Procedures for Environmental Performance Assessment of Solar Thermal Systems

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Author: Åsa Wahlström

SP Technical Research Institute of Sweden

Reviewers: Jan Erik Nielsen, Elke Streicher and Uwe Trenkner

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SUMMARY

The NEGST group has prepared proposals for rules on how to produce an environmental fact sheet that will make it possible to compare different environmental investigations of solar thermal systems (STS), and to compare the performances of different solar thermal products and heating systems.

The aim of the Environmental Fact Sheet is both objectively to declare a thorough presentation of an inventory of resource use (energy and material), emissions, waste, recycling etc. for the STS product's complete life cycle, and at the same time to provide an immediate, objective and easily understandable overview of the most important assessments of the STS's environmental impact.

The Environmental Fact Sheet therefore consists of the following:

- Rules for performing a life cycle inventory
- Declarations of the STS product
- Annual collector energy output
- Energy yield ratio
- Avoided global warming impact

The Environmental Fact Sheet should be a certified declaration, and may form the basis for future labelling of Solar Thermal Systems. An example of an environmental fact sheet is given in the Appendix.

1. Introduction

This part of the NEGST project is to coordinate, develop and agree on procedures for environmental performance assessment of solar thermal systems (STS). The final objective is to achieve a common European procedure for environmental Life Cycle Assessment (LCA). The procedure is needed, since it has become important to declare the environmental impact of a product in a straightforward, independent and uniform manner. This could be the final argument for convincing decision-makers (house-owners, builders etc.) to invest in solar technology. The purpose with these procedures is to produce a certified environmental product declaration of the STS product based on life cycle assessment (LCA) of the product's total cradle-to-grave environmental impact. With the procedure, it will be possible to rank different systems according to their environmental performance, which is an important base for future environmental labelling of STS.

The pre-normative work towards standards for environmental LCA procedures can be divided into:

- literature survey and information gathering
- exchange of experience and know-how
- agreement on priorities for urgent needs for standards
- working towards a common European approach for standards
- validating assessment methods and procedures
- passing on requests and suggestions for new work areas to CEN Solar Thermal Work Group, TC312.

2. State-of-the-art survey

The work started with a literature survey, coupled with knowledge information collection from all NEGST participants. The collected information has been described in a state-of-art-article /Wahlström05/.

The state-of-the-art survey showed three important aspects. The first is that there are several ways of performing an LCA of STS. The different studies use different assumptions, boundary conditions, functional units, data bases and assessment methods, as well as reference systems (conventional system), all of which make direct comparison between different assessments impossible. There is a need for common procedures for environmental LCAs of STS, and for all hot water and space heating systems.

The second aspect is that an environmental impact description can be expressed in different ways, depending on the objective and scope of the LCA and on which environmental impact that is considered. The literature survey shows that there are two common ways of performing the environmental impact description. The first describes the environmental impact in respect of primary energy use. In this context, primary energy use considers not only the energy input in each life cycle phase, but also how this energy input is produced with the production unit’s efficiency. This means that the LCA considers the kind of energy used in each life cycle phase in order to determine the primary energy use. The second describes the environmental impact in terms of emissions to air. Here, the kind of energy used in each life cycle phase must be considered in order to determine the primary energy use, as well as the specific energy source’s life-cycle emissions. In addition to these two common ways, an environmental impact description may also consider the use of rare materials such as heavy metals, hazardous waste from heavy metals or radioactive deposits.

The third aspect is that energy payback time is commonly used as assessment of the environmental impact.

3. Content and presentation of the Environmental Performance Assessment

Based on discussions and the literature survey, the NEGST group set up the following requirements for the environmental performance assessment of STSs:

- the content should provide an immediate, objective and easily understandable overview of the most important assessments of the STS's environmental impact
- with the results it should be relatively easy to make an environmental assessment between:
    - different solar thermal products
    - different heating systems
- the environmental assessment should include two parts:
    - a declaration of the impact from the STS unit, based on life cycle assessment
    - an assessment of the environmental impact from the STS unit
- procedures should include specific rules on how to perform the life cycle assessment of the STS in order to ensure that it will be made in the same way, regardless of whether it is performed by different persons or in different European countries
- the procedures should include specific rules on how to perform the environmental assessment of the STS in order to ensure that it will be made in the same way, regardless of whether it is performed by different persons or in different European countries
- the material used in the STS unit should be clearly declared in order to show the base input for the environmental assessment and also to assist other environmental assessments
- waste should also be declared in order to show the amount of hazardous waste left, and to assist investigation of ways in which materials could be reused
- only the most important environmental aspects should be considered, in order not unnecessarily to confuse the user of the assessment. This means that only global warming should be considered, while ozone depletion, acidification, eutrophication, photochemical ozone formation, fine particles and toxic substances are not considered.
- the STS unit's impact on the environment should be clearly declared in forms of:
    - primary energy use (resource use)
    - emissions to air (effect on global warming etc.)
- the STS unit's impact on the environment should be assessed in respect of
    - primary energy use (resource use)
    - emissions to air (effect on global warming etc.)
- specifications of the STS unit's energy performance will be needed in addition to the environmental assessment, in order to make comparisons between systems
- rules should be created on how the results from the environmental performance assessment should be presented.

The content should provide an immediate, objective and easily understandable overview of the most important assessments of the STS's environmental impact. Since STS systems are mostly added as complementary installations, without replacement of a conventional system, it is important to consider the STS's embodied energy. One way of doing that is to calculate the energy payback time, which describes how long time it takes for the STS unit to produce the same amount of energy as needed during production, maintenance and final disposal/recycling of the STS unit. The reason for using energy payback time is because it is easy to understand and to communicate, and because it is already commonly used.

Several investigations during the last decade have shown that the energy payback times for different solar thermal systems are between 1 and 4.3 years /Wahlström05/. Solar thermal systems for domestic hot water preparation have typical energy paybacks time between 1.3 and 2.3 years, while those for combined hot water and space heating preparation have energy payback times of between 2.0 to 4.3 years /Streicher, Drück07/. This indicates that STS are a good environmental alternative compared with conventional systems, even though the system may be added as a complement to an existing installation. When comparing different STS units, it is important to remember that small differences in real energy payback times are not important. The importance is that the STS unit has a low payback time.

However, an assessment of energy payback time alone could give a wrong evaluation, as shown in Figure 1. Unit B will have a slighter longer energy payback time than unit A, even though the energy gain after two years would be higher for unit B. Therefore the energy payback time needs to be used together with other aspects, such as lifetime of the STS unit and/or annual energy output from the STS unit.

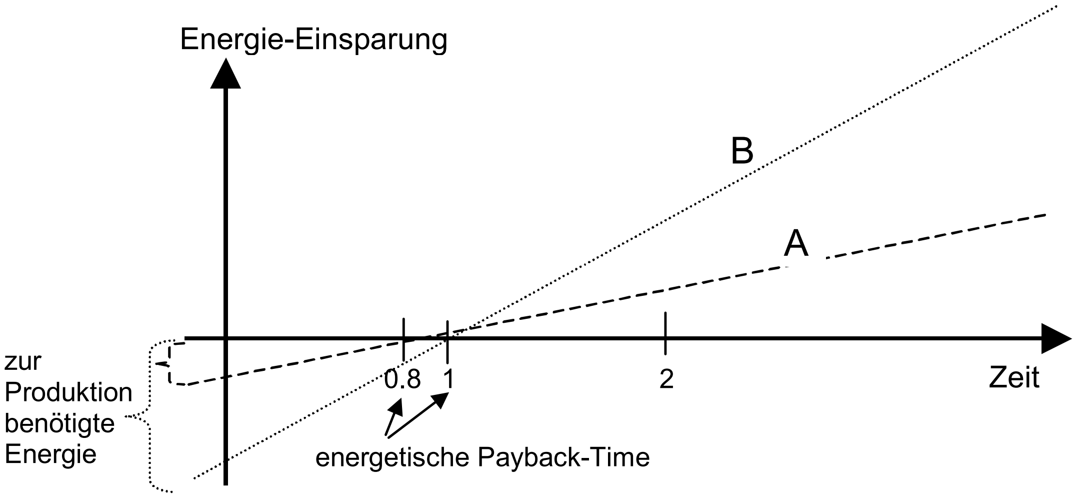

Figure 1: Illustration of two STS systems with small and similar energy payback times /Haller,Vogelsanger05/.

One way of doing this is to use the Energy Yield Ratio (EYR), which describes how many times the invested energy is returned. With this approach, an STS unit with a relatively high energy payback time but with a long lifetime will be evaluated as better than a unit with a low energy payback time and a short lifetime. This expression has previously been used by /White, Kulcinski00/ as *energy payback ratio* for environmental assessment of coal, fission, wind and DT-fusion electric power plants. More recently, it has also been used (and given the name of EYR) by /Wagner, Pick04/ in order to assess wind energy converters, and by /Richards, Watt07/ to assess photovoltaic performance. This last was done in order to kill the myth that photovoltaic production does not pay back the energy used to make the cells. With EYR, the primary energy use can be assessed.

The EYR and primary energy represent the environmental impact in terms of use of natural resources, while emissions to air represent the environmental impact in terms of different effects, such as global warming: see Figure 2. Disposal of waste may also be an important environmental impact factor, as may reuse of material from the STS in connection with disposal/recycling, and should be indicated in the Environmental Fact Sheet.

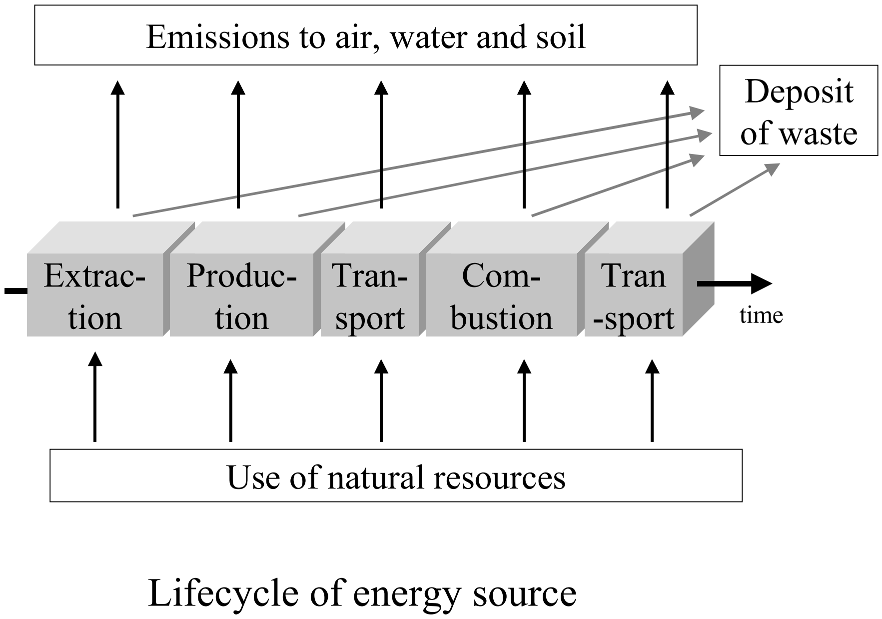

Figure 2: *Illustration of the environmental impact during the energy source's life cycle /Wahlström03/.*

In order to assess the STS's effect on the environment, it is <u>not</u> enough to consider the impact from emissions during construction, maintenance, operation and disposal/recycling of the unit itself. A very important contribution is that of the avoided impact on the environment resulting from the use of an STS instead of a conventional system. In this work, we have limited consideration of the impact of emissions to one environmental effect (global warming), since this will provide an objective evaluation without complications in the form of subjective assessments between different environmental effects. Emissions of global warming gases shall be accounted as the summary of Global Warming Potential (GWP), i.e. as CO_2-equivalents over 100 years of perspective. Characterization factors that represent each gas impact on GWP can be found in /MSR00/ and with the most common global warming gases in energy applications the calculations can be performed according to:

$$CO_2 \cdot 1 + N_2O \cdot 310 + CH_4 \cdot 21 \text{ (g } CO_2\text{-equivalents)}$$

where the gases are in gram.

An assessment that includes the benefit of avoided global warming (i.e. from replacement of a conventional system) together with EYR and annual energy output will give a more complete picture of the total environmental impact. EYR tells us that the STS is environmentally beneficial, even though it is a complementary system. Avoided global warming gives a picture of its contribution to reduce the environmental impact, while the annual energy output gives the energy gain from the system.

4. Environmental Fact Sheet

Based on the discussion, it was decided that rules for an Environmental Fact Sheet should be established with the following aspects:

- Rules for performing a life cycle inventory
- Declarations of the STS product
- Annual collector energy output
- Energy yield ratio
- Avoided global warming impact

The established rules should be passed on to CEN/TC312, and the final purpose with the Environmental Fact Sheet is that it should be a certified environmental product declaration of the STS product. The Environmental Fact Sheet may be the basis for future labelling of Solar Thermal Systems.

4.1 Rules for performing the life cycle inventories

The rules are needed in order to allow comparison of LCIs of different products within the same group, even though they may have been performed by different persons or in different countries. An LCI is a quantitative description of a product's environmental characteristic, but without assessment. The objectives of the rules are to achieve:

- *Credibility*: ensuring transparent, independent and competent control of data.
- *Relevance*: ensuring that the main environmental aspects have been analysed.
- *Comparability*: allowing the user to compare different products on the basis of their environmental impacts.

The ISO 14040 – ISO 14043 standards (/ISO 14040 -14043/) should be followed when performing the LCI. The rules define primarily how to consider the following criteria within the life cycle inventory:

- Functional unit
- System boundary conditions and assumptions
- Data bases of primary energy and emissions for different materials and energy sources

4.1.1 *Functional unit*

The functional unit is the reference unit, expressed as the quantified performance of the system. The choice of functional unit will influence the environmental assessment when LCIs of different products are compared. Three different kinds of functional units could be considered: entire equipment, collector area and energy output.

To refer to the environmental impact from an STS with the *entire equipment* as the functional unit has advantages for environmental performance declarations of the product and when comparing two similar STS units. However, the disadvantage is that a comparison with conventional systems will be complicated. This has previously been used by /Ardante et al.03/. To choose *collector area* as the functional unit could be misleading, since there is no correlation between two different system collector areas and their energy output. Two systems with the same total environmental impact and energy output could very well have different collector areas. Furthermore, there is no linear relationship between collector surface area and collected energy quantity, and increasing the collector area does not necessarily deliver more energy output.

Energy output as the functional unit has benefits when comparing the LCI for an STS with another LCI for a conventional system: for example, as kWh of output heat, as used by /Nielsen et al.99/ and /Sköld, Olsson01/. Solar thermal systems are, however, often added as complementary installations, and the assessment might not require a comparison with the conventional system's complete LCI, but only with the energy source's LCI. It is also difficult directly to apply this procedure to a specific STS, since the energy output depends on the solar energy input and may be completely different for the same system in a different location.

Since the Environmental Fact Sheet will be an environmental performance declaration of a STS unit, the *entire equipment* has been chosen as the functional unit. However, comparisons with other systems will be possible, since the Environmental Fact Sheet also will include annual collector energy output and therefore it will be possible to calculate environmental performance for energy output. Furthermore, the Environmental Fact Sheet will include a declaration of materials etc. so that it will be possible to perform other analyses as well.

4.1.2 *System boundary conditions and assumptions*

System boundary conditions and assumptions must be clearly defined for an independently performed LCI, and the following rules are suggested. The primary energy use embodied in the STS unit and the corresponding emissions should include production, maintenance and disposal/recycling of the STS unit. The production stage includes materials, transport of the STS unit to the installation site, assembly and installation.

The material includes each component of the STS; collectors, mounting frame, heat store, circulation pumps,and piping. The piping can differ, depending on where the STS is to be installed, and therefore an assumption is that according to /EN 12976-1, 2/ the collector is connected to an overall length of 20 m of piping (material: copper) with an outer diameter of 15 mm and a thickness of 1 mm. The insulation of the piping can be considered to be synthetic elastomer rubber, with a thickness of 20 mm and an average density of 80 kg/m^3 /Streicher, Drück07/.

Since transport of the STS from the manufacturer to the place of installation may differ, depending on where the STS is to be installed, the following assumption may be used:

- a distance of 300 km from the manufacturer to the wholesale dealer, by heavy goods vehicle
- a distance of 100 km from the wholesale dealer to the place of installation, by van

The environmental impact of transportation is directly linked to the total weight of the STS including packaging. If the weight of packaging is unknown, an assumed value of 10 % of the STS weight is taken /Streicher, Drück07/.

No general data base is available for the impact of assembly and installation, and so this is assumed to amount to 10 % of the sum of impact from material and transport /Streicher, Drück07/.

Maintenance of STSs consists mainly of general checking tasks such as checking the antifreeze concentration of the heat transfer fluid, the leak tightness, the pressure of the expansion vessel, the operating pressure etc. Replacement of certain components is seldom necessary. Since these tasks involve mainly labour costs, the assumption for the environmental impact is restricted to driving 30 km by car (one way) once a year //Streicher, Drück07/.

Disposal/recycling consists mainly of transport to waste or recycling stations, followed mainly by a labour input. This is therefore assumed to amount to 100 km of van transport and the environmental impact corresponding to the weight of the STS. However, by considering recycling of system materials, the considered environmental impact can be significantly reduced, as shown by /Ferrão, Lage01/. This implication is in accordance with that described by /Cellura et al. 05/, which adds the “feedstock” energy to the embodied energy of materials. The feedstock energy quantifies the potential of materials (such as wood or plastic) for delivering energy when they are burned with heat recovery after their useful life. This energy can theoretically be recovered by waste burning or recycling. The STS may be credited with half the impact from recycled materials or energy recovered by heat recovery at from waste incineration.

Other credits that can be considered are for the hot water tank and the in-roof mounting. Since the hot water tank of the conventional (non-solar) heating system is replaced by the STS’s tank, the environmental impact may be credited with the impact from a 135 litres tank of unalloyed steel of 86 kg and 4 kg of polyurethane insulation /Streicher, Drück07/. If the collector is integrated into the roof, a large number of roof tiles are saved. An approach can be made that the environmental impact may be credited with that of an average roof tile with a weight of 3.4 kg, of which 14.8 are needed per m^2 roof area. The average transport of roof tiles is 400 km by heavy goods vehicle.

/Streicher, Drück07/ also suggest how to calculate credits for solar combi-systems with integrated burners.

4.1.3 *Data bases*

Data bases of primary energy and emissions for different materials and energy sources are important for the results of the LCI. The cumulative energy demand and emissions to air include all phases of production of the materials, including extraction, mining of raw materials, semi-manufactured products and the production process itself.

Input data are needed from a reliable, transparent and representative data base. Several European organisations are dealing with collection and provision of this LCI data for different materials and energy sources. However, the values in the different data bases may differ, and it is important to specify a few, or preferably one, third-party data base that should be used for the LCI in the Environmental Fact Sheet.

One example of a data base that is structured, free to use and independent is the Commission’s ELCD (European Reference Life Cycle Data System) with LCI data sets /ELCD07/. This data base is continuously developed, with more LCI information constantly being added.

Another data base is the “ecoinvent 2000”, that includes many solar-specific data sets /Ecoinvent07/. It has been developed by the Swiss Centre of Life Cycle Inventories, with the aim of harmonisation of different data bases, and includes more than 3500 data sets for products, services and processes. All data are based on market and consumption situations in the year 2000, and are valid for Swiss and western European conditions. The data sets are regularly updated. This data base has the advantage that nearly all data sets that are necessary for balancing STSs are included, which means that no other data base is needed /Streicher, Drück07/.

Another option is to use a recommended data base and, in parallel with it, to create a small data base in an Annex to the Environmental Fact Sheet, with the most common materials used in STSs, and with only primary energies and emissions considered in the Environmental Fact Sheet.

4.2 Declarations of the STS product

The results from the LCI should be declared in the Environmental Fact Sheet. Information needed to calculate EYR or avoided global warming impact should be normative, while it should also be possible to add other information that may be used for other environmental assessments. The declaration includes the following information:

- Material used in the STS unit (*normative*)
- Wastes
  - Dangerous wastes
  - Material resources suitable for recycling or burning with heat recovery
  - Other wastes
- Energy needed for production, disposal/recycling and maintenance of the STS unit
  - Primary energy use (*normative*)
  - Renewable, non-renewable and electricity
- Emissions during production, disposal/recycling and maintenance of the STS unit
  - Global warming gases (*normative*)

4.3 Annual collector energy output

The most important function of a solar collector is its energy performance, i.e. the energy output during one year. In an environmental assessment, the impact must be evaluated in relation to the gain of energy output. However, the energy output will be dependent on where the solar collector is installed and used in practice, i.e. the outdoor climate, the tilt angle and the collector mean temperature. Furthermore, the energy output might differ depending on different calculation procedures. A standardised procedure for calculation of the annual collector energy output based on the performance parameters resulting from efficiency tests according to /EN 12975 -1 2/and reference climates is now under development /Wahlström et al.07/ and is meant to be an informative annex to /EN 12975 -1, 2/ in the future. The main aim is to facilitate performance comparisons for potential buyers, and these future procedures are meant to be used for the Environmental Fact Sheet.

4.4 Energy yield ratio

Energy Yield Ratio (EYR) describes how many times the energy invested is returned. A real energy yield ratio considers the energy saved by the solar system as equal to the primary energy that would have been used for tap water or space heating by a conventional system, reduced by the amount of operational energy, while the energy invested is the STS's embodied energy:

$$EYR = \frac{\left(\frac{E_{delivered}}{\eta_{conventional}} - E_{operation}\right) \cdot Lifetime_{STS}}{Embodied\ Energy_{STS}}$$

where:

EYR = Real energy yield ratio (times),

$E_{delivered}$ = Energy delivered for tap water or space heating by the STS (annual energy output) (kWh/year),

$E_{operation}$ = Operational energy needed by the STS (mainly the circulation pump) (kWh/year)

$\eta_{conventional}$ = efficiency of the conventional system that the STS is replacing

$Lifetime_{STS}$ = The lifetime of the STS unit; often 10 – 30 years,

$Embodied\ Energy_{STS}$ = Primary energy incorporated (for production, disposal/recycling and maintenance) in the STS during its complete life cycle (kWh).

Energy output or energy delivered from the STS is highly dependent on the solar radiation input as mentioned above, and thus dependent on where the STS is installed. This requires a definition of the climate, which will be defined within the rules that will be developed for calculating annual energy collector output. The advantage with expressing the environmental performance of the STS in terms of simple EYR is that it is independent of the type of conventional system that the renewable system replaces. A real EYR is more correct, but requires information on the application of the STS. To use real EYR in a common procedure therefore requires a definition of a reference system. In addition, lifetime is an important factor in the EYR and needs specification of how it should be estimated. The EYR is independent of the functional unit.

In order to be able to compare real EYR directly between different investigations, the Environmental Fact Sheet will give rules for definition of:

- A reference system (the conventional system that the STS is replacing)
- Climate application of the STS
- Lifetime of the STS

The reference systems have been chosen as a boiler with an efficiency of 85 %. The climate application follows the rules for annual collector energy output, with specifications for Athens, Davos, Stockholm and/or Wurtsburg. The annual collector energy output used is for 25 ºC collector inlet temperature and a tilt angle of 45 degrees. The lifetime of the STS is simply how many years the STS unit works without deterioration of its performance, with the maximum lifetime to be considered being 20 years.

4.5 Avoided global warming impact

The actual avoided emissions provide another way of describing the environmental impact, instead of using the payback time. This analysis is done by comparing the emissions caused by the STS with the emissions caused by the conventional (replaced) system over a defined period of time (for example, the lifetime of the STS).

In general, assessment of life cycle inventories may be performed with several assessment methods intended for different purposes that have been developed during the last decade. They weigh different environmental effects and resource consumption into one or a few figures. The weighting factors could be based on societal aspects, resource availability etc., and are decided with limited scientific background. In order to arrive at a scientific evaluation, only global warming is considered. Avoided global warming can be calculated from:

$$CO_{2,avoided} = (CO_{2,conventional} \cdot \frac{E_{delivered}}{\eta_{conventional}} - E_{operation} \cdot CO_{2,operation}) \cdot Lifetime_{STS} - Embodied\ CO_{2,STS}$$

where:

$CO_{2,\ avoided}$ = emissions avoided by the STS by replacing a conventional system (CO_2 equivalents),

$CO_{2,\ conventional}$ = annual emissions per kWh of the conventional system that the STS is replacing (CO_2 equivalents/(year, kWh)),

$CO_{2,\ operation}$ = annual emissions released due to use of operational energy in the STS (CO_2 equivalents /year),

Embodied $CO_{2,STS}$ = CO_2 emissions during the complete life cycle of the STS (production, maintenance and disposal/recycling) (CO_2-equivalents).

In order to be able to compare avoided global warming impact directly between different investigations, the Environmental Fact Sheet will give rules for definition of:

- A reference system (the conventional system that the STS is replacing)
- Climate application of the STS
- Lifetime of the STS

The climate applications and lifetime consideration are the same as for calculating the EYR. Also the reference system has the same efficiency (85%) and is using natural gas as energy source. Besides the defined reference system the avoided global warming also may be calculated for another reference system that is common for the area around the chosen climate application (Athens, Davos, Stockholm and/or Wurtsburg).

5. Conclusions and further work

Rules have been established within the NEGST group for producing an environmental fact sheet for solar thermal systems (STS). The purpose of the Environmental Fact Sheet is that it should be possible to compare, on equal bases, different environmental investigations of STSs and other heating systems. The procedure aims to declare the environmental impact of a product in a straightforward, independent and uniform manner. The Environmental Fact Sheet has therefore been structured so that it objectively will declare:

- a thorough presentation of the results from the STS's life cycle inventory with use of resources such as energy and materials, emissions, waste and recycling etc,

- the energy delivered by the STS in terms of annual collector energy output,

- an immediate, objective and easily understandable overview of the most important assessments of the STS's environmental impact. For this purpose, energy yield ratio and avoided global warming have been chosen as bases for environmental assessment.

Energy yield ratio has the benefit of illustrating the environmental impact of use of resources, while avoided global warming demonstrates the impact of global warming. Both assessments are important in order to show the STS's environmental benefits.

The annual energy output and assessment of the environmental impact is specific for each climate application (Athens, Davos, Stockholm and/or Wurtsburg). For covering all Europe four Environmental Fact sheets are needed for each STS.

Rules for performing the life cycle inventory have also been established, with a functional unit, suggestion for data bases, system boundaries and assumptions. The work is now ready to be passed on as requests and suggestions for new work areas to CEN Solar Thermal Work Group (TC312), and finally for standardisation on how to make an Environmental Fact Sheet. The standard procedures will be an important base for future ranking of different STSs in terms of their "environmental performance" and for environmental labelling of STSs.

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	Environmental Fact Sheet for Solar Thermal Systems	Certification No: *Example*

Manufacturer: **Address:** **Telephone:**	**Brand Name:**	**Type of STS:**	**Certification performed by**: Organisation: Address: Telephone:

The life cycle environmental assessment is performed according to the NEGST's rules.
Reference:

Results from Life Cycle Inventory
Environmental product declaration of the STS unit

Material used in the STS unit

Material (*normative*)	Amount (kg)
Glass	
Cupper	
Aluminium	
Chrome	
Plastic	
Steel	
Iron	
Etc……..	
Etc………..	

Waste	Amount (kg)
Dangerous waste	
Material resources to recycling or burned with heat recovery	
Other waste	
Total waste	

Emissions and amount of energy as needed during production, maintenance and final disposal/recycling

Global warming gases (*normative*)	CO_2-equivalents

Primary energy use	Amount (kWh)
Renewable	
non-renewable	
electricity	
Total primary energy use (embodied energy) (*normative*)	

Annual collector energy output (*normative*) (kWh/m^2, year)

Tilt angel (degrees)	Collector inlet temperature 25 ºC	50 ºC	75 ºC
0			
30			
45			
60			
90			

Values above are given for the location:
Athens, Davos, Stockholm or Wurtsburg

Environmental Life Cycle Assessment of the STS unit

Reference system		**STS unit** (*normative*)		
Climate application	*Athens, Davos, Stockholm or Wurtsburg*	Lifetime of the STS		Years
Replaced system	*Natural gas boiler*	Energy Yield Ratio (EYR)		Times
Efficiency	*85 %*	Avoided global warming impact		CO_2-Equivalents

Reference system		**STS unit**		
Replaced system		Energy Yield Ratio (EYR)		Times
Efficiency		Avoided global warming impact		CO_2-Equivalents

Date:	Signed by: