Roadmapping for Sustainability; How to Navigate a Social, Political, and Many Systems-of-Systems Playing Field? A Local Initiative

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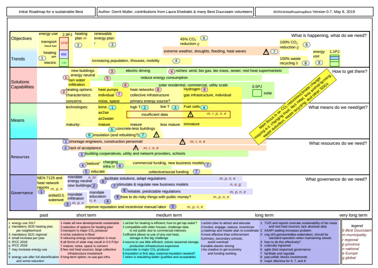
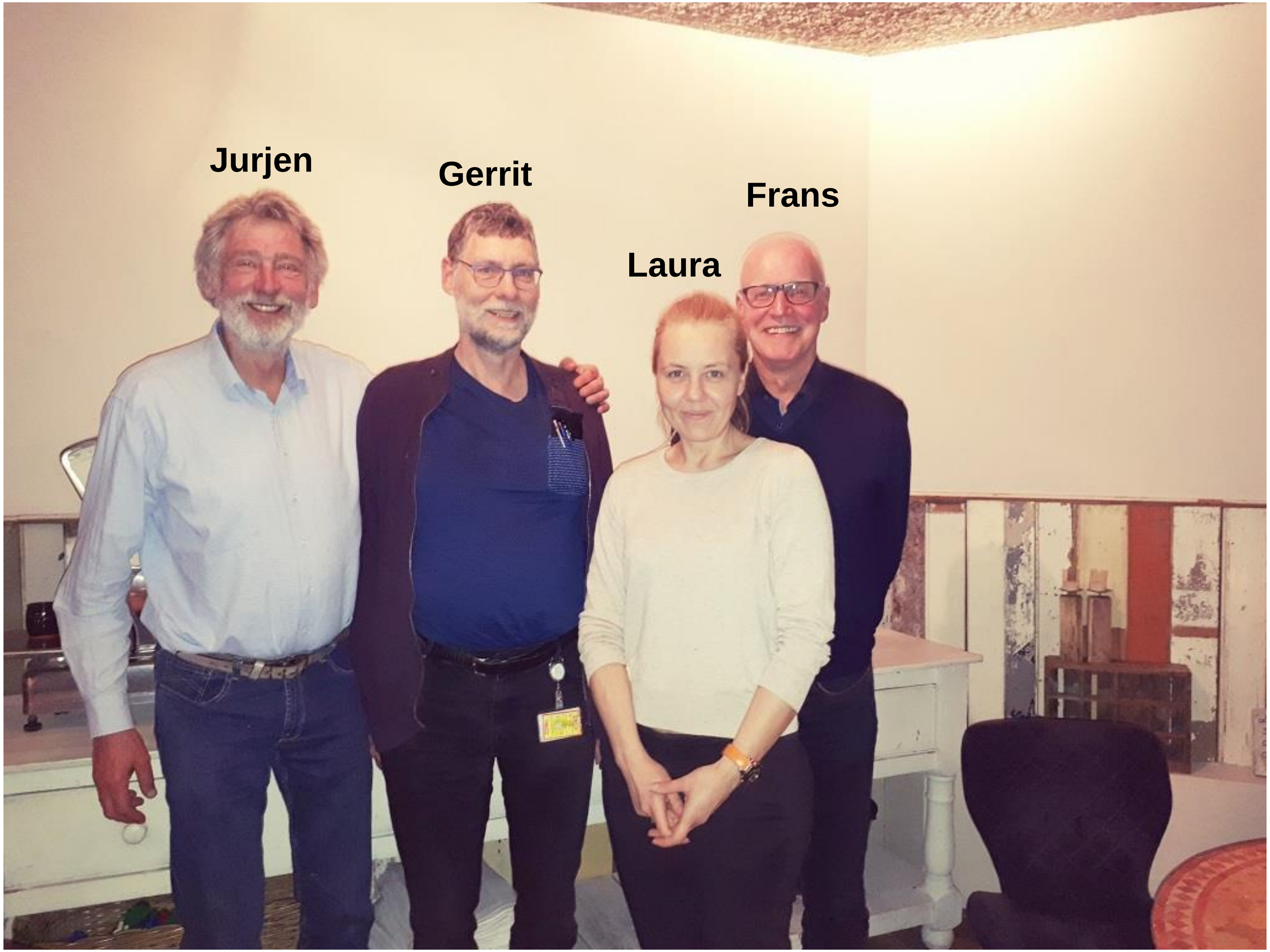
Abstract

The United Nations have defined 17 Sustainability Development Goals (SDGs). These goals cascade down to all governmental levels, such as EU, national, province, regional, and municipality. The realization of these goals requires developments in many systems, including non-technical systems (e.g. social, political, and ecological). One of the challenges is the complexity due to the large number of stakeholders (individuals, as well as many types of organizations) and the number of systems, all of them interacting and mutually dependent. We are applying roadmpping at municipality level to study the tools effectiveness.

March 26, 2023
status: finished
version: 0



The Authors



Location and key Figures of the village Best

Municipality Best

30k inhabitants
average income: 26kEuro/yr
12k houses

Cooperation Best Sustainable:
340 members
Mission:

- promote sustainability
- Intermediary
- Consultant

Ambition:

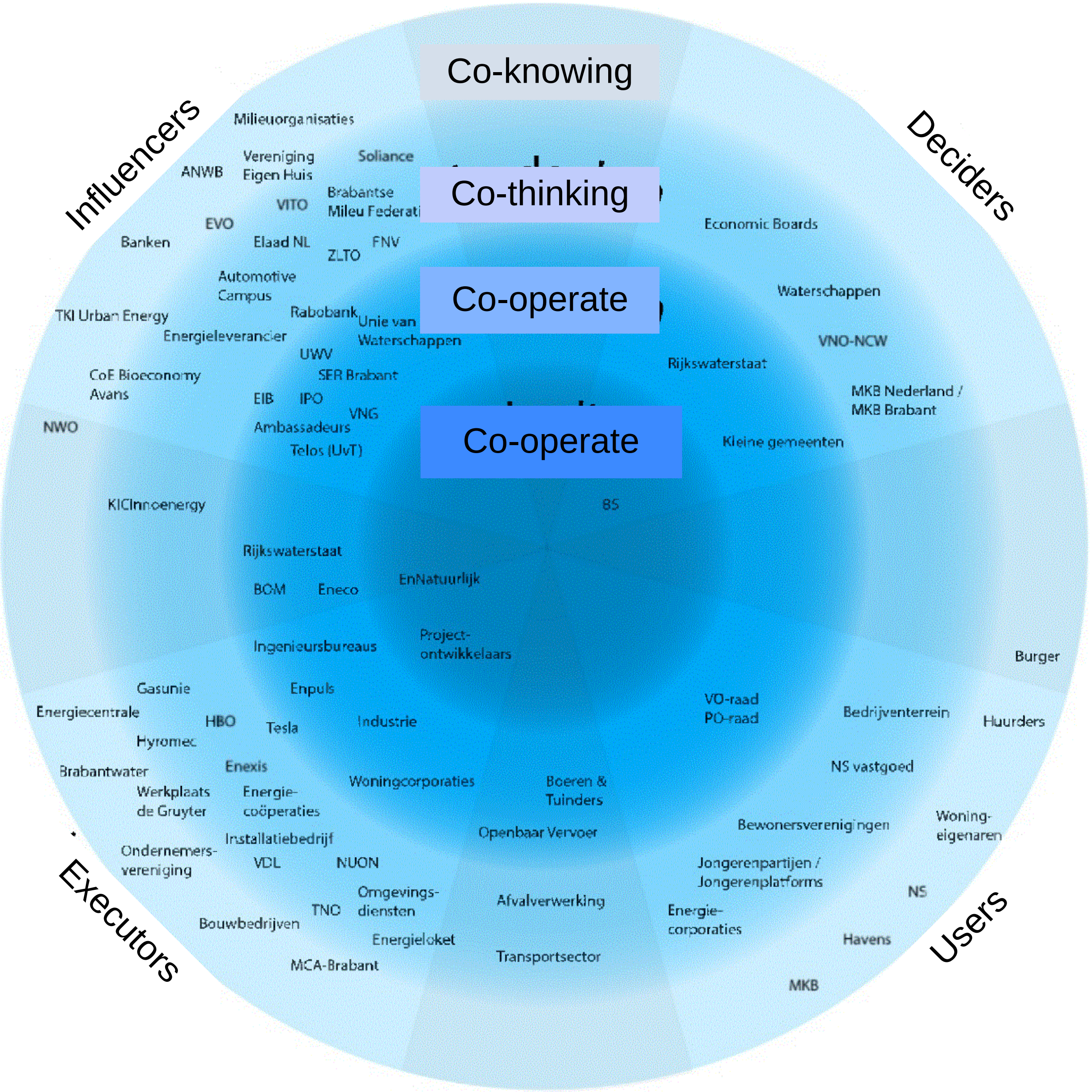
- Energy neutral in 2030
- No waste in 2030

Organization:

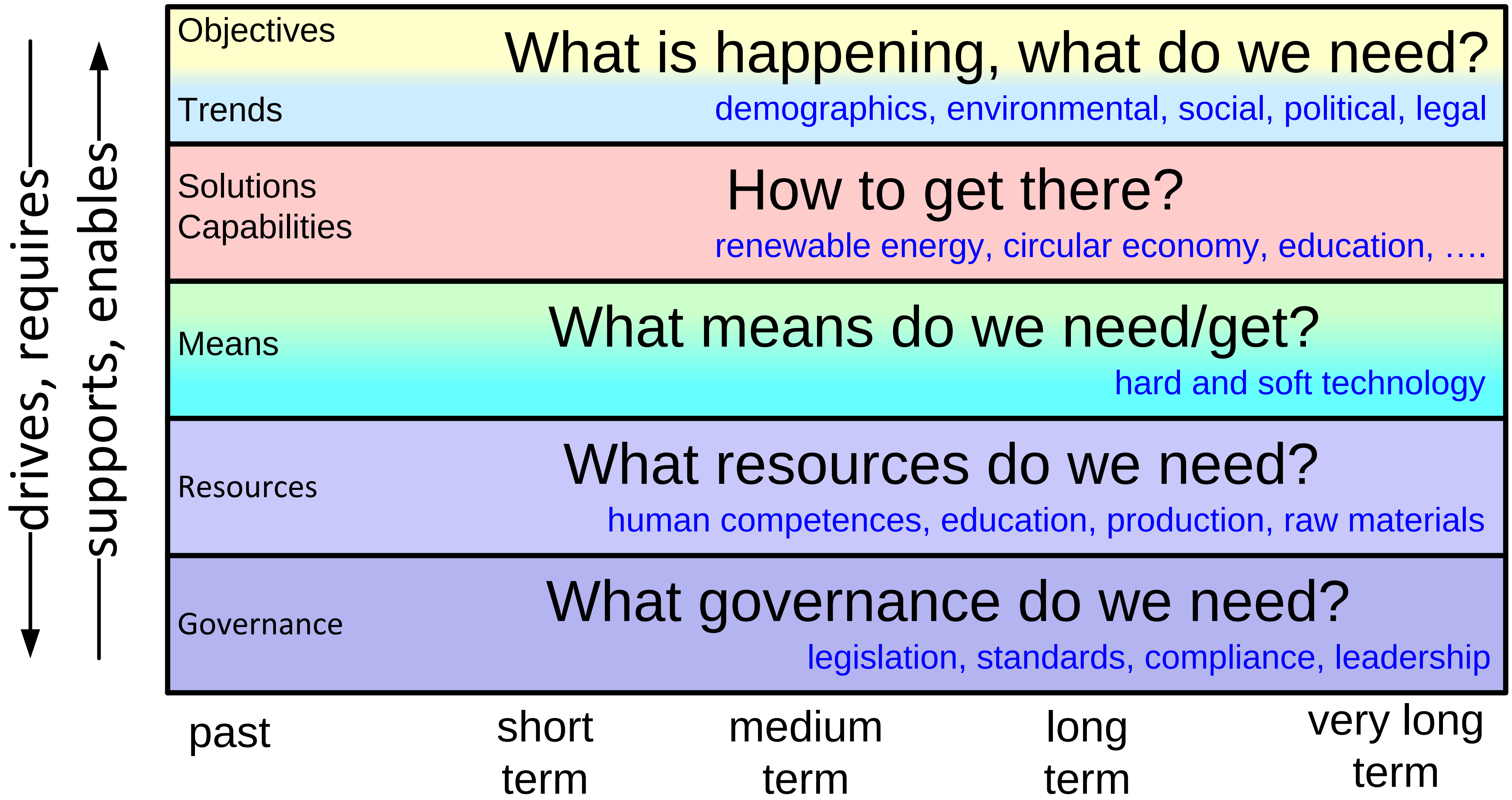
- Volunteers
- Working groups
    - Technology, education, communication
    - Bottom-up

How to make larger steps?
-> transition into project organization
-> roadmap setting the context

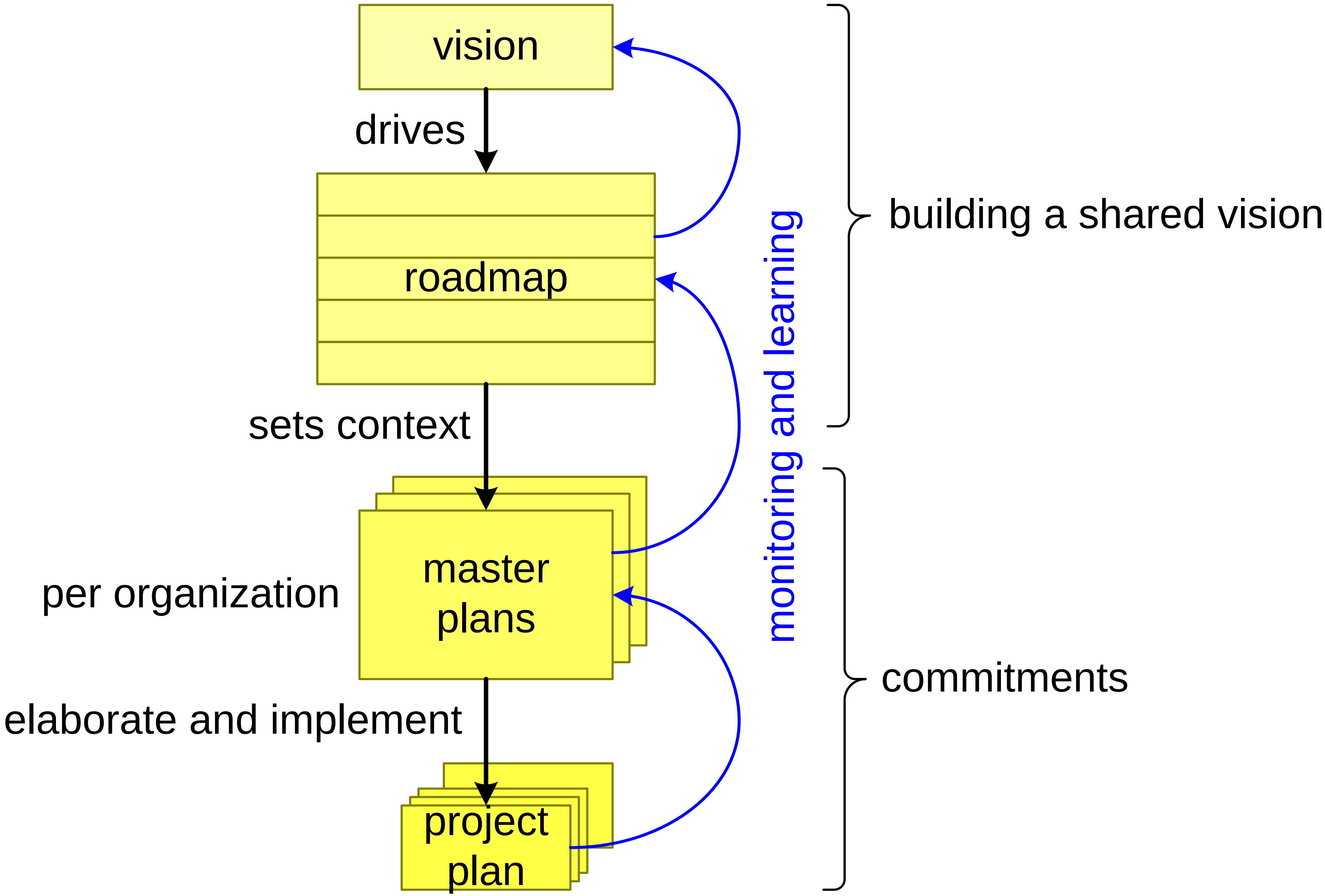
StakeholderMap



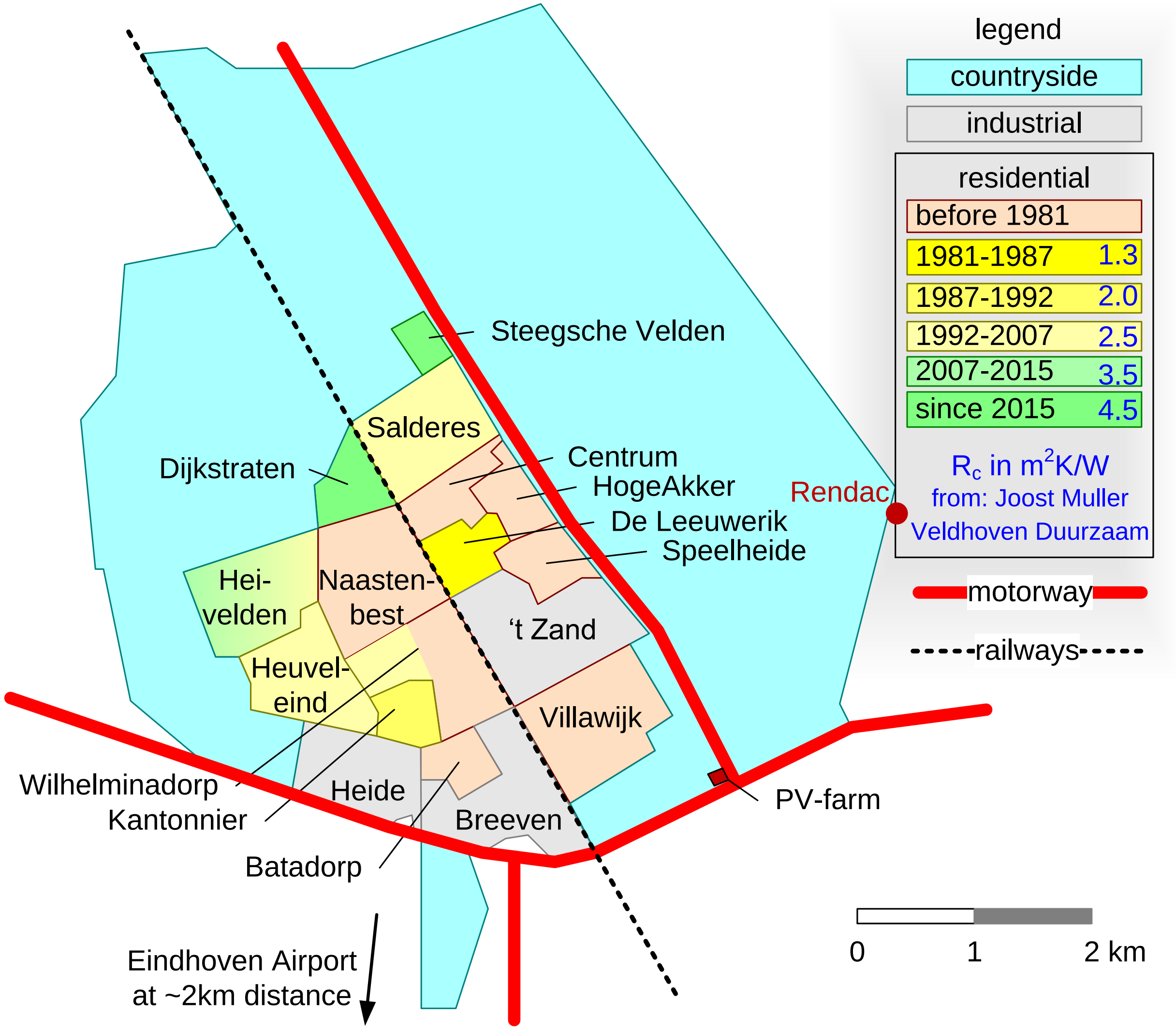
Roadmapping Layers



Strategy and Planning Tiers



Neighborhoods in Best



Example Back of the Envelope Estimate

cost/house

	cost in k€ incl. install incl VAT
16kW heat pump	18
insulation	4
PV system with 16 solar panels, 5.4kWp	7
miscellaneous	1
total	30

heat pump in&out	11
mounting material	1
installation	6
total	18

16 panels 340kWp	3.7
optimizers	0.7
inverter	1.0
mounting material	1.0
installation	1.0
total	7.4
excl VAT	

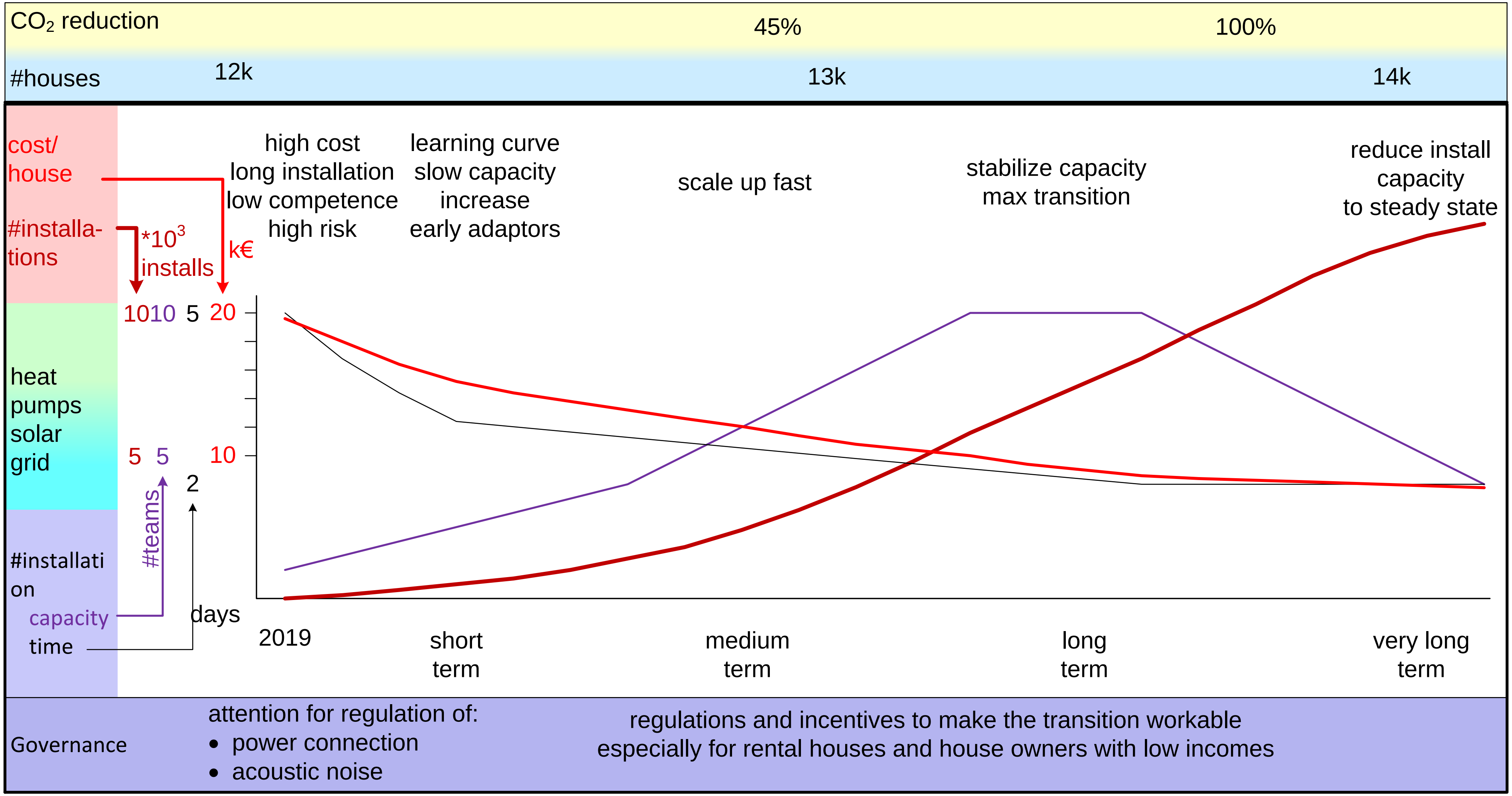
cost for all houses in Best

12k houses
30 k€/house
360 M€

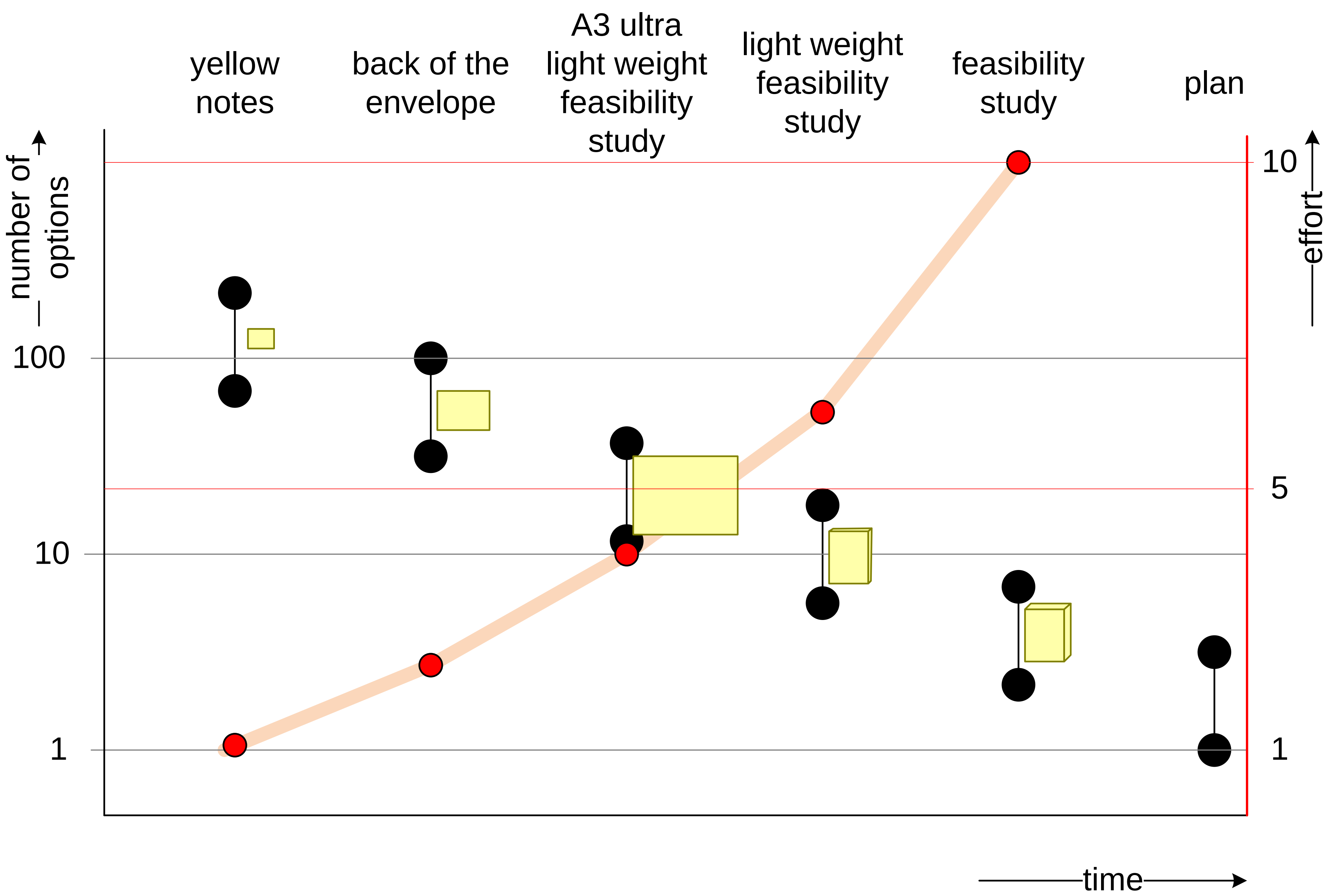
assumptions:
prices 2018
effort 2018
VAT return on solar
no infrastructure cost

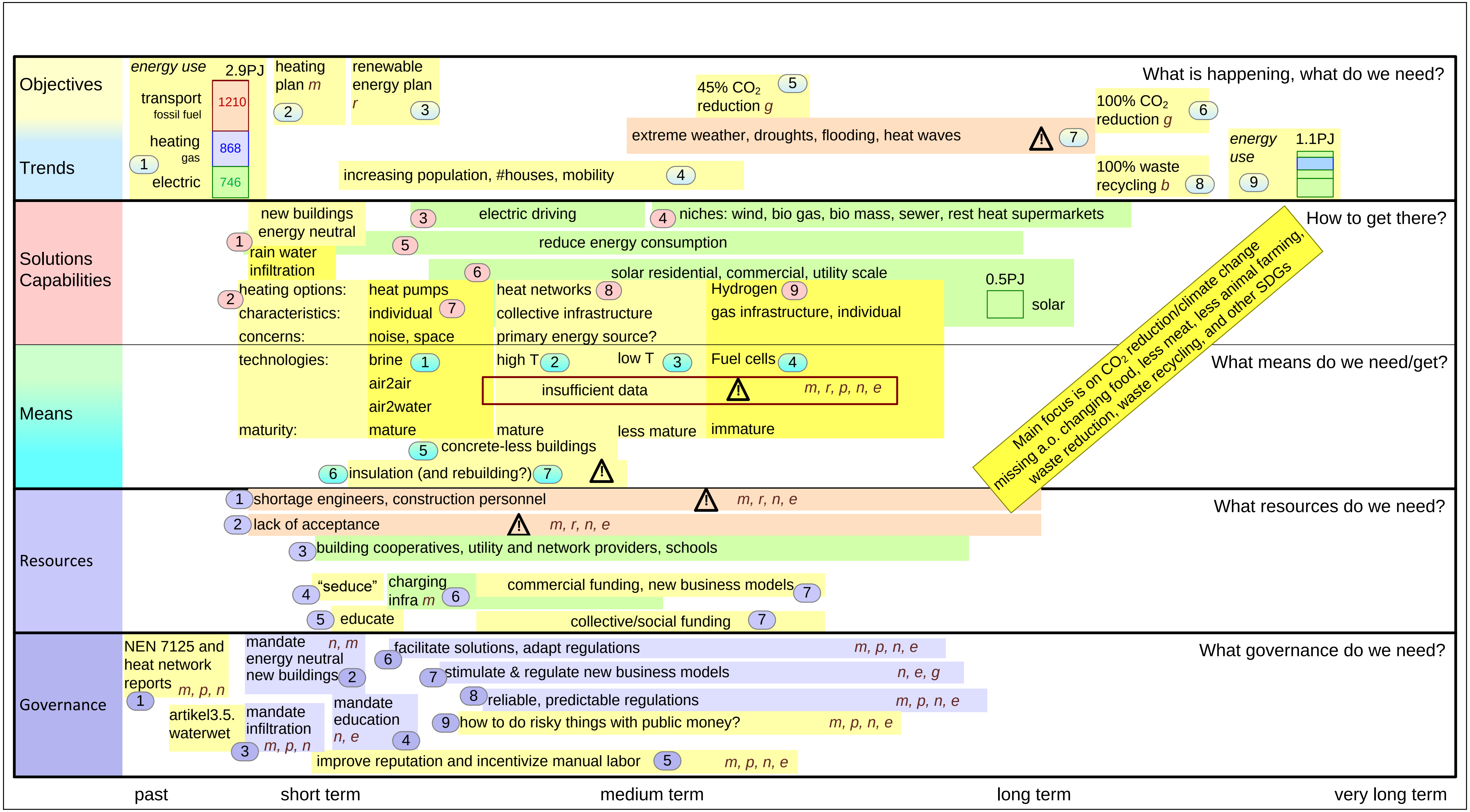
this is a very coarse estimate, e.g. +/- 50%

Example Heating Scenario



Funnel from Ideas to Decisions





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

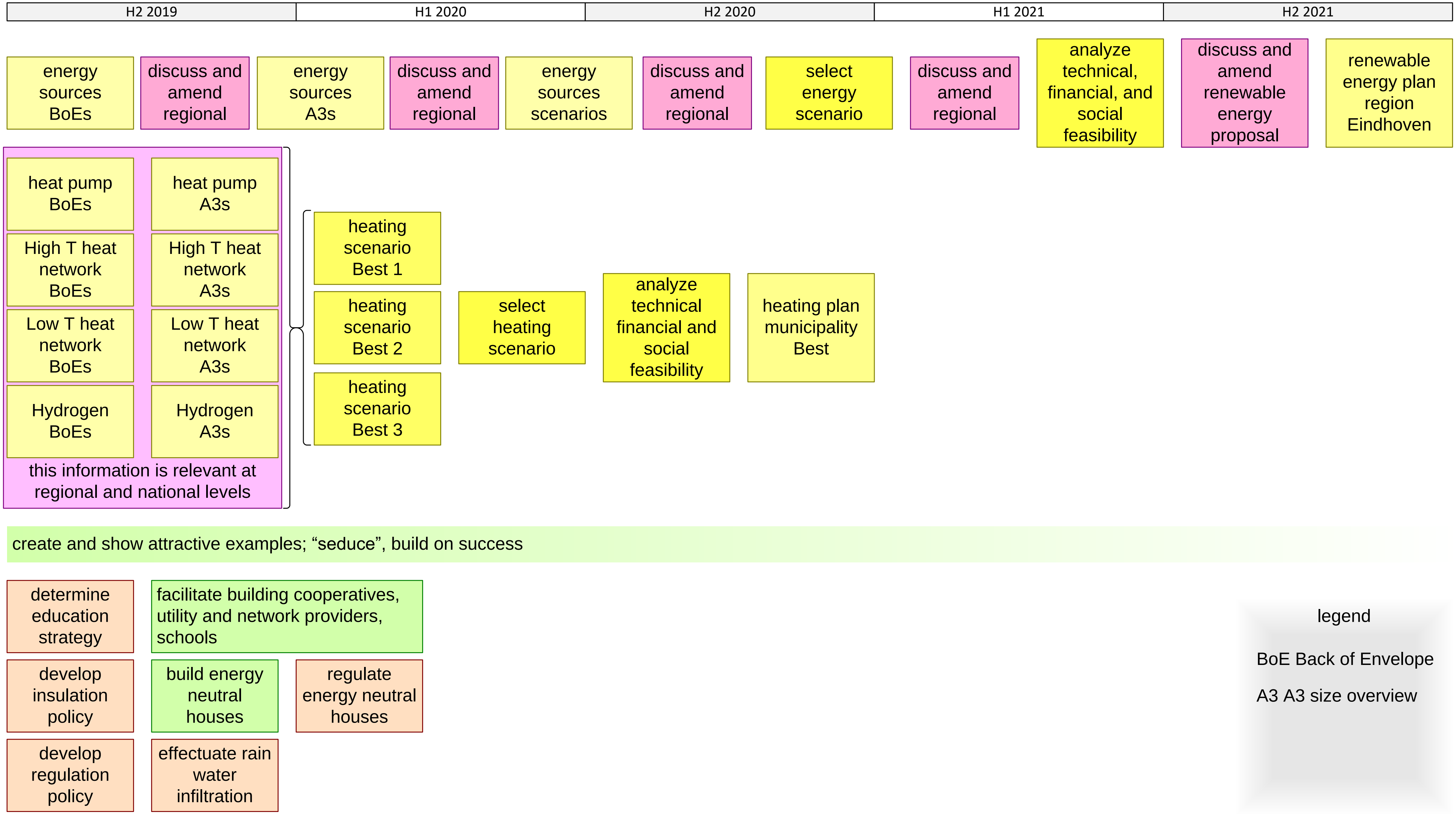
1 make all new developments sustainable
2 selection of options for heating plan
3 transport is major CO_2 producer
4 niche solutions in Best
5 reducing energy consumption is must
6 all forms of solar may result in 0.5 PJ/yr
7 mature; noise, space is concern
8 few rest heat sources; large collective infrastructure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

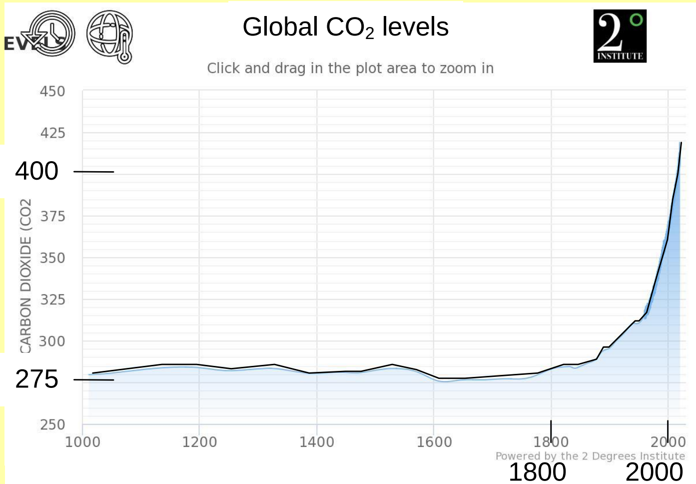
1 action plan to attract and educate
2 involve, engage, seduce, incentivize
3 roadmap and master plan to coordinate
4 more effective than enforcement
5 primary, secondary schools; avoid overload
6 enable electric driving
7 be creative to get economy and funding working

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

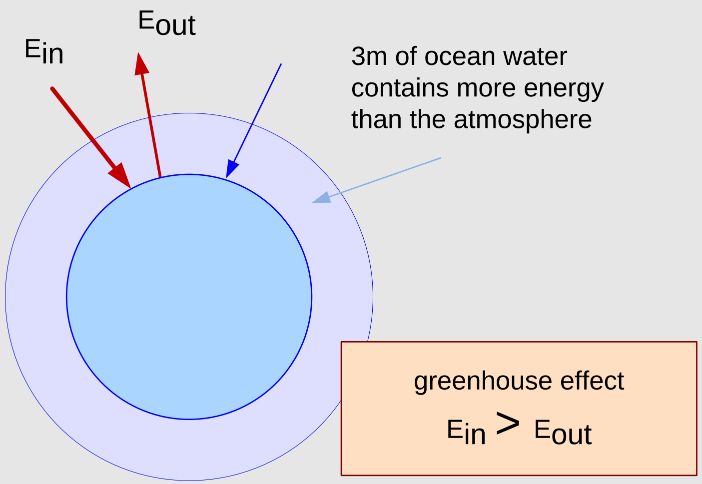
1 *CO2 ppm*



CO2levels.org

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

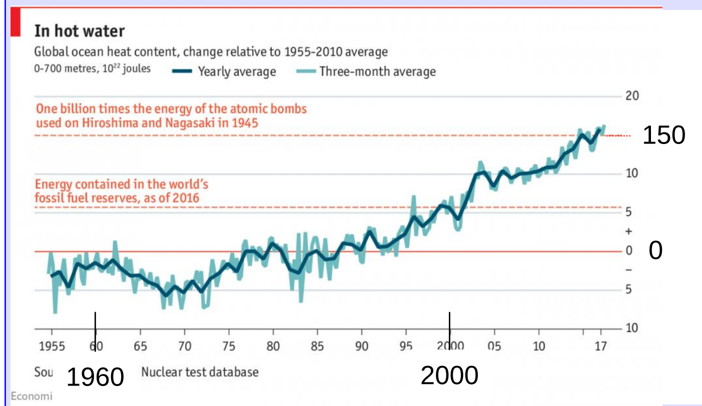
2 *physics/nature of earth*



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***

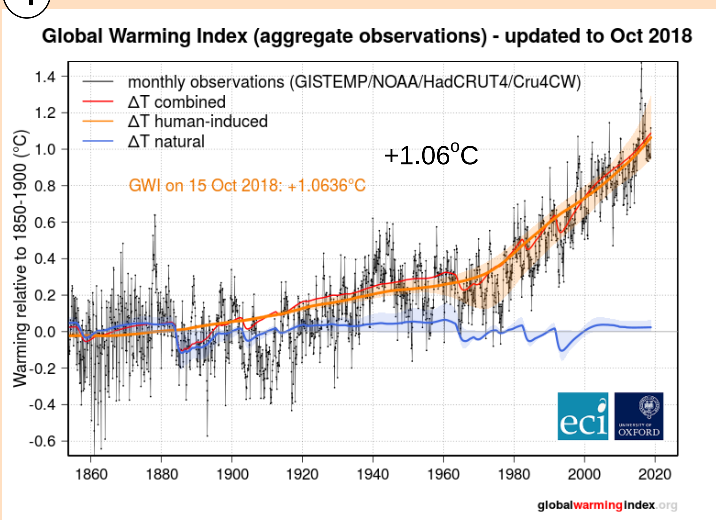
in 10^{21} Joules (=10^6 PJ; NL uses 3 PJ/yr))



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

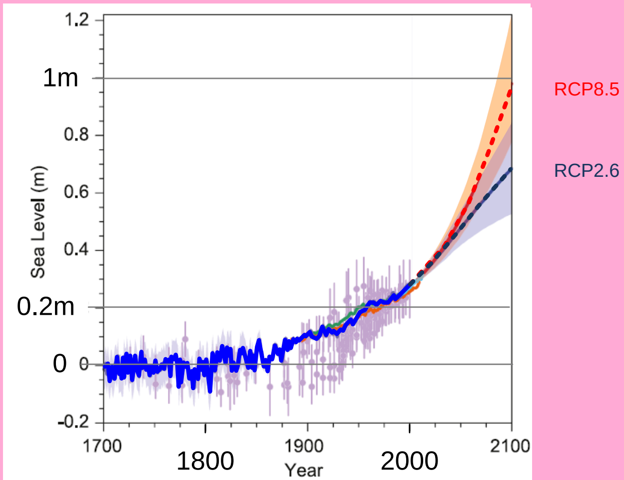
4 *temperature on earth*



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*

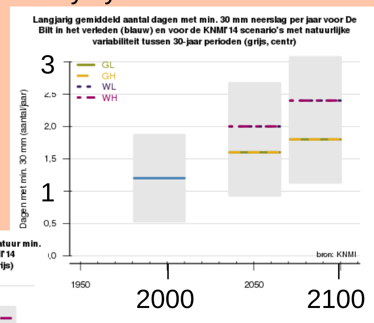


5th IPCC report via realclimate.org

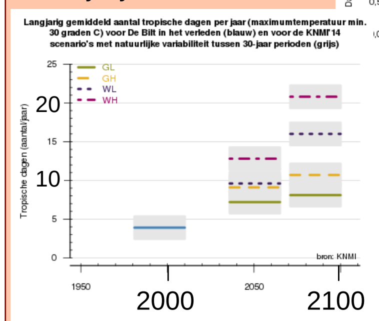
Combination of smelting land ice and increasing see water temperature will increase see water level. In a few centuries this increase can be tens of meters

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

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

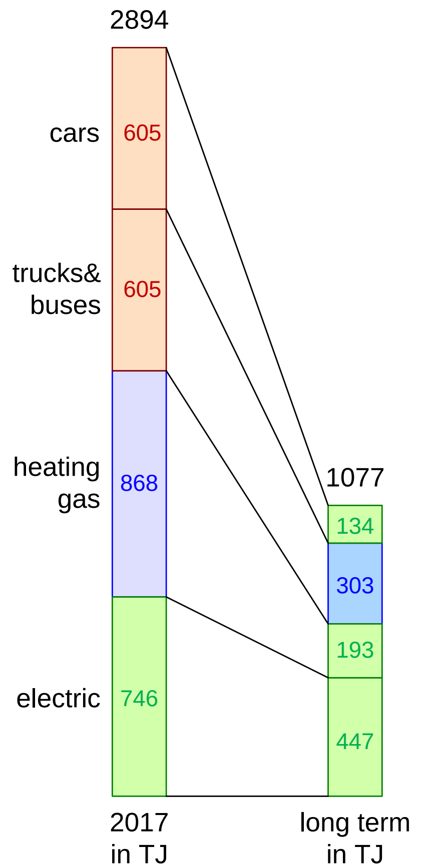
electricity

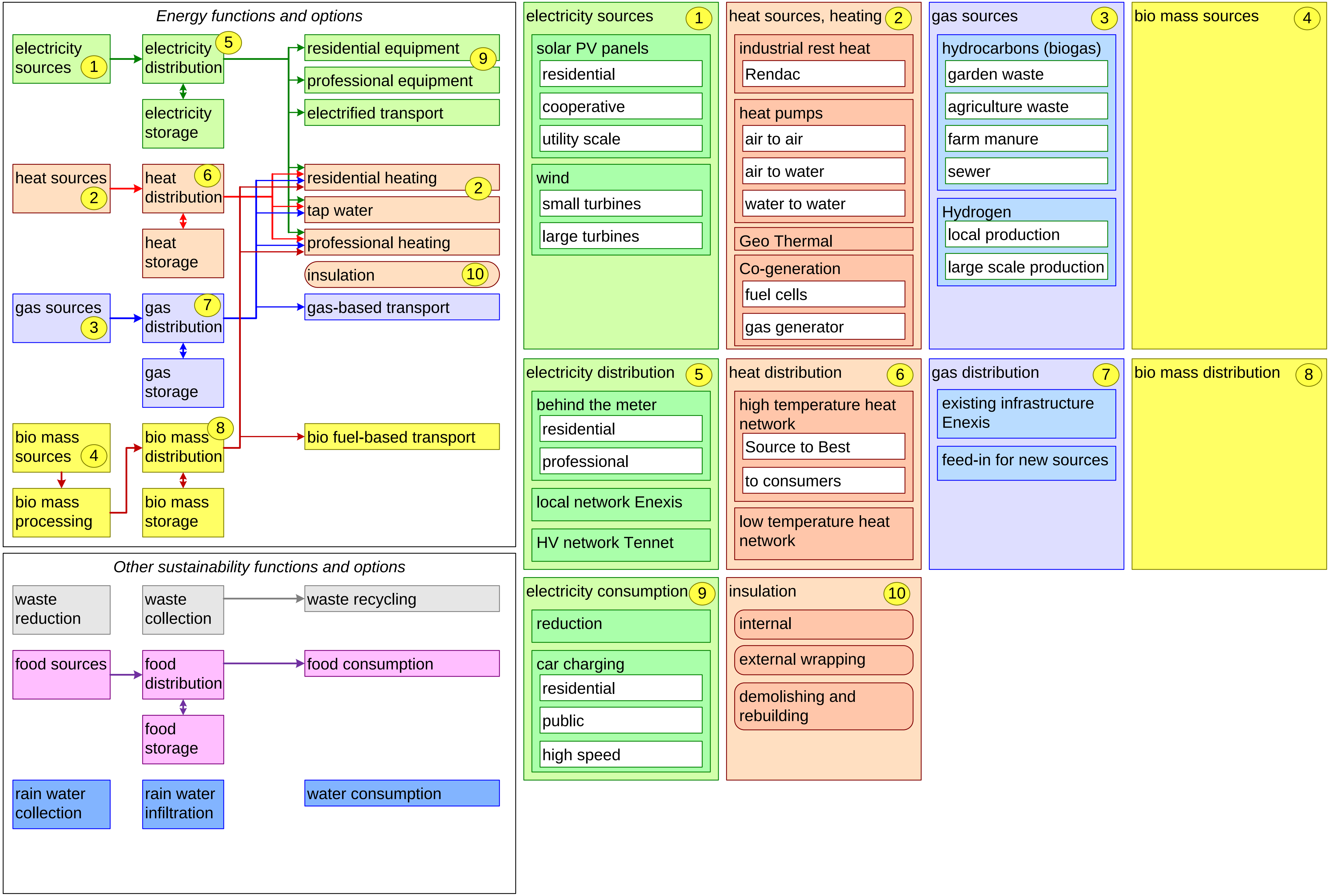
efficiency gain using modern equipment 1.5
reduce consumption 10%
746 / 1.5 * 0.9 = 447

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




Energy functions and options
electricity sources 1
electricity distribution 5
electricity storage
residential equipment 9
professional equipment
electrified transport
heat sources 2
heat distribution 6
heat storage
residential heating 2
tap water
professional heating
insulation 10
gas sources 3
gas distribution 7
gas storage
gas-based transport
bio mass sources 4
bio mass distribution 8
bio mass processing
bio mass storage
bio fuel-based transport
Other sustainability functions and options
waste reduction
waste collection
waste recycling
food sources
food distribution
food storage
food consumption
rain water collection
rain water infiltration
water consumption
electricity sources 1
solar PV panels
residential
cooperative
utility scale
wind
small turbines
large turbines
heat sources, heating 2
industrial rest heat
Rendac
heat pumps
air to air
air to water
water to water
Geo Thermal
Co-generation
fuel cells
gas generator
gas sources 3
hydrocarbons (biogas)
garden waste
agriculture waste
farm manure
sewer
Hydrogen
local production
large scale production
bio mass sources 4
electricity distribution 5
behind the meter
residential
professional
local network Enexis
HV network Tennet
heat distribution 6
high temperature heat network
Source to Best
to consumers
low temperature heat network
gas distribution 7
existing infrastructure Enexis
feed-in for new sources
bio mass distribution 8
electricity consumption 9
reduction
car charging
residential
public
high speed
insulation 10
internal
external wrapping
demolishing and rebuilding

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:

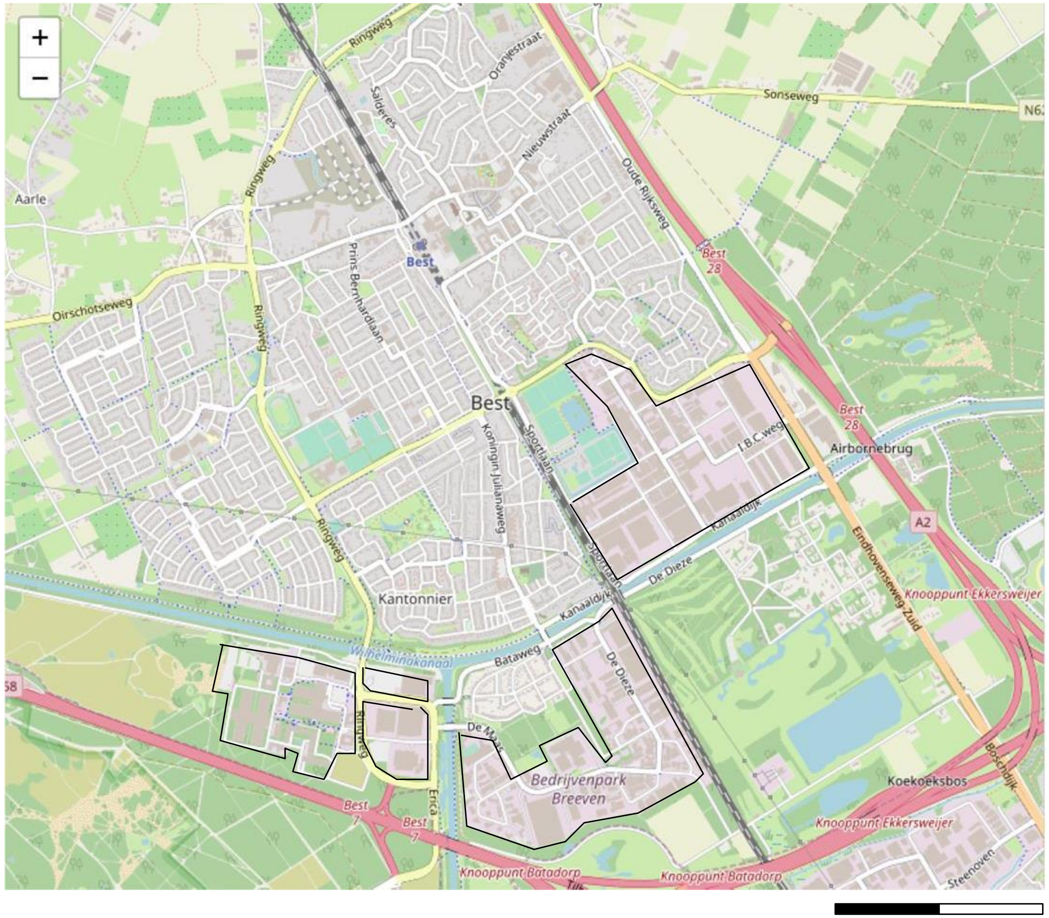
~7 kWh/m^2 (4% of solar)

Best Duurzaam Solar Opportunities

Author: Gerrit Muller, contributions from many Best Duurzaam volunteers

BDRA3solarOpportunities Version 0.1, September 29, 2019

Solar PV commercial and residential areas



Commercial ca 1.5 km²

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

km^2	MW_{peak}	GWh	TJ
0.26	52	43	155

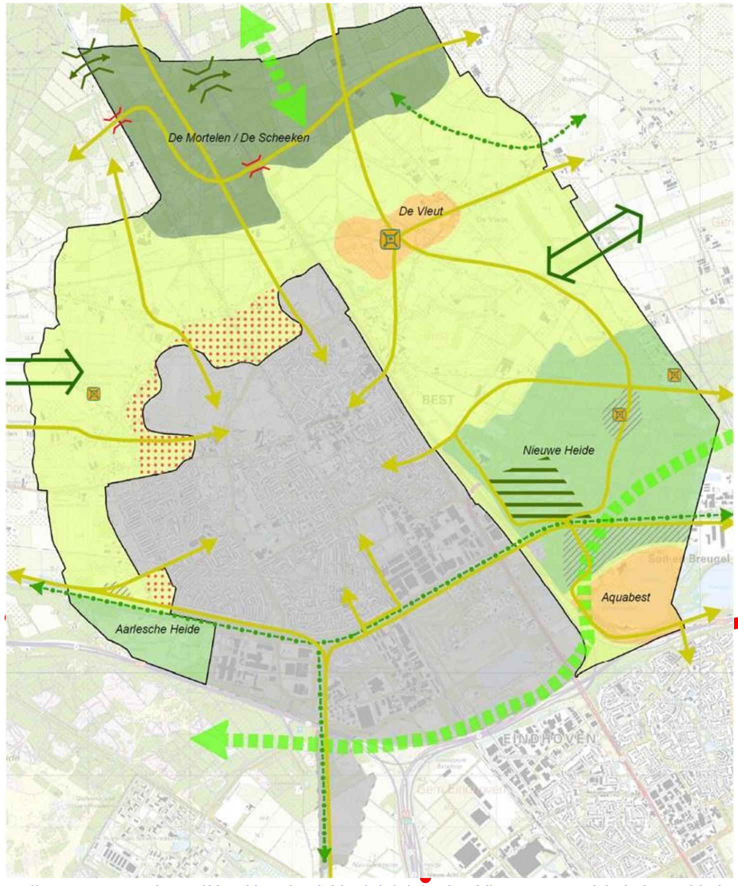
Residential ca 6 km²

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

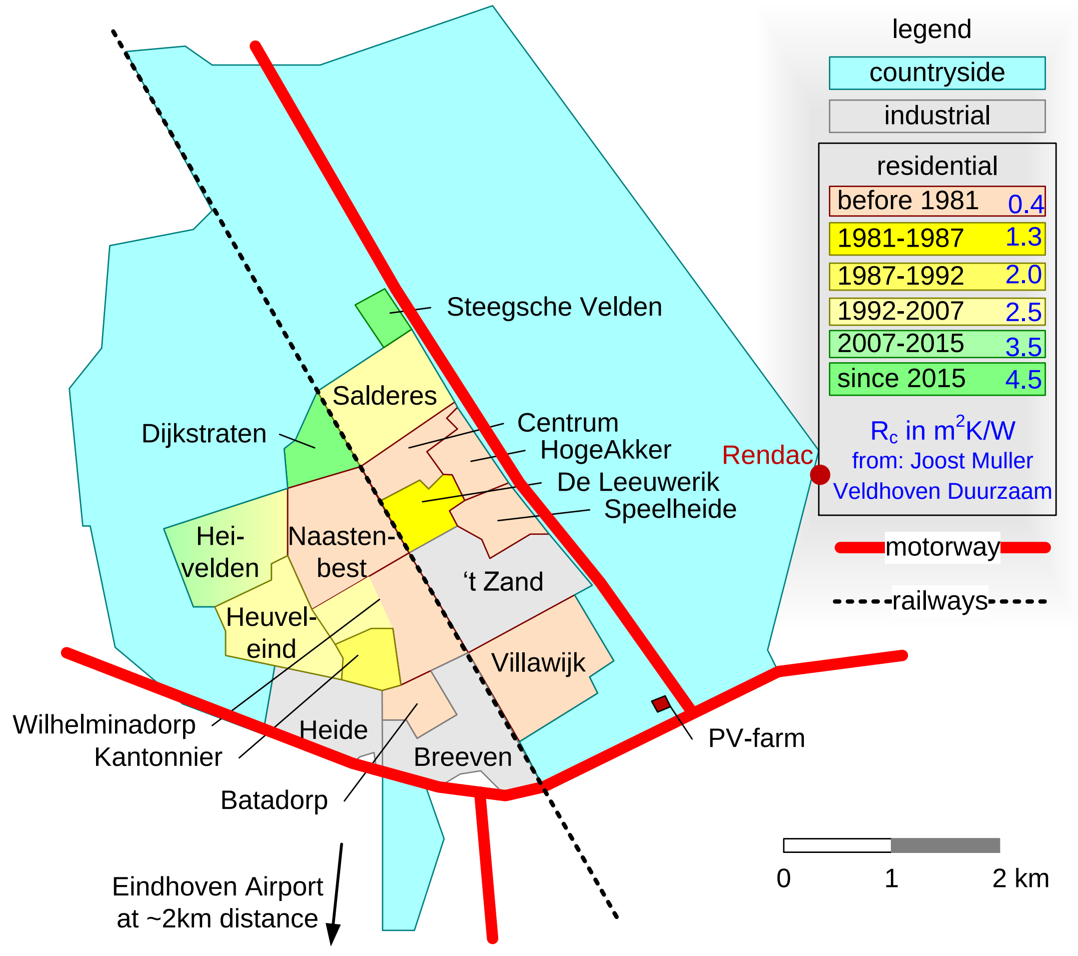
W_{peak}	0,2 kW/m^2
W_{peak} to kWh/yr	0.825

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

Insulation level per neighborhood

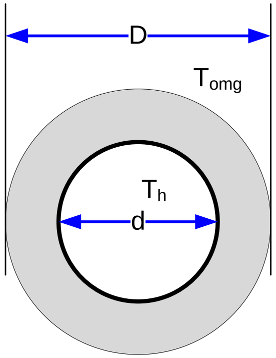


heat loss in isolated pipe

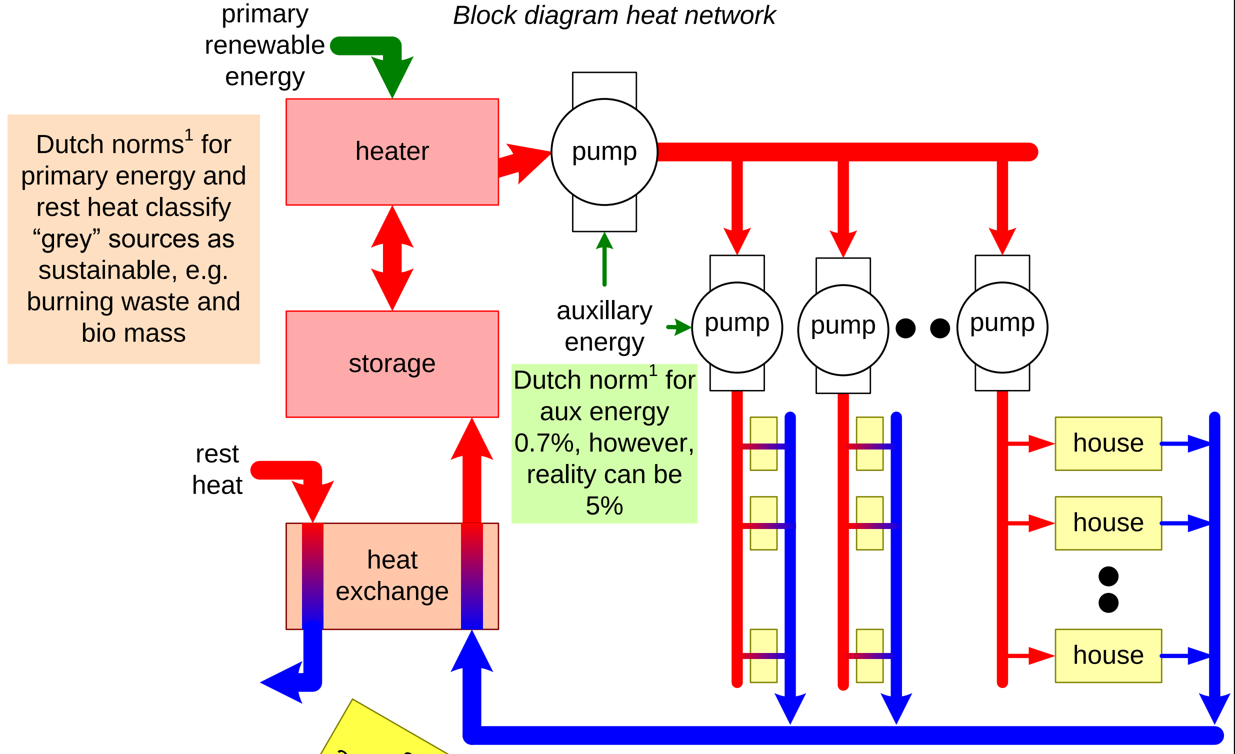
$Qv = (2*\pi*\lambda*(T_h - T_{omg})) / (\ln(D/d))$

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)

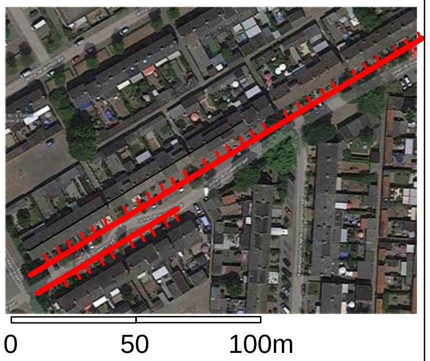
http://www.humsterlandenergie.nl/Energiebesparingsopties/Warmteverlies%20leidingen/



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

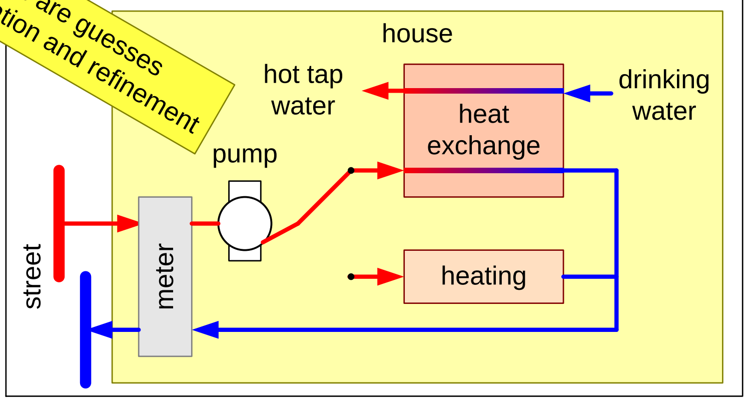
typical heat loss in isolated pipe in numbers

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

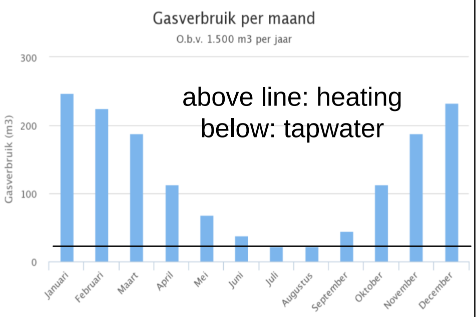
all diagrams are guesses and need validation and refinement

Block diagram single house



gas consumption per month

in summer time the energy loss, to heat tap water only, is 50 to 100%

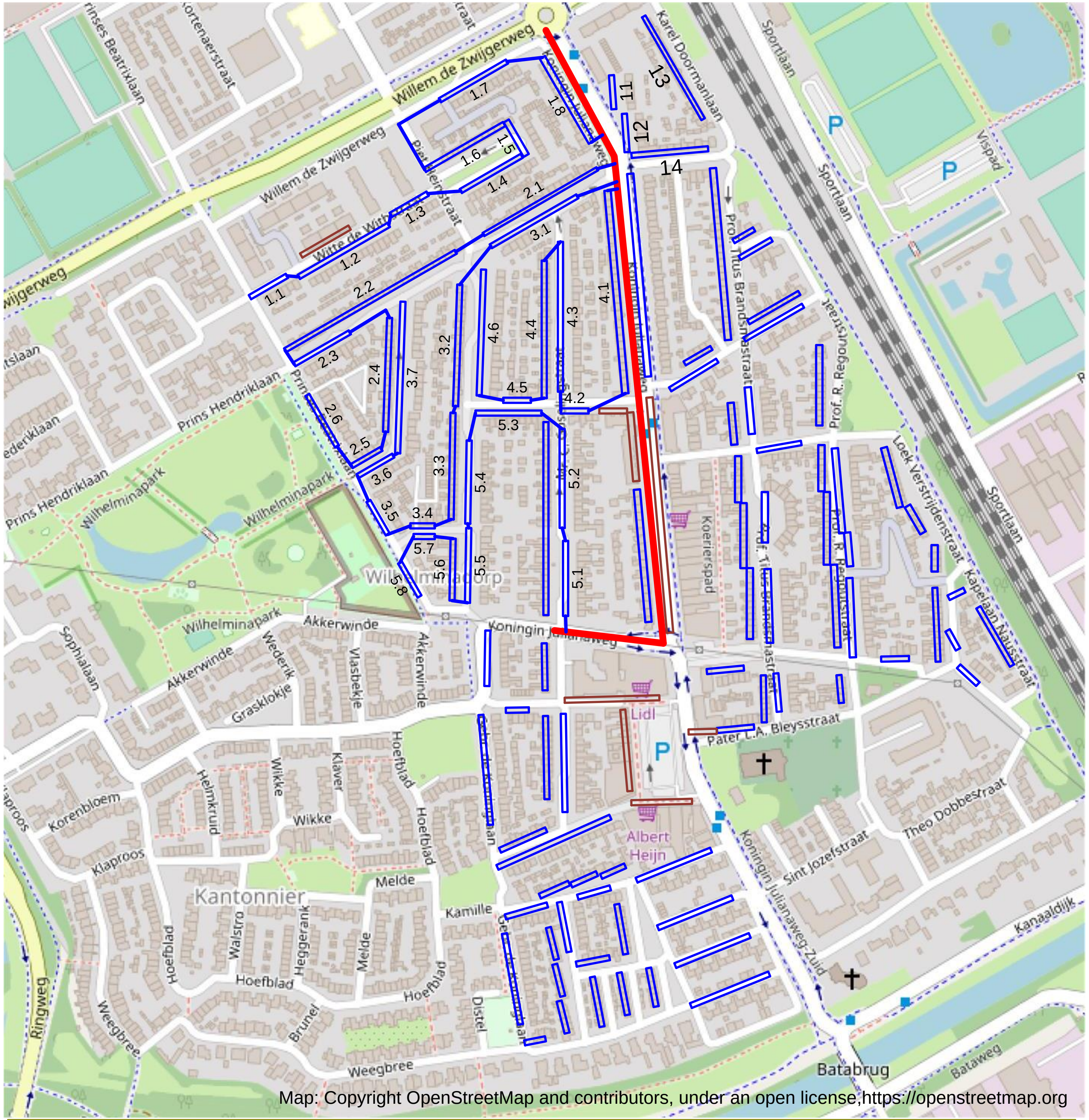


https://www.energiesite.nl/veelgestelde-vragen wat-is-een-gemiddeld-gasverbruik/

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

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		

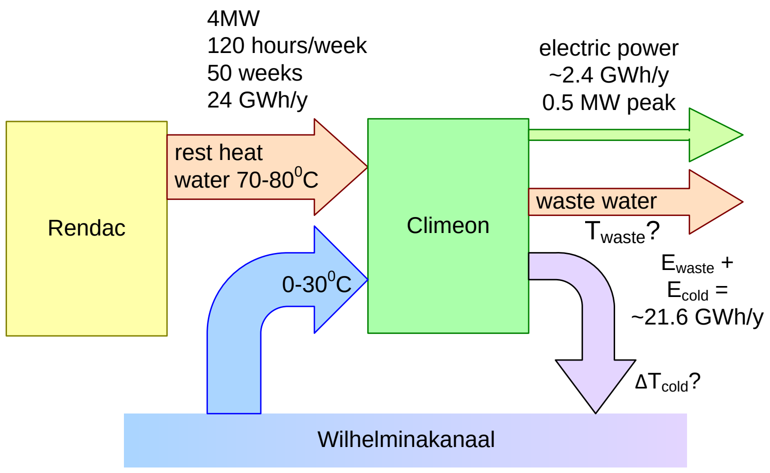


Darling-Rendac, exploration of using Climeon to transform rest heat into electricity

Author: Gerrit Muller, contributions from many Best Duurzaam volunteers

Version 1.1, January 19, 2019

1 *System level block diagram*

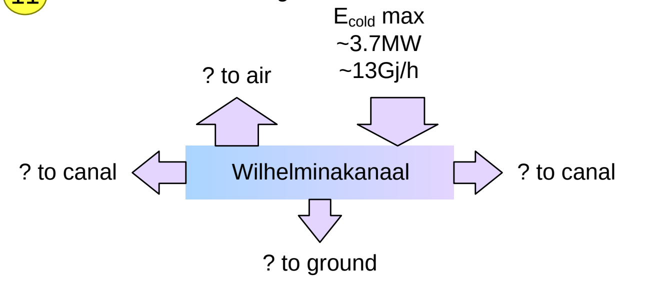


10 *Assumptions, limitations*

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?*

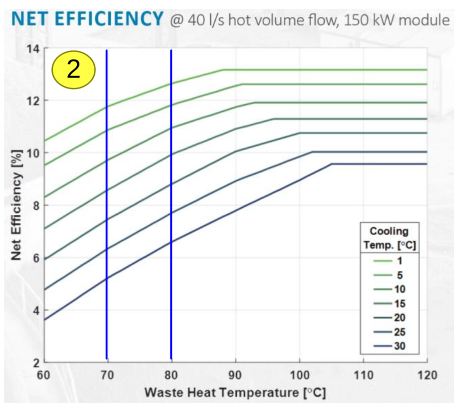


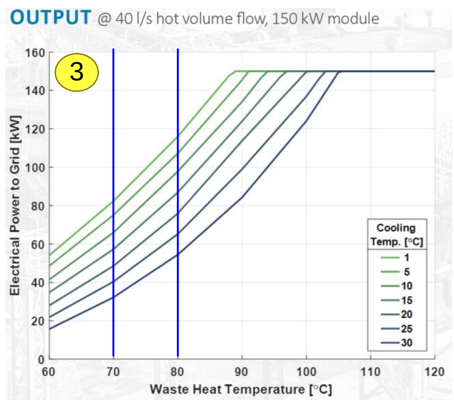
Explanations

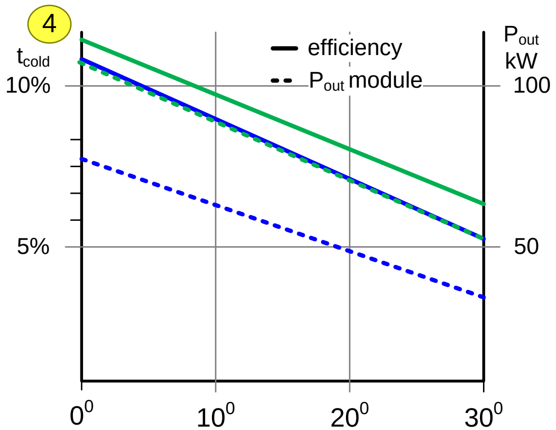
This A3 explores how the Climeon system may transform rest heat into electricity at Rendac in Son. Purpose is to understand this option and to find out what questions we need to ask. Feedback is welcome. Blame Gerrit for mistakes.

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°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°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

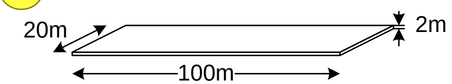
Climeon data from https://climeon.com/wp-content/uploads/2017/04/Climeon-Tech-Product-Sheet.pdf







12 *Estimate of warming of canal water*

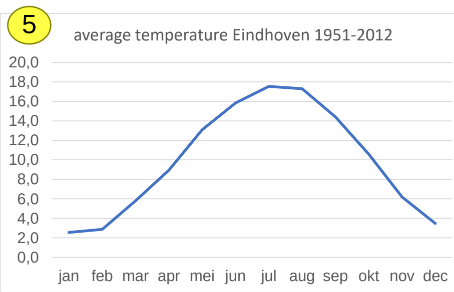


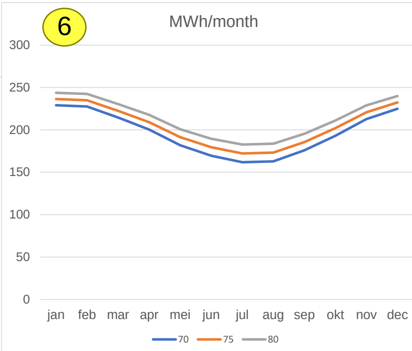
V_{water} = 100 * 20 * 2 = 4000 m^3
m_{water} = V_{water} * 1000 kg/m^3
c_{water} = 4.2 J/gK
E_{in} = 3.7 MW/h * 3600 = 13.3 GJ
$\Delta T = P_{in} / m_{water} * c_{water}$
$= 13.3 * 10^9 / 4 * 10^9 * 4.2$
$\sim= 0.8$ K

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.

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°C)

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

9 *Cost and Income*

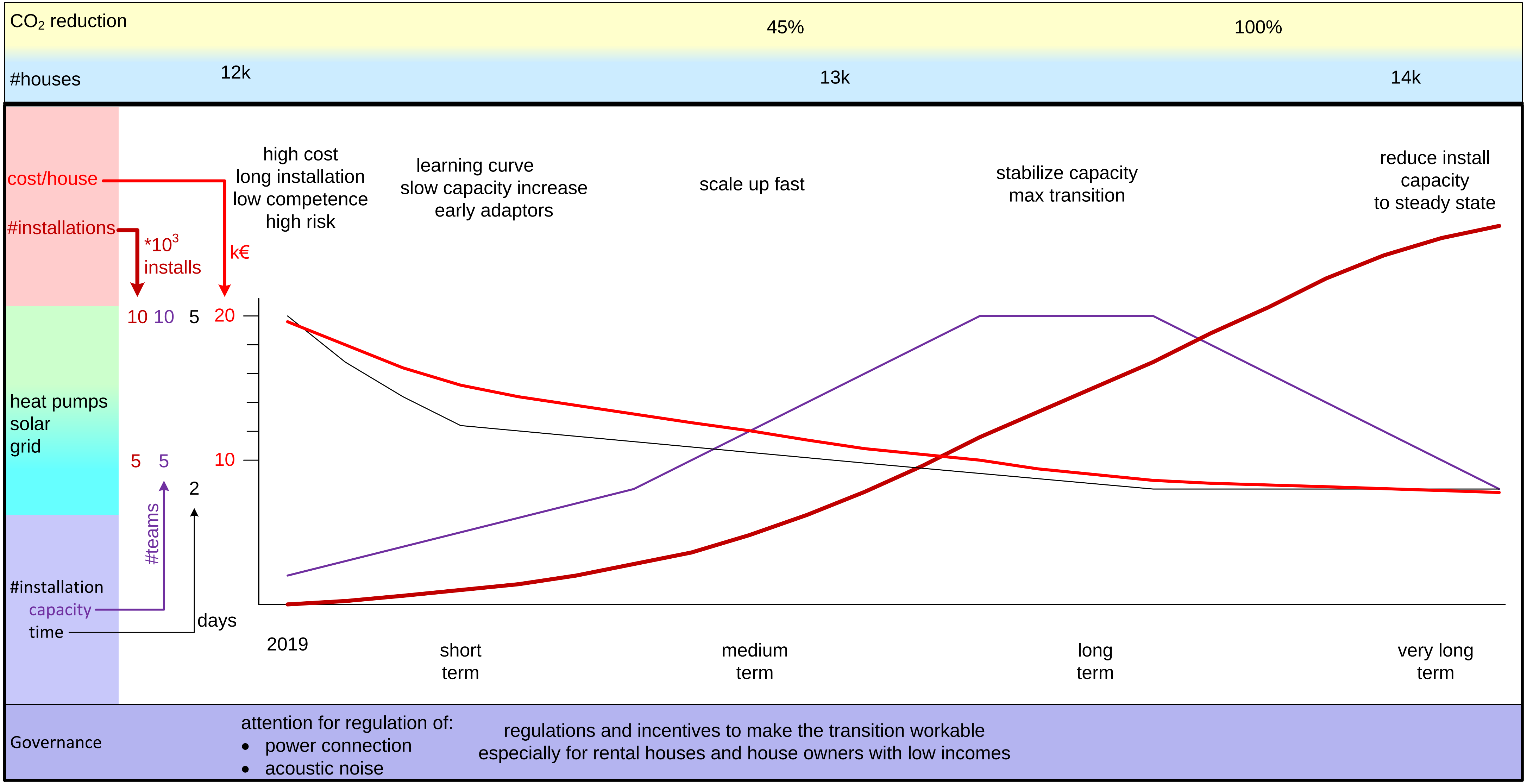
Cost/module 350 k€
install cost (wild guess GM) 300 k€
electricity price 0.05€/kWh

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

Heat Pump transition scenario for Best | Author: Gerrit Muller | BDRA3heatpumpHeatingTransitionScenario Version 0.1, May 9, 2019



Solar PV cost and efficiency evolution

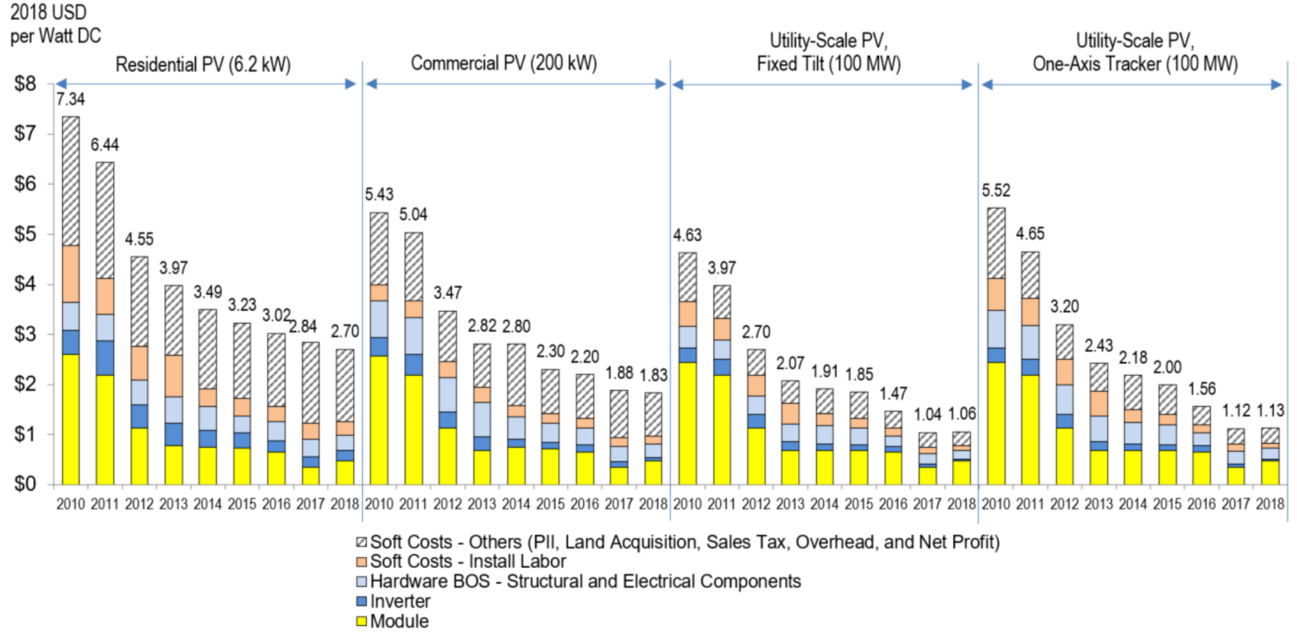
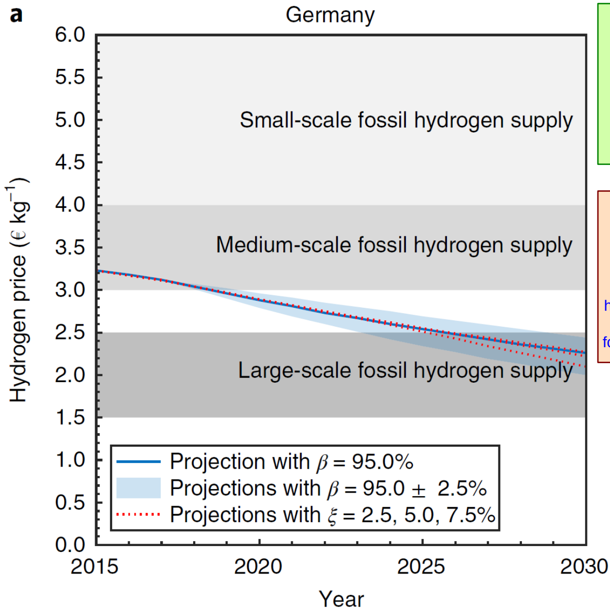


Figure ES-1. NREL PV system cost benchmark summary (inflation adjusted), 2010–2018

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

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

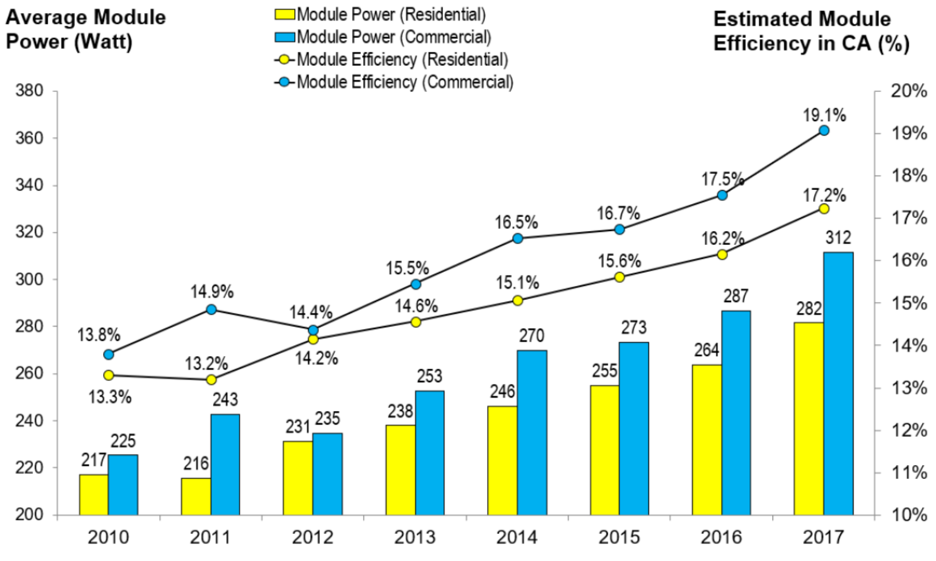
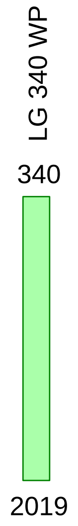
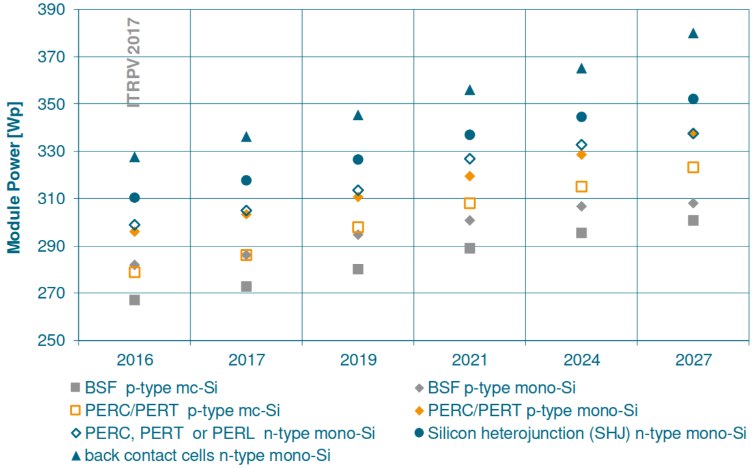


Figure 3. Module power and efficiency trends from the California NEM database (Go Solar CA 2018), 2010–2017





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

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