DTU


2016 Integration of District Heating in a Sustainable Energy System
2016中丹可再生能源系统区域供热研讨会
– Technologies, Markets and Policies
—技术、市场与政策
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Solar District Heating in Denmark

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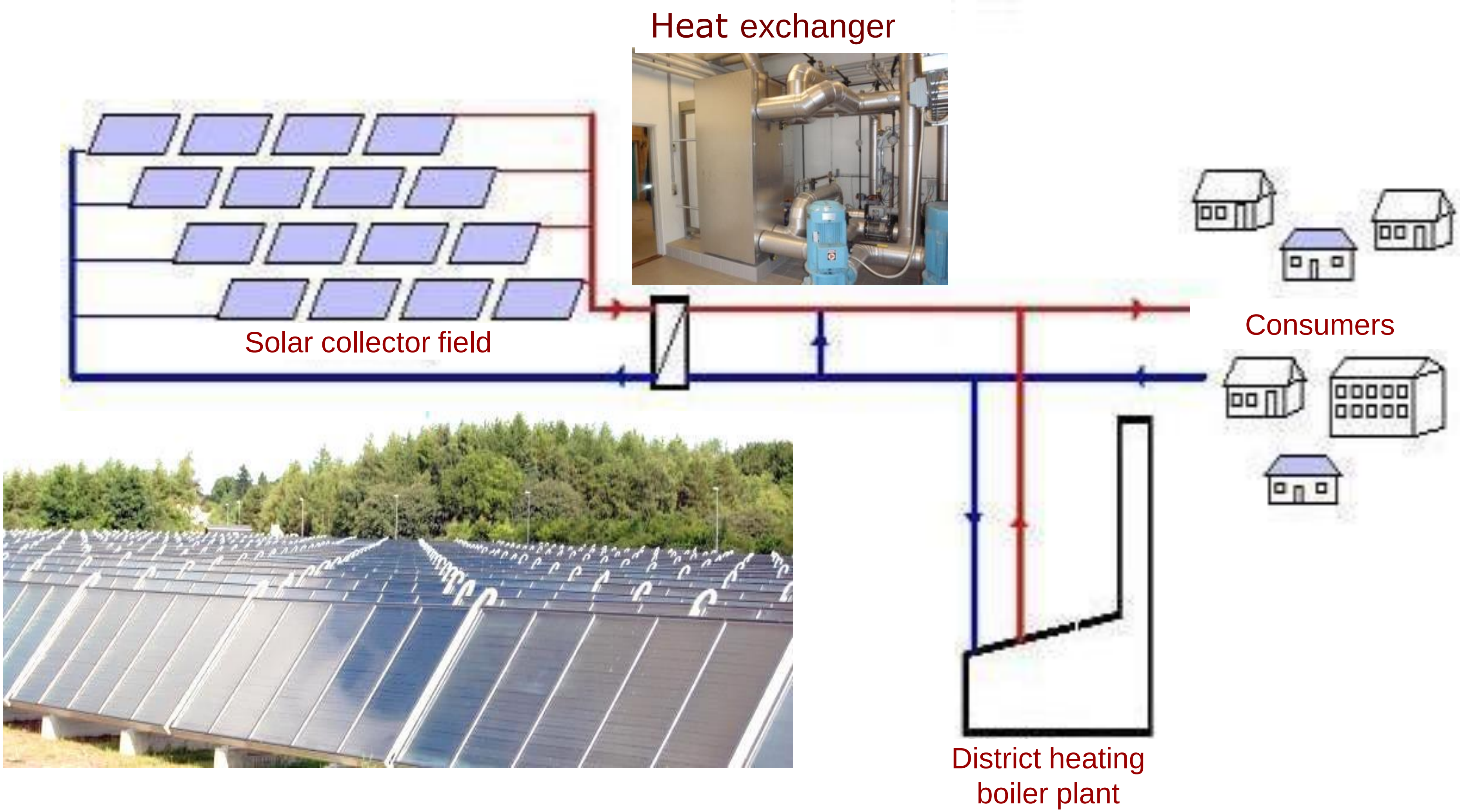
Country/countries	Inhabitants	Percentage of World's population	Inhabitants per km²
Denmark	5.7 M	0.08%	133
EU - 28 European countries	510 M	7.0%	118
China	1379 M	18.8%	142

Solar heating plant - principle



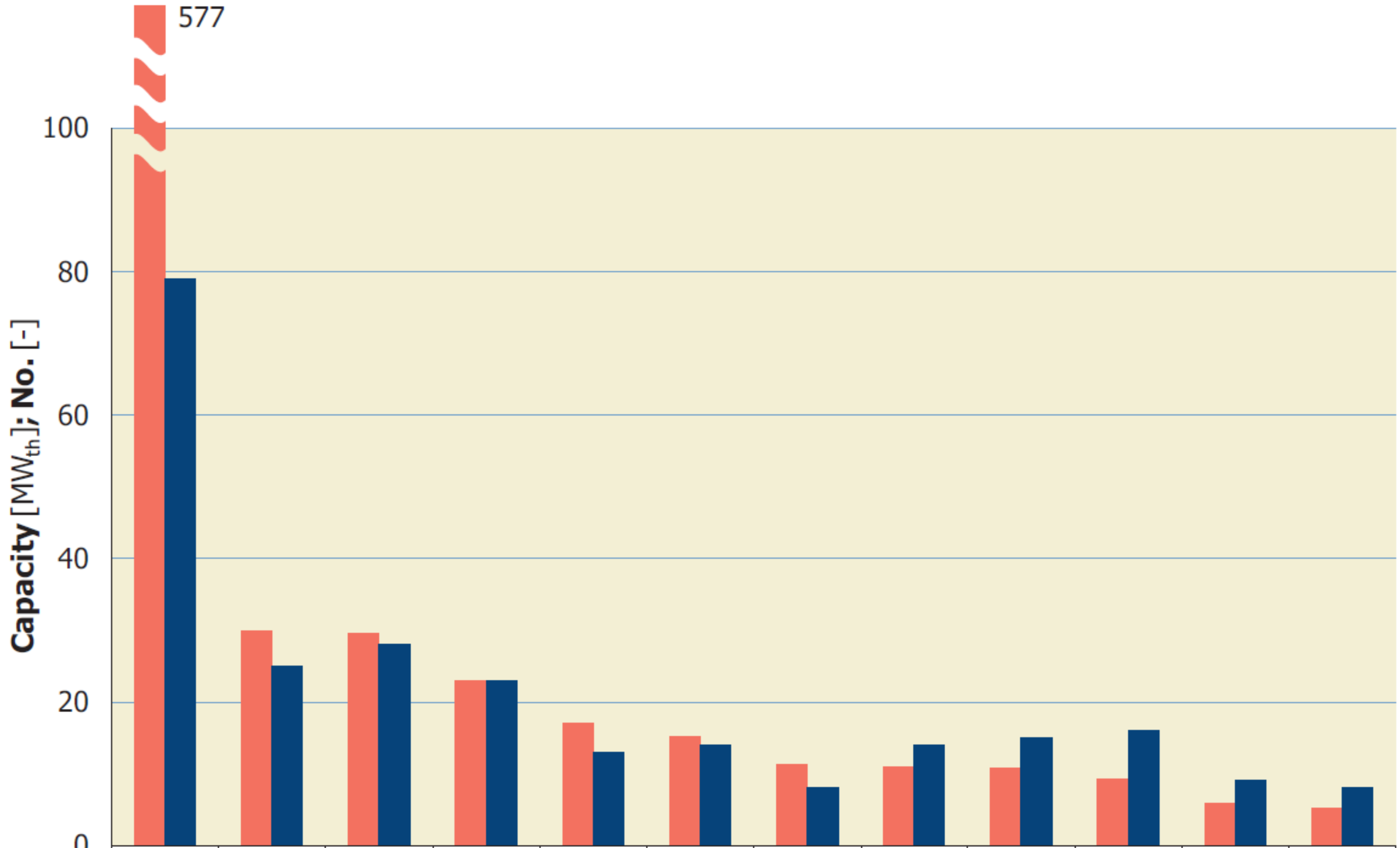
Solar heating plants


Vojens 70000 m²

Europe end of 2015:

235 solar heating plants > 500 m². 79 in Denmark, 34%

1,063,791 m² in operation. 823,838 m² in Denmark, 77%!

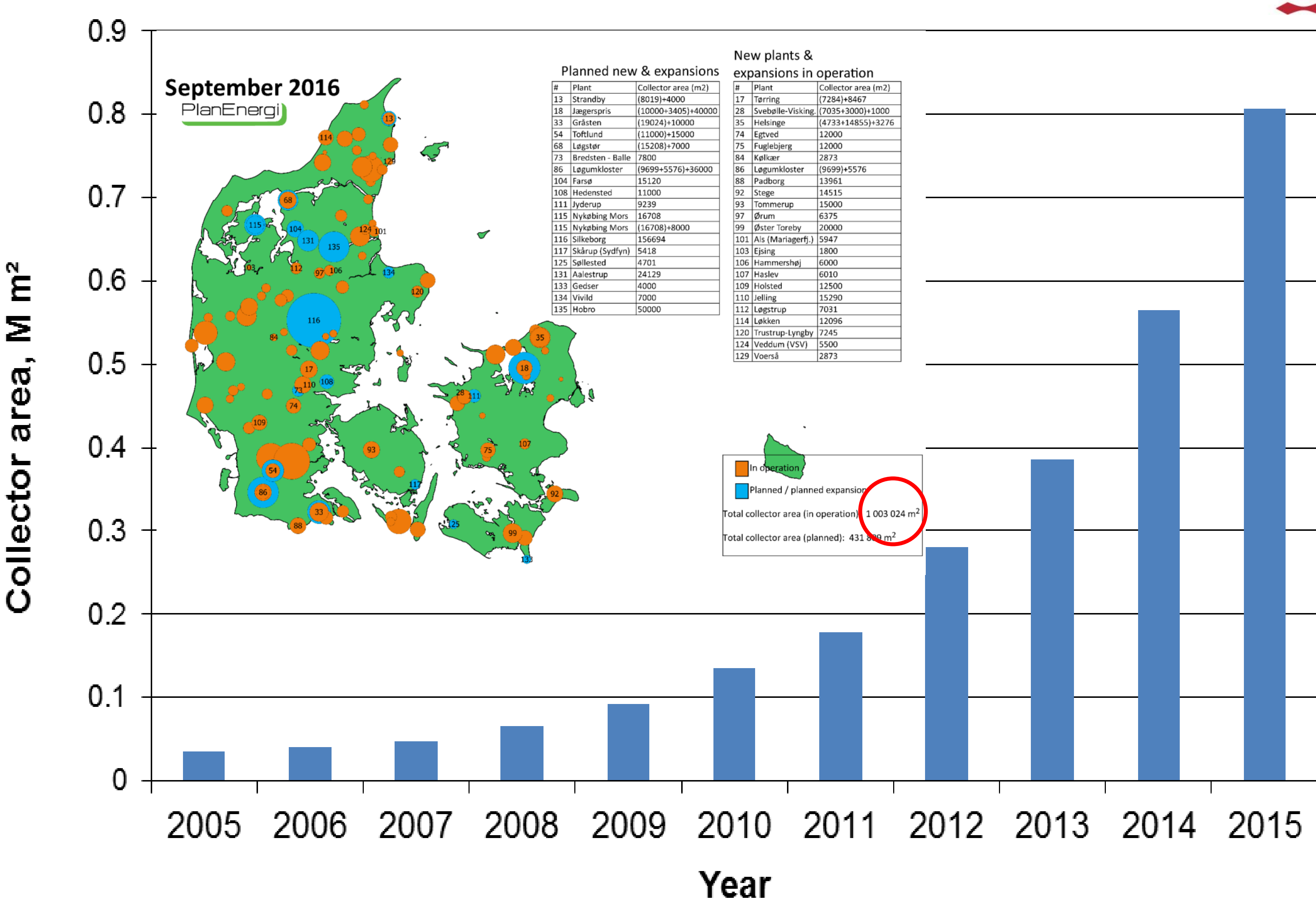


	DK	DE	AT	SE	OTH	PL	NL	GR	FR	ES	CH	IT
Capacity [MW_{th}]	577	30	30	23	17	15	11	11	11	9	6	5
No. of systems [-]	79	25	28	23	13	14	8	14	15	16	9	8

Figure 41: Solar district heating and cooling in Europe – capacities installed and No. of systems in 2015

(Data source: Jan-Olof Dalenbäck – Chalmers University of Technology, SE)

Solar heating plants in Denmark



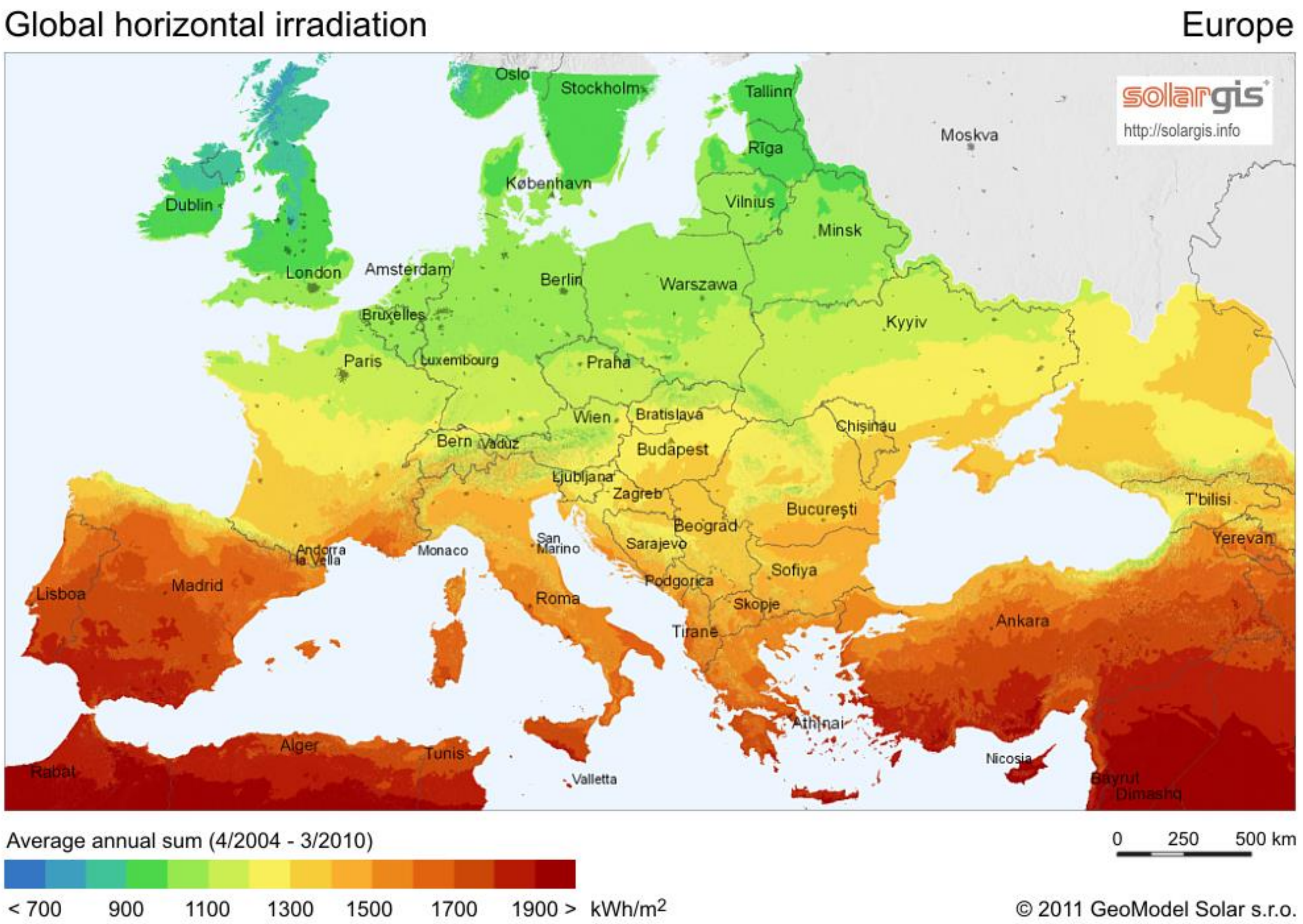
Planned new & expansions

#	Plant	Collector area (m2)
13	Strandby	(8019)+4000
18	Jægerspris	(10000+3405)+40000
33	Gråsten	(19024)+10000
54	Toftlund	(11000)+15000
68	Løgstør	(15208)+7000
73	Bredsten - Balle	7800
86	Løgumkloster	(9699+5576)+36000
104	Farsø	15120
108	Hedensted	11000
111	Jyderup	9239
115	Nykøbing Mors	16708
115	Nykøbing Mors	(16708)+8000
116	Silkeborg	156694
117	Skårup (Sydfyn)	5418
125	Søllested	4701
131	Aalestrup	24129
133	Gedser	4000
134	Vivild	7000
135	Hobro	50000

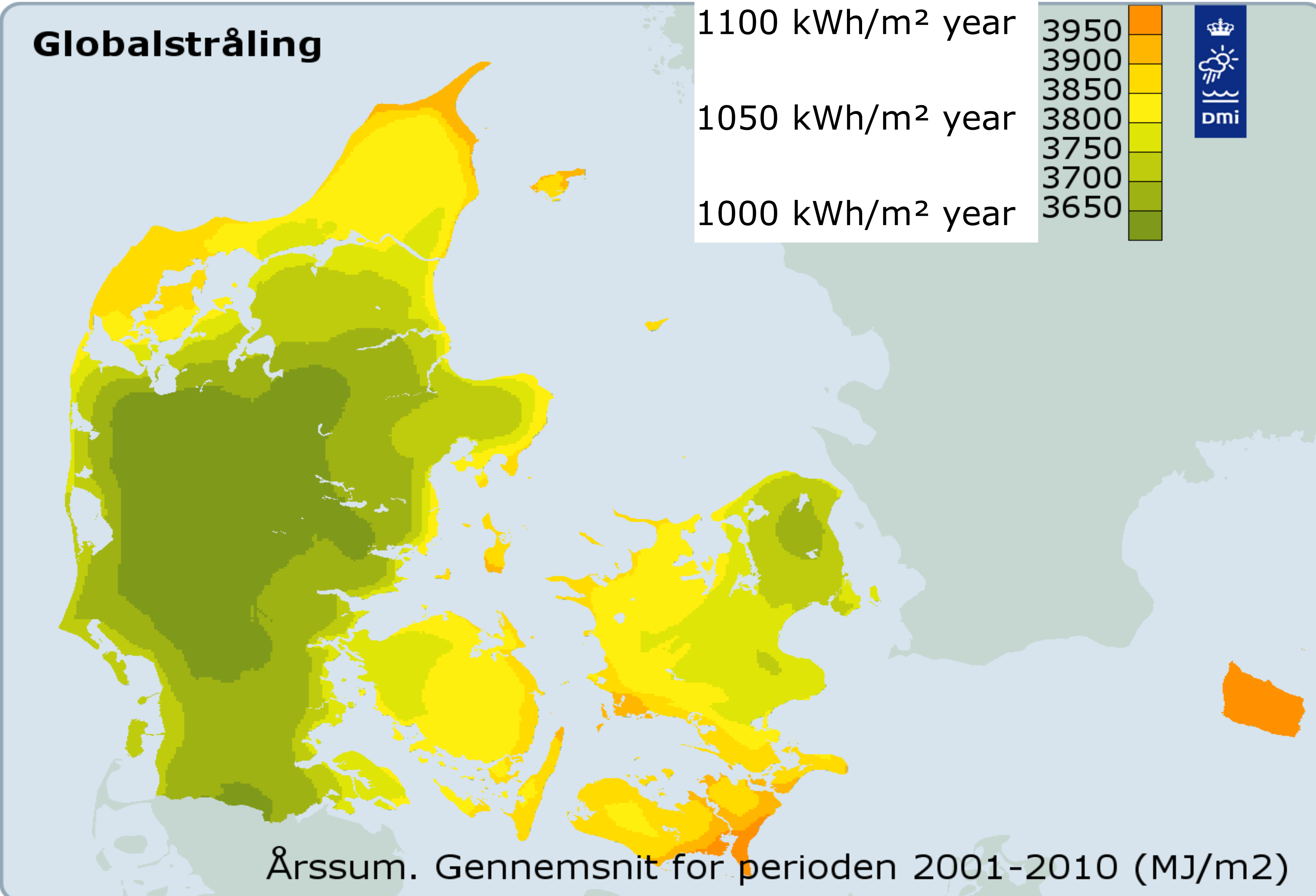
New plants & expansions in operation

#	Plant	Collector area (m2)
17	Tørring	(7284)+8467
28	Svebølle-Visking.	(7035+3000)+1000
35	Helsinge	(4733+14855)+3276
74	Egtved	12000
75	Fuglebjerg	12000
84	Kølkær	2873
86	Løgumkloster	(9699)+5576
88	Padborg	13961
92	Stege	14515
93	Tommerup	15000
97	Ørum	6375
99	Øster Toreby	20000
101	Als (Mariagerfj.)	5947
103	Ejsing	1800
106	Hammershøj	6000
107	Haslev	6010
109	Holsted	12500
110	Jelling	15290
112	Løgstrup	7031
114	Løkken	12096
120	Trustrup-Lyngby	7245
124	Veddum (VSV)	5500
129	Voerså	2873

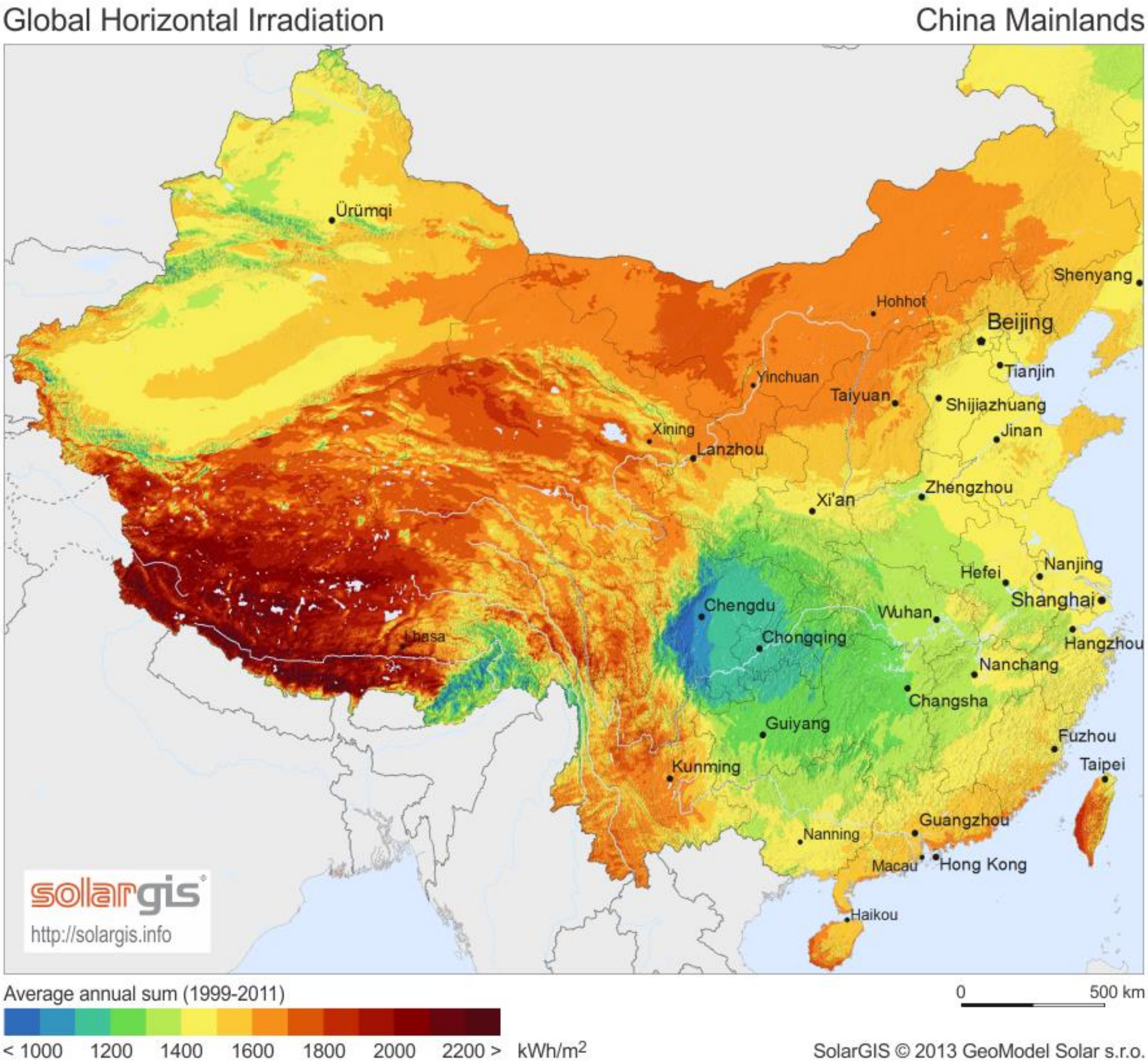
Europe - latitude: 35° - 60°



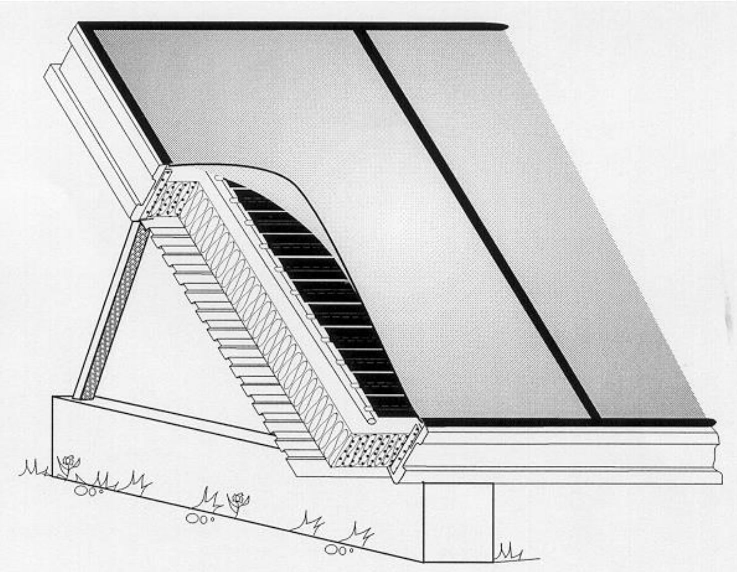
Denmark - latitude 55° - 57° Solar radiation on horizontal



China - latitude: 20° - 50°



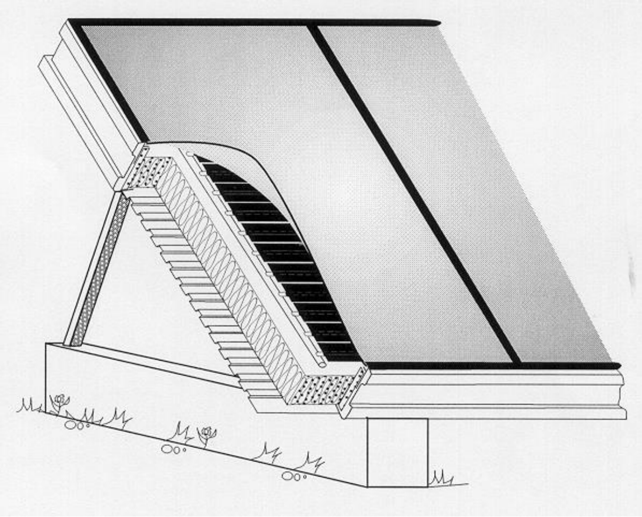
Flat plate solar collectors from Arcon-Sunmark A/S



Collectors with foil between absorber and glass

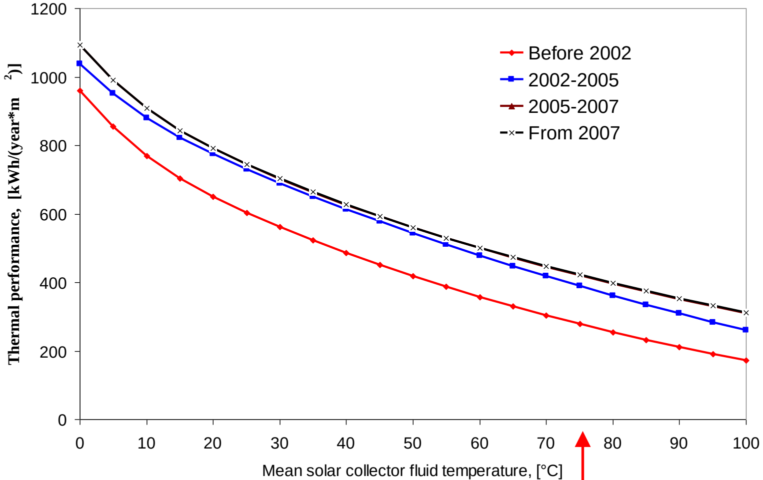
Collectors without foil between absorber and glass

Solar collector for solar heating plants



Arcon-Sunmark A/S's HT collector Design 2002

• Cover	Numbers	2
	Material	Glass & foil
	Thickness	4 & 0.025 mm
• Absorber	Type	Sunstrip Niox
	Material	Copper/Aluminium
	Surface	Selective nickel, absorptance: 0.95, emittance: 0.12
	Channel system	16 parallel channels
	Cross section area	60 mm²
	Strip thickness	0.5 mm
	Mass of fluid	8.5 kg
• Collector box	Material	Aluminium
	Outer dimensions	2.27 x 5.96 x 0.14 m
• Insulation	Material	Glass wool
	Back side insulation	75 mm
	Edge insulation	30 mm
• Collector area		12.53 m²



Yearly thermal performance of solar heating plant, kWh/m² year

Design changes 2002 - 2007:

- Insulation material: Rockwool industribatts 80 instead of Isover glass wool
- **Absorber: Absorptance still 0.95. Emittance reduced from 0.12 to 0.06**
- Glass: AFG Solatex instead of AFG Solite
- **Antireflection treated glass: Glass surfaces etched by Sunarc Technology A/S**
- **Installation of foil improved to decrease thermal bridges**
- Improved edge insulation

Improved thermal performance 2002-2007:

- 40° C: 29% - **60° C: 39%** - 80° C: 55% - 100° C: 79%

Life time for solar collectors

Investigations:

- 13 and 15 years old solar collectors from solar heating plants investigated
- Reduction of thermal performance caused by the age of the collectors evaluated
- Status for solar collectors investigated, internal as well as external
- Life time for solar collectors estimated

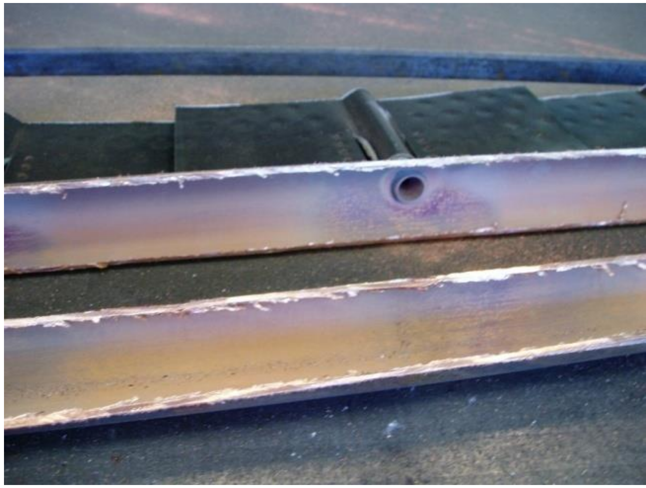
Conclusions:

- Reduced thermal performance after about 15 years of operation mainly due to wrong installation of the foil:

  40° C: About 2%

  60° C: About 10%

  80° C: About 25%



☺ Life time of solar collectors: About 30 years

☺ Most likely: New collectors without foil problems

Measured yearly thermal performances of 40 Danish solar heating plants for 2012-2015 available from:

www.solvarmedata.dk

www.solarheatdata.eu

Collector area, m^2	Collector tilt, °	Year of installation
2970-70000	30-45	1996-2015


Measured yearly thermal performances of solar collector fields

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Year	Number of solar heating plants	Yearly thermal performance kWh/m²	Average yearly thermal performance kWh/m²
2012	16	313-484	411
2013	21	389-493	450
2014	31	390-577	463
2015	36	322-518	439

Year	Number of solar heating plants	Yearly solar radiation kWh/m²	Average yearly solar radiation kWh/m²	Yearly utilization of solar radiation %	Average yearly utilization of solar radiation %
2012	16	942-1274	1102	28-45	37
2013	21	1039-1363	1135	31-46	40
2014	31	991-1474	1114	30-51	42
2015	36	876-1325	1101	31-47	40

Thermal performance influenced by:

Design of solar collector field

- Solar collector type
- Age of solar collector
- Design af pipings
- Shadows
- Heat loss from solar collector loop
- Solar collector tilt
- Solar collector orientation
- Solar collector fluid
- Moisture in solar collectors

Operation

- Solar collector fluid temperatures/operation temperatures/solar fraction
- Control strategy inclusive volume flow rate
- Flow distribution in solar collector field

Weather

- Solar radiation – direct and diffuse
- Outdoor temperature
- Wind
- Snow
- Dirt

Control strategy

- Solar irradiance on collectors measured
- Volume flow rate through collector field determined by calculations based on simple collector efficiency expression and solar irradiance in such a way that the outlet temperature from the solar collector field is constant, about 90°C

Calculated yearly thermal performances of solar collector fields

Solar collector efficiencies

Arcon-Sunmark with foil:

$$\eta = (K_\theta \text{ x } 0.802) - 2.226 * \frac{T_m - T_a}{G} - 0.01 * \frac{(T_m - T_a)^2}{G}$$

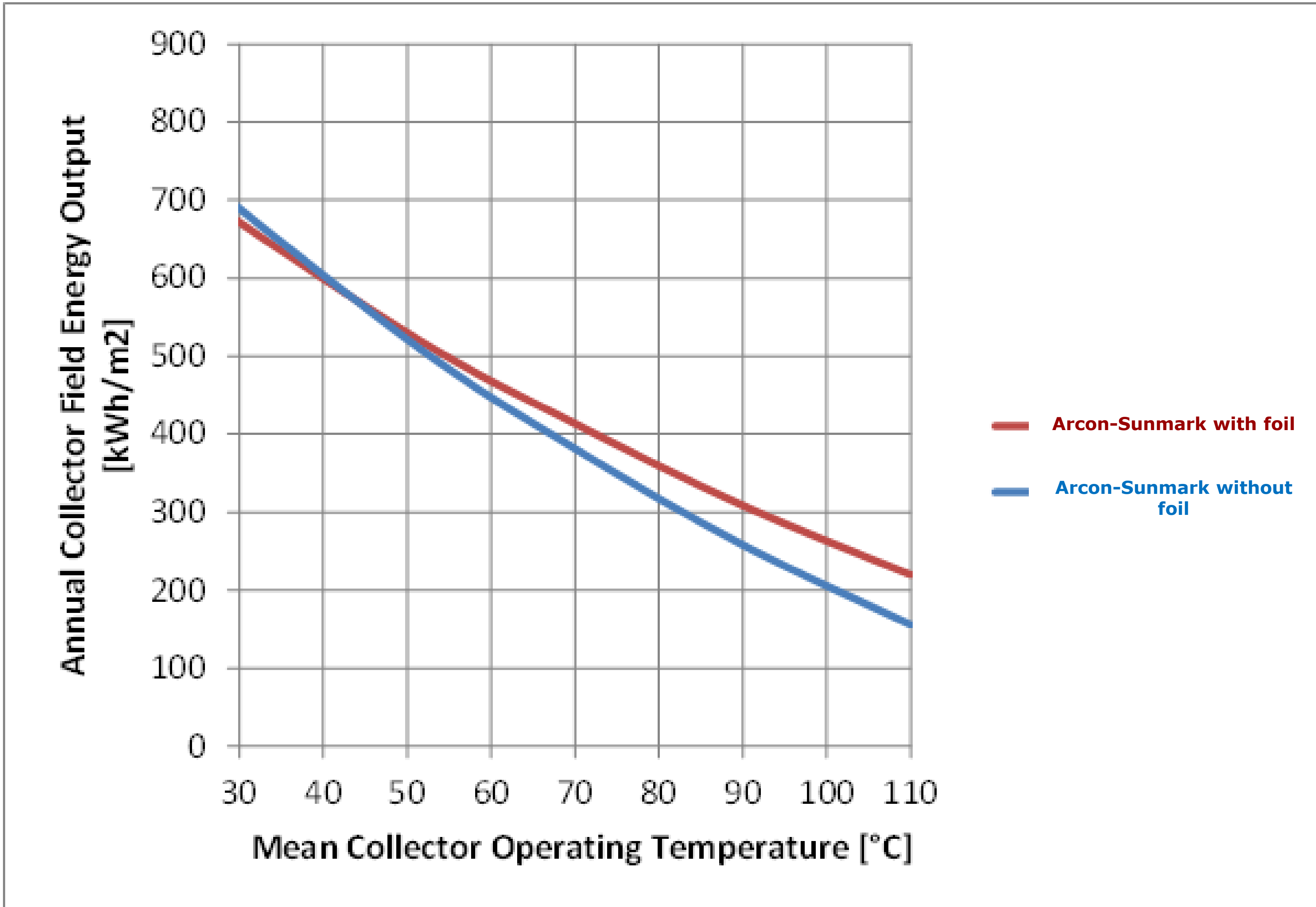
$$K_\theta = 1 - \tan^{3.66}(\theta / 2)$$

Arcon-Sunmark without foil:

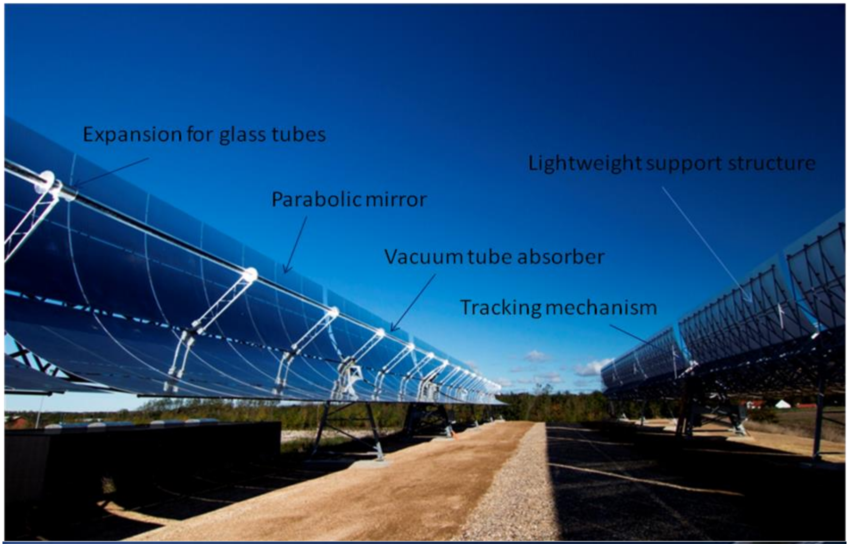
$$\eta = (K_\theta \text{ x } 0.839) - 2.596 * \frac{T_m - T_a}{G} - 0.016 * \frac{(T_m - T_a)^2}{G}$$

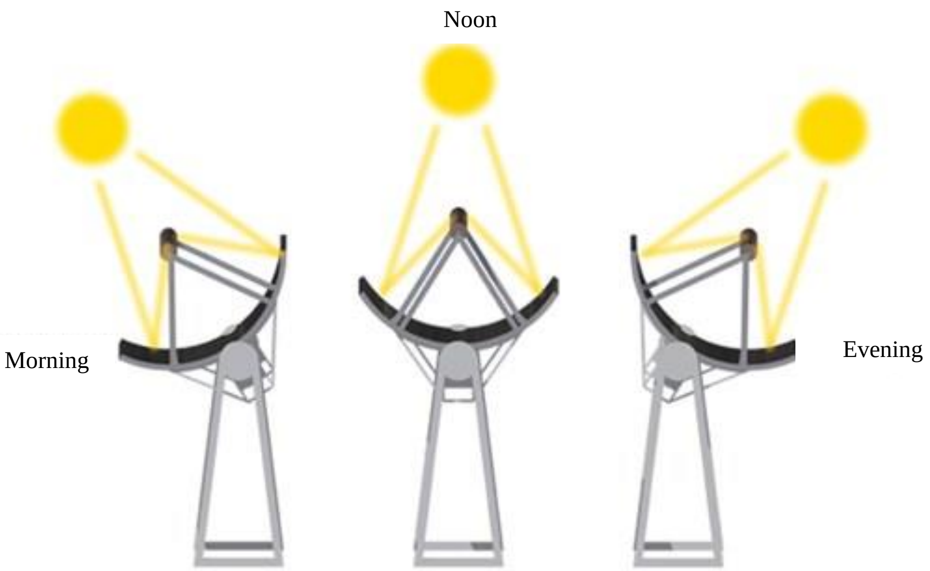
$$K_\theta = 1 - \tan^{3.66}(\theta / 2)$$

Yearly thermal performance DRY Denmark



Concentrating tracking solar collectors





Collector efficiency

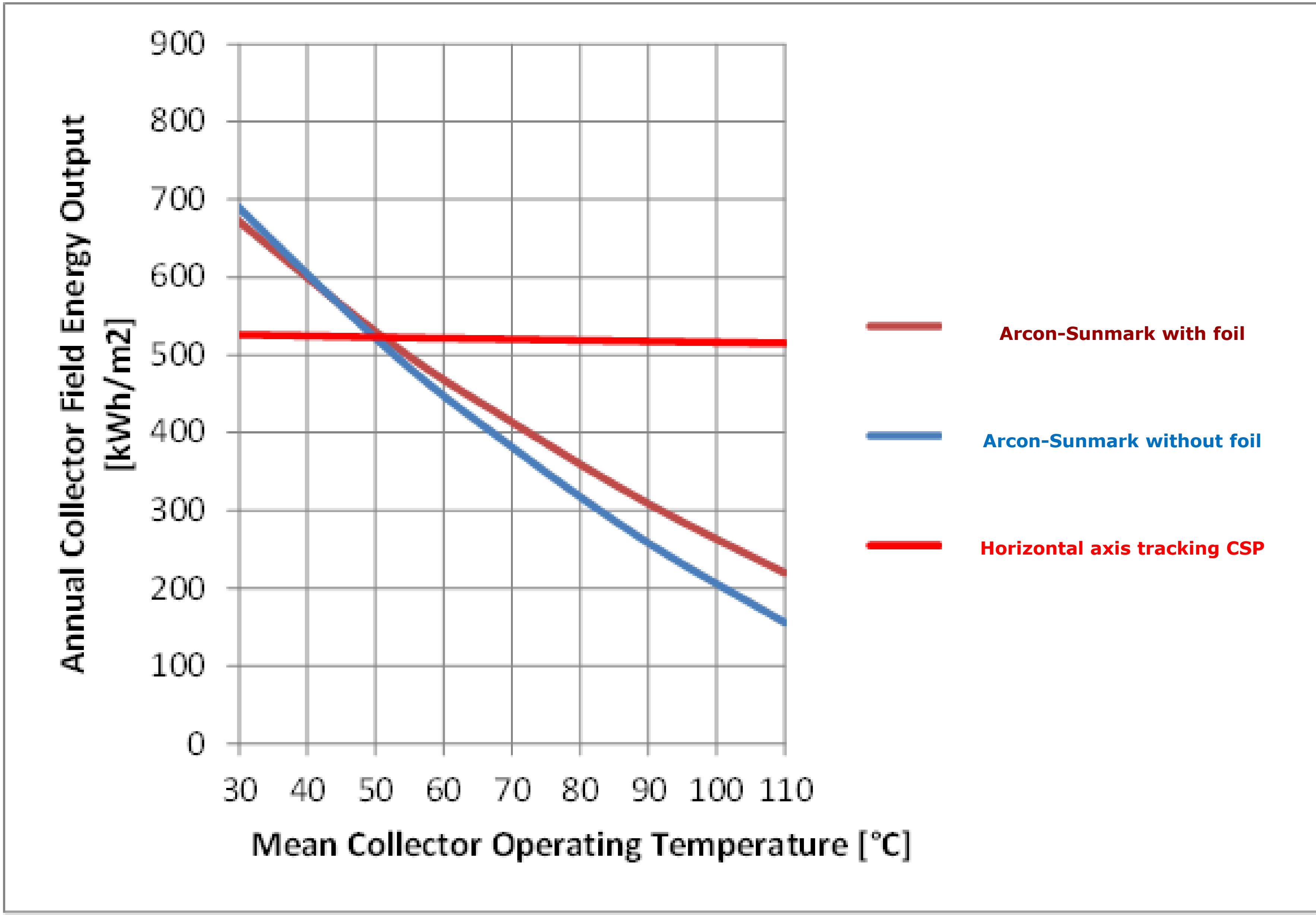
Aalborg CSP – concentrating tracking:

$$\eta = (K_\theta \times 0.75) - 0.04 * \frac{T_m - T_a}{G} - 0 * \frac{(T_m - T_a)^2}{G}$$

$$K_\theta = 1 - \tan^{2.40}(\theta / 2)$$ for direct radiation

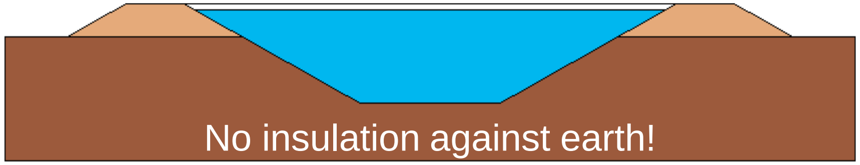
$\boldsymbol{K_\theta}$ = 0.03 for diffuse radiation

Yearly thermal performance DRY Denmark

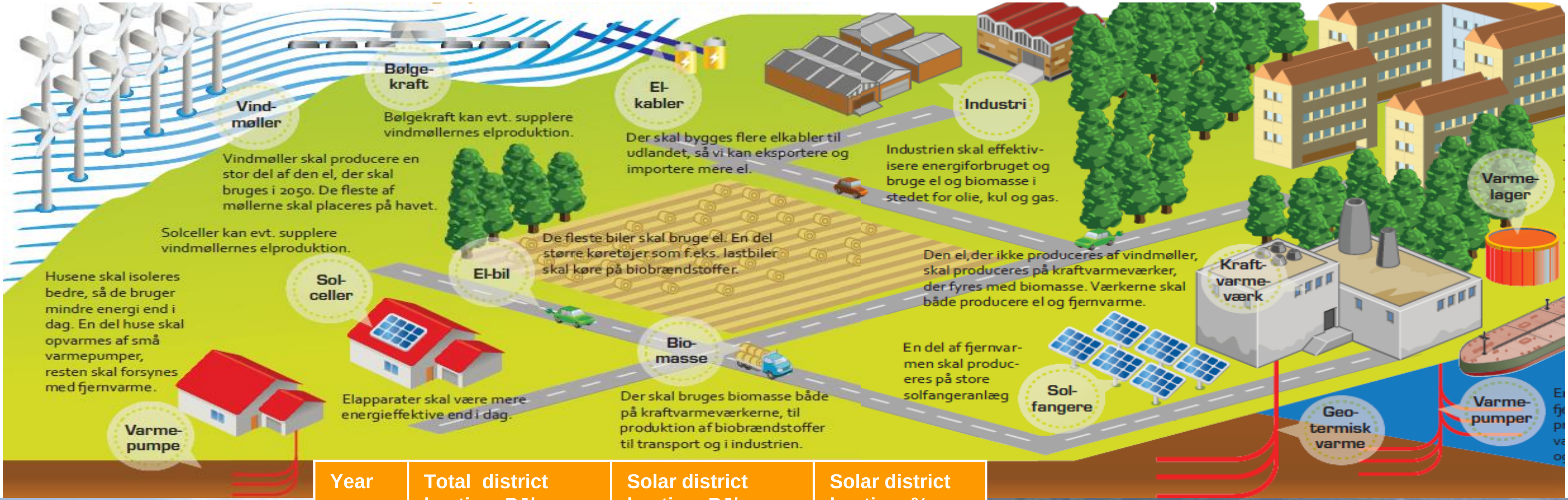


Seasonal heat storage: Water pond - Marstal: 75,000 m^3

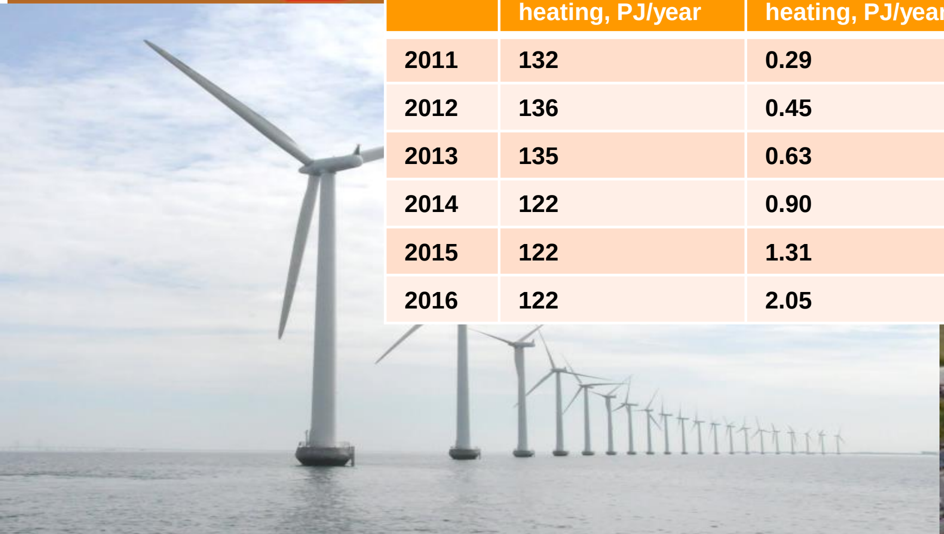
- **Gram: 110,000 m^3**
- **Vojens: 200,000 m^3**



Denmark 2050: All fossil fuels phased out - 2035: All heat and electricity from renewables



Year	Total district heating, PJ/year	Solar district heating, PJ/year	Solar district heating, %
2011	132	0.29	0.2
2012	136	0.45	0.3
2013	135	0.63	0.5
2014	122	0.90	0.7
2015	122	1.31	1.1
2016	122	2.05	1.7



Wind energy:
2015: 42% of electricity consumption
2020: 50% of increased electricity consumption (incl. transport, heat pumps, …)
Solar heating:
2030: 15% of decreased heating demand
2050: 40% of decreased heating demand - 80% of this by solar heating plants & 20% individual systems

International research projects

- IEA Task 45 Large Systems: Large Solar Heating/Cooling Systems, Seasonal Storage, Heat Pumps, homepage: www.iea-shc.org/task45/objectives.htm

- IEA Task 55 Integrating Large SHC Systems into DHC Networks, http://www.iea-shc.org/tasks-current

- SDHtake off - Solar District Heating in Europe, homepage: www.solar-district-heating.eu

Homepages

A high number of Danish solar heating plants

www.solvarmedata.dk
www.solarheatdata.eu

Solar collector manufacturers

- Arcon-Sunmark A/S, www.arcon.dk/?sc_lang=en
- Aalborg CSP A/S, www.aalborgcsp.com
- Savosolar ApS, http://www.savosolar.fi/dk/kontakt

Pipe manufacturer

- LOGSTOR, www.logstor.com

District heating systems

- Marstal fjernvarme, www.solarmarstal.dk
- Brædstrup Fjernvarme, www.braedstrup-fjernvarme.dk/side1298-cid-1291.html

Consultants

RAMBØLL, www.ramboll.dk
PlanEnergi, www.planenergi.dk

Reasons for rapid growth of Danish solar heating plants

- Ambitious Danish energy plan. By 2030 no fossil fuels must be used for heat, by 2035 no fossil fuels must be used for heat and electricity and by 2050 no fossil fuels must be used
- **A lot of district heating**. Today 64% of all Danish buildings are heated by district heating
- Low temperature levels in district heating systems. A typical forward temperature to towns is about 80°C and a typical return temperature from towns is about 40°C
- **High taxes for fossil fuels**. Typical tax is about 0.035 euro/kWh produced heat, CNY ¥ 0.27/kWh produced heat
- Decentralized energy supply system
- **High share of wind energy for electricity production**. In 2015, 42% of the Danish electricity consumption was produced by wind turbines. By 2020, 50% of the Danish electricity consumption must be produced by wind turbines
- **Low costs** for marketed solar collector fields installed on the ground, < 200 euro/m², CNY ¥ 1540/m²
- Relative low ground costs
- High efficiency of marketed solar collectors
- Long life time of marketed solar collectors, about 30 years
- Simple and well proven and reliable technology
- Good cooperation between solar heating plant owners. Regular meetings with experience exchange
- **Good thermal performance** of existing solar heating plants: About 450 kWh/m² year
- Ongoing efforts to develop solar collectors and solar collector fields
- Ongoing efforts to develop and demonstrate seasonal heat storage and to improve the interplay with the energy system

Thank you for your attention