{TH\ consumption} = c_{th} * E_{el\ consumption}$

$\Delta T = T_i - T_o$

$E_{TH\ heating} = E_{TH\ loss} - E_{TH\ consumption}$

$E_{TH\ loss} = c_{loss} * \Delta T * t$

*insulation thermal resistance*

*R = d / λ*

| material | λ | $R_{5cm}$ |
|---|---|---|
| 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 |
| | W/mK | $m^2K/W$ |
| 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

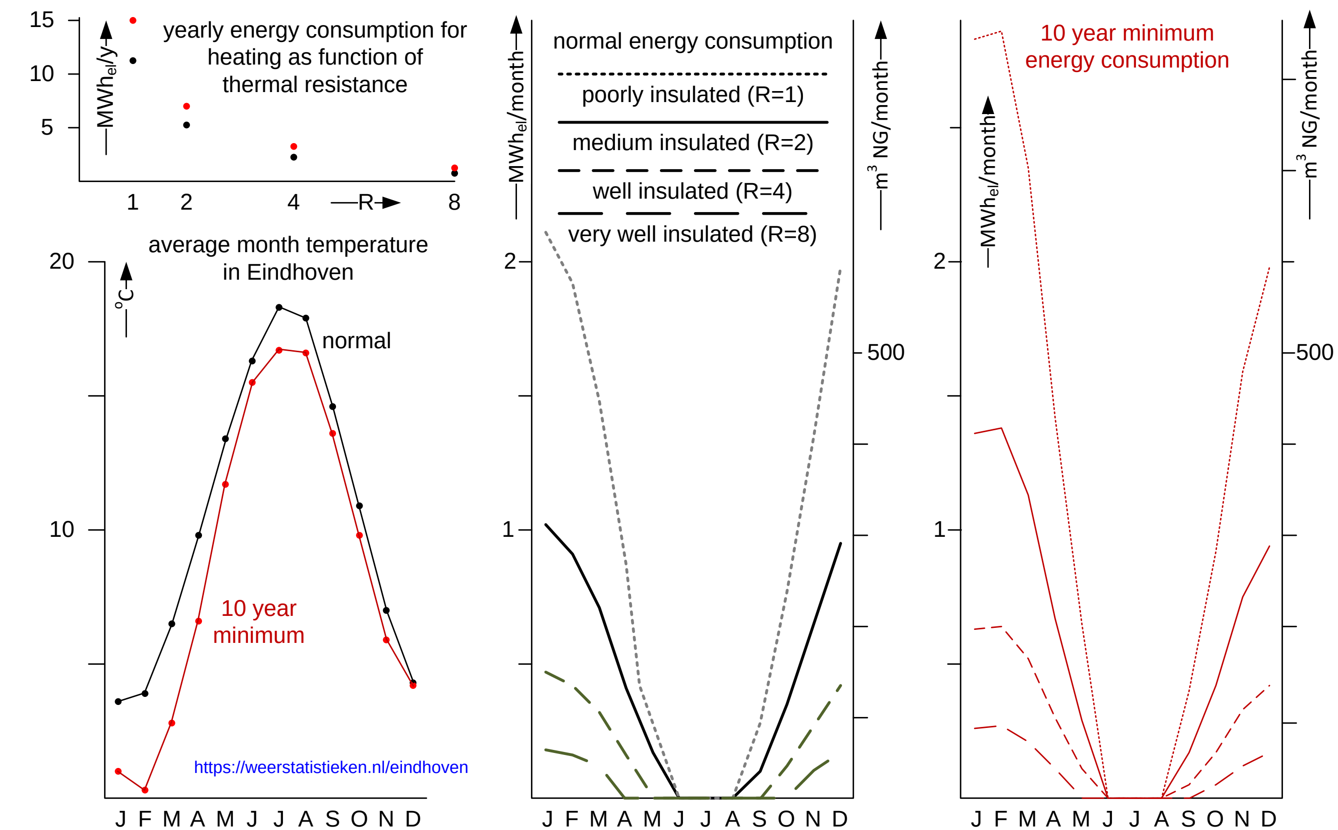
https://bouw-energie.be/nl-be/bereken/r-waarde-isolatie
https://glasherstelhermans.nl/isolatiewaarde-glas/

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

January 2021
$T_o$ = 3.1
$T_i$ = 18
$c_{th}$ = 1
$c_a$ = 0.1
$c_b$ = 2
R = 2 (medium)

| |
|---|
| month [MWh]<br>$E_{el\ total}$ = 1.56 |
| hour [kWh]<br>$E_{el\ total}$ = 2.09<br>$E_{el\ consumption}$ = 0.3<br>$E_{el\ heating}$ = 1.44<br>$E_{TH\ heating}$ = 3.63 |
| $c_{loss}$ = 0.244<br>$kWh_{TH}\ {}^oC^{-1}hr^{-1}$ |

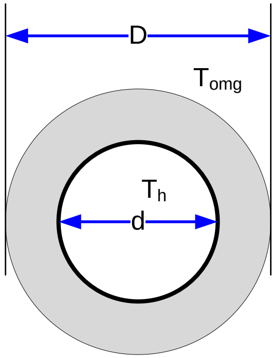
*energy consumption for heating over a year*



*heat loss in isolated pipe*

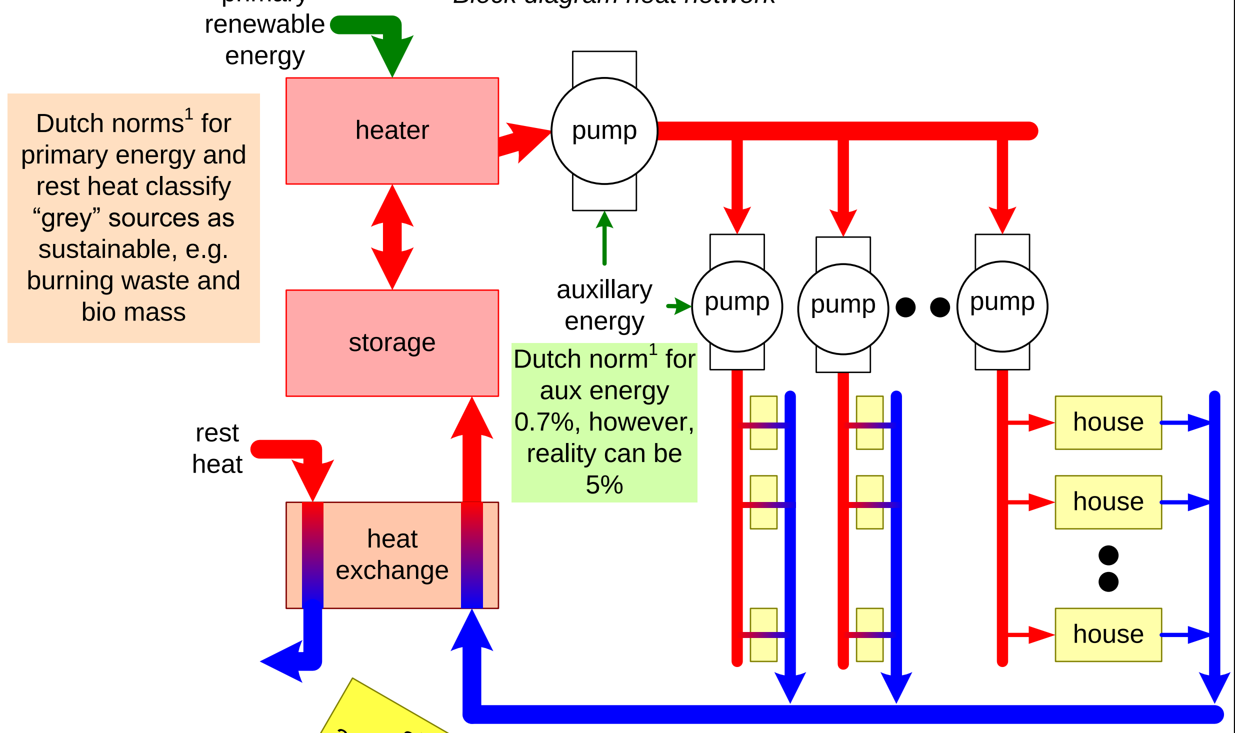
$Qv = (2*\pi*\lambda*(T_h - T_{omg})) / (\ln(D/d))$

| | |
|---|---|
| $Q_v$ | heat loss (W/m) |
| λ | isolation factor (W/mK) |
| $T_h$ | water temperature (°C) |
| $T_{omg}$ | environmental temperature (°C) |
| D | pipe outside diameter with isolation (mm) |
| d | pipe diameter without isolation (mm) |

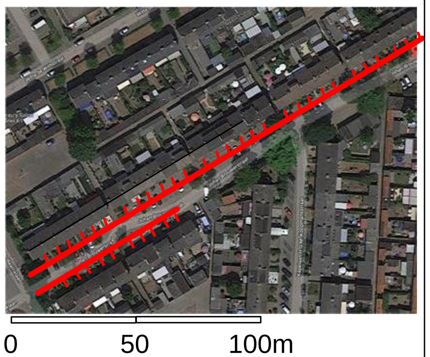



http://www.humsterlandenergie.nl/Energiebesparingsopties/Warmteverlies%20leidingen/

*Block diagram heat network*




*example, Johan Brouwerstraat*




38 houses
240 m thick pipe
114 m thin pipe
average heat loss per house:
354m/38 *(13.6+6.8) ~=
190 W/house ~=
**1660 kWh/yr/house**
(using input pipe of 60°C, return 35°C same length)

average gas use:
corner house 1540 $m^3$ gas/yr
middle house 1350 $m^3$ gas/yr
total 38 houses:
53960 $m^3$ gas/yr ~= 485 MWh/yr
12.8 MWh/yr/house
**13% heat loss at street level.**
www.cbs.nl data from 2017

all numbers are coarse estimates and need validation and refinement

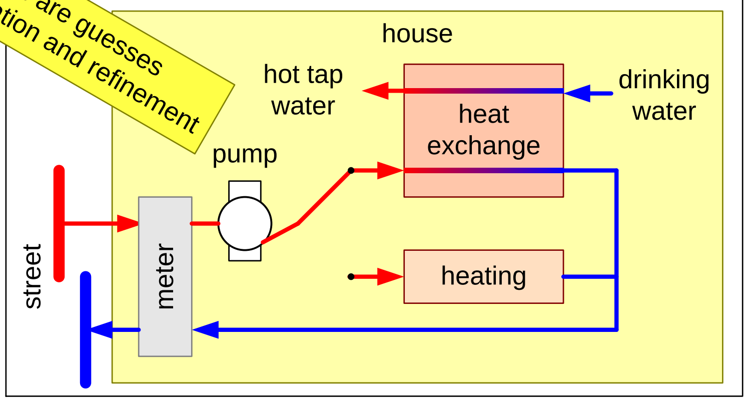
*typical heat loss in isolated pipe in numbers*

| $T_{hot}$ network | | $T_{return}$ network | |
|---|---|---|---|
| λ | 0.03 W/mK | λ | 0.03 W/mK |
| $T_h$ | 60°C | $T_h$ | 35°C |
| $T_{omg}$ | 10° C | $T_{omg}$ | 10° C |
| D | 100 mm | D | 100 mm |
| d | 50 mm | d | 50 mm |
| $Q_v$ | **13.6 W/m** | $Q_v$ | **6.8 W/m** |

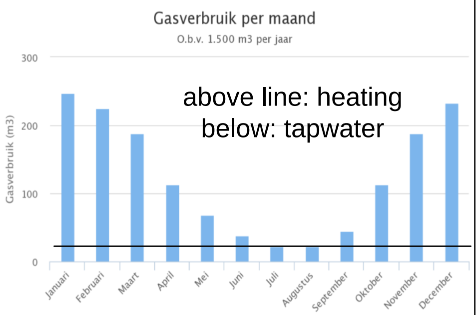
http://www.ekbouwadvies.nl/tabellen/lambdamaterialen.asp

all diagrams are guesses and need validation and refinement

*Block diagram single house*




*gas consumption per month*
in summer time the energy loss, to heat tap water only, is 50 to 100%



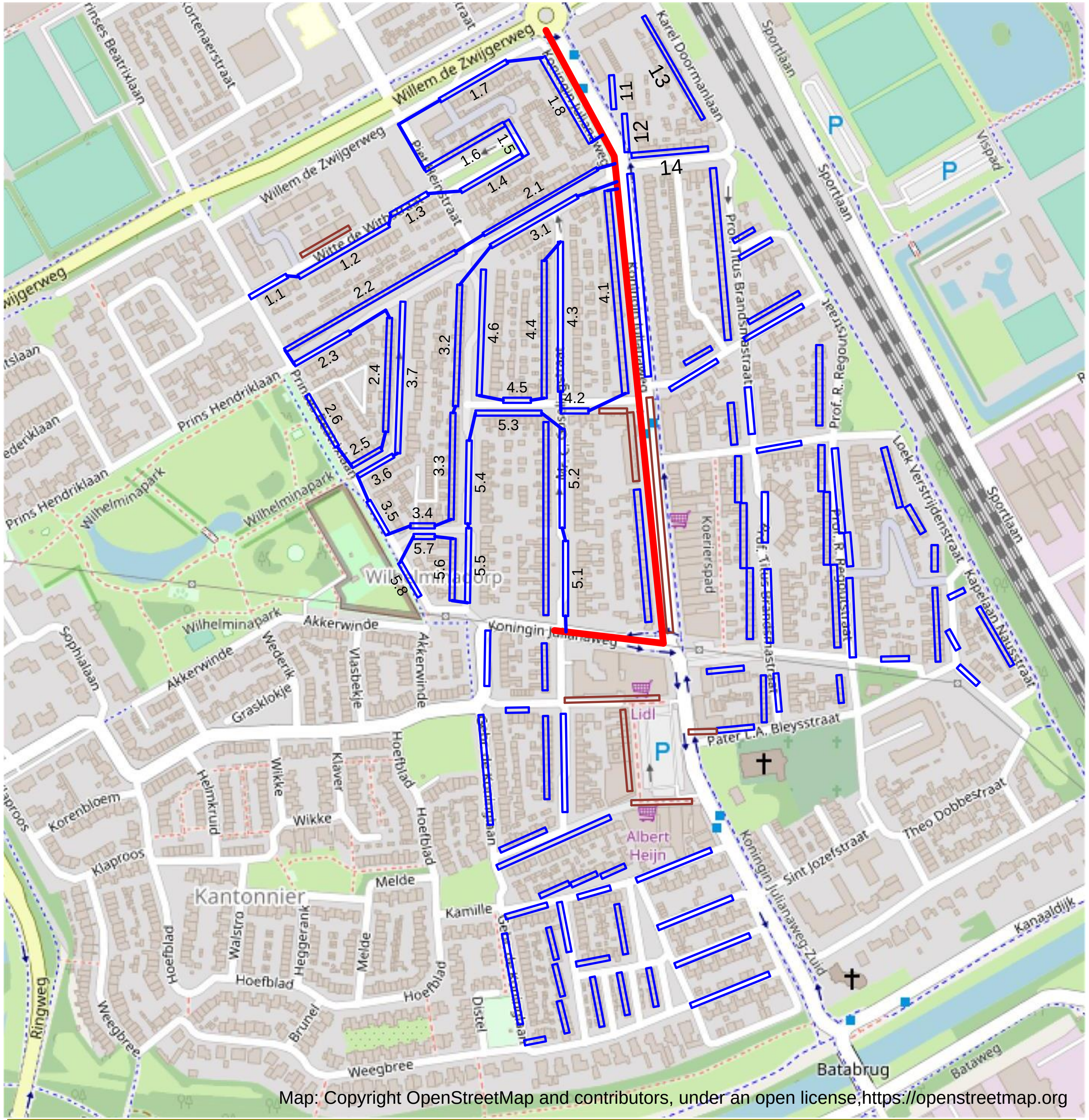

https://www.energiesite.nl/veelgestelde-vragen wat-is-een-gemiddeld-gasverbruik/

*background documentation*

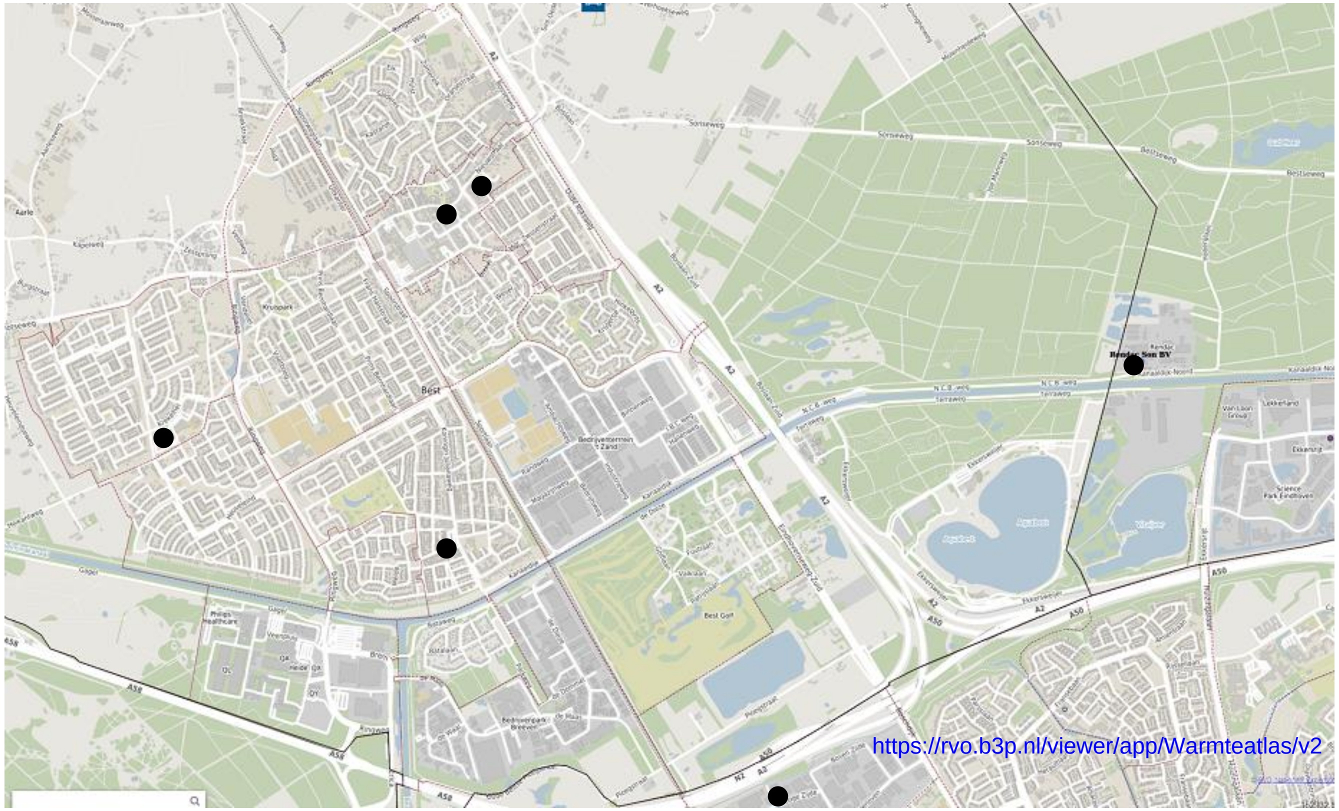
[1]Energiemaatregelen op gebiedsniveau (EMG), NEN 7125 https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/wetten-en-regels-gebouwen/nieuwbouw/energieprestatie-epc/energiemaatregelen-op-gebiedsniveau-emg
Aansluiten op warmtenetten Handreiking April 2018 https://www.ce.nl/publicaties/download/2564
Ketenemissies warmtelevering; Directe en indirecte CO2-emissies van warmtetechnieken https://www.ce.nl/publicaties/download/2069
Collectieve warmte naar lage temperatuur: Een verkenning van mogelijkheden en routes https://projecten.topsectorenergie.nl/storage/app/uploads/public/5aa/012/b89/5aa012b8926fd834673493.pdf

Heat Network Scenario Wilhelminadorp | Author: Gerrit Muller, contributions from many Best Duurzaam volunteers | BDRA3heatNetworkScenarioWilhelminadorp Version 0.1, April 28, 2019

| 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 |

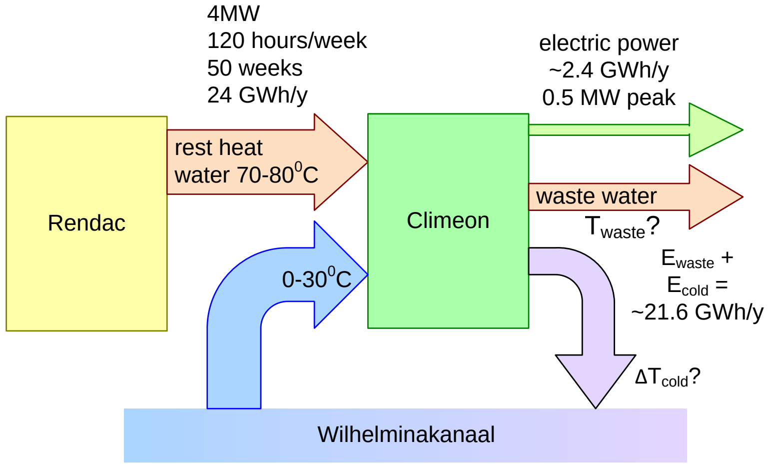
supermarket anno 2030
new, well insulated cooling cabinets

| | 1 supermarket | all 6 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

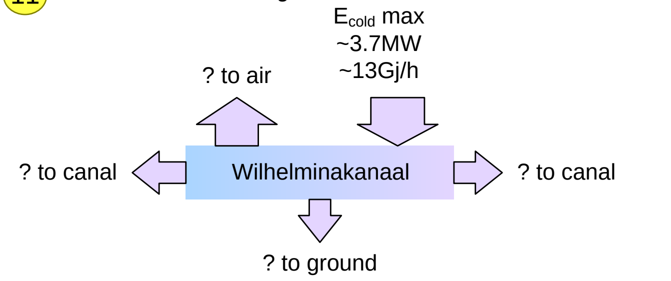



## 10 Assumptions, limitations

ignored:

- Operational cost
- effect of climate change (higher temperatures)
- warming up of Wilhelminakanaal
- energy use of auxillary 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$^0$C as function of $t_{cold}$ between 0 and 30$^0$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$^0$C; it also shows $E_{month}$ @ 30$^0$C

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

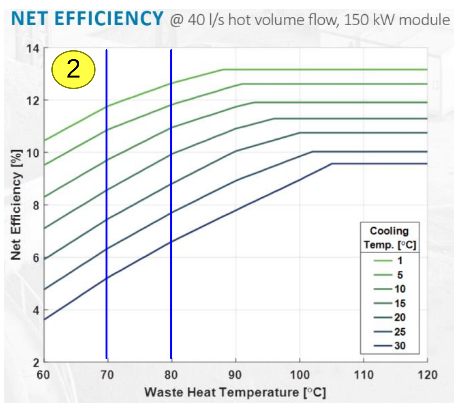
10 we have simplified a lot, here are some limitations

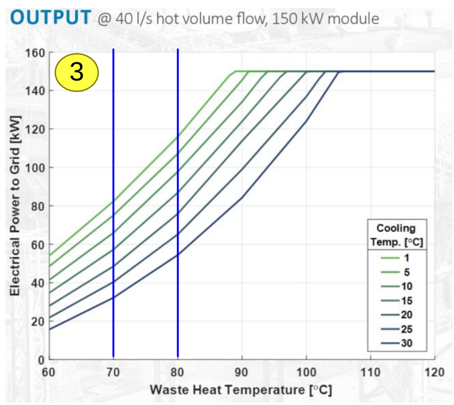
11 warming up of the canal has a big impact on environment and efficiency of the solution. Where does all the remaining heat go?

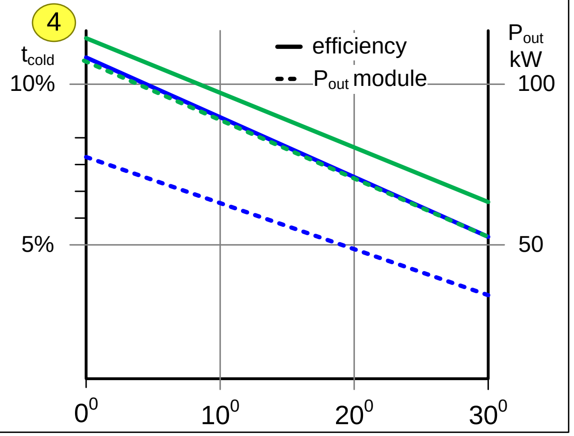
12 to get a feel for the impact, we estimate how much a stretch of 100m of the canal gets warmer per hour or per day, if all rest heat stays in the that part of the canal.

13 shows the impact of canal water that is 3$^0$C warmer than the average air temperature

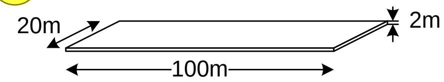
## Climeon data from https://climeon.com/wp-content/uploads/2017/04/Climeon-Tech-Product-Sheet.pdf




## 12 Estimate of warming of canal water




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

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

$c_{water}$ = 4.2 J/gK

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

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

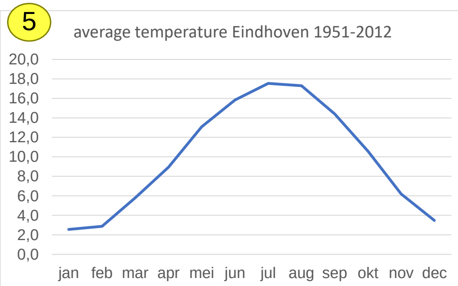
= 13.3 * 10$^9$ / 4 * 10$^9$ * 4.2

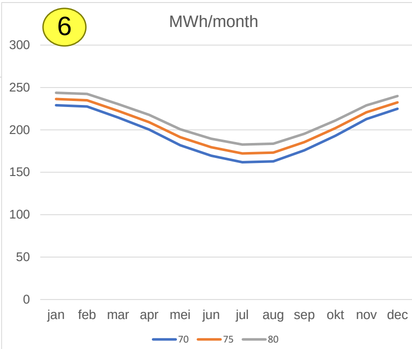
~= 0.8 K

this stretch of the channel would heat 0.8 K /hour if no heat escape or 20$^0$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.

## Electricity production in Eindhoven area




7

| $t_{hot}$ | MWh/y |
|---|---|
| 70 | 2354 |
| 75 | 2460 |
| 80 | 2566 |

8 #modules, $E_{month}$ @ worst case ($t_{cold}$=30$^0$C)

| $t_{hot}$ | #mod | MWh/m |
|---|---|---|
| 70 | 7 | 106 |
| 75 | 6 | 119 |
| 80 | 5 | 132 |

## 9 Cost and Income

Cost/module 350 k€

install cost (wild guess GM) 300 k€

electricity price 0.05€/kWh

| $t_{hot}$ | #mod | cost k€ | income k€/y | ROI years |
|---|---|---|---|---|
| 70 | 7 | 2750 | 118 | 23.3 |
| 75 | 6 | 2400 | 123 | 19.5 |
| 80 | 5 | 2050 | 128 | 16.0 |

## 13 What if $t_{cold}$ is 3 degrees warmer?

| $t_{hot}$ | MWh/y | income k€/y | ROI years |
|---|---|---|---|
| 70 | 2193 | 109 | 25.2 |
| 75 | 2306 | 115 | 20,9 |
| 80 | 2402 | 120 | 17,1 |

*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

*concerns*

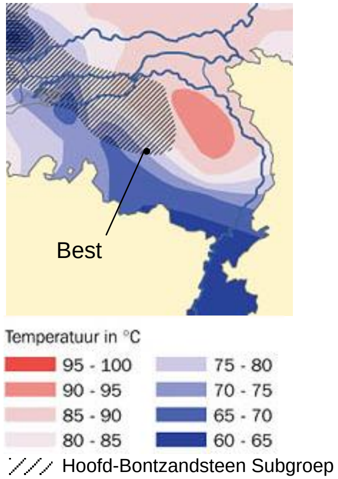
- what is the environmental impact of drilling, penetrating geological layers, and extracting this amount of heat?
- detailed knowledge about geological layers Is missing, resulting in drilling and exploration risks.
- brine water may contain sand and other polluting particles, increasing OPEX, decreasing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

*geothermal in Brabant*

geothermal gradient in the Netherlands: 30 °C/km

this is low enthalpy geothermal heat

| depth | temp[1] | Cost of drilling[2] |
|---|---|---|
| 10 m | 10 °C | |
| 1 km | 40 °C | 1 M€ |
| 2 km | 70 °C | 5.5 M€ |
| 3 km | 100 °C | 14 M€ |




1 https://www.geologievannederland.nl/ondergrond/afzettingen-en-delfstoffen/aardwarmte

2 https://edepot.wur.nl/5772

*geothermal formulas, technical and economic*

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

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

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

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

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

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

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

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

*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 elevant for high density buildings?

Example Case van den Bosch https://edepot.wur.nl/5772

application: heating green houses

location: Bleiswijk, the Netherlands

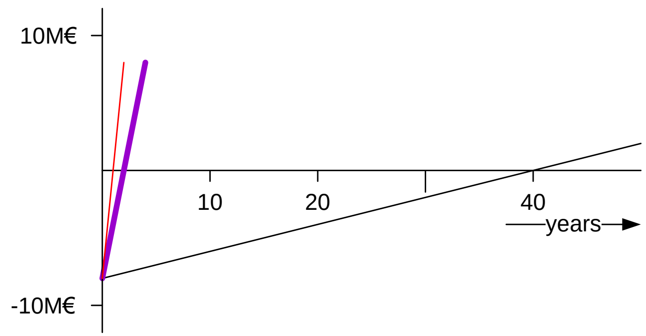
| | per hour | per year |
|---|---|---|
| depth: | 1700 m | |
| $temperature_{source}$: | 60 °C | |
| $temperature_{injected}$: | 30 °C | |
| volume: | 150 | 12000 $m^3$ |
| heat production: | 5 | 40000 $MWh_{th}$ |
| electricity consumption: | 275 kWh | 2200 MWh |
| COP: | 18 | |
| gas equivalent | | $4 * 10^6\ m^3$ |

| $p_{gas}$ €/$m^3$ | $cost_{gas}$ M€/year | ROI year |
|---|---|---|
| 0.1 | 0.4 | 40 |
| 1 | 4 | 2.2 |
| 2 | 8 | 1.1 |

| electricity €/kWh | M€/year |
|---|---|
| 0.1 | 0.2 |

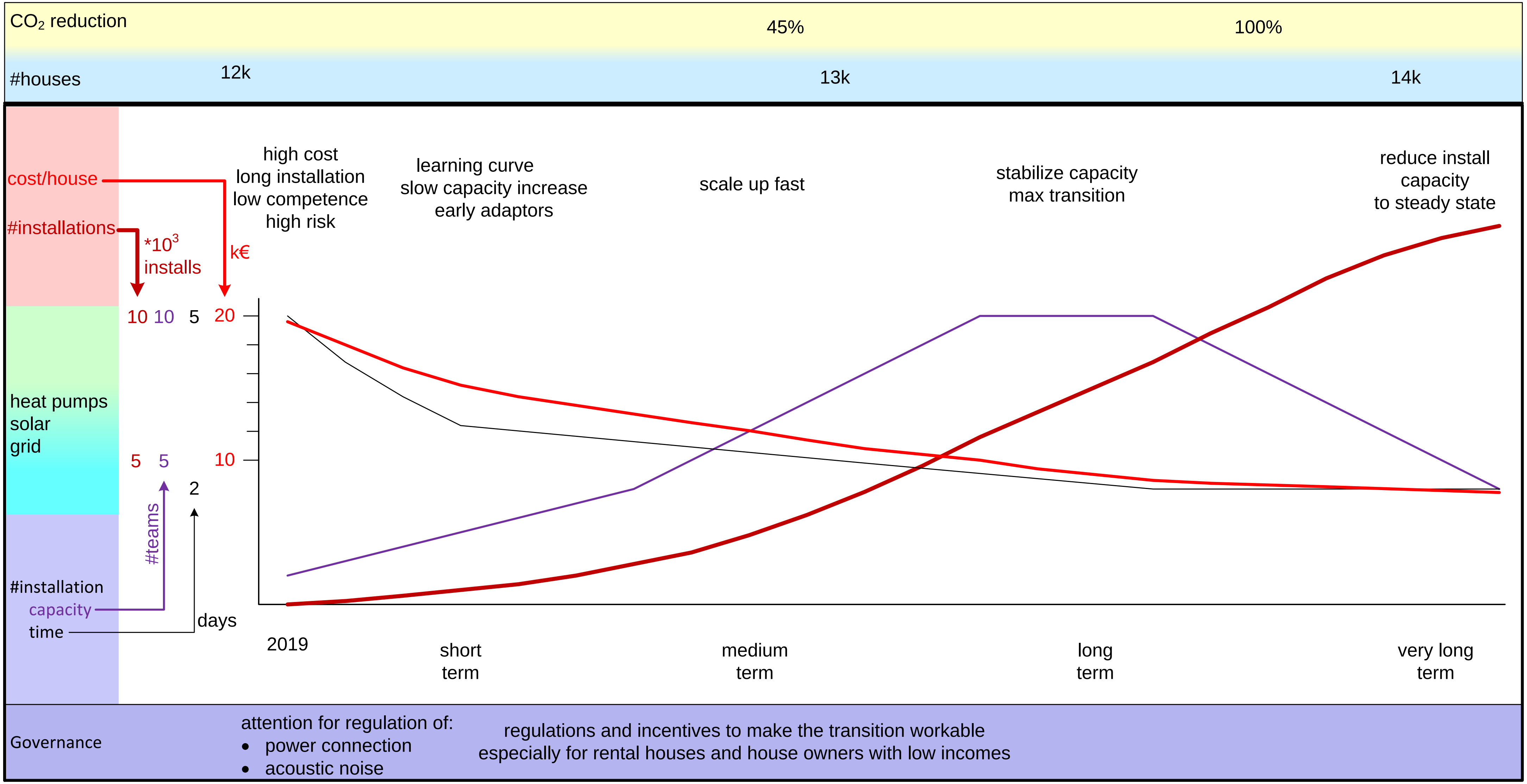
CAPEX 8M€

OPEX ignored




*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-glastuinbouw
- https://www.triaswestland.nl/project/de-proefboring
- https://www.youtube.com/watch?v=2Yx00PHDtaQ


CO2 reduction
45%
100%
#houses
12k
13k
14k
cost/house
#installations
*10^3
installs
k€
high cost
long installation
low competence
high risk
learning curve
slow capacity increase
early adaptors
scale up fast
stabilize capacity
max transition
reduce install
capacity
to steady state
10 10 5 20
5 5 10
2
#teams
heat pumps
solar
grid
#installation
capacity
time
days
2019
short
term
medium
term
long
term
very long
term
Governance
attention for regulation of:
• power connection
• acoustic noise
regulations and incentives to make the transition workable
especially for rental houses and house owners with low incomes

## *Solar PV cost and efficiency evolution*

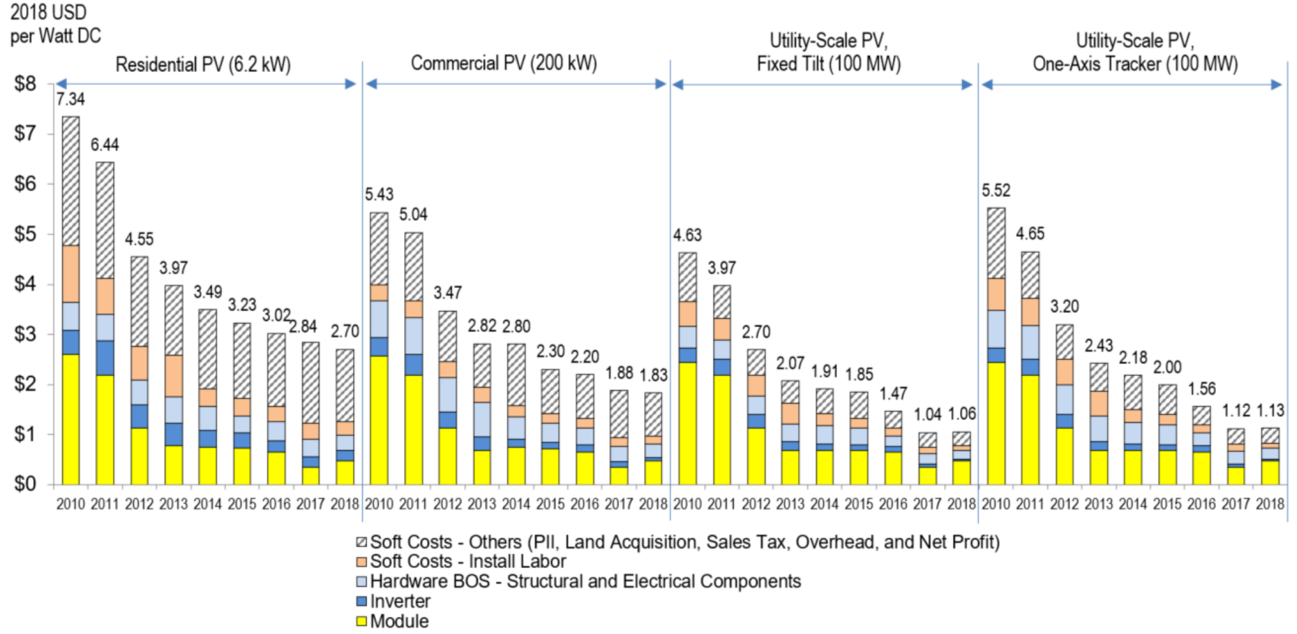



**Figure ES-1. NREL PV system cost benchmark summary (inflation adjusted), 2010–2018**

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

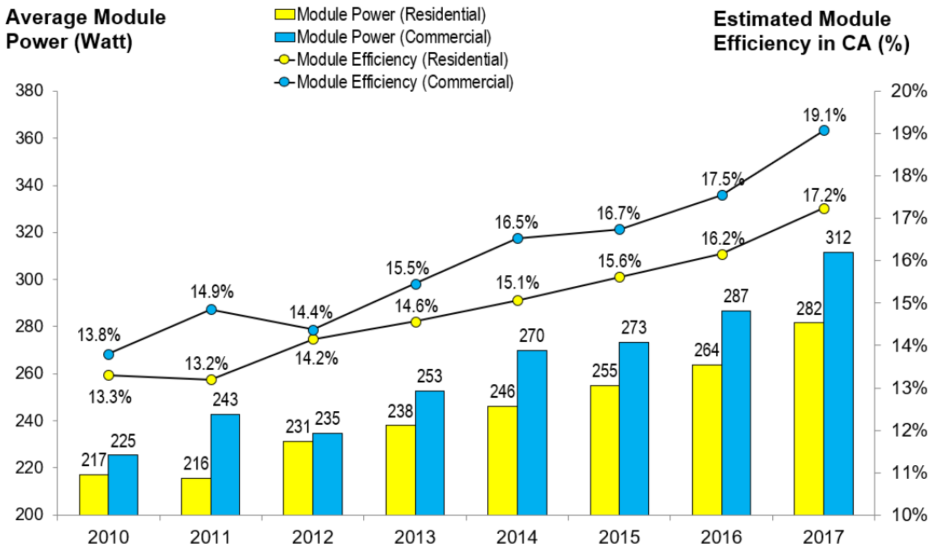
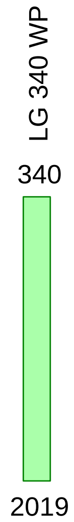
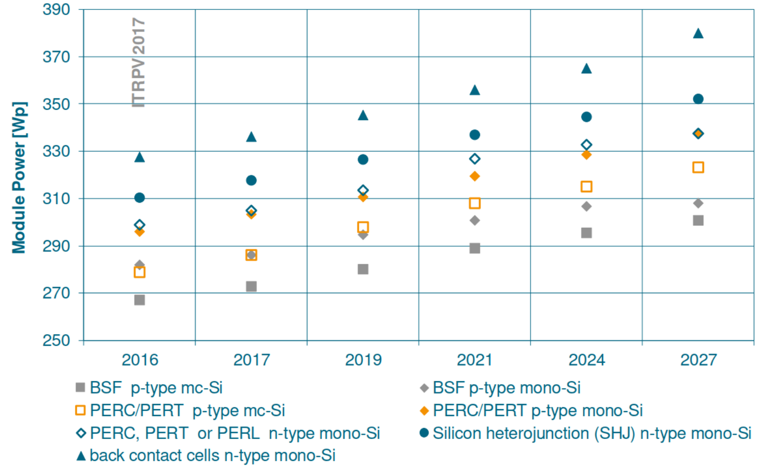


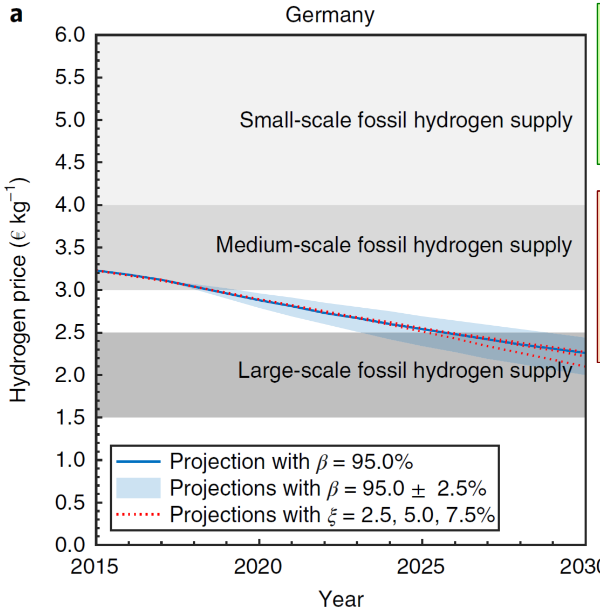

**Figure 3. Module power and efficiency trends from the California NEM database (Go Solar CA 2018), 2010–2017**




https://cleantechnica.com/2017/08/15/efficient-will-solar-pv-future-10-year-predictions-industry/

## *Hydrogen cost evolution*



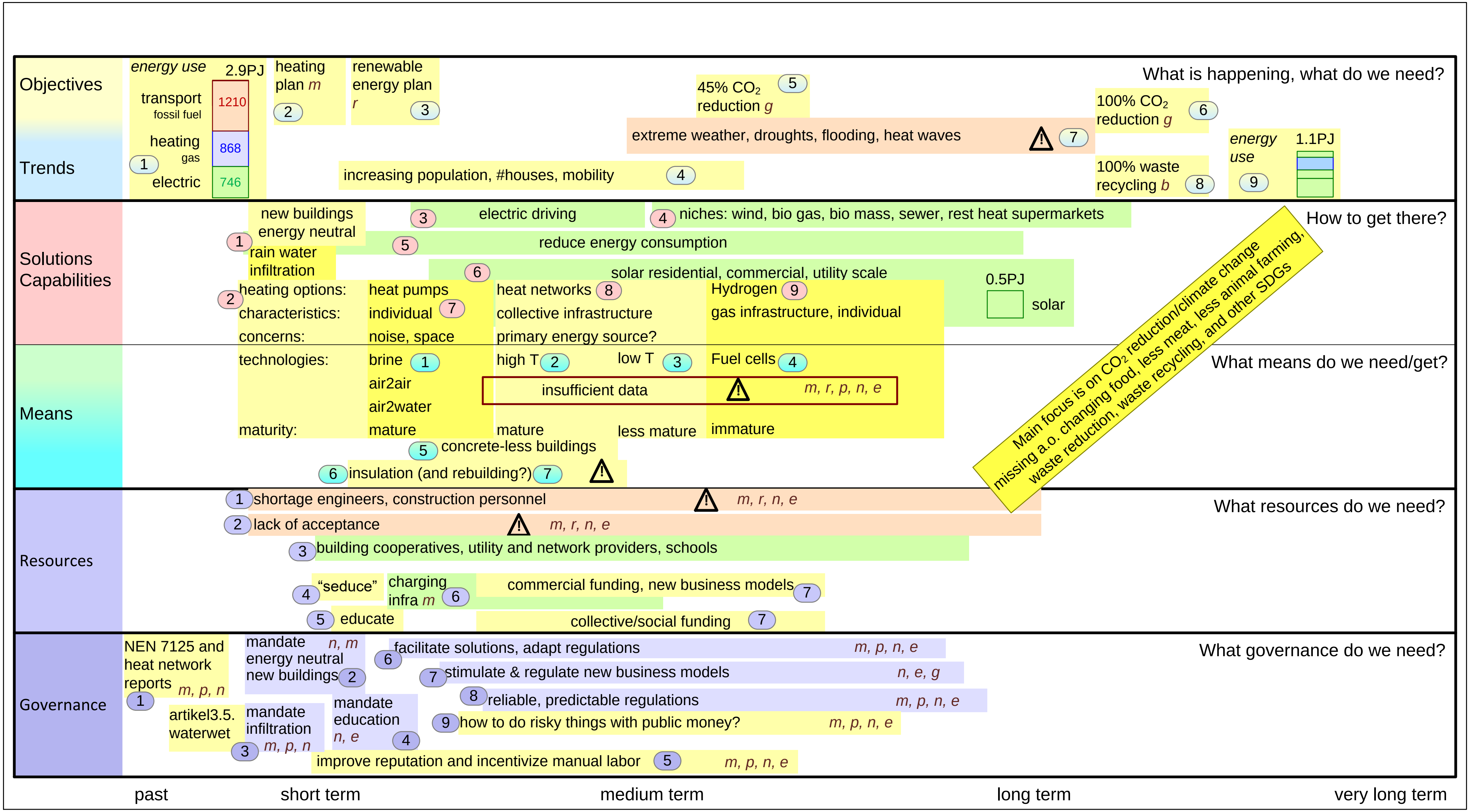

energy content of 1 Kg $H_2$ = 33.3 kWh

fuel cell efficiency 40..60%
https://www.energy.gov/sites/prod/files/2015/11/f27/fcto_fuel_cells_fact_sheet.pdf

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 Eneregy https://doi.org/10.1038/s41560-019-0326-1

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

Initial Roadmap for a sustainable Best | Author: Gerrit Muller, contributions from Laura Elvebakk & many Best Duurzaam volunteers | BDRA3initialRoadmapBest Version 0.7, May 8, 2019




1 energy use 2017
2 mandatory 2020 heating plan per neighborhood
3 mandatory 2021 regional
4 small increase per year
5 IPCC 2018
6 IPCC 2018
7 may increase energy use
8
9 energy use after full electrification and some reduction

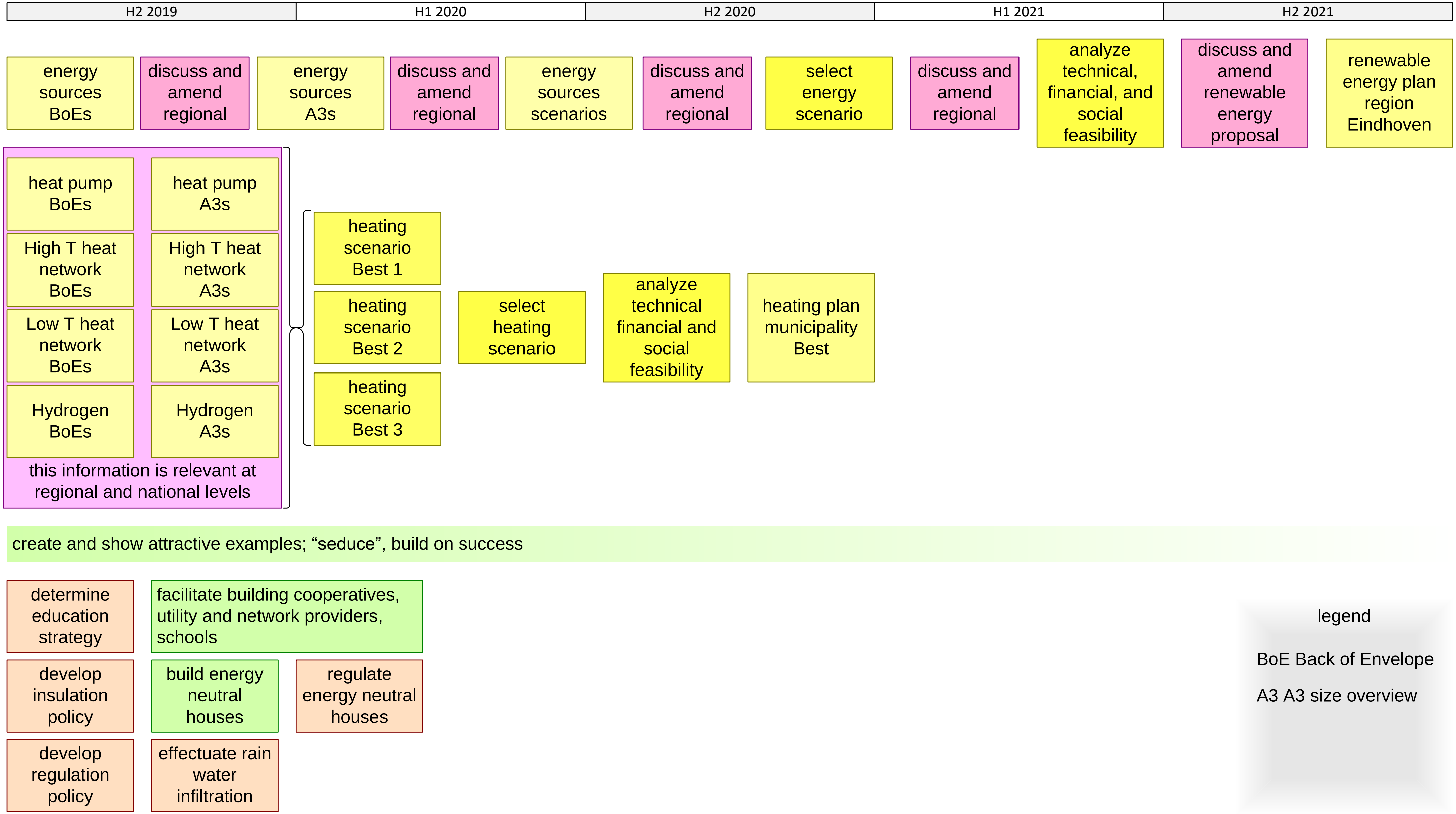
1 make all new developments sustainable
2 selection of options for heating plan
3 transport is major $CO_2$ producer
4 niche solutions in Best
5 reducing energy consumption is must
6 all forms of solar may result in 0.5 PJ/yr
7 mature; noise, space is concern
8 few rest heat sources; large collective infrastructure investment
9 long-term option; re-use gas infra

1 air2air for heating is efficient; how to get tap water?
2 compatible with older houses; challenge data is not public due to commercial interests
3 efficient allows re-use of any rest heat; storage is the big challenge
4 source to use little efficient; solves seasonal storage; production infrastructure expensive
5 concrete is major $CO_2$ producer
6 insulation is first step; external insulation needed?
7 when is rebuilding better (justified and acceptable)

1 action plan to attract and educate
2 involve, engage, seduce, incentivize
3 roadmap and master plan to coordinate
4 more effective than enforcement
5 primary, secondary schools; avoid overload
6 enable electric driving
7 be creative to get economy and funding working

1 7125 and reports overrate sustainability of bio mass and rest heat sources; lack absolute data
2 ASAP! waiting increases problem
3 vng.nl/3-gemeentelijke-watertaken; should be standard operation when maintaining streets
4 how to do this effectively?
5 culturally ingrained
6 agile (fast response) governance
7 facilitate and regulate
8 past pitfall; blocks investments
9 major dilemma for 6, 7, and 8

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


H2 2019
H1 2020
H2 2020
H1 2021
H2 2021
energy sources BoEs
discuss and amend regional
energy sources A3s
discuss and amend regional
energy sources scenarios
discuss and amend regional
select energy scenario
discuss and amend regional
analyze technical, financial, and social feasibility
discuss and amend renewable energy proposal
renewable energy plan region Eindhoven
heat pump BoEs
heat pump A3s
High T heat network BoEs
High T heat network A3s
Low T heat network BoEs
Low T heat network A3s
Hydrogen BoEs
Hydrogen A3s
this information is relevant at regional and national levels
heating scenario Best 1
heating scenario Best 2
heating scenario Best 3
select heating scenario
analyze technical financial and social feasibility
heating plan municipality Best
create and show attractive examples; “seduce”, build on success
determine education strategy
facilitate building cooperatives, utility and network providers, schools
develop insulation policy
build energy neutral houses
regulate energy neutral houses
develop regulation policy
effectuate rain water infiltration
legend
BoE Back of Envelope
A3 A3 size overview