Best Duurzaam Roadmap A3s

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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.
CO\textsubscript{2} levels started to increase with the industrial revolution. The rate of change is very high on cosmic time scale.

High CO\textsubscript{2} 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.

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

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.

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.

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


<table>
<thead>
<tr>
<th>Buildings</th>
<th>Residential</th>
<th>Commercial</th>
<th>Public</th>
<th>Total buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>fossil fuels</td>
<td>566</td>
<td>130</td>
<td>45</td>
<td>739</td>
</tr>
<tr>
<td>gas</td>
<td>141</td>
<td>328</td>
<td>38</td>
<td>507</td>
</tr>
<tr>
<td>electric</td>
<td>702</td>
<td>427</td>
<td>82</td>
<td>1211</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic</th>
<th>On roads</th>
<th>Mobile equipment</th>
<th>Ships</th>
<th>Rail (diesel only)</th>
<th>Total traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1146</td>
<td>49</td>
<td>4</td>
<td>11</td>
<td>1210</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industry and construction</th>
<th>Industry</th>
<th>Construction</th>
<th>Total industry &amp; construction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>103</td>
<td>211</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>211</td>
<td>312</td>
<td>217</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>312</td>
<td>326</td>
<td>326</td>
</tr>
</tbody>
</table>

| Agriculture                | 16          | 22               | 38                            |

| Renewable energy           | 68          | 41               | 1210                         |
| Other                      | 41          |                  | 868                          |
|                            | 746         |                  | 2894                         |

## 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% efficiency gain

\[
0.5 \times 1210 / 3 \times 0.67 + 0.5 \times 1210 / 2 = 437
\]

### Heating/Gas
- Efficiency gain using heat pumps: 3
- Reduce consumption by improving insulation: 30%

\[
868 / 3 \times 0.67 = 193
\]

### Electricity
- Efficiency gain using modern equipment: 1.5
- Reduce consumption: 10%

\[
746 / 1.5 \times 0.9 = 447
\]

### Energy need after transition and full reduction

1077 TJ/yr

---

\(^1\)[https://www.fueleconomy.gov/fg/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]
Funnel from Ideas to Decisions

Best Duurzaam Roadmap A3s

Gerrit Muller

version: 0.3
June 16, 2019
BDRA3funnel
Energy functions and options

**electricity sources**
- solar PV panels
  - residential
  - cooperative
  - utility scale
- wind
  - small turbines
  - large turbines
- gas sources
  - hydrocarbons (biogas)
  - local production
  - large scale production

**heat sources**
- industrial rest heat
- heat pumps
  - air to air
  - air to water
  - water to water
- Geo Thermal
  - Co-generation
  - fuel cells
  - gas generator

**gas sources**
- garden waste
- agriculture waste
- farm manure
- sewer

**heat sources, heating**
- residential
- cooperative
- utility scale
- air to air
- air to water
- water to water

**heat distribution**
- behind the meter
  - residential
  - professional
- high temperature heat network
  - Source to Best
  - to consumers
- low temperature heat network

**gas distribution**
- existing infrastructure
- Enexis
- feed-in for new sources

**electricity distribution**
- local network Enexis
- HV network Tennet

**bio mass sources**
- bio mass processing
- bio mass storage

**bio mass distribution**
- bio fuel-based transport

**electricity consumption**
- reduction
- car charging
  - residential
  - public
  - high speed

**insulation**
- internal
- external wrapping
- demolishing and rebuilding

**waste reduction**
- waste recycling

**food sources**
- food distribution
  - food storage

**food consumption**

**water consumption**
- rain water collection
- rain water infiltration

Other sustainability functions and options

- waste collection
- food distribution
- food storage
- insulation
- water consumption
Assessment Criteria

PESTEL
- Political
- Economic
- Social

Technical
- readiness level
- complexity
- competence level
- effectivenes/ 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
- biomass
### Heat Pump

<table>
<thead>
<tr>
<th>Cost per house</th>
<th>18k€ incl. VAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pump in/out</td>
<td>11</td>
</tr>
<tr>
<td>Mounting material</td>
<td>1</td>
</tr>
<tr>
<td>Installation</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average gas consumption per house in Best</th>
<th>1430 m³/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>~13 MWh/yr</td>
<td></td>
</tr>
</tbody>
</table>

#### Advantages:
- Energy efficiency
- Independent of other houses

#### Disadvantages:
- Initial cost
- Acoustic noise
- Space for equipment

### High T heat network

- Heat production: $300 \times 10^6 \text{g} / \text{h} \times 60 \text{°C} \times 4.2 \text{J/g°C} 
  
$\approx 80 \text{ GJ/hr} \approx 24 \times 365 \times 80 \text{ GJ/yr} 
  
$\approx 700 \text{ TJ/yr}$

#### Unknowns
- Energy consumption of pumps
- OPEX
- Environmental impacts

### 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

### Low T heat network

#### Advantages:
- Compatible with old houses
- Individual control
- Energy efficient

#### Disadvantages:
- Costly infrastructure
- Limited individual control
- Efficiency?

### Residential Solar PV system

<table>
<thead>
<tr>
<th>Cost per house</th>
<th>3.7 incl. install</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 panels 340kW</td>
<td></td>
</tr>
<tr>
<td>Optimizers</td>
<td>0.7</td>
</tr>
<tr>
<td>Inverter</td>
<td>1.0</td>
</tr>
<tr>
<td>Mounting material</td>
<td>1.0</td>
</tr>
<tr>
<td>Installation</td>
<td>1.0</td>
</tr>
</tbody>
</table>

| PV system with 16 solar panels, 5.4kW | 7k€ |

<table>
<thead>
<tr>
<th>Electricity production</th>
<th>~4.5 MWh/yr</th>
</tr>
</thead>
</table>

| ~26 m² roof space |                |
| Yearly energy production solar | 173 kWh/m²/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

- Wood production 1.1 to 1.5 Kg/m²/yr

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

https://www.rnc.nl/nieuws/2019/06/14/
een-waterput-on-je-huis-te-verwarmen-a3963783
Solar PV commercial and residential areas

Commercial ca 1.5 km²
building area 25%
parking area 10%
used for solar 50%
km² MW_peak GWh TJ
0.38 52 43 155

Residential ca 6 km²
building area 15%
used for solar 50%
km² MW_peak GWh TJ
0.9 90 74 267

Utility scale
Best has about 10km motor way
assume that 200m at both sides is a good option for utility scale solar.
assume that only 2.5% is usable
km² 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 m²
assume that 50% is usable
km² MW_peak GWh/yr TJ/yr
0.01 1.3 1.0 4

Total potential solar PV TJ/yr
Commercial 155
Residential 267
Utility scale 59
Country side 4
Total 486

input data
W_peak 0.2 kW/m²
W_peak to kWh/yr 0.825

all numbers are coarse estimates and need validation and refinement


Author: Gerrit Muller, contributions from many Best Duurzaam volunteers
Version 0, March 24, 2019
Insulation level per neighborhood

Legend:
- Residential
  - Before 1981: 0.4
  - 1981-1987: 1.3
  - 1987-1992: 2.0
  - 1992-2007: 2.5
  - 2007-2015: 3.5
  - Since 2015: 4.5

R in m²K/W

Author: Gerrit Muller, contributions from many Best Duurzaam volunteers

Version 0, March 26, 2019
heat loss in isolated pipe

\[ Q_v = \frac{(2\pi d^2 \lambda (T_h - T_{\text{amb}}))}{\ln(D/d)} \]

- \( Q_v \): heat loss (W/m)
- \( \lambda \): isolation factor (W/mK)
- \( T_h \): water temperature (°C)
- \( T_{\text{amb}} \): environmental temperature (°C)
- \( D \): pipe outside diameter with isolation (mm)
- \( d \): pipe diameter without isolation (mm)

Dutch norm for aux energy 0.7%, however, reality can be 5%

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 m³ gas/yr
middle house 1350 m³ gas/yr

total 38 houses:
53960 m³ gas/yr ~ 485 MWh/yr
12.8 MWh/yr/house

13% heat loss at street level.

all numbers are coarse estimates and need validation and refinement

Typical heat loss in isolated pipe in numbers

- \( T_{\text{hot network}} \): network hot temperature
- \( T_{\text{return network}} \): return network hot temperature
- \( \lambda \): isolation factor
- \( D \): pipe diameter
- \( d \): pipe diameter
- \( Q_v \): heat loss

Sustainable, e.g. burning waste and biomass

Gas consumption per month

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

Gasverbruik per maand

Above line: heating
Below: tap water

All diagrams are guesses and need validation and refinement

Background documentation

- Aansluiten op warmtenetten Handreiking April 2018 https://www.cea.nl/publicaties/download/2564
- Ketenenissies warmtelevering: Directe en indirecte CO2-emissies van warmtebouwtechnieken https://www.cea.nl/publicaties/download/2069
- Collectieve warmte naar lage temperatuur: Een verkenning van mogelijkheden en routes https://projecten.topsectorenergie.nl/storage/app/uploads/public/5aa/01/2/b89/5aa01/7b892b8d6834673493.pdf
## Heat Network Scenario Wilhelminadorp

**Author:** Gerrit Muller, contributions from many Best Duurzaam volunteers  
**Version:** 0.1, April 28, 2019

<table>
<thead>
<tr>
<th>section</th>
<th>total houses</th>
<th>total thick pipe (m)</th>
<th>total thin pipe (m)</th>
<th>energy for heating and tapwater MWh/yr</th>
<th>total loss/yr/house MWh/yr</th>
<th>loss as percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. total</td>
<td>48</td>
<td>677</td>
<td>249</td>
<td>1053</td>
<td>1.99</td>
<td>16%</td>
</tr>
<tr>
<td>2. total</td>
<td>38</td>
<td>689</td>
<td>258</td>
<td>1093</td>
<td>1.97</td>
<td>15%</td>
</tr>
<tr>
<td>3. total</td>
<td>40</td>
<td>685</td>
<td>249</td>
<td>1049</td>
<td>2.01</td>
<td>16%</td>
</tr>
<tr>
<td>4. total</td>
<td>31</td>
<td>728</td>
<td>276</td>
<td>1171</td>
<td>1.95</td>
<td>15%</td>
</tr>
<tr>
<td>5. total</td>
<td>35</td>
<td>609</td>
<td>255</td>
<td>1062</td>
<td>1.82</td>
<td>15%</td>
</tr>
<tr>
<td>total</td>
<td>192</td>
<td>3388</td>
<td>1287</td>
<td>5428</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Map: Copyright OpenStreetMap and contributors, under an open license [https://openstreetmap.org](https://openstreetmap.org)
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

System level block diagram

- 4MW rest heat water 70-80°C
- 24 GWh/y 50 weeks 120 hours/week
- Electric power ~2.4 GWh/y 0.5 MW peak
- Waste water T_waste
- Waste water 0-30°C
- Climeon
- Wilhelminakanaal

Assumptions, limitations

10. 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? E_{cool} max 3.7 MW

? to air ~13 GJ/h

? to canal Wilhelminakanaal

? to canal

? to ground


Output @ 40 ℃ hot volume flow, 150 kW module

.NET EFFICIENCY

Estimate of warming of canal water

V_{water} = 1000 m³
m_{water} = V_{water} * 1000 kg/m³
C_{water} = 4.2 J/gK
E_w = 3.7 MW * 3600 = 13.3 GJ
\Delta T = \frac{P_{out}}{m_{water} \times C_{water}}
= 13.3 \times 10^3 / 4 \times 10^3 \times 4.2
= 0.8 K

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

Electricity production in Eindhoven area

MWh/year 2750 118 23.3
70 7 106 119 19.5
75 6 2400 123 16.0
80 5 2050 128 16.0

Cost and Income

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

What if t_{cool} is 3 degrees warmer?

heating cost k€/y
70 2193 109 25.2
75 2306 115 20.9
80 2402 120 17.1

Calculations:

- Operational cost
- Efficiency of modules P_{out} kW
- MWh/month
- Average temperature Eindhoven 1951-2012
- Waste water 80-30°C
- Electricity production in Eindhoven area
- Electricity price 0.05 k€/kWh
- Cost/module 350 k€
- Cost/income ROI

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
2. How does the rest heat leave the system? How much is hot waste water, how much is the cold water warmed up?
3. The efficiency of the Climeon system depends on t_{hot} and t_{cool}
4. We need the efficiency and P_{out} @ t_{hot} = 70-80°C as function of t_{cool} between 0 and 30°C, we derived a linear relation from 2 and 3
5. KNML.nl provides the temperature per month for the region 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 energy per year
8. We use 4 to calculate the required #modules at worst case conditions, which is when t_{cool} = 30°C; it also shows E_{waste} @ 30°C
9. Cost = #modules * cost/module + installation cost
   Income per year = E_{waste} * 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 of a stretch of 100 m of the canal gets warmer per hour or per day, if all rest heat stays in the part of the canal. Where does all the remaining heat go?
13. Shows the impact of canal water that is 3°C warmer than the average air temperature.

Feedback is welcome.
Heat Pump transition scenario for Best

Author: Gerrit Muller

Version 0.1, May 9, 2019

### 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

---

### CO₂ reduction

<table>
<thead>
<tr>
<th>#houses</th>
<th>12k</th>
<th>13k</th>
<th>14k</th>
</tr>
</thead>
<tbody>
<tr>
<td>45%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### #installations

- cost/house
- high cost
- long installation
- low competence
- high risk

- long installation
- learning curve
- slow capacity increase
- early adaptors

- scale up fast
- stabilize capacity
- max transition
- reduce install capacity to steady state

---

### #teams

- heat pumps
- solar
- grid

- 5
- 5
- 10
- 20

### time

- days
- 2019
- short term
- medium term
- long term
- very long term

---

### #teams

- 10
- 10
- *10⁷*
- installs

---

### k€

- 12
- 14
- 13
- 100
- 14

---

### #teams

- 10
days
Best Duurzaam Solar Opportunities

Author: Gerrit Muller, contributions from many Best Duurzaam volunteers

Version 0, March 24, 2019


Average Module Power (Watt) and Estimated Module Efficiency in CA (%)

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

**Hydrogen cost evolution**

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 [link](https://doi.org/10.1038/s41560-019-0326-1)

**Energy content of 1 Kg H₂ = 33.3 kWh**

**Fuel cell efficiency 40...60%**


Warning: none of the numbers are for Best or the Netherlands!
### Objectives

- 2.9 TJ energy use
- 1210 transport fossil fuel
- 868 heating gas
- 746 electric

### Trends

- New buildings energy neutral
- Gas infrastructure
- Heat networks
- Solar residential
- Commercial, utility scale
- Hydrogen
- Gas infrastructure, individual

### Solutions

#### Capabilities

- Electric driving
- Niches: wind, bio gas, bio mass, sewer, rest heat supermarkets
- Insufficient data
- Insulation (and rebuilding?)

#### Means

- Technologies:brine, heat pumps, air2air, water
- Characteristics: maturity, individual, noise, space

#### Resources

- Insufficient data
- Solar residential
- Commercial funding, new business models
- Collective infrastructure

### Governance

- Mandate infiltration
- Mandate education
- Improve reputation and incentivize manual labor

### How to get there?

- Main focus is on CO2 reduction/climate change, less meat, less animal farming, waste reduction, waste recycling, and other SDGs

### What is happening, what do we need?

- Extreme weather, droughts, flooding, heat waves

### What means do we need/get?

- Mandate new developments sustainable

### What resources do we need?

- Energy use
- Energy use
- Energy use

### What governance do we need?

- 7125 and reports overrate sustainability of bio mass and rest heat sources; lack absolute data
- ASAP; waiting increases problem
- VNG/3-nummerlijke-watertaken; should be standard operation when maintaining streets
- How to do this effectively
- Culturally ingrained
- Agile (fast response) governance
- Facilitate and regulate
- Past pitfall; blocks investments
- Major dilemma for 6, 7, and 8

---

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 2020
7. may increase energy use
8. energy use after full electrification and some reduction
9. make all new developments sustainable
10. selection of options for heating plan
11. transport is major CO2 producer
12. niche solutions in Best
13. reducing energy consumption is must
14. all forms of solar may result in 0.5 TJ/yr
15. mature; noise, space is concern
16. few rest heat sources; large collective infrastructure investment
17. air2air for heating is efficient; how to get tap water?
18. compatible with older houses; challenge data
19. is not public due to commercial interests
20. efficient allows re-use of any rest heat; storage is the big challenge
21. source to use little efficient; solves seasonal storage; production infrastructure expensive
22. concrete is major CO2 producer
23. insulation is first step; external insulation needed
24. when is rebuilding better (justified and acceptable)
25. action plan to attract and educate
26. involve, engage, seduce, incentivize
27. roadmap and master plan to coordinate
28. more effective than enforcement
29. primary, secondary schools; avoid overload
30. enable electric driving
31. be creative to get economy and funding working
32. 7125 and reports overrate sustainability of bio mass and rest heat sources; lack absolute data
33. ASAP; waiting increases problem
34. VNG/3-nummerlijke-watertaken; should be standard operation when maintaining streets
35. How to do this effectively
36. culturally ingrained
37. agile (fast response) governance
38. Facilitate and regulate
39. Past pitfall; blocks investments
40. Major dilemma for 6, 7, and 8

---

**Legend**

- NEN 7125 and heat network reports
- Concrete-less buildings
- Educate
- Mandate
- Education
- N, E
- Charging infrastructure
- Waste reduction, waste recycling, and other SDGs
### Energy Sources BoEs

- Discuss and amend regional
- Select energy scenario
- Analyze technical, financial, and social feasibility

### Heat Pump BoEs

- Heating scenario Best 1
- Heating scenario Best 2
- Heating scenario Best 3

### Hydrogen BoEs

- Heating plan municipality Best

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**Legend**

- BoE Back of Envelope
- A3 A3 size overview

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**Initial Master Plan Sustainable Best**

Author: Gerrit Muller, contributions from many Best Duurzaam volunteers

Version 0, April 23, 2019

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**Create and show attractive examples; “seduce”, build on success**

- Determine education strategy
- Develop insulation policy
- Develop regulation policy
- Facilitate building cooperatives, utility and network providers, schools
- Build energy neutral houses
- Regulate energy neutral houses
- Effectuate rain water infiltration