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fair consulting in sustainability

# Key parameter model for solar thermal installations

## Report

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| About us | ESU-services Ltd. has been founded in 1998. Its core objectives are consulting, coaching, training and research in the fields of life cycle assessment (LCA), carbon footprints, water footprint in the sectors energy, civil engineering, basic minerals, chemicals, packaging, telecommunication, food and lifestyles. Fairness, independence and transparency are substantial characteristics of our consulting philosophy. We work issue-related and accomplish our analyses without prejudice. We document our studies and work transparency and comprehensibly. We offer a fair and competent consultation, which makes it for the clients possible to control and continuously improve their environmental performance. The company worked and works for various national and international companies, associations and authorities. In some areas, team members of ESU-services performed pioneering work such as development and operation of web based LCA databases or quantifying environmental impacts of food and lifestyles. |
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# 1 Background and Objectives

Different types of solar thermal installations can be used for hot water provision and room heating. Sebasol offers one-day courses to people who are interested and motivated to install themselves thermal solar installation. They also collaborate with installation engineers who can mount solar thermal installations all-inclusive and they have an internal formation to educate generalist installers. The majority of the solar installation constructed by Sebasol is combining the domestic hot water and building heating supply. Sebasol also offers advanced courses for solar and solar-wood heating. In addition, they also organise educational events for children.

Sebasol has several centres in the French-speaking part of Switzerland: Vaud, Geneva, Jura and Valais.

In order to better show the advantages of solar thermal installations they wish to use a simple key parameter model in Excel which enables them to calculate the **cumulative energy demand (CED)** of a specific solar thermal installation.

Cumulative Energy Requirements Analysis (CERA) aims to investigate the energy use throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect use or grey consumption of energy due to the use of, e.g. construction materials or raw materials. This method has been developed in the early seventies after the first oil price crisis and it has a long tradition (Boustead & Hancock 1979; Pimentel 1973).

According to VDI – Verein Deutscher Ingenieure (1997) "*the data on the cumulative energy demand ... form an important base in order to point out the priorities of energy saving potentials in their complex relationship between design, production, use and disposal*". However, the CED is also widely used as a screening indicator for environmental impacts. Indeed, cumulative energy analysis can be a good 'entry point' into life cycle thinking. But it does not replace an assessment with the help of comprehensive impact assessment methods such as Eco-indicator 99, ReCiPe or Ecological Scarcity (Frischknecht et al. 2009; Goedkoop et al. 2009).

Different concepts for determining the primary energy requirement exist: For CED calculations one may chose the lower or the upper heating value of primary energy carriers whereupon the latter includes the evaporation energy of the water present in the flue gas. Furthermore one may distinguish between energy requirements of renewable and non-renewable resources. Finally, different ways exist how to handle nuclear energy and hydroelectricity (Jungbluth & Flury 2013a).

Within this project we use the methodology as defined for the ecoinvent database, which is widely used in Switzerland (Frischknecht et al. 2007). This method accounts for the total (renewable and non-renewable) primary energy entering the technical system. Further information can be found in chapter 5.1.

A special way of discussing the CED is the use of so called **Primärenergiefaktoren (PEF, primary energy factors)**. For this type of evaluation the total CED (including all renewable and non-renewable energy resources) is shown per MJ of energy output (e.g. MJ of heat or electricity). The upper heating value is used as a reference for fuels. In nearly all cases the PEF for renewable and non-renewable energy is larger than 1 MJ-eq per MJ because the supply of the energy carrier is included as well as the energy carrier itself. Only in some special cases where e.g. waste heat from a municipal waste incineration is used the factor can be smaller than 1 because waste heat is not regarded as an energy resource (Jungbluth & Flury

2013a). PEF can be used to compare different types of energy systems (Frischknecht et al. 2012) or transport systems (Frischknecht et al. 2011). The concept has also been used to evaluate solar thermal installations (Stucki & Jungbluth 2010a).

The goal of this project is to develop a simple key parameter model which allows calculating and comparing the primary energy factors of different solar thermal installations.

ESU-services has long term experience in investigating the life cycle assessment of energy systems and solar thermal installations. ESU calculated the primary energy demand of several energy systems and developed the idea of key parameter models for the certification scheme naturemade star (Frischknecht et al. 2012; Jungbluth 2002; Jungbluth et al. 2002; Jungbluth 2007a, b; Jungbluth et al. 2010; Jungbluth & Flury 2013b; Stucki & Jungbluth 2010b).

# 2 Goal of this project

The following goals are achieved with this project.

## 2.1 Development of a key parameter model for solar thermal installations

The first goal is the development of an Excel file to make the simplified LCA of solar thermal installations and to calculate the primary energy factors (Primärenergiefaktoren – PEF).

The tool follows the idea of key parameter models (Kennwertmodell – KWM) which have been developed by ESU-services to allow the certification of energy systems for the naturemade star label. Further information about such models is given in chapter 6 on page 18.

Fig. 2.1 shows an evaluation of a solar hot water system (20 m$^2$ Cu collector, multiple dwelling, slanted roof, for hot water in Zürich) according to the available life cycle inventories (Stucki & Jungbluth 2010b). The electricity consumption of the pump is the most important input for the non-renewable cumulative energy demand. Other relevant inputs are the flat plate collector, hot water tank, propylene glycol and the mounting system.

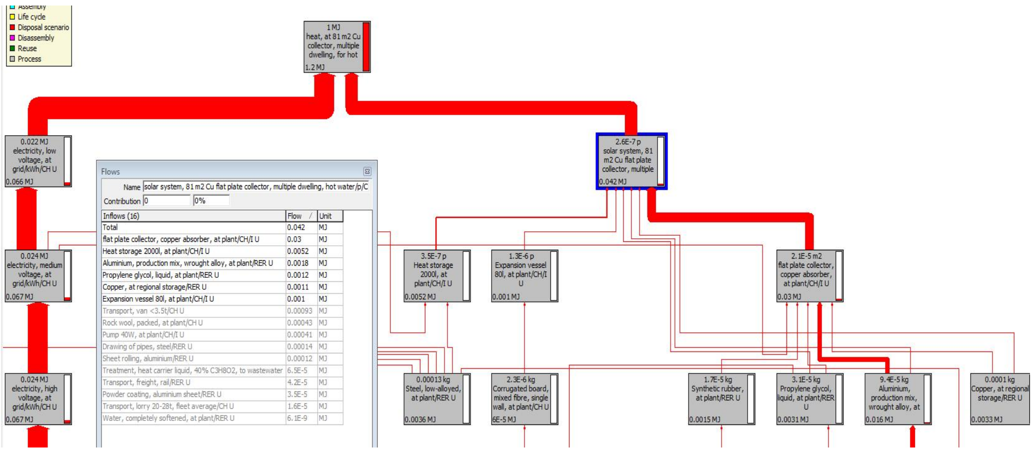


Fig. 2.1 Extract of the process tree of a solar thermal installation evaluated with the non-renewable primary energy demand

## 2.2 Key parameters

The following key parameters are used in the tool. The proposal is based on suggestions made by the customer and an evaluation of the available data (Stucki & Jungbluth 2010a, b):

Output:

- kWh heat per $m^2$ collector and year (collector brut heat yield)
- kWh heat per year in the tank (has to be calculated by the user with Polysun simulation or measurement in the field)

Inputs:

- Estimated life time of the installation (years). The standard assumption is 25 years. For some parts as e.g. the heat carrier medium a shorter life time is already considered in the tool.
- Type (flat plate collectors with copper or aluminium-copper absorbers, flat plate collector with wood frame or evacuated tube collectors) and size of the absorber ($m^2$)
- Total electricity consumption during operation from the Swiss grid and/or photovoltaic electricity in kWh per year (sum of pump, standby, all).
- Total mass of the hot water tank (boiler) and the room heating tank.
- Percentage of the two tanks attributed to solar heating. For instance, with a 50% solar factor index (SFi)[1] and a 50% wood coverage, only 50% of the tank is attributed to solar thermal heating.
- Weight (kg) of the pump
- Amount of heat carrier medium in the system including propylene glycol and water (kg)
- Kilogram of material of the solar pipes from basement to roof (amount of steel and copper pipes, including insulation (EPDM) and coating (polyethylene) according to Stucki & Jungbluth 2010b: 2.22.7)
- Type of the mounting system for absorbers according to Stucki & Jungbluth 2010b: 2.22.6) or direct entry of materials for mounting. The direct entry is normally more accurate.
- Transport distance between suppliers and the installation site (km)
- Annual distance for maintenance and control of the plant (km).

Fig. 2.2 shows the interface for the key parameter model of solar thermal installations. The model is available in French and German.

[1] A SFi of 50% means that solar energy covers 50% of the domestic hot water need.

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**Facteurs d'énergie primaire: Produits énergétiques issus des installations solaires thermiques**

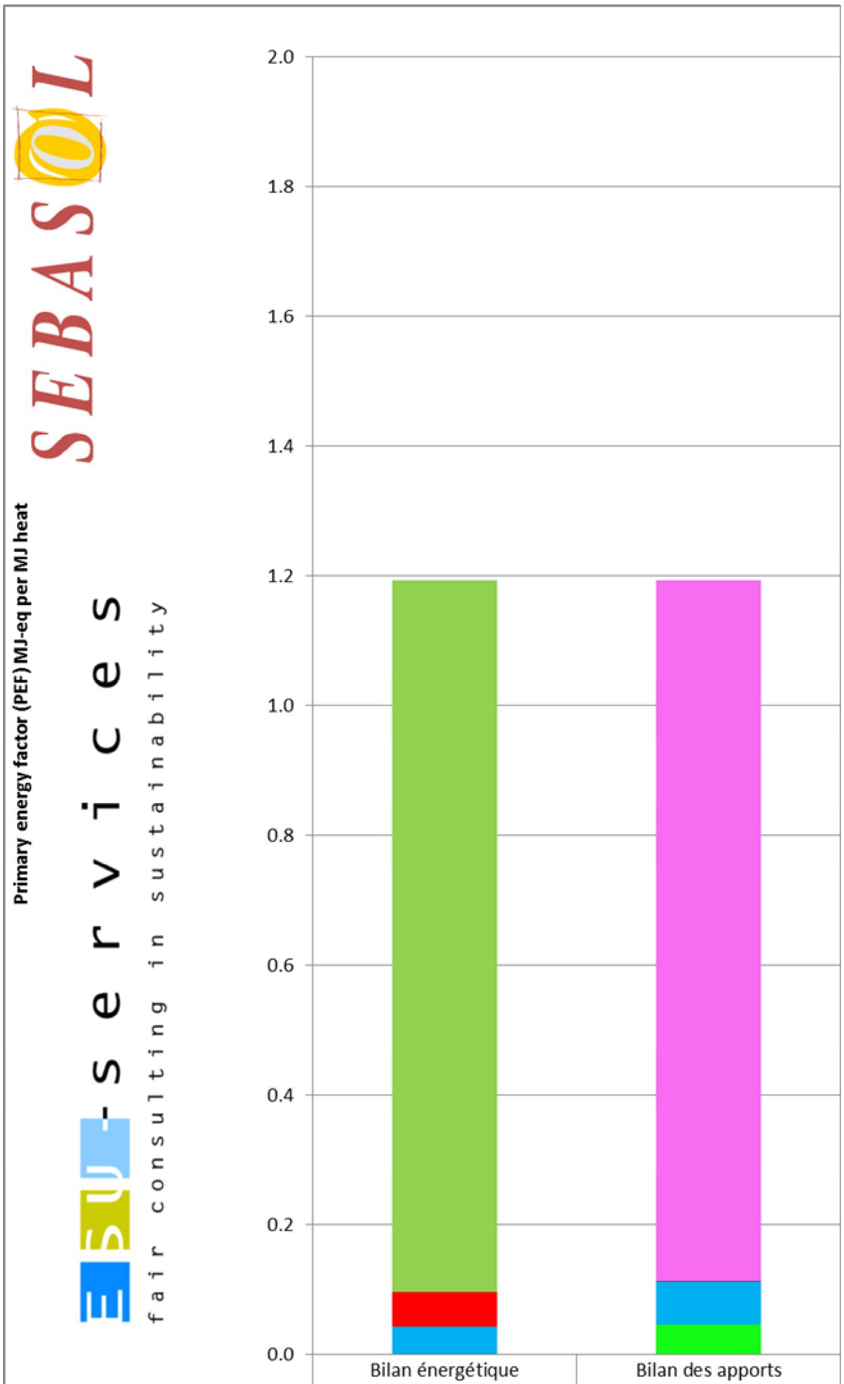
| | | | | |
|---|---|---|---|---|
| **Entrée:** Français | | | | |
| **Nom de l'installation, place de installation et période de référence** | **Flachkollektor, WW, 81 m2** | | **2010** | **Zurich** |
| Durée de vie | 25 Jahre | | | |
| **Entrées** | Poids | Dimensions (surface d'ouverture) | Installation solaire thermique (SFi) | Distance moyenne de transport, installation |
| Capteur (surf. ouvert.) — Capteur plan vitré, absorbeur en cuivre, cadre métal | 1'741.5 kg | 81.0 m2 | | 50 km |
| Chauffe-eau (avec isolation) | 0.0 kg | | 0% | 50 km |
| Accumulateur(s) avec isolation et son/ses vase(s) d'expansion | 550.5 kg | | 100% | 50 km |
| Vase d'expansion solaire | 9.8 kg | 50 l | | 50 km |
| Circulateur(s) et échangeurs à plaques externes | 19.6 kg | | | 50 km |
| Type de construction — Toiture inclinée, intégration (env. 12m2), ferblanterie type montagne, zinc | 162.3 kg | 81.0 m2 | | 50 km |
| Support/ancrages, parties en acier | 0.0 kg | | | 50 km |
| Ferblanterie, tôle en aluminium | 0.0 kg | | | 50 km |
| Ferblanterie, tôle en cuivre | 0.0 kg | | | 50 km |
| Ferblanterie, tôle en acier chromé (uginox, mattplus, inox) | 0.0 kg | | | 50 km |
| Ferblanterie, tôle en zinc-titane | 0.0 kg | | | 50 km |
| Support/ancrages, parties en béton | 0.0 kg | | | 50 km |
| Support/ancrages, parties en bois non traité | 0.0 kg | | | 50 km |
| Tuyauterie circuit solaire (sans absorbeur), acier noir | 0.0 kg | | | 50 km |
| Tuyauterie circuit solaire (sans absorbeurs), cuivre | 127.1 kg | | | 50 km |
| Isolation EPDM, circuit solaire et additionnelle (sauf stocks) | 87.1 kg | | | 50 km |
| Isolation, laine minérale or de verre, circuit solaire et additionnelle (sauf stocks) | 9.6 kg | | | 50 km |
| Protection isolation, aluminium (p.ex coquilles) | 0.2 kg | | | 50 km |
| Protection isolation, polyéthylène (p. ex. feuille grise) | 9.6 kg | | | 50 km |
| Glycol pur pour circuit solaire, sans absorbeurs | 32.5 kg | | | 50 km |
| Poids total de l'installation | **2'749.8 kg** | | | 137 tkm |
| Distance simple pour réparations, entretien annuel | | | | 10 km |
| **Consommation d'électricité de l'installation solaire par an** | **938 kWh** | | | |
| Consommation d'électricité du réseau suisse | 938 kWh | | | |
| Consommation d'électricité photovoltaïque | 0 kWh | | | |
| **Sorties** | | | | |
| Rendement du champ de capteurs (=rendement collecteur X surface d'absorption) | 46'303 kWh | | | |
| Energie solaire nette (après part solaire des pertes réservoir) | 42'843 kWh | 46 COP/JAZ | | |
| Vente de chaleur (incl. pertes distribution) | 42'843 kWh | | | |
| **PEF fossile** | **0.043 MJ** | | | |
| **PEF nucléaire** | **0.054 MJ** | | | |
| PEF renouvelable | 1.097 MJ | | | |
| **Total** | **1.194 MJ** | | | |

Fig. 2.2 Excel™ interface for the key parameter model for solar thermal installations

## 2.3 Presentation of results

The tool calculates the primary energy factors with the same method used in previous publications (Frischknecht et al. 2012; Stucki & Jungbluth 2010a). For all inputs and outputs of the system linked to the key parameters described above (e.g. transports, solar heat) standard assumptions according to Stucki & Jungbluth 2010b) are used. Actual background data are used for further inputs (ecoinvent v2.2, ecoinvent Centre 2010; LC-inventories 2014). The calculation is made with SimaPro 7.3.3 (PRé Consultants 2013). For some components new life cycle inventory data have been investigated for this project. They are documented in a confidential annexe to this report. The model is developed for the situation in Switzerland and all background data are representative for this country. Thus, it cannot be used in other countries.

The primary energy demand is shown in the table of results in the tool (Fig. 2.3). On the left side, the total primary energy demand of the heat provided is differentiated according to the fossil, nuclear and renewable fractions. On the right hand side, the contribution of the different components of the solar collector to the total primary energy demand is illustrated.




| | Bilan énergétique | Bilan des apports |
|---|---|---|
| Total | 1.194 | 1.194 |
| Rayonnement solaire | | 1.081 |
| Transport | | 0.001 |
| Consommation d'électricité | | 0.066 |
| Materiaux | | 0.045 |
| PEF renouvelable | 1.097 | |
| PEF nucléaire | 0.054 | |
| PEF fossile | 0.043 | |

Fig. 2.3 Presentation of results in the key parameter model for solar thermal installations (MJ-eq per MJ of heat provided by the solar thermal installation).

# 3 Validity of comparisons

Figures of CED and PEF of especially energy systems are often compared. Hereby it is important that the actual value and the reference value for the comparison have been calculated with the same methodology and the same life cycle perspective. In this chapter different types of comparisons based on CED and PEF calculated with the tool are discussed.

## 3.1 Direct comparison of primary energy factors

The first possibility is the direct comparison with other heating systems. Standard PEF for heating systems are shown in Tab. 5.5 in the annexe. The following are examples of valid statements:

- The PEF of the solar thermal installation is 1.2 MJ-eq/$MJ_{heat}$, an average Swiss heating has a PEF of 1.3 MJ-eq/$MJ_{heat}$.
- The non-renewable PEF of the solar thermal installation is 0.098 $MJ\text{-}eq_{non\text{-}renewable}/MJ_{heat}$, an oil heating has a non-renewable PEF of 1.3 $MJ\text{-}eq_{non\text{-}renewable}/MJ_{heat}$.
- An air heat pump using the Swiss electricity mix has a non-renewable PEF of 0.9 $MJ\text{-}eq_{non\text{-}renewable}/MJ_{heat}$. Thus, the solar thermal installation consumes only 11% of the non-renewable CED.
- A solar thermal system with a non-renewable PEF of 0.25 uses at least 4 times less energy than a heating system using only fossil and nuclear energy.

It is important to transparently document what the characteristics of the systems under comparison are in order get a correct interpretation of the results. An example is the electricity mix used for heat pumps or the pump in the solar thermal installation.

## 3.2 Sebasol's methodology commented by ESU

For the comparisons of heating process, Sebasol scope is to relate all results to the non-renewable primary energy factor consumptions. Sebasol warranty to it is that non-renewable primary energy must be spared, for thermodynamically and political/ethical reasons (entropy = pollution/disorder produced in the biosphere, and depletion of non-renewable resources for today and future generations).

This drive to a choice of methodology and definition. ESU testify them as one possibility, in the scope Sebasol want to use them. They are

- Assessment: for heating systems, Primary energy factor are defined according to end use heat (defined so in ESU file).
- Assessment : Primary energy factor Total ($PEF_T$) is = Primary energy factor fossil ($PEF_F$) + Primary energy factor nuclear ($PEF_N$) + Primary energy factor renewable ($PEF_R$)
- Assessment : Primary energy factor Non-Renewable ($PEF_{NR}$) is = Primary energy factor fossil ($PEF_F$) + Primary energy factor nuclear ($PEF_N$)

Then

<u>Definition 1</u> : the way to calculate the $PEF_{NR}$ and $PEF_T$ or any other combination of primary energy factor for a mix of two or more heating process, is to do a ponderated mean with the respective coverage of the end use heat. For instance for a house heating WW+RH solar thermal for 40% of the total end use heat in a year & wood logs for the remaining part, $PEF_{NR\ mix} = 0.4^* PEF_{NR\ WW+RH} + (1\text{-}0.4)^* PEF_{NR\ Stückholz}$.

<u>Definition 2</u> : when the solar installation and others systems use common infrastructures, these are allocated 100% to the solar thermal LCA if the others systems could cover the end-use heat without them. Example: with solar thermal and a gas heater on a heating + hot water tank-in-tank system, the

heating part of the tank has to be allocated 100% to the solar thermal, as the gas heater could deliver end-use heat to the heating space without it. The hot water part as to be allocated to both with a repartition key, as the gas heater couldn't deliver end-use heat to hot water without it.

Definition 3: when the solar installation and other system do need a common infrastructure to cover the end-use heat needs, the fraction coverage of these needs through the solar installation ($SF_i$) is used to attribute a $SF_i$ part of the infrastructure to the solar thermal LCA. The remaining parts are allocated to the other systems. For instance, with 70% of hot water needs delivered by the solar installation ($SF_i$ 70%) and so a remaining 30% delivered by the gas, the part of a hot water tank to allocate to solar thermal LCA is 70%.

Definition 4: Two options exist for comparisons:

a) Different energy options are compared directly with the PEF

b) A reference process is defined and all comparisons and calculations must be referenced to it.

Definition 5: let's say $PEF_{NR\ R}$ the $PEF_{NR}$ of the reference process R, and $PEF_{NR\ O}$ the $PEF_{NR}$ of another process O. Then the following assumptions hold

- [$PEF_{NR\ R}$ - $PEF_{NR\ O}$] is the difference of non-renewable primary energy consumption between process O and process R. As a corollary, if positive, $PEF_{NR\ O}$ is sparing [$PEF_{NR\ R}$ - $PEF_{NR\ O}$] MJ of non-renewable primary energy on $PEF_{NR\ R}$ for each MJ of end use heat. If negative, $PEF_{NR\ O}$ is wasting -1*[$PEF_{NR\ R}$ - $PEF_{NR\ O}$] MJ of non-renewable primary energy on $PEF_{NR\ R}$ for each MJ of end use heat. Sparing means that non-renewable primary energy doesn't need to be used, i.e. extracted nor processed.
- [$PEF_{NR\ R}$/ $PEF_{NR\ O}$] measure the relative efficiency of process O according to non-renewable primary energy consumption according to process R. If > 1, it means $PEF_{NR\ O}$ is more efficient of an amount of [$PEF_{NR\ R}$/ $PEF_{NR\ O}$] time more. If < 1, $PEF_{NR\ O}$ is less efficient, i.e. wasting non-renewable primary energy on $PEF_{NR\ R}$. As a corollary, if more efficient, one can say $PEF_{NR\ O}$ is sparing [1- $PEF_{NR\ O}$/ $PEF_{NR\ R}$] % non-renewable primary energy on $PEF_{NR\ R}$ for each MJ of end use heat.

A point: the reference process proposed by ESU is the average heating in Switzerland: 1.3 MJ-eq/MJ according to 3.2. This choice is proposed for comparisons made for the situation in Switzerland.

The model is developed for the situation in Switzerland and cannot be applied in other countries due to differences in the economic structure e.g. supply of electricity or the disposal of materials which is important for the calculation of the PEF. Sebasol aims for a reference for the world on a physical theoretical basis. ESU proposes to stick to the usual Swiss reference but recognise as pertinent the Sebasol goal to try to develop a more general one. Validity of such a new reference would have to be discussed by scientific LCA community.

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