Solar Power and Chemical Energy Systems
IEA Technology Collaboration Programme

SolarPACES Guideline for Bankable STE Yield Assessment

Appendix T - Terminology

Version 2017

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T. Appendix Terminology

This document provides a compilation of top level terms needed for yield analysis. Most of the terms have been defined in order to be applicable for all STE technologies.

T.1. General aspects

T.1.1. General symbol structure

A general structure for the use of mathematical symbols is introduced. The structure is used throughout the document.

$A^{\mathrm{D}}_{\mathrm{B,C}}$	A	Elementary symbol indicating the physical property (length, power, temperature, …) that also defines the unit. Usually typed in italic style since it represents a variable.
	B	Main identifier to distinguish between different applications of the elementary symbol (e.g. distinguish different angles, distinguish between thermal and electrical) Usually typed in roman style since it is an identifier.
	C	Extension further specifying the main identifier. A number of pre-defined indices are defined. These should be located at position C: - "0" rated conditions - "max" maximum value (e.g. storage maximum charge mass flow) - "min" minimum value - "set" setpoint value - "grad" gradient e.g. "grad,max" indicates maximum tolerated gradient Usually typed in roman style since it is an identifier.
	D	Location in sub-system (SF … Solar field, TES … Thermal Storage). The index D should be used with all variables that represent interfaces between sub-systems and for variables that are used for reporting of results. Variables that describe the performance of the system as a whole, like the gross electricity production, do not have an sub-system identifier although they also belong to sub-system PB. The identifier for the sub-system should always be given as long as there are strong reasons for neglecting the index (strong reasons would be a unnecessarily complex notation when there is no doubt on its meaning). Usually typed in roman style since it is an identifier. For describing transient effects identifier D can be used to describe the time step. The time step is identified by the time t. Reference to the last time step is done by t-Δt. The time step index is added separated by a comma in position D to any other index.

T.1.2. Units

The guidelines are based on the SI units wherever possible. For consistence in equation formulation the basic units (e.g. W) are given in the nomenclature although in reports more convenient SI prefixes might be used (e.g. k for kilo or M for Mega). Instead of using the derived SI unit J for energy we suggest to use Wh since this allows easy cross-checking with power in W and time intervals in h. With the same intention we use bar instead of Pa. The units given here should be used as preferred units in reports. All units are typed in roman style and are separated by a blank from the value This rule also holds for "%" and "°C".

T.1.3. Instantaneous versus time averaged values

In order to clearly mark a certain variable as"time averaged" a bar over the symbol is used. Thus, η indicates an instantaneous efficiency whereas $\bar{\eta}$ describes an efficiency value which is averaged over a certain time interval. Since we assume for yield analysis a temporal discretization into time steps the values during one time step are usually assumed as constant and the notation as instantaneous value is used. A time averaged value is usually used when the value is obtained by an averaging procedure over several time steps, in STE yield analysis typically one year.

T.1.4. References to existing standards

Existing international standards are used wherever possible. Important references considered are:

- ISO 80000-x Quantities and units
  - ISO 80000-1: General
  - ISO 80000-2: Mathematical signs and symbols to be used in the natural sciences and technology
  - ISO 80000-3: Space and time
  - ISO 80000-4: Mechanics
  - ISO 80000-5: Thermodynamics
  - ISO 80000-7: Light
- ISO 9488 Solar energy – Vocabulary
- ISO 12975 Thermal solar systems and components – Solar collectors (for completeness, not used in this document)
  - ISO 12975-1: General requirements
  - ISO 12975-2: Test methods
- UNE 206009 Solar thermal electric plants – Terminology
  (Spanish standard issued in 2013, used as a draft in the IEC-TC 117 standardization commitee)

ASTM E 722-11 Standard terminology of solar energy conversion has not been taken into consideration in the definition of terms so far.

T.2. Abbreviations

The following abbreviations are used within this terminology. An abbreviation rule is introduced that makes reading of indices more intuitive:

- The index is given in lowercase letters if it is the abbreviation for one word (e.g. “soil” for soiling, “opt” for optical,…).
- The index is given in capital letters if it is an abbreviation for more than one word (e.g. “SF” for solar field, “BL” for base load).

Abbreviations	
A	Azimuth
abs	Absorbed, absorber
AF	Anti-freeze
AH	Auxilliary heater
amb	Ambient
AST	Apparent solar time
aux	Auxillary
avail	Available
b	Beam radiation
BL	Base load
ch	Charging
clean	Cleanliness
cloud	Cloud passage
conc	Concentrator
cool	Cooling
CSP	Concentrating solar thermal power
d	Diffuse radiation
dis	Discharging
defoc	Defocussing
end	End loss
EOH	Equivalent operating hours
EoT	Equation of time
EPC	Engineering, procurement and construction company
equ	Equipment
extract	(To) extraction
foc	Focusing
g	Global radiation
head	Header pipes
HR	Heat rejection
HT	Heat tracing

HTF	Heat transfer fluid (fluid that is used to transfer thermal energy between sub-systems)
i	Incidence
IAM	Incidence angle modifier
in	Inlet
inertia	Thermal inertia
inter	Intercepted
IPP	Independent power producer
lat	Latitudinal
LF	Linear Fresnel collector
lim	Limitation
long	Longitudinal
max	Maximum
min	Minimum
MS	Molten salt
MST	Mean solar time
N	Normal (geometry), in direction of normal vector
nom	Nominal value, also denoted as “0” when refered to time variying values
off	Offline
OLT	Official local time
on	Online
opt	Optical
out	Outlet
over	Overhaul
Pxy	Value that has a xy% probability of exceedance
PB	Power block
pipe	Piping
proj	Projected
PT	Parabolic trough collector
pumps	Pumping
rec	Receiver
set	Setpoint value
SF	Solar field
SLT	Standard local time
SM	Solar multiple
SOC	State of charge
SS	Substation
ST	Solar Time
STE	Solar thermal electricity
startup	Start-up

steady	Steady-state
TES	Thermal energy storage
TF	Transformer
theo	Theoretical
TM	Transmission
tr	Transversal
track	Tracking
UTC	Coordinated Universal Time
var	variable consumption
WB	related to wet bulb temperature
Z	Zenith

T.3. Elementary symbols

The following symbols are elementary symbols for physical quanties.

T.3.1. Small letters

Name	Symbol	Unit	Description
diameter	d	m	
dynamic viscosity	η	kg/ms	
efficiency (instantaneous value) efficiency (averaged value)	η $\bar{\eta}$	-	Ratio of output to input quantity for a given system usually expressed in terms of power. bar over the symbol indicates an averaged value, usually averaged over a number of time steps.
state of a system (e.g. focus state/track fraction)	f	-	In comparison to the efficiency the states of the system are actively influenced by the plant control.
specific enthalpy	h	kJ/kg	
counter	i	-	For time steps, elements, …
mass	m	kg	
mass flow	$\dot{m}$	kg/s	
expected value (statistics)	μ	application dependent	
kinematic viscosity	ν	m^2/s	
pressure	p	bar	Pressure difference indicated as Δp
specific electric power	p	W/m	Used e.g. for trace heating
specific heat flow	q	W/m, W/m^2	Unit depending on reference

calorific value of fuel [1]	*q*	kJ/kg	also called „heating value“
specific entropy	*s*	kJ/kg	
wall thickness [2]	*s*	m	
variability (of mean values or sums)	*s*	application dependent	Standard deviation of the inter-annual variability. Expressed as W/m^2, kWh/m^2a
standard deviation	σ	application dependent	
time	*t*	h	The variable *t* is also used to indicate a certain time step. According to the definitions in meteo data files time stamp t indicates the time at the end of the respective time step. If a continuous time variable is needed e.g. in time integration formulas, it is recommended to use t* for a continuous time variable whereas t denotes a specific time instant.
time step	Δt	s, h	Depending on the context, both s and h can be used.
specific internal energy	*u*	kJ/kg	
uncertainty	*u*	case specifiv	Uncertainty of any quantity
speed [3]	*v*	m/s	
cartesian coordinates [4]	*x, y, z*	m	

[1] Note: ISO 1928:2009 defines the net caloric value with symbol q_{net}

[2] Note: ISO 80000-3 defines „s“ as distance and „ρ“ as radial distance. Both symbols are used for other variables in our context. We use “s” since spec. entropy is usually not used together with wall thickness but density is.

[3] Note: ISO 80000-3 defines v as vector of speed but also as the magnitude of this vector. Thus, v should be used for speed. Velocity vector components are not explicitly defined since they are usually not used in annual yield calculations.

[4] ISO 80000-3 3-1.10 clearly defines x, y, z as Cartesian coordinates.

T.3.2. Capital letters

Name	Symbol	Unit	Description
Area	A	m^2	Quantity of a two-dimensional surface. Reference: [ISO 80000-3 3-3]
Irradiance	G	W/m^2	Power density of radiation incident on a surface, i.e. the quotient of the radiant flux incident on the surface and the area of that surface, or the rate at which radiant energy is incident on a surface, per unit area of that surface. Reference: [ISO 9488-3.4]
Irradiation	H	Wh/m^2	Incident energy per unit area of a surface, found by integration of irradiance over a specified time interval, often an hour, a day, or a year Reference: [ISO 9488-3.5]
Level	L	-	Ratio of a quantity between a present and design condition, e.g. storage level.
Electric power[5]	P	W	The electric power represents an instantaneous or averaged value over a certain time period. Reference: [ISO 80000-4 4-26]
Electric energy	E	Wh	The electric energy is the integral of the power over a time period. Reference: [ISO 80000-5 5-20.1]
Thermal power[6] (instantaneous value)	$\dot{Q}$	W	The heat flow represents an instantaneous or averaged value over a short time period. It includes heat flow by conduction, convection, radiation. Thermal power is often called heat flow.
Thermal Energy (integral value)	Q	Wh	The heat is the integral of the heat flow over a time period. Reference: [ISO 80000-5 5-6]
Thermodynamic temperature [7]	T	K	The thermodynamic temperature measured in Kelvin (K) is the primary temperature scale to be used. All equations should use this temperature scale in order to avoid possible confusion. Temperature differences are always expressed with the unit K. Reference: [ISO 80000-5 5-1.a]
Celsius temperature	ϑ	°C	The Celsius temperature scale should not be used in equations but can be provided in addition to the Kelvin temperature in yield analysis reports. Reference: [ISO 80000-5 5-1.b]

[5] The symbol P and E is introduced to distinguish between heat and electric power / power flows. This is useful to avoid confusions since both forms of energy are used in yield analysis.

[6] [ISO 80000-5 5-7] defines symbol Φ. Nevertheless, $\dot{Q}$ is widely used in thermodynamics.

[7] A single temperature scale is chosen to avoid any possible confusion. The Kelvin scale is understandable world-wide and the standard in the scientific world.

T.4. Sun position, sun angles, irradiance and ambient conditions

T.4.1. Position on earth and time frames

Name	Symb.	Unit	Description	Zero	Range
Latitude	φ	°	Minimum distance, measured in degrees, from a site on the Earth's surface to the Equator. Positive on the northern hemisphere, negative on the southern hemisphere. Reference: [ISO 6709-6.4b]	Equator	+/- 90°
Longitude	λ	°	Distance measured in degrees between the Meridian of a site and the Greenwich Meridian. Positive East of Greenwich. Reference: [ISO 6709-6.4c]	Greenwich meridian	+/-180°
Elevation [8] (of a site)	H	m	Geometric height of a site (above sea level) Reference: [ISO 80000-3 3-1.3]		
Time zone longitude	λ_{ST}	°	Distance measured in degrees between the time zone meridian of a site and the Greenwich Meridian. Positive East of Greenwich.	Greenwich meridian	+/- 180°
Declination	δ	°	Angle subtended between the Earth–sun line and the plane of the equator (north positive). Note: The solar declination is zero on equinox dates, varying between +23,45° (June 22) and –23,45° (December 22). Reference: [ISO 9488-2.3]	equinox	+/- 23,45°

[8] ISO 80000-3 uses H to mark a height over a normal-height (h would also be allowed, but we would have confusion with spec. enthalpy symbol). The term elevation is used since it is considered the mostly used name for the height of a site compared to altitude).

Solar hour angle	ω	°	Angle between the sun projection on the equatorial plane at a given time and the sun projection on the same plane at solar noon. Note: The solar hour angle changes by approximately 360° within 24 hours (approximately 15° per hour). This angle is negative for morning hours and positive for afternoon hours, i.e. $$\omega = 15 \cdot (t_{\mathrm{AST}} - 12)$$ Reference: [ISO 9488-2.8]	Solar noon	+/- 180°
Official local time	t_{OLT}	h	Time defined by the local authorities (i.e. what the clock shows at that site) including daylight savings time shifts. It is the time on a conventional clock.		0 ... 24 h
Standard local time	t_{SLT}	h	Also called "legal time" or "local winter time", is the reference time corresponding to all locations within the same "Time Zone", a function of the "Time Zone Convention" by which the Earth is divided into 24 zones by equidistant meridians called "Time Zones" with a width of 15º longitude at the Equator. The meridian that divides each zone in two equal parts is called the Reference Time Meridian and its identification is indispensable to correctly set the Standard Time. The standard time does not include any dalight saving time shifts.		0 ... 24 h
UTC	t_{UTC}	h	Coordinated universal time (replace the fomer Greenwich mean time since it is more precise)		0 ... 24 h

Apparent/True solar time	t_{AST}	h	Hour of the day as determined by the apparent angular motion of the sun across the sky, with solar noon as the reference point for 12:00 h. The apparent solar time is negative before noon and positive after noon. Note: At 12:00 apparent solar time, the shadow of a vertical pole exactly points north or south. After about 24 h there is again an instant when the shadow points exactly north or south. The time between these two instants is called apparent solar day. During one apparent solar day the sun seemed to have covered a 360° arc around the earth' axis. Every 15° of sun revolution the apparent solar time changes by 1 h thus summing up to 24 h. The length of the apparent solar day changes over the year due to the non-ideal motion of the earth around the sun. This means that one hour of apparent solar time is not exactly one hour of clock time. Reference: [ISO 9488-2.10]	At 12:00 sun reaches maximum elevation.	0 ... 24 h
Mean solar time	t_{MST}	h	Time indicated by a steady clock set so that over the year its differences from apparent/true solar time average to zero (with zero net gain or loss over the year).		0 ... 24 h
Equation of time	Δt_{EoT}	s	Difference between apparent/true solar time and mean solar time (due to the elliptical form of the Earth's orbit and the obliquity of the ecliptic).		-14min 6s … 16min 33s

T.4.2. Solar and collector angles

Name	**Symb.**	**Unit**	**Description**	**Zero**	**Range**
Solar zenith angle	θ_{Z}	°	Angular distance of the sun beam from the vertical. Note: Values >90° are possible for elevated sites. Reference: [ISO 9488-2.6]	Vertical	0 … 93°
Solar altitude angle[9]	α_{S}	°	Complement of the solar zenith angle Note: Values <0° are possible for elevated sites. Reference: [ISO 9488-2.7]	Horizontal	(-3°) 0 … 90°

[9] Definition directly taken from ISO 9488 while the symbol is modified from h to α_{S} with reference to ISO 80000-3 3-5 which defines angle symbols α, β, γ, ϑ, φ. φ is used for latitude and ϑ for temperature, so selection of α and γ is a good choice for the angles. Since h is used in another context, it should not be reused for this angle.

Solar azimuth angle	γ_S	°	Projected angle between a straight line from the apparent position of the sun to the point of observation and due south (in the northern hemisphere) or due north (in the southern one), measured clockwise in the northern hemisphere and anticlockwise in the southern one, using the projections on the local horizontal plane. Note: The solar azimuth is negative in the morning (eastern directions), 0° or 180° at noon (depending on the relative values on solar declination and local latitude), and positive in the afternoon (western directions), over the whole globe. It diverges from the geographical azimuth, which is measured clockwise from due north, over the whole globe. Reference: [ISO 9488-2.4]	Due south on northern hemisphere. Due north on southern hemisphere.	-180° ... 180°
Collector axis azimuth angle[10] [11]	γ_A	°	Direction of the positive collector axis, expressed as the azimuth angle of the horizontal projection of the collector axis. The angle definition is the same as for the solar azimuth angle.	Due south on northern hemisphere. Due north on southern hemisphere.	-180° ... 180°

Different symbols have the advantage that the two types of angles (height and azimuth) can clearly be distinguished.

[10] In general, there are two options to describe the orientation of a collector, the orientation of the collector axis or the orientation of the collector normal. Especially for linear Fresnel collectors the definition based on the aperture normal is not applicable since it always directs vertically upwards.

[11] The definition of a positive collector axis is important in order to uniquely define the orientation of the collector. This is important for non-symmetric characteristics of the system or unique identification of end losses, etc.

Positive collector axis[12]		The collector axis is used as a measure to define the orientation of the collector. Besides its alignment in space a direction is associated with the axis. The projection of the positive collector axis into the horizontal plane has a component pointing due south on northern hemisphere and due north on southern hemisphere. In case of east-west aligned collectors, the positive collector axis is due west.	-		
Collector normal azimuth angle[13]	γ_{N}	Direction which a collector faces, expressed as the azimuth angle of the horizontal projection of the surface normal. The angle definition is the same as for the solar azimuth angle. Reference: [ISO 9488-11.3]	°	Due south on northern hemisphere. Due north on southern hemisphere.	-180° … 180°
Collector axis tilt angle[14]	β_{A}	Angle between the horizontal plane and the collector axis (defined when looking in positive collector axis).	°	Axis horizontal	-90 … 90°
Collector normal tilt angle	β_{N}	Angle between the horizontal plane and the aperture plane of the collector. Reference: [ISO 9488-11.2]	°	Collector aperture area horizontal	0 … 90°

[12] The option of relating the positive collector axis to the flow direction of the fluid was not chosen since the collectors in the field would have different positive directions and therefore, alternating track/transversal angles would occur from row to row. The proposed definition using different directions on northern and southern hemisphere is chosen to be in accordance with the solar azimuth angle definitions in ISO 9488. The concept is also used for the new definition for the collector axis azimuth angle. Note: It would also be possible to define the collector axis with a unique direction on northern and southern hemisphere (e.g. due south). However, this would not follow the general concept of ISO 9488 which makes use of different direction on both hemispheres. In order to have highest consistence and easy to use definitions we recommend following ISO 9488.

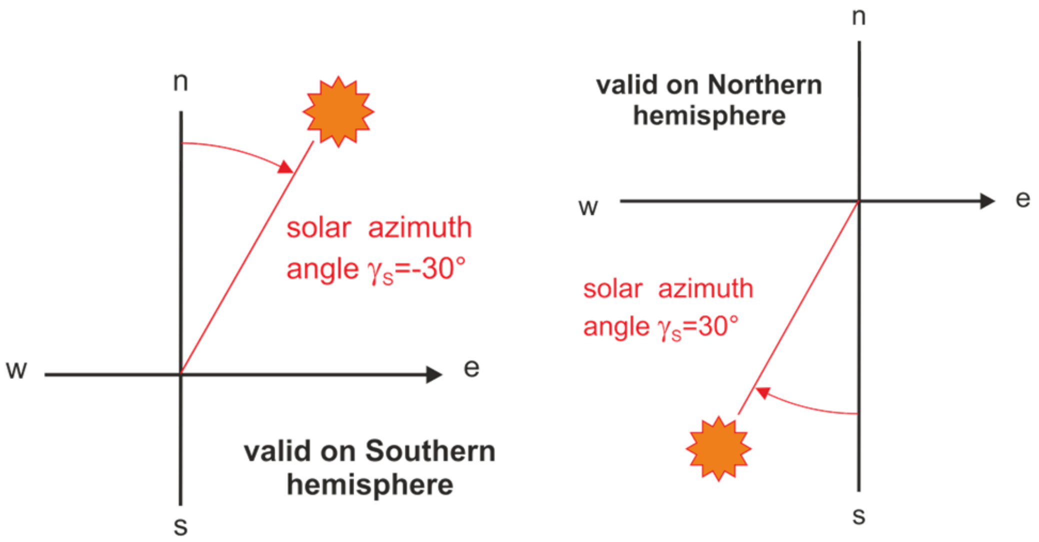
[13] ISO 9488-11.3 defines the collector orientation of flat plate collectors, but the description is basically the definition of any collector normal azimuth angle and also valid for heliostats.

[14] The definition needs to take care for the direction of the positive collector axes since the alignment of the collector needs to be uniquely defined. Only referring to an positive angle is not sufficient to the describe incidence angles in a general form.

Incidence angle of a solar collector[15]	θ_i $\theta_{i,axial}$ $\theta_{i,trans}$	Parabolic trough and parabolic dish: For parabolic trough and parabolic dishes it is the angle between the normal to the solar collector aperture plane and the line along the incident solar beam towards the center of the solar disk. Linear Fresnel: For linear Fresnel collectors the surface exposed to the sun is fixed in space and usually horizontal. The incidence angle on the aperture plane θ_i is only dependent on the solar position and for horizontally aligned Fresnel collectors it is equal to the solar zenith angle θ_Z. To fully describe the change of optical efficiency for non-perpendicular solar irradiance at least three more angles have to be introduced: The axial angle $\theta_{i,axial}$ is the projection of the incidence angle into the plane spanned by the collector axis and the incident solar beam. It can also be described as the angle between the transversal plane - the plane perpendicular to the collector axis - and the incident solar beam. The transversal angle $\theta_{i,trans}$ is defined as the projection of the incidence angle into the transversal plane. It can also be described as the angle between the collector aperture normal and the incident solar beam projected on the transversal plane. The longitudinal angle $\theta_{i,long}$ is defined as the projection of the incidence angle into the longitudinal plane - the plane spanned by the collector axis and the collector aperture normal. It can also be described as the angle between the collector aperture normal and the projection of the solar beam into the longitudinal plane. Note 1: Usually, for symmetric collector systems it is sufficient to use the magnitude of the angle independent of the direction (0…90°). For non-symmetric conditions, the incident angle is defined positive when the sun is located in positive collector axis direction, otherwise negative. Reference: [UNE 206009-3.1.6], [ISO 9488-2.11] Note 2: The axial angle of incidence is historically often called longitudinal angle of incident.	°		-90° … 90°

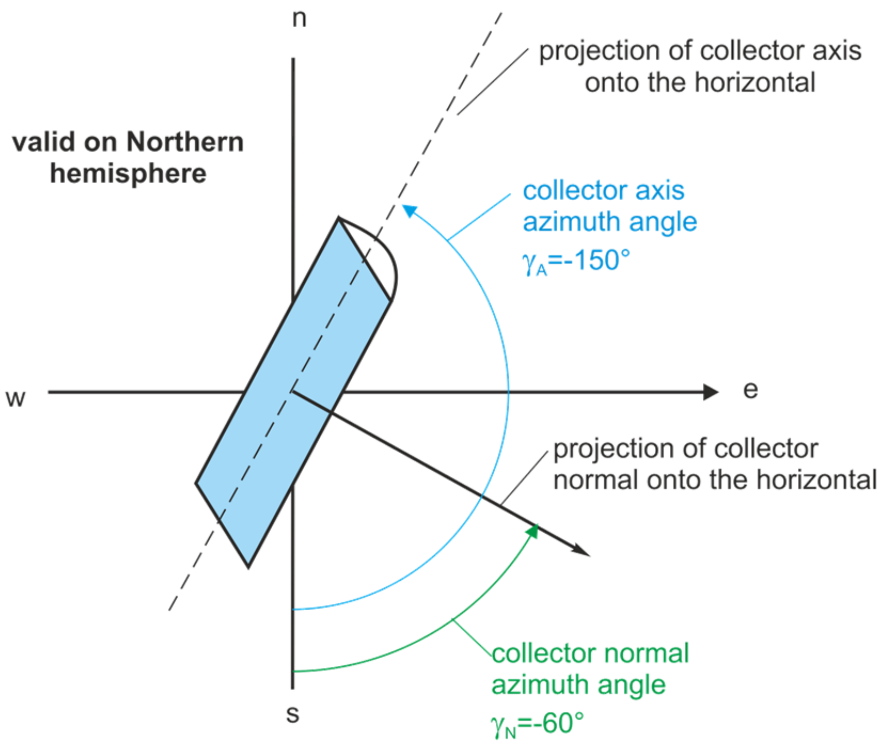
[15] The incident angle should be defined with positive and negative values in order to allow different incident angle modifiers depending on the direction (this is especially valuable for short collector rows with installations at the end shading the aperture area).

Tracking angle[16]	ρ_{track}	For parabolic trough collectors, angle between the vertical and the aperture normal. For linear Fresnel the tracking angle is individual for each mirror line of the collector and measured as the angle between the collector aperture plane and the normal of each individual mirror line. The angle gets positive if the aperture normal rotates in clockwise direction when looking along the positive collector axis. Switching the axis direction means a change in the sign of the track angle. Note: For tilted collectors the angle is measured in the plane perpendicular to the collector axis.	°	Aperture normal is directed vertically upwards. For tilted collectors: the plane defined by collector axis and aperture normal is vertical.	- 180° ... 180°

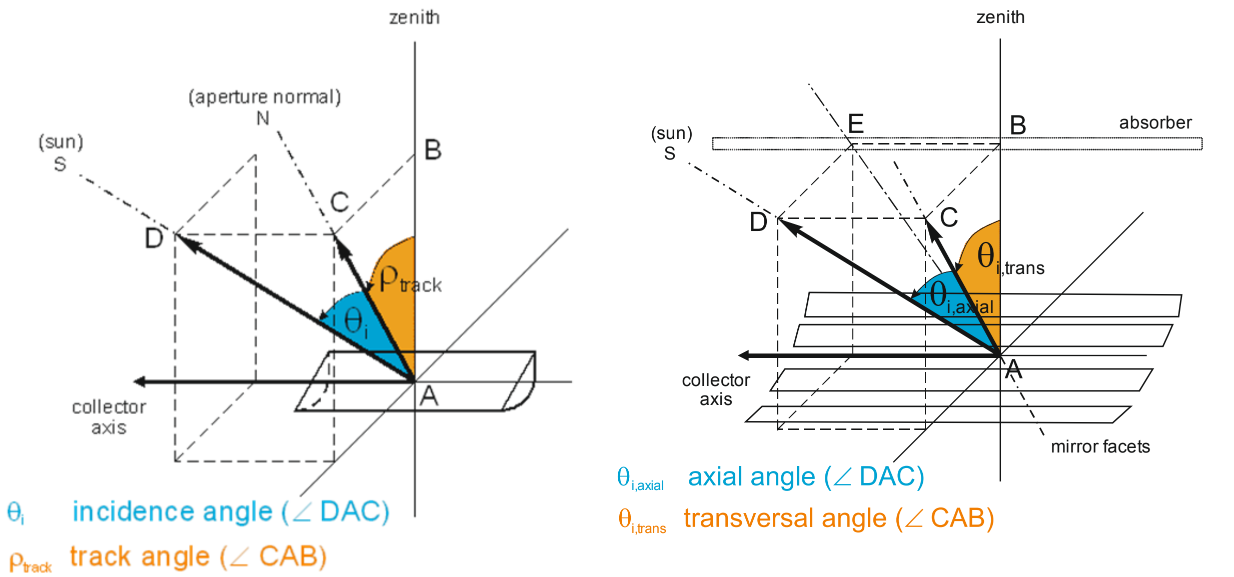


T-1 Illustration of solar azimuth angle definition

[16] The tracking angle itself is not defined by the solar position, but by the orientation of the normal of the collector normal (or linear Fresnel mirror line). An ideal tracking angle can be calculated using the sun position. The real tracking angle can differ from the ideal tracking angle, e.g. due to defocusing. Tracking angles below -90° and above +90° are possible, e.g. for defocusing or stow position.



T-2 Illustration of collector axis and collector normal azimuth angle (example for northern hemisphere)



T-3 Illustration of collector incident angle, its decomposition into transversal and axial angle of incidence as well as the longitudinal angle.

T.4.3. Irradiance and ambient conditions

Name	Symb.	Description	Unit	Zero	Range
Direct solar irradiance[17] (also find definition for Direct solar radiation and Direct solar irradiance)	G_b	Direct radiation (also called, direct solar radiation, beam radiation or beam solar radiation) is the radiation incident on a given plane, and originating from a small solid angle centered in the sun's disk. The quotient of the radiant flux of the direct radiation on a given plane receiver surface to the area of that surface is called direct solar irradiance. NOTE 1: If the receiver plane is perpendicular to the axis of the solid angle, the direct solar irradiance is called "direct normal solar irradiance". Direct solar irradiance is usually measured at normal incidence. An index "n" can be used to express the normal orientation (G_{bn}). Index "h" can be used for a horizontal surface (G_{bh}). An index "t" can be used to express an arbitruarily tilted surface (G_{bt}). NOTE 2: Direct solar irradiance is expressed in watts per square metre (W · m-2). NOTE 3: In general, direct normal solar irradiance is measured by instruments with field-of-view angles of up to 6º. Therefore, a part of the scattered radiation around the Sun's disk *circumsolar radiation* (see definition of this term) is included, as the solar disk itself has a field-of-view angle of about 0,5 º. NOTE 4: In order to describe direct normal solar irradiance accurately, it is necessary to specify how circumsolar radiation is included in it. Therefore, the following definitions are required: • $B_n^{ideal}(\alpha)$ the direct normal irradiance up to a given angular limit ? $$B_n^{ideal}(\alpha) = \int_0^{2\pi}\int_0^{\alpha} L(\xi,\varphi)\cos(\xi)\sin(\xi)d\xi d\varphi.$$ • B_n, the experimental direct normal irradiance $$B_n = \int_0^{2\pi}\int_0^{\alpha_l} P(\xi,\varphi)L(\xi,\varphi)\cos(\xi)\sin(\xi)d\xi d\varphi.$$ Here, $L(\xi,\varphi)$ is the broadband sky radiance — usually expressed in W m^{-2} sr^{-1}— for an element of sky whose angular position is defined by the angular distance ξ from the center	W/m²		

[17] The definition as well as the symbol are taken from ISO 9488. Although the symbol DNI is commonly used the suggested letter G is consistent with the rest of the nomenclature.

		of the sun and its corresponding azimuth angle φ. The angle ξ is the angular distance of the considered point in the sky with respect to the angular position of the sun's center. P(ξ,φ) is the "penumbra function" of the measurement device that is sometimes also called "acceptance function". NOTE 5: Approximately 99% of the direct solar radiation received at ground level is contained within the wavelength range from 0,3 µm to 3 µm. Depending on the direct irradiance measurement instrument or the application of the direct irradiance different wavelength ranges are included. In order to describe direct irradiance correctly, the wavelength range or the spectral response of the instrument or application has to be specified. Reference: *The definition is taken from the most recent(Oct 2015) definition discussed in IEC/TC-117*			

Diffuse irradiance[18]	G_d	Hemispherical solar irradiance minus direct solar irradiance. Note: The tilt angle and the azimuth of the receiving surface should be specified, e.g. horizontal. Note: Indices h, n, t can be used to specify the orientation of the surface as described in direct solar irradiance. Reference: [ISO 9488-3.21] [ISO 9488-3.28] [UNE206009]	W/m²		0 ...
Global irradiance	G_g	Hemispherical solar irradiance received by a horizontal plane. Note: Indices h, n, t can be used to specify the orientation of the surface as described in direct solar irradiance. Reference: [ISO 9488-3.27]	W/m²		0 ...
Irradiation	H H_d H_m H_y	Integral of irradiance over a certain period of time as one day H_d, one month H_m, one year H_y. If no index is given it refers to direct normal irradiance and integration over one year.	Wh/m²		0 ...
Ambient temperature	T_{amb}	Dry bulb temperature (of the ambient)	K		
Wet bulb temperature	T_{WB}	Wet bulb temperature (of the ambient)	K		
Ambient pressure	p_{amb}	Atmospheric pressure of the ambient	bar		
Relative humidity	φ	Relative humidity of the ambient Reference: [ISO 80005-5-5.30]	-		0 ... 1
Wind speed[19]	v_{wind}	Wind speed is measured by an anemometer at a height of 10 m above the local ground level, the surrounding ground being flat and open, i.e. such that the horizontal distance between any obstacle and the anemometer is at least 10 times the height of the obstacle. Note: Surrounding air speed near a collector system may differ from the meteorological wind speed. Reference: [ISO 9488-6.2]	m/s		
Wind direction[20]	γ_{wind}	Indicates the direction of origin of the wind. Wind coming from North has a	°	North is zero,	0 ... 360°

[18] The term "radiation" from ISO 9488 is replaced by "irradiance" here.

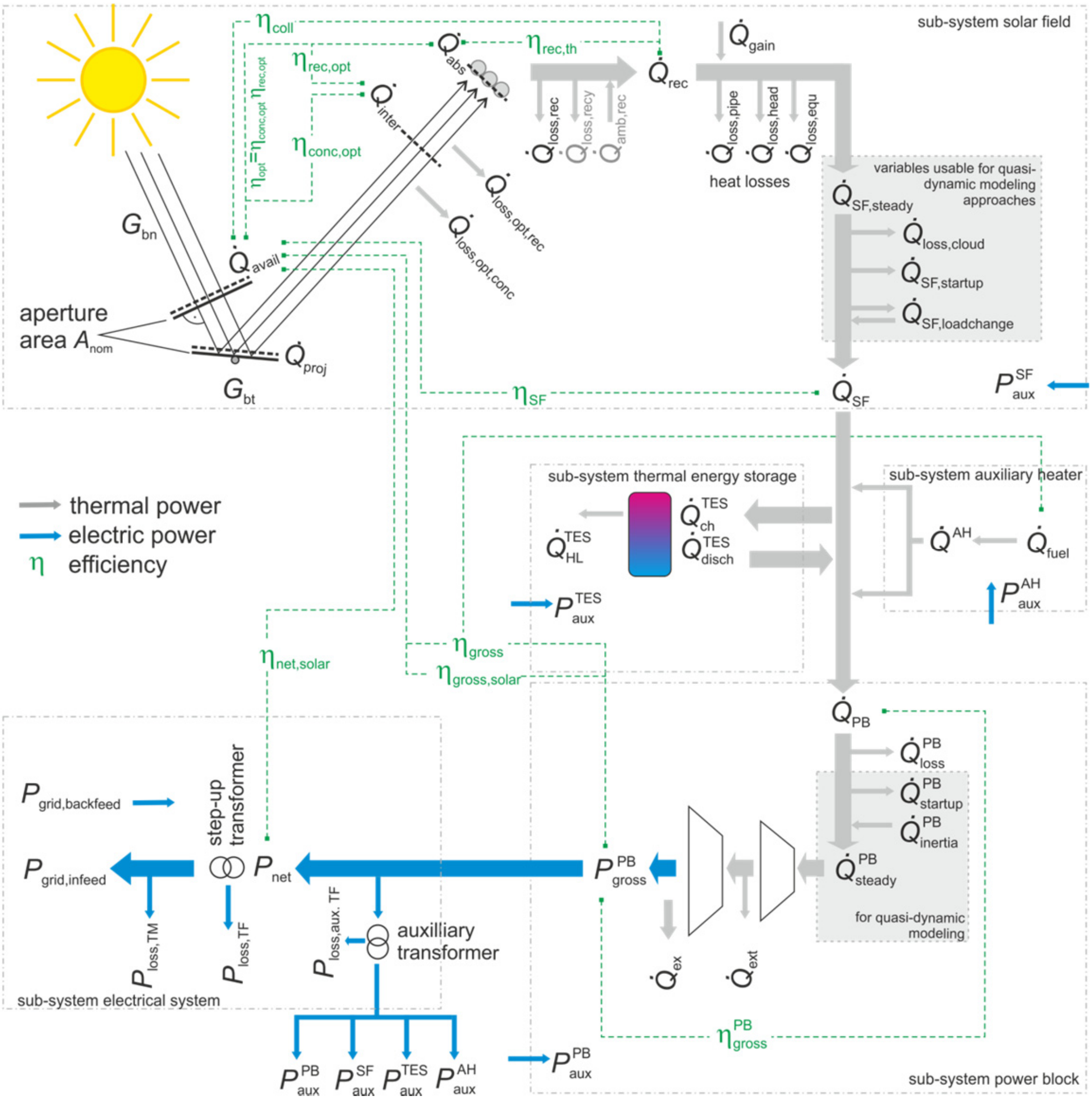
[19] ISO 9488 suggests symbol W for wind speed. Symbol v is used here instead since this is consistent with the general symbol for velocity.

[20] Even though collector orientation angle and wind direction share the same symbol, their definition differs.

		direction of 0°. Wind from East has a direction of 90°.		Clockwise positive.	

T.5. Top level STE variables for describing the energy chain

The principles of heat flow from the sun to the heat transfer fluid and the transformation to electricity are similar for all STE technologies. Thus, it is reasonable to uniquely define common variables used by all technologies.



T-4 Overview on top-level STE variables

T.5.1. Top level STE variables related to the sub-system "solar field"

The following variables are defined for the sub-system solar field. As long as the meaning is clear the index "SF" at position D (high to the right of the symbol) is left away. In case the variables are used in a context where misunderstanding may appear this index can be set.

Name	Symbol	Description	Unit
Solar collector gross aperture area	$A_{\mathrm{gross}}^{\mathrm{coll}}$	General Maximum flat area which accepts (direct or reflected) solar radiation and is defined by the outer perimeter of the optical sub-systems under consideration. Concentrating solar collector: The area of the flat surface defined by the outer perimeter of the collector, including the gaps between adjacent reflectors. For concentrators consisting of several optical sub-systems, the overall aperture area is the sum of the aperture areas of these sub-units. Parabolic trough: The flat rectangular area defined by the outer perimeter of the collector (gross collector area). Linear Fresnel: For linear Fresnel systems the gross aperture area of a collector is defined as the sum of the reflector row gross aperture areas. A reflector line gross aperture area of LFC is defined by its outer perimeter, including the very small gaps between adjacent reflector tiles in axial direction. Tower power plant: In tower power plants the solar collector is usually called heliostat. The heliostat aperture area is the flat rectangular area defined by the outer perimeter of the mirror panels including the small gaps between adjacent mirror facets, but excluding the large gap (if any) caused by the tracking device. Note 1: For most collectors the optical sub-system is the individually tracked collector unit. The collector aperture area does not include larger gaps e.g. caused by the tracking device. Or the large gaps between Fresnel primary mirrors. Note 2: The aperture area is a constant technical parameter for a given system and does not change with operation state or track angle. Note 3: Gross aperture area includes small gaps between mirrors. Net area only considers the active area of the primary optical component (primary mirrors).	m^2

Solar collector net aperture area	$A_{\mathrm{net}}^{\mathrm{coll}}$	The flat area of all reflectors and absorber tube backside (if active) projected into the aperture plane. The net aperture area only considers the active area of the primary optical component. Note 1: The net aperture area excludes the area between adjacent collector modules which is caused by pylons or drives, and it also does not include the small gaps between adjacent reflectors (if any). <u>Linear Fresnel:</u> For linear Fresnel systems, the net aperture area is defined as the sum of the net aperture area of its mirror segments. The net aperture area of a mirror segment is the perpendicular projection of the reflective mirror area over its aperture plane when they are in horizontal position. With this definition, gaps between reflectors in axial direction are not included in the net aperture area. <u>Tower power plant:</u> In tower power plants the solar collector is usually called heliostat. The heliostat net aperture area is the sum of the mirror facet areas (flat area, not canted!) defined by their outer perimeter. It does not include any gaps between the mirror facets either of neighbouring facets nor caused by the gap caused by the tracking device.	m^2
Solar collector nominal aperture area	$A_{\mathrm{nom}}^{\mathrm{coll}}$	The collector aperture area that is defined by the manufacturer and is used in context of all efficiency and performance figures referring to such nominal value. Usually, the value of the nominal aperture area lays within the one of the net and gross aperture area. For calculations where the solar collector nominal aperture area is not given (e.g. design studies) this value should be set to the solar collector net aperture area. Note 2:Usually, the nominal aperture area for parabolic trough systems includes the receiver area directly heated.	m^2
Solar field gross aperture area	$A_{\mathrm{gross}}^{\mathrm{SF}}$	The solar field gross aperture area is the sum of the gross aperture area of the collectors installed in the solar field. $A_{\mathrm{net}}^{\mathrm{SF}} = \sum A_{\mathrm{net}}^{\mathrm{coll}}$	
Solar field net aperture area	$A_{\mathrm{net}}^{\mathrm{SF}}$	The solar field gross aperture area is the sum of the net aperture area of the collectors installed in the solar field. $A_{\mathrm{net}}^{\mathrm{SF}} = \sum A_{\mathrm{net}}^{\mathrm{coll}}$	

Solar field nominal aperture area	A_{nom}^{SF}	The solar field gross aperture area is the sum of the nominal aperture area of the collectors installed in the solar field. $$A_{nom}^{SF} = \sum A_{nom}^{coll}$$	
Available radiant solar power[21]	$\dot{Q}_{avail}$	Product of nominal aperture area and the direct normal irradiance. $$\dot{Q}_{avail} = G_{bn} * A_{nom}$$ Note: The available solar power represents the maximum in irradiance that can be collected by a certain aperture area without considering shading (namely when the whole collecting area is oriented perpendicular to the sun beams). Depending on the collector technology this maximum can be reached - Parabolic dish: always - Parabolic trough: if incident angle is 0 (except shading) - Linear Fresnel: never (since at no instant all of the mirror lines are perpendicular to the sun rays) - Tower: never (see explanation for Fresnel) Since solar field costs are almost linear in aperture area the available solar power is a good measure to compare different collector technologies. Reference: [UNE 206009-3.1.68-slightly adapted]	W
Available radiant solar energy	Q_{avail}	The integral of the available radiant solar power over the time interval considered. Reference: [UNE 206009-3.1.37]	Wh
Projected radiant solar power	$\dot{Q}_{proj}$	Available solar power multiplied by the cosine of the incident angle. $$\dot{Q}_{proj} = G_{bn} * A_{nom} * \cos(\theta_i) = \dot{Q}_{avail} * \cos(\theta_i)$$ Note: For parabolic trough collectors this is the theoretical peak power that could be obtained if the collector is optically ideal (especially no shading) and does not show heat losses. For other concentrating systems this definition is not useful.	W
Projected radiant solar energy	Q_{proj}	The integral of the useful radient solar power over the time interval considered. Reference: [UNE 206009-3.1.38]	Wh

[21] We use the concept of nominal area in accordance with optical properties of the collector.

Optical loss power[22]	$\dot{Q}_{\text{loss,opt}}$	Difference between available radiant solar power and absorbed power. The losses can be splitted into a fraction occurring before and after the intercept plane. This is usually done when a strong separation between concentrator and receiver description is desired.	W
Optical loss energy	$Q_{\text{loss,opt}}$	Integral of optical loss power.	Wh
Intercepted power	$\dot{Q}_{\text{inter}}$	Radiant power entering though the intercept area of the receiver. The intercept area is the interface between the concentrator system and the receiver system. The intercept plane is defined as: -the outer surface of the glass envelope for parabolic trough systems, -the aperture area of the secondary concentrator/receiver structure through which the irradiance enters for linear Fresnel systems, - the curved surface area of the receiver exposed to the heliostat field for external tower receivers - the aperture area of the cavity that is exposed to the heliostat field for cavity type tower receiver	W
Intercepted energy	Q_{inter}	Integral of intercepted power.	Wh
Absorbed power	$\dot{Q}_{\text{abs}}$	Thermal power induced by absorbtion at the surface of the receiver. Note: The absorbed power is equal to the receiver power in case there is no emission, heat conduction, or heat convection on the receiver surface.	W
Absorbed energy	Q_{abs}	Integral of absorbed power at the surface of the receiver.	Wh
Heat flow to receiver from ambient	$\dot{Q}_{\text{amb,rec}}$	Heat flow transported by ambient air sucked through the receiver (for open volumetric receiver concepts).	W
Energy to receiver from ambient	$Q_{\text{amb,rec}}$	Integral of heat flow to receiver from ambient.	Wh
Receiver heat loss power[23]	$\dot{Q}_{\text{loss,rec}}$	Loss of thermal power by emission of the receiver surface, by convective, or conductive heat transfer from the receiver to the surrounding. Note: For parabolic troughs and linear Fresnel, the receiver heat losses include the heat losses from the interconnections between two consecutive receiver tubes but not the heat losses from the interconnections between two collectors. The boundary is defined between the last receiver support structures of the collector.	W

[22] This definition includes incident angle losses as part of the overall optical losses. For parabolic troughs there is often used a calculation step in between, thus defining the incident angle losses and additional optical losses. Since this is not applicable to linear Fresnel and tower systems the presented definition is more general and allows direct comparison of technologies.

[23] Linear Fresnel modeling will be based on heat loss data for the whole receiver structure. For better comparability, also the interconnections between the receiver pipes should be included in the receiver heat losses (heat losses by interconnections between two collectors are separately considered). Since laboratory data

Receiver heat loss energy	$Q_{\mathrm{loss,rec}}$	Integral of receiver heat loss power.	Wh
Receiver thermal power lost by air	$\dot{Q}_{\mathrm{loss,recy}}$	Thermal power lost to the ambient by air leaving the receiver (used for open air receivers)	
Receiver thermal energy lost by air	$Q_{\mathrm{loss,recy}}$	Integral of receiver thermal power lost by air.	
Receiver power[24]	$\dot{Q}_{\mathrm{rec}}$	Sum of the net thermal power transferred to the heat transfer fluid from the receiver inlet to the receiver outlet, and the thermal power lost in the receiver. It may also be calculated as the sum of the net thermal power transferred to the heat transfer fluid from the solar field inlet to the solar field outlet and the thermal power lost in the solar field components. $$\dot{Q}_{\mathrm{rec}} = \dot{Q}_{\mathrm{abs}} - \dot{Q}_{\mathrm{loss,rec}} + \dot{Q}_{\mathrm{amb,rec}}$$ Reference: [UNE 206009-3.1.66]	W
Receiver energy	Q_{rec}	Integral of receiver power.	Wh
Solar field piping thermal loss power	$\dot{Q}_{\mathrm{loss,pipe}}$	Heat losses in the solar field except those in the receiver and header system.	W
Solar field piping thermal loss energy	$Q_{\mathrm{loss,pipe}}$	Integral of field piping thermal loss power.	Wh
Header piping thermal loss power	$\dot{Q}_{\mathrm{loss,head}}$	Heat losses in the header piping. (only used for line focus systems)	W
Header piping thermal loss energy	$Q_{\mathrm{loss,head}}$	Integral of header piping thermal loss power.	Wh
HTF equipment thermal loss power	$\dot{Q}_{\mathrm{loss,equ}}$	Heat losses of the HTF equipment like pumps, or expansion vessel. Heat loss of the heat exchanger belongs by definition to the power block or the storage sub-system.	W
HTF equipment thermal loss energy	$Q_{\mathrm{loss,equ}}$	Integral of HTF equipment thermal loss power.	Wh
Maximum load defocussing power [25]	$\dot{Q}_{\mathrm{defoc,max}}$	Virtual heat flow from the solar field that could be generated but actually is not generated, because maximum load in heat consumer is reached (theoretical value).	W

on receiver tube heat losses are not directly transferable to the receiver tube under irradiation the receiver heat losses specified for the yield analysis need not be identically defined as the receiver tube heat loss data (which would not include intersections).

[24] In UNE 206009 defined as solar radiant power absorbed by the receiver. We use “receiver power” instead since absorbed has a different meaning in this context (difference between both are the heat losses of the receiver).

Maximum load defocussing energy	$Q_{\text{defoc,max}}$	Integral of maximum load defocussing power (theoretical value)..	Wh
Minimum load defocussing power	$\dot{Q}_{\text{defoc,min}}$	Virtual heat flowfrom the solar field that could be generated but actually is not generated, because minimum load in heat consumer cannot be reached (theoretical value).	W
Minimum load defocussing energy	$Q_{\text{defoc,min}}$	Integral of minimum load defocussing power (theoretical value).	Wh
Non-solar heat gain power	$\dot{Q}_{\text{gain}}$	Thermal power induced in the solar field by non-solar resource, e.g. by electrical heating or dissipation from of pressure head.	
Solar field steady-state power[26]	$\dot{Q}_{\text{SF,steady}}$	Sum of the net thermal power transferred to the heat transfer fluid from the solar field inlet to the solar field outlet and the thermal power lost in the receiver and other solar field components under steady-state operation. $\dot{Q}_{\text{SF,steady}} = \dot{Q}_{\text{rec}} - \dot{Q}_{\text{loss,pipe}} - \dot{Q}_{\text{loss,head}} - \dot{Q}_{\text{loss,equ}}$ Reference: [UNE 206009-3.1.67]	W
Solar field steady-state energy[27]	$Q_{\text{SF,steady}}$	Integral of solar field steady-state power.	Wh
Solar field cloud passage loss power[27]	$\dot{Q}_{\text{loss,cloud}}$	Thermal power lost in the solar field due to effects of passing clouds.	W
Solar field start-up power[27]	$\dot{Q}_{\text{SF,startup}}$	Thermal power required for heating up the solar field during the start-up procedure.	W
Load change thermal power[27]	$\dot{Q}_{\text{SF,loadchange}}$	Thermal power gained from or required by the solar during load changes compared to steady-state conditions, usually induced by thermal interia.	W
Solar field power [28]	$\dot{Q}_{\text{SF}}$	Thermal power produced by the solar field sub-system and available for usage in other sub-systems. For quasi dynamic approaches often calculated from the solar field steady-state power corrected by heat flows for modeling transient conditions. $\dot{Q}_{\text{SF}} = \dot{Q}_{\text{SF,steady}} - \dot{Q}_{\text{loss,cloud}} - \dot{Q}_{\text{loss,startup}} - \dot{Q}_{\text{loss,loadchange}}$	W

[25] The energetic figures represent the real plant situation, thus, defocusing due to overload is already included in the solar field power. The maximum load defocussing is thus a virtual quantity for reporting purpose. The same holds for minimum load defocussing.

[26] This variable is used in quasi-dynamic calculation approaches to epxress the solar field power before any transient effect contributions are subtracted.

[27] This variable is usually used in quasi-dynamic calculation approaches.

[28] In UNE 206009 the name “solar radiant power absorbed by the solar field” is used.

Solar field energy [29]	Q_{SF}	Integral of solar field power. The definition is consistent with the following definition used in UNE: Net thermal energy delivered by the *beam solar radiation* and transferred to the *heat transfer fluid* of the *STE plant* as it circulates through the solar field (or the *solar tower plant receiver system*) over a given period of time. It is calculated as the time integral of the product of the *heat transfer fluid* mass flow and the increase in specific enthalpy of the *heat transfer fluid* from the *solar field* (or the *solar tower plant receiver system*) inlet to the outlet. Reference: [UNE 206009-3.1.36]	Wh
Solar field theoretical power	$\dot{Q}_{\mathrm{SF,theo}}$	Thermal power theoretically delivered by the solar field without de-focusing.	W
Solar field theoretical energy[30]	$Q_{\mathrm{SF,theo}}$	Integral of Solar field theoretical power.	Wh
optical efficiency [31]	η_{opt}	Ratio of the power absorbed by the receiver and the available radiant solar power. This is equal to the product of optical efficiencies of concentrator and receiver. $$\eta_{\mathrm{opt}} = \frac{\dot{Q}_{\mathrm{abs}}}{\dot{Q}_{\mathrm{avail}}} = \eta_{\mathrm{conc,opt}} \cdot \eta_{\mathrm{rec,opt}}$$ Note: The optical efficiency includes component induced losses like reflectivity, maintenance depend parameters like soiling, as well as effects originating from a non-perpendicular incident of the sun beams. Thus the optical efficiency is usually described as a product of different efficiency factors like solar collector peak optical efficiency, incident angle modifier, endloss factor, cleanliness, etc. … $$\eta_{\mathrm{coll,opt}}(\theta_{\mathrm{i}}) = \eta_{\mathrm{opt,0}} \cdot K(\theta_{\mathrm{i}}) \cdot \eta_{\mathrm{end}}(\theta_{\mathrm{i}}) \cdot \eta_{\mathrm{clean}} \cdot \ldots$$	-

[29] In UNE 206009 the name “net thermal energy of the solar field” is used.
[30] Not really needed in the calculation of the efficiency chain but interesting as a monitoring variable.

optical efficiency at normal incidence [32]	$\eta_{\text{opt,0}}$	Ratio of the power absorbed by the receiver and the available solar power under the following conditions: - Sun beams are vertical to the aperture - Perfectly clean collector (perfectly should be used to define a maximum!) - No external shadows on the aperture Note: This variable is not used for solar tower systems.	-
Receiver efficiency [33]	η_{rec}	Ratio of the receiver power to the intercepted power, both integrated over a given period of time Δt. $\eta_{\text{rec}} = \int_{\Delta t} \dot{Q}_{\text{rec}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\text{inter}} dt = Q_{\text{rec}}/Q_{\text{inter}}$	-

Concentrator optical efficiency	$\eta_{\text{conc,opt}}$	Ratio of the intercepted power to the available power, both integrated over a given period of time Δt $\eta_{\text{conc,opt}} = \int_{\Delta t} \dot{Q}_{\text{inter}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\text{avail}} dt = Q_{\text{inter}}/Q_{\text{avail}}$	
Receiver optical efficiency	$\eta_{\text{rec,opt}}$	Ratio of the absorbed power to the intercept power, both integrated over a given period of time Δt $\eta_{\text{rec,opt}} = \int_{\Delta t} \dot{Q}_{\text{abs}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\text{inter}} dt = Q_{\text{abs}}/Q_{\text{inter}}$	-
Receiver thermal efficiency	$\eta_{\text{rec,th}}$	Ratio of the receiver power to the absorbed power, both integrated over a given period of time Δt. $\eta_{\text{rec,th}} = \int_{\Delta t} \dot{Q}_{\text{rec}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\text{abs}} dt = Q_{\text{rec}}/Q_{\text{abs}}$	-

[31] Since the incident angle alone is not a representative quantity for all CSP technologies the optical efficiency should be defined with the available radiant solar power. It thus contains all optical losses also cosine losses. UNE 206009 defines the collector optical efficiency as "Ratio of the *radiant solar power absorbed by the receiver* to the *useful radiant solar power* at the collector" which does not include cosine losses.

[32] Do not use at incident angle=0 since this is not true for all definitions of the incident angles (see incident angle definitions. UNE 206009 defines the "Peak Collector optical efficiency" as *Collector optical efficiency* when the *incidence angle* is zero, i.e., when direct solar radiation is perpendicular to the collector aperture plane, with a perfectly clean collector and no shadows on the aperture plane. It is the product of reflector reflectance (or refractor transmittance), cover transmittance if any, absorber absorptance, intercept factor, and the *effective length factor*, all at an angle of incidence equal to zero.

[33] It is useful to define all efficiencies by means of time averaged values since they are usually used as average values over a certain period of time. For dt→0 this converges to the instantaneous value.

Solar collector efficiency	η_{coll}	Ratio of the receiver power to the available power, both integrated over a given period of time Δt. $\eta_{\mathrm{coll}} = \int_{\Delta t} \dot{Q}_{\mathrm{rec}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\mathrm{avail}} dt = Q_{\mathrm{rec}}/Q_{\mathrm{avail}}$	-
Solar field efficiency	η_{SF}	Ratio of the *solar field energy* to the *available radiant solar power*, both integrated over a given period of time Δt. $\eta_{\mathrm{SF}} = \int_{\Delta t} \dot{Q}_{\mathrm{SF}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\mathrm{avail}} dt = Q_{\mathrm{SF}}/Q_{\mathrm{avail}}$ Reference: [UNE 206009-3.1.82]	-
Cleanliness factor	η_{clean}	Ratio of the power absorbed by the receiver in certain operating conditions to the power absorbed by the receiver in the same operating conditions if the collector (mirrors and receiver) are perfectly clean.	-
End loss factor	η_{endloss}	Factor considering optical end losses (and end gains) due to reflection out of the range of the absorber at the end of a linear collector. The end loss factor is a function of the collector incidence angle. Note: For parabolic trough systems the end losses induced by the gaps between two collectors are not defined by the incident angle correction but by means of the end loss factor.	-
Average solar field availability	$\eta_{\mathrm{avail}}^{\mathrm{SF}}$	Ratio of the nominal aperture area continuously available for operation to the total installed nominal aperture area. This value represents the reduction of the total installed nominal solar field area due to damage or maintenance. The ratio can be used as an instantaneous value or an average value over one year. Note: This definition refers to availability while the next two definitions refer to the real operation condition. The average solar field availability does not cover scheduled and un-scheduled outages. It only covers a planned, continuous non-availability of solar field units e.g. due to continuous maintenance or calibration activities. $\eta_{\mathrm{avail}} = A_{\mathrm{nom,\,avail}}/A_{\mathrm{nom}}$	-

Percentage of field in focus	$f_{\mathrm{foc,A}}$	Percentage of the nominal aperture area in operation over the installed nominal aperture area multiplied by the average solar field availability. $$f_{\mathrm{foc,A}} = A_{\mathrm{nom,\ operational}} / \left(A_{\mathrm{nom}} \eta_{\mathrm{avail}}^{\mathrm{SF}}\right)$$ Reference: Based on [UNE 206009-3.1.64] with adaptions in the area definitions.	-
Focusing factor [34]	$f_{\mathrm{foc,Q}}$	Ratio of the solar field power to the theoretical solar field power. $$f_{\mathrm{foc,Q}} = \dot{Q}_{\mathrm{SF}} / \dot{Q}_{\mathrm{SF,theo}}$$	-

[34] In principle, there are two options:

1. Use the ratio of areas like nominal aperture areas in focus to total area.
2. Use the ratio of effective power generated by the solar field to the theoretical power that could be produced without defocusing.

Incidence angle modifier Incident angle correction factor [35]	$K(\theta_i)$ $K'(\theta_i)$	The incident angle correction factor *K'* describes the angular dependent optical properties η_{phi} of a collector including cosine losses but excluding end losses[36]. The corresponding incident angle modifier *K* describes the angular dependent optical properties η_{phi} of a collector excluding both, cosine losses and end losses. $\eta_{phi}(\theta_i) = K'(\theta_i) \cdot \eta_{end}(\theta_i)$ $\eta_{phi}(\theta_i) = K(\theta_i) \cdot \cos(\theta_i) \cdot \eta_{end}(\theta_i)$ The incidence angle correction factor/incident angle modifier is normalized to unity for $\theta_i = 0$. Note 1: It is useful to define both K and K' since K is traditionally used for parabolic trough systems whereas K' is needed for linear Fresnel systems. Note 2: Both terms do not include endlosses[37]. Note 3: For some collectors (e.g. linear Fresnel) the incidence angle modifier *K'* depends on the two projections of the incidence angle into the incident plane (index i) and into the transversal plane (index tr). In that case, the resulting incidence angle correction factor K' may be approximated by the product of the two separate incidence angle corrections as $K'(\theta_{i,axial}, \theta_{i,trans}) \cong K'_i(\theta_{i,axial}) * K'_{tr}(\theta_{i,trans})$	-

[35] We use the index' for the factor since the incident angle modifier itself is a known quantity in parabolic trough technology.
[36] We use the symbol K instead of IAM for consistency reasons with the philosophy of variable naming used in this guideline (a variable should consist of only one letter).
[37] Endlosses are not included in the incident angle correction factor since the end losses of module-based line focusing systems depend also on the number of modules installed and not only on the incident angle. In case experimental data for a certain collector already include the end loss effect the respective end loss term in the equation can be set to 1.

T.5.2. Top level STE variables for the power block and auxiliary heater

Name	Symbol	Description	Unit
Thermal power to power block	$\dot{Q}_{\mathrm{PB}}$	Thermal power consumed by power block	W
Thermal energy to power block	Q_{PB}	Time integral of thermal power to power block.	Wh
Thermal power to extraction	$\dot{Q}_{\mathrm{extract}}$	Heat flow to following external devices/processes like desalination via steam extraction or waste heat usage	W
Thermal energy to extraction	Q_{extract}	Integral of thermal power to extraction.	Wh
Cooling / exhaust thermal power	$\dot{Q}_{\mathrm{cool}}$	Heat flow to condenser ("cool" refers to cold end of the turbine).	W
Cooling / exhaust thermal energy	Q_{cool}	Integral of Cooling/exhaust thermal power.	Wh
Power block rated power	P_{gross}^{0}	Electrical power specified on the generator nameplate. It takes the smaller value between the sum of the powers indicated in the turbine low and high pressure stages nameplates and the power indicated on the electrical generator nameplate. Note: For yield analysis without specified turbine data the power block rated power is the design power at the chosen 100% load case. Reference: [UNE 206009-3.1.64]	W
Power block gross power	P_{gross}	Electrical power measured at the generator terminals Reference: [UNE 206009-3.1.62]	W
Gross plant electricity production	E_{gross}	Electricity produced by the plant generating equipment during a given production period, as measured at the equipment outlet, (only active electricity will be taken into account) $E_{\mathrm{gross}} = \int_{\Delta t} P_{\mathrm{gross}}\, dt$ Reference: [UNE 206009-3.1.70]	Wh
Solar field baseload electric consumption	$P_{\mathrm{aux,BL}}^{\mathrm{SF}}$	Baseload electric consumption in the solar field. This value is independent of the load and includes instrumentation, control, lightening.	W
Solar field tracking consumption	$P_{\mathrm{aux,track}}^{\mathrm{SF}}$	Electric consumption for the tracking of the mirrors.	W
Solar field pumping electric consumption	$P_{\mathrm{aux,pumps}}^{\mathrm{SF}}$	Electric consumption for pumping the HTF in regular operation	W
Solar field heat tracing electric consumption	$P_{\mathrm{aux,HT}}^{\mathrm{SF}}$	Electric consumption of electric heaters that are needed to keep the HTF fluid temperature above a certain value.	W

Solar field anti-freeze electric consumption	$P_{\mathrm{aux,AF}}^{\mathrm{SF}}$	Sum of the solar field pumping and solar field heat tracing consumption in anti-freeze operation. $$P_{\mathrm{aux,AF}}^{\mathrm{SF}} = P_{\mathrm{aux,pump}}^{\mathrm{SF}} + P_{\mathrm{aux,HT}}^{\mathrm{SF}}$$	W
Power block base load offline consumption	$P_{\mathrm{aux,BL\_off}}^{\mathrm{PB}}$	Base load consumption of the power block when block is not in operation (instrumentation, control system, offices)	W
Power block base load online consumption	$P_{\mathrm{aux,BL\_on}}^{\mathrm{PB}}$	Base load consumption of the power block when block is in operation (see above	W
Power block heat rejection system consumption	$P_{\mathrm{aux,HR\_on}}^{\mathrm{PB}}$	Electric consumption of the heat rejection system.	W
Power block variable online consumption	$P_{\mathrm{aux,var\_on}}^{\mathrm{PB}}$	Variable consumption of the power block when block is in operation	W
Plant auxilliary consumption (power)	P_{aux}	Electricity consumed by the *solar thermal electricity plant*. It comprises: • Consumption of electricity from the grid by the solar thermal electricity plant. • Consumption of electricity from its own production by the solar thermal electricity plant at generating conditions (*electricity self-consumption*) $$P_{\mathrm{aux}} = P_{\mathrm{aux}}^{\mathrm{SF}} + P_{\mathrm{aux}}^{\mathrm{TES}} + P_{\mathrm{aux}}^{\mathrm{PB}} + P_{\mathrm{aux}}^{\mathrm{AH}} + P_{\mathrm{aux}}^{\mathrm{EL}} + P_{\mathrm{aux}}^{\mathrm{System}}$$ Reference: [UNE 206009-3.1.27] (for energy!)	W
Baseload auxiliary consumption	$P_{\mathrm{aux,BL}}$	Auxilliary consumption of the whole plant that is not dependend on the load.	W
Variable auxiliary consumption	$P_{\mathrm{aux,var}}$	Auxilliary consumption of the whole plant that directly depends on the load.	W
Anti-freeze auxiliary consumption	$P_{\mathrm{aux,AF}}$	Auxilliary consumption needed for anti-freeze operation, both pumping and heat tracing.	W
Plant auxilliary consumption (energy)	E_{aux}	Integral value of plant electricity consumption	Wh
Transmission losses	$P_{\mathrm{loss,TM}}$	Electric losses between plant and substation	W
Transformation losses	$P_{\mathrm{loss,TF}}$	Electric losses in the main transformer of the plant	W
Transformation losses	$P_{\mathrm{loss,auxTF}}$	Electric losses in the auxilliary transformer of the plant	W
Net plant power	P_{net}	Electrical power available after auxiliary electrical consumption of the plant is subtracted. $$P_{\mathrm{net}} = P_{\mathrm{gross}}^{\mathrm{PB}} - P_{\mathrm{aux}}$$	W
Net plant electricity production	E_{net}	Integral value of net plant power	Wh

Grid power	P_{grid} $P_{\text{grid,infeed}}$ $P_{\text{grid,backfeed}}$	Electrical power as measured at the grid connecting point, usually the sub-station. $P_{\text{grid}} = P_{\text{net}} - P_{\text{loss,tm}} - P_{\text{loss,tf}} - P_{\text{loss,ss}}$ Note 1: substation and transmission losses are included in the formula. In case the interconnection point is upstream of the substation these values would be zero. Note 2: The symbol $P_{\text{grid,infeed}}$ is used to characterize the power delivered to the grid whereas $P_{\text{grid,backfeed}}$ is used to describe the power purchased from the grid.	W
Electricity production to/from grid	E_{net} $E_{\text{grid,infeed}}$ $E_{\text{grid,backfeed}}$	Integral value of grid power	Wh
Gross power block efficiency	$\eta_{\text{gross}}^{\text{PB}}$	The ratio of the *gross plant electricity production* to the thermal energy delivered to the *power block* in the same period of time. $\eta_{\text{gross}}^{\text{PB}} = \int_{\Delta t} P_{\text{gross}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\text{PB}} dt = E_{\text{gross}}/Q_{\text{PB}}$ Reference: [UNE 206009-3.1.80]	-
Net power block efficiency	$\eta_{\text{net}}^{\text{PB}}$	Ratio of *net plant electricity production* to the thermal energy input to the *power block* in the same period of time. $\eta_{\text{net}}^{\text{PB}} = \int_{\Delta t} P_{\text{net}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\text{PB}} dt = E_{\text{net}}/Q_{\text{PB}}$ Reference: [UNE 206009-3.1.85]	-
Net calorific value also called lower heating value	q_{net}	Absolute value of the specific heat (enthalpy) of combustion, for unit mass of the fuel burned in oxygen at constant pressure under such conditions that all the water of the reaction products remains as water vapour (at 0,1 MPa), the other products being as for the gross calorific value, all at the reference temperature. Reference: [ISO 1928:2009 3.1.4]	kJ/kg
Auxilliary heater thermal power	$\dot{Q}_{\text{AH}}$	Thermal power provided by the auxiliary heater to the heat transfer fluid.	W
Auxilliary heater thermal energy	Q_{AH}	Thermal energy provided by the auxiliary heater to the heat transfer fluid.	Wh

T.5.3. Top level STE variables for the storage system

Name	Symbol	Description	Unit
Nominal storage thermal capacity	$C^{\mathrm{TES,0}}$	Amount of thermal energy that the storage system can supply by full discharge (under nominal discharging conditions, i.e., HTF inlet temperature and pressure and flow) under nominal starting conditions.	Wh
Present storage thermal capacity	C^{TES}	Amount of thermal energy that the storage system can supply by full discharge (under nominal discharging conditions, i.e., HTF inlet temperature and pressure and flow) under current starting conditions.	Wh
Present storage state of charge	$f_{\mathrm{SOC}}^{\mathrm{TES}}$	The state of charge of the storage system describes the amount of energy wich is stored inside the storage due to rated conditions.	-
Storage heat loss power	$\dot{Q}_{\mathrm{HL}}^{\mathrm{TES}}$	Heat losses of the storage without charging or discharging.	W
Auxillary power consumption	$P_{\mathrm{aux}}^{\mathrm{TES}}$	Auxillary power consumption of storage system.	W
Charging thermal power of storage	$\dot{Q}_{\mathrm{ch}}^{\mathrm{TES}}$	Heat flow to storage system during charging.	W
Discharging thermal power of storage	$\dot{Q}_{\mathrm{disch}}^{\mathrm{TES}}$	Heat flow from storage system during discharging.	W

T.5.4. Top level STE variables on system level[38]

Name	Symbol	Description	Unit
Gross plant solar efficiency	$\eta_{\text{gross,solar}}$	The ratio of the gross plant electricity production to the radiant solar energy available over a given period of time. This term is equivalent to the gross plant efficiency in solar only plants. $$\eta_{\text{gross,solar}} = \int_{\Delta t} P_{\text{gross}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\text{avail}} dt = \frac{E_{\text{gross}}}{Q_{\text{avail}}}$$ Reference: [UNE 206009-3.1.89]	-
Net plant solar efficiency	$\eta_{\text{net,solar}}$	The ratio of the net plant electricity production to the available solar power over a given period of time. This is equal to the net plant efficiency in solar only plants. $$\eta_{\text{net,solar}} = \int_{\Delta t} P_{\text{net}}\, dt \Big/ \int_{\Delta t} \dot{Q}_{\text{avail}} dt = E_{\text{net}}/Q_{\text{avail}}$$ Reference: [UNE 206009-3.1.90]	-
Gross plant efficiency	η_{gross}	The ratio of *gross plant electricity production* to the total *available solar power* and *non-solar fuel consumption* over a given period of time. This term is equivalent to the gross plant solar efficiency in solar only plants. Reference: [UNE 206009-3.1.81]	-
Net plant efficiency	η_{net}	The ratio of *net plant electricity production* to the total available solar power and *non-solar fuel consumption* over a given period of time. This term is equivalent to the net plant solar efficiency in solar only plants. Reference: [UNE 206009-3.1.86]	-
Solar multiple	F_{SM}	Ratio of the solar field power at the design point to the thermal power required from the solar field to run *the power block* at rated conditions. Reference: [UNE 206099-3.1.59]	-
Solar fraction (over a given period of time)[39]	F_{S}	Ratio of the net plant electricity production from beam solar radiation to the total net plant electricity production over a given period of time. Reference: [UNE 206099-3.1.48]	-
Equivalent operating hours	f_{EOH}	Ratio of the gross plant electricity production in a year to the nominal STE plant power. Reference: [UNE206009-3.1.51]	-
Equivalent plant efficiency	$\bar{\eta}_{\text{net}}$	Net plant efficiency for one year. Reference: [UNE206009-3.1.83]	-
Annual plant capacity factor	F_{C}	Ratio between the number of equivalent full load hours and the total number of hours in a year. Reference: [UNE 206009-3.1.40]	-
Annual electricity production to grid (P50)	$E_{\text{grid,P50}}$	Annual electricity production of the plant delivered to the grid and calculated by the expectancy values from all inputs (50 % of realization are above, 50 % are below this value).	

[38] The order might be changed using a differentiation between input and output variables

[39] This definition needs further refinement in the way the solar part of the electricity production is determined.

Annual electricity production to grid (P90)	$E_{\text{grid,P90}}$	Annual electricity production of the plant delivered to the grid representing a 90 % probability (90 % of realization are above this value, 10 % are below this value).	
Overhaul period	Δt_{over}	Number of days a plant is scheduled down for overhaup purposes. This does not include down-times that result from certain operation strategies (e.g. operation only in summer).	
Plant availability	$f_{\text{avail,plant}}$	Ratio of hours the plant as a whole is available to the number of hours the plant is scheduled to be available. The hours the plant is scheduled available is 8760 h minus the scheduled overhaul periods. In case a plant is foreseen to only operate during day-time the availability factor still refers to 24 ha day. The factor represents an effective value for the whole system which has to be estimated by sub-system availabilities.	
Grid availability factor	$f_{\text{avail,grid}}$	Ratio of hours the grid can accept electricity input from the STE plant to the total number of hours the grid is planned to be operational.	
Effective plant availability	F_{avail}	Effective availability of a plant including scheduled overhaul periods, unscheduled down-times due to problems with the plant or the grid. It can be calculated from the other availability factors by the equation: $F_{\text{avail}} = \frac{8760 - \left(\Delta t_{\text{over}} + (1 - f_{\text{avail,plant}}) \cdot (8760 - \Delta t_{\text{over}})\right)}{8760} \cdot f_{\text{avail,grid}}$	