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Author:	Jan Erik Nielsen, PlanEnergi – jen@planenergi.dk
Co-author(s):	Riccardo Battisti, Ambiente Italia – riccardo.battisti@ambienteitalia.it
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Availability of solar radiation

For assessing the feasibility of a SDH plant, the first parameter to take into account is the available solar resource.

The key figure needed is the global solar irradiation on a horizontal plane (G_0), usually expressed in kWh/m² per year. This figure must be related to the location where the plant will be installed or to a different location, but very close to the real one and with similar climatic characteristics.

The solar radiation data could be taken from different sources:

- Meteonorm software: www.meteonorm.com (example given in the figure below)
- National solar maps - from e.g. national meteorological institute.
- Photovoltaic Geographical Information System (PV GIS): re.jrc.ec.europa.eu/pvgis. Though created for photovoltaic, this **online platform** provides solar radiation data, which can be used also for the assessment of solar thermal plants. It also allows calculations of solar radiation on tilted surfaces.

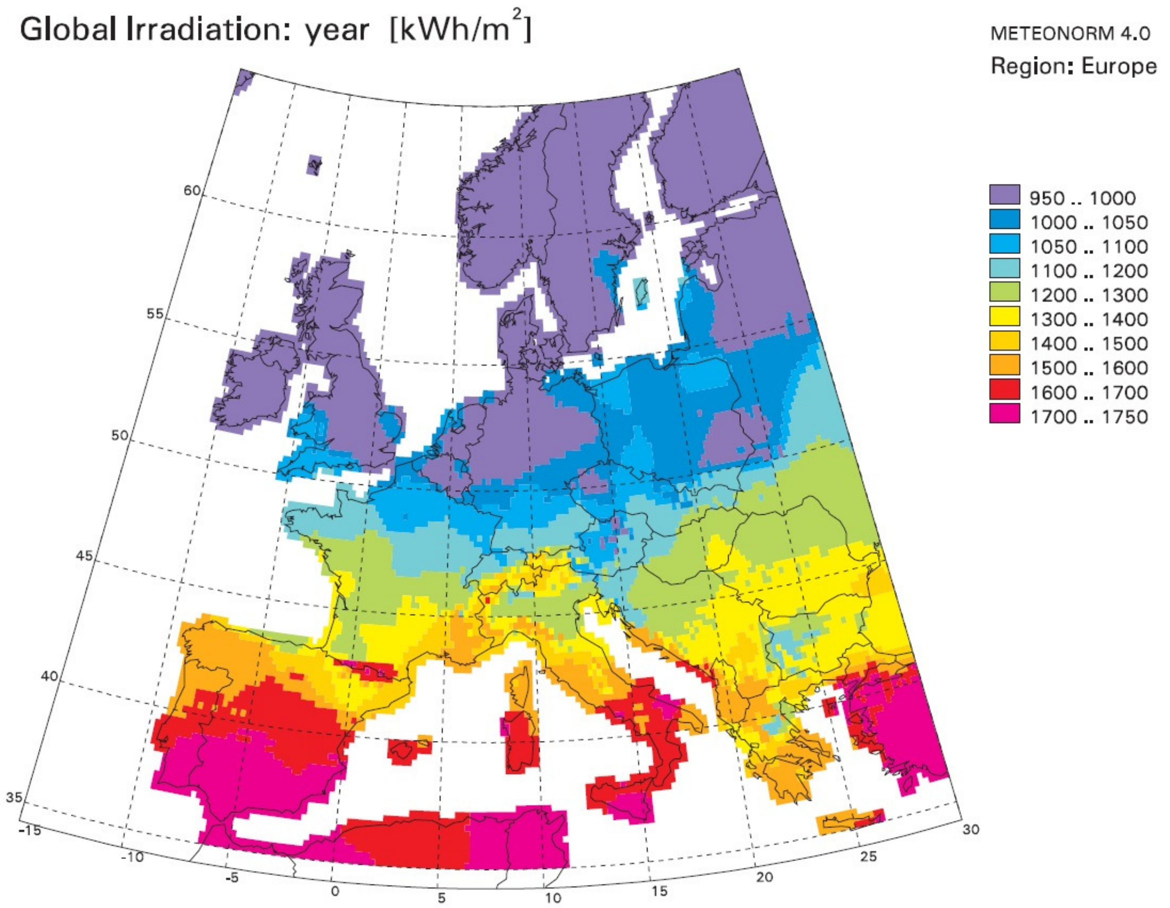

Fig. 2.3.1. Average global annual solar irradiation in Europe on horizontal surfaces [1].

By tilting the collectors the irradiation on the surface is increased. In general the further away from equator the location is, the more tilt is needed, but there are several things to consider when optimizing the tilt. This issue is addressed in fact sheet 2.2 *"Where to place the collectors"* in the subsection *"Ground mounted collectors"*. Below is seen a similar map with average daily irradiation levels for surfaces tilted 40° to the south.

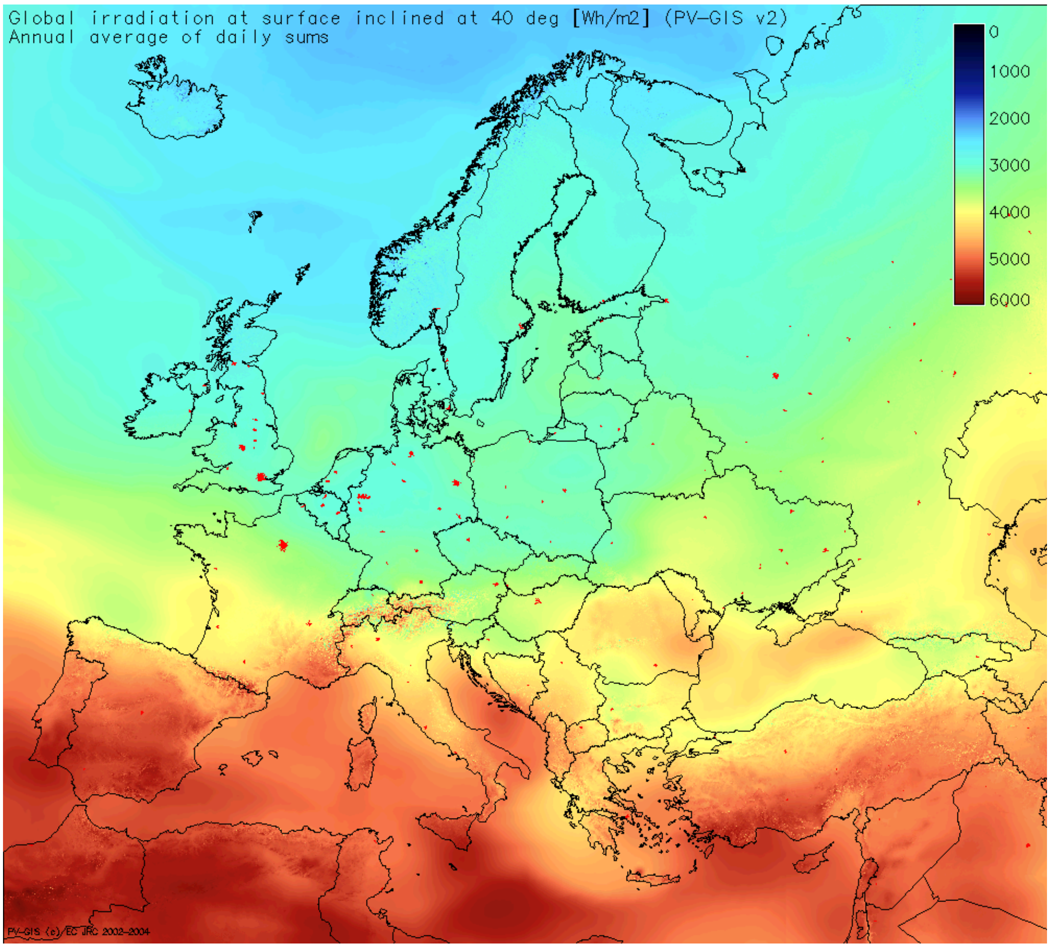

Fig. 2.3.2. Average global daily solar irradiation on a surface tilted 40° from horizontal, facing south [2].

Define locations available for collectors, storage, and the costs of land

Another key issue to be taken into account is the location of the collectors:

- How much area is available both for the collectors and the storage?
- Where should they be placed – on the ground and/or mounting on roofs?
- What is the cost of renting the land/roof for installing the plant?

Collectors on roofs

It is important to differentiate between "roof-mounted collectors" (normally flat roof) and "roof-integrated collectors" where tilt and orientation of roof has to be suitable for collector integration.

The cost of a roof-mounted collector field heavily depends on the characteristics of the building and the roof:

- structural analysis of roof and building: are reinforcements necessary? Is it possible to use concrete blocks in order to resist wind forces (often cheapest solution)?
- if concrete blocks are not possible: how can collectors get connected to the roof? Often construction/renovation of roof is the best moment for integration of collector mountings. Drilling into flat roofs otherwise often results in leakage problems.

In best-case scenario the collector field and the technical equipment can be mounted with concrete blocks on the roof just like a ground-mounted solar plant. Costs for land preparation works are saved but there are maybe some extra costs for stronger substructures because of higher wind loads on top of the building than on ground level.

Worst-case scenario is that reinforcements and expensive mounting works are necessary for each collector and that the technical equipment needs to be installed in a remote room of the building below.

For roof-integrated collectors costs for roof tiles are saved, but there are extra costs in terms of special methods necessary for leak-proof roof integration.

Collectors on land

For each possible collector land area the investment costs [€] are given by

$$pr_{land,location} = A_{land} \cdot pr_{land} + D_{location} \cdot pr_{location} \qquad \text{(eq. 2.3.1)}$$

where

A_{land}:	Area of land used for the collector field	[m²]
pr_{land}:	Price of land	[€/m²]
$D_{location}$:	Distance from collector field to network connection point (half the length of the total transmission pipe length)	[km]
$pr_{location}$:	Price per km distance	[€/km]
	(as a first estimate one could use $pr_{location} = 1400 \cdot \sqrt{A_{land}}$ *[€/km])*	

Another relevant factor linked to the use of land, is the consideration of heat loss from long transmission pipe, which will influence the total energy output of the plant. Below in fig. 2.3.3 the loss in % of collector output is given for 1 km distance between collector field and network connection point. It is assumed here that the area of land is around 3.5 times the area of collectors. It is common to use the *aperture area** when referring to the collector area. This is also the case in this fact sheet.

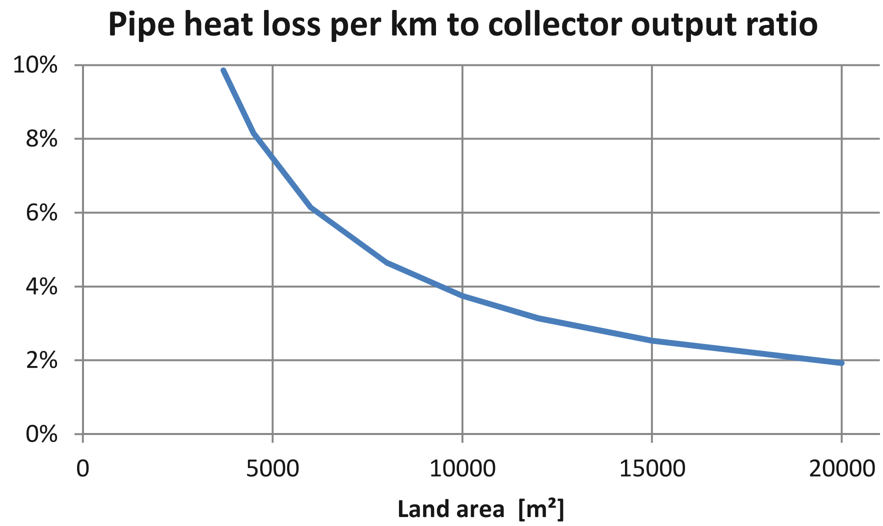

Fig. 2.3.3. Pipe heat loss per km distance between collector field and district heating network connection point related to collector output for varying land area (3.5 m^2 of land is used per m^2 of collector). (Source: PlanEnergi)

The equation behind the figure is:

$$Q_{pipe,loss} / Q_{collector,output} = 350 / A_{land} + 0.24 / \sqrt{A_{land}} \quad [-] \qquad \text{(eq. 2.3.2)}$$

where

$Q_{pipe,loss}$:	Heat loss from pipe in kWh/y per km distance between collector field and network connection point	[kWh/y/km]
$Q_{collector\ output}$:	Collector output	[kWh/y]

It is seen that for large collector fields it is possible to transport the heat over long distances without loosing very much in percent.

<u>Example:</u>

* *See fact sheet 7.1 Solar collectors for a description of the area definitions.*

It is possible to use an area of 20000 m² 2 km outside the town. From the figure you can see that the performance reduction will be 2 % per km, so 2 km · 2 %/km = 4 % of the collector output.

Estimated solar output

A first rough estimate on the solar energy output for simple systems operating around an average annual operating temperature of 50 °C [kWh per m^2 of land used and per year]:

$$q_{land} = 0.15 \cdot G_0 \quad \text{(eq. 2.3.3a)}$$

This equation can be used only for system with low solar fraction (< 10 %), that is when storage heat losses are negligible.

However, the solar output depends very much on the operating temperatures of the DH network, as well as on the collector technology and on several additional parameters[†]. An example of temperature correction can be seen in figure 2.3.4. Here the relative values for the annual output, corresponding to constant DH network operating temperatures, are shown (reference collector temperature is 50 °C).

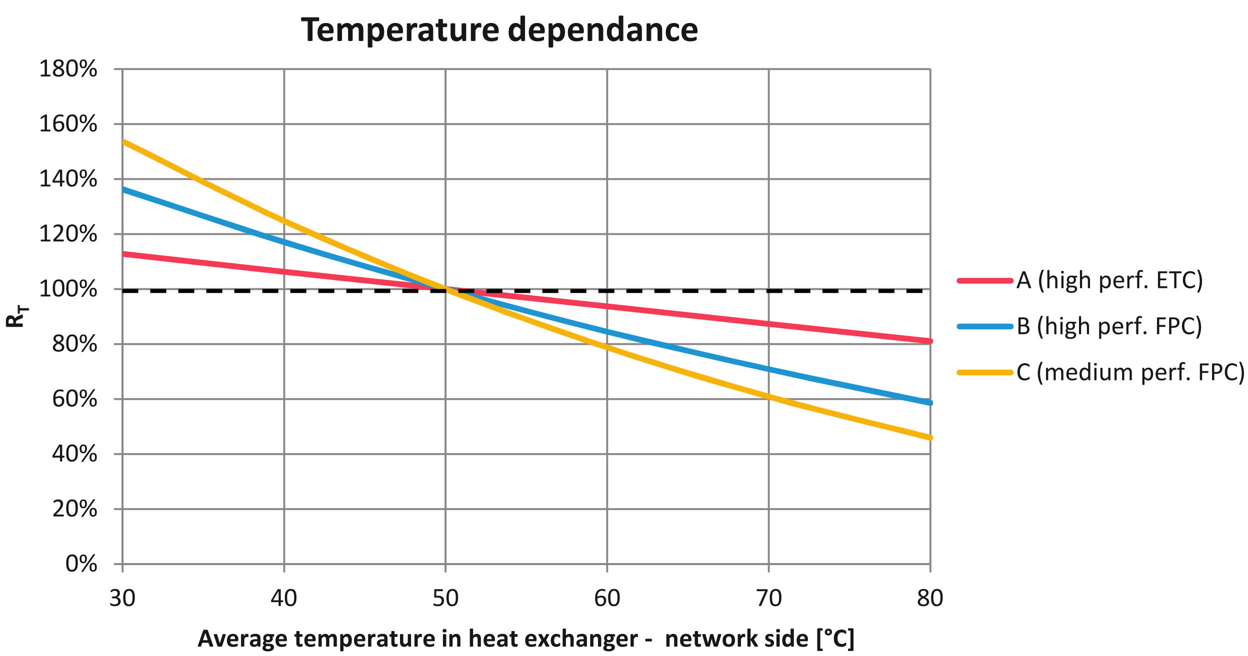

Fig. 2.3.4. Example of how the annual output is influenced by the DH network operating temperature (the temperature on the secondary side of the collector loop heat exchanger). (Source: PlanEnergi)

[†] *Collector orientation, distance between collector rows, control strategy, heat exchanger, storage type, combination with other energy technologies, etc.*

R_T is a “temperature correction factor” defined as the solar output at the actual operating temperature related to the solar output at 50°C:

$$R_T = Q_{solar,actual} / Q_{solar,50} \qquad \text{(eq. 2.3.4)}$$

Figure 2.3.4 shows that the solar output depends strongly on the operating temperature of the DH network. An increase of 1 °C in operating temperature reduces the solar output 1-2 %, since higher temperatures imply lower operating efficiency for the solar collectors.

Solar fraction

The solar fraction tells you how much the solar system contributes to the total production from the entire heat generating system:

$$S_F = Q_{solar\ output} / Q_{total,production} \qquad \text{(eq. 2.3.5)}$$

where $Q_{solar\ output}$ is solar system output and $Q_{total,production}$ is the total heat production of all units.

For low solar fractions (< 10 %) it will often be possible to keep the average operating temperature down around the 50 °C and equation 2.3.3a can be used in the following way:

$$Q_{solar,low} = 0.15 \cdot G_0 \cdot A_{land} \qquad \text{(eq. 2.3.3b)}$$

$$S_F = Q_{solar,low} / Q_{total,production} \qquad \text{(eq. 2.3.6)}$$

Beware that the uncertainty of eq. 2.3.3b is increased for S_F higher than 10 % since the storage heat losses will not be as negligible in this case. For high solar fractions and if a long term storage is included, it is necessary to make more detailed calculations. The higher the solar fraction and the longer the storage time - the higher the average operating temperature and the lower the solar output. A feeling of the performance reduction could be obtained looking at figure 2.3.4 showing for different types of collectors the influence of the operating temperature.

Storage size

The size of the storage depends on several different parameters e.g.:

- Collector area
- Solar fraction
- Other heat generating systems (heat pump, gas motor etc.)

- Total load

In figure 2.3.5 the "optimal" storage size in m^3 per m² collector is plotted against the solar fraction. This can be used as a first estimate on storage size; but especially for large solar fractions - and if combined with a heat pump - the storage size should be carefully optimized with detailed calculations/simulations - and the optimum could differ significant from what is suggested in figure 2.3.5. See fact sheet 7.2 *"Storage"* for more information.

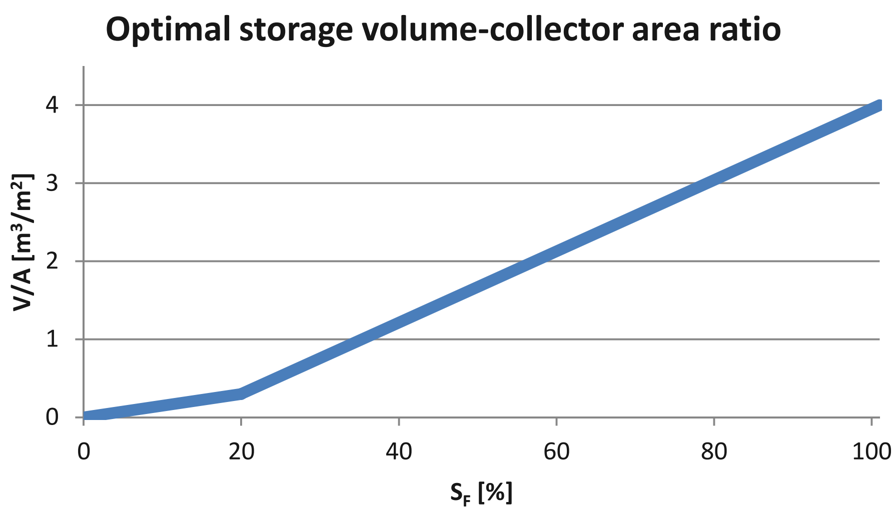

Fig. 2.3.5. First rough estimation of optimal ratio between storage volume and collector area as function of solar fraction [3].

Cost estimation

Based on experiences from existing solar district heating plants the approximated component costs can be estimated. The total costs of the solar district heating system comprise:

- Cost of land
- Collectors
- Collector field installation including piping in the field
- Anti-freeze fluid
- Transmission piping (collector field to heat exchanger unit)
- Heat exchanger (HX) unit (including pumps, expansion vessels, control, etc.)
- Connection to existing district heating system
- Storage

- Control system
- Design & optimization
- Miscellaneous (e.g. building, ground shaping, fence, plants)

The cost of land has to be determined for the specific location.

Costs of collectors, collector field installation (on flat ground) including field piping and fluid, and heat exchanger unit can be estimated by the curve shown in figure 2.3.6.

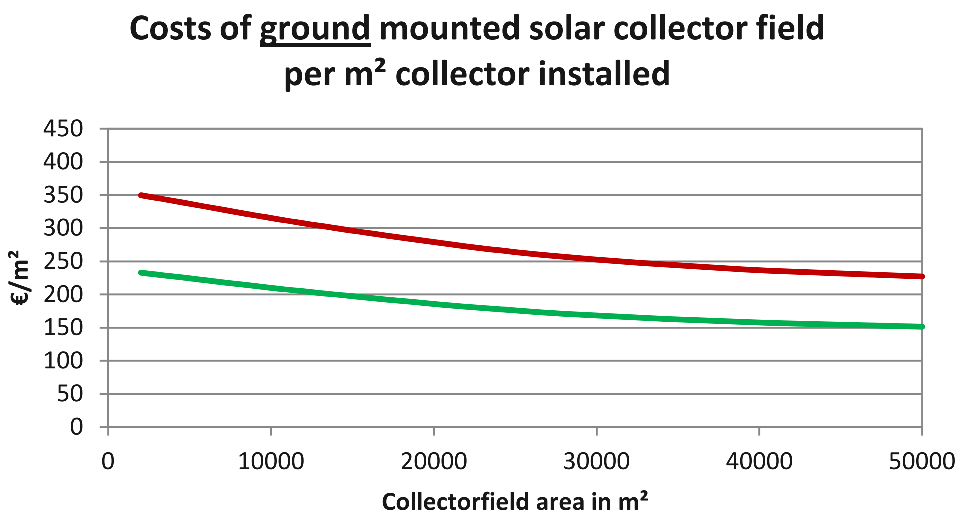

Fig. 2.3.6. Approx. price per m² collector field - including installation, piping, HX-unit, etc. (excl. storage and VAT). Prices will typically be between the upper red and the lower green line. Values valid for ground mounted collectors‡. (Source: PlanEnergi)

The cost of transmission piping has been estimated in the section "Define locations available for solar collectors and storage, and the costs of land" above.

An approximate price of the glycol-water mixture is 1000 €/m^3. This corresponds roughly to a price per m^2 collector of 3 €/m^2 - but depends of course very much on the fluid content in the chosen collectors.

For collectors installed on roofs the prices are seen in figure 2.3.7.

‡ *Based on Danish examples.*

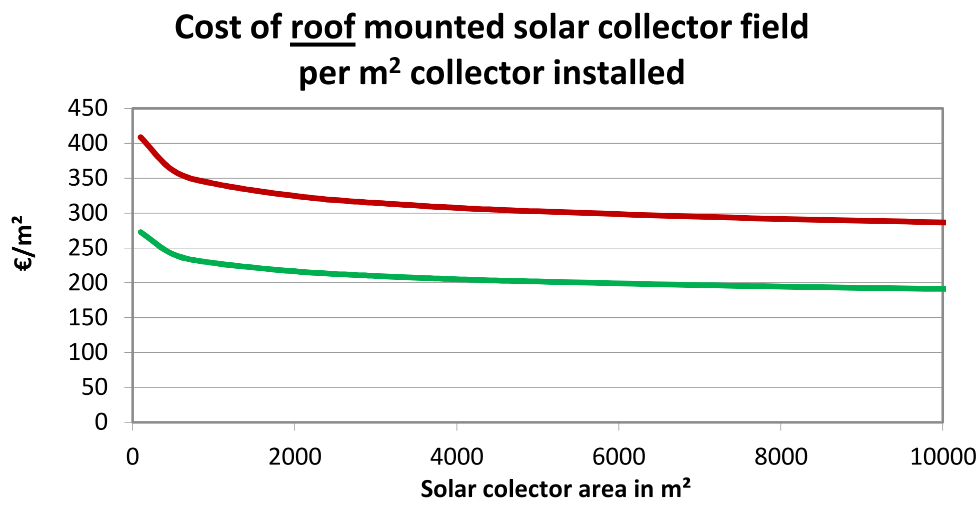

Fig. 2.3.7. Approx. price per m² collector - including installation, piping, HX-unit, etc. - but excl. storage, designing and VAT. Prices will typically between the upper red and the lower green line. Values valid for roof mounted collectors§. (Source: Solites)

In figure 2.3.8 the cost of pit storages are seen for different volumes. The blue curve represents the experiences from Marstal Denmark. The red curve represents the costs incl. possible extra costs due to difficult excavation etc. The green curve represents the expected lower costs due to a newly designed lid type. Examples from different realized storage systems in Germany are shown in fact sheet 7.2 *"Storage"*.

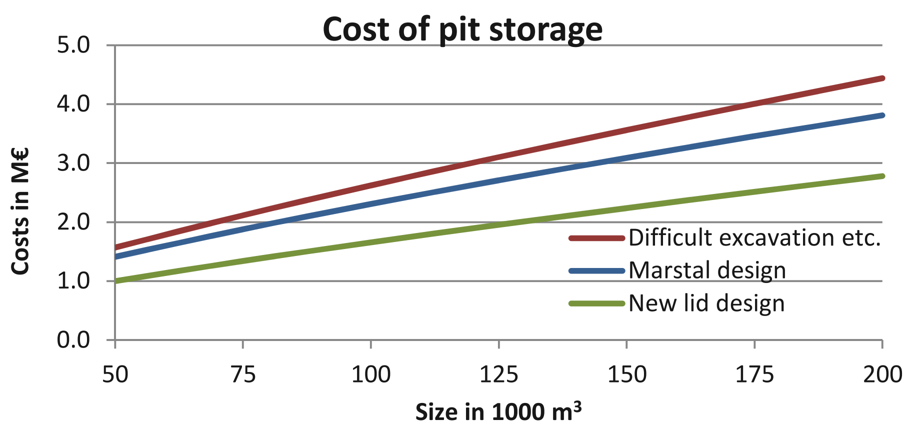

Fig. 2.3.8. Approximated price of total storage as function of volume [4].

The cost of the planning, designing & optimization is approximately 2-5 % of the total investments. Other

§ *Based on German examples.*

costs than mentioned here, have to be considered before summing up the approximated total installation costs e.g. the costs of shaping the ground for the collector field which depend highly on how extensive the work has to be.

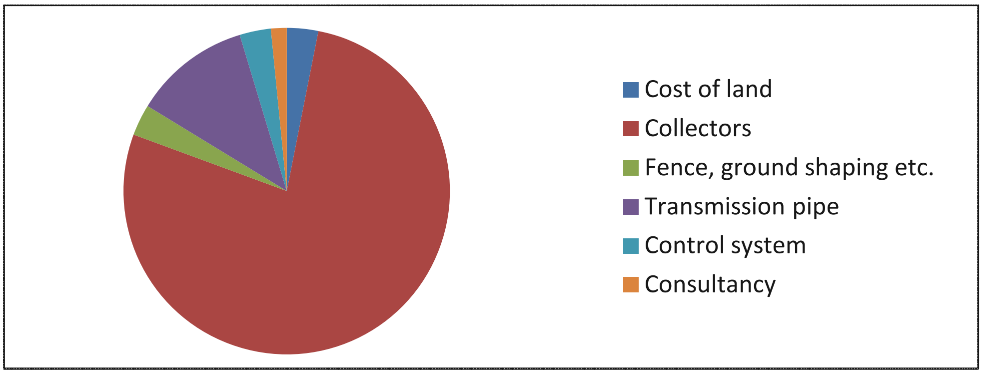

Fig. 2.3.9. Example of cost distribution (Tørring, DK). Note that storage is not included. (Source: PlanEnergi)

An on-line calculation tool has been created to give - in a quick and easy way - such kind of rough estimations based on experiences from existing SDH plants:

www.solarkey.dk/f-easy/f-easy.xlsx

Fact sheet 2.4 *"Questionnaire for SDH site assessment"* contains a template which can be used when collecting the base data for assessing the feasibility of a solar district heating system at a specific site.

References

[1] Meteonorm, www.meteonorm.com

[2] "PVGIS", European Commission, Joint Research Centre re.jrc.ec.europa.eu/pvgis/solres/solrespvgis.htm#inclined

[3] "Energistyrelsens Teknologikatalog" (*The Danish Energy Agency Technology Catalog)*, 2010, p. 163, www.ens.dk/Documents/Netboghandel%20-%20publikationer/2010/Technology_data_for_energy_plants.pdf

[4] SUNSTORE 4, WP5 - European level concept study, Feasibility/simulation studies, Draft 1, p. 34.

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

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