

Solar Thermosyphon Energy Savings & GHG Reduction Assessment Methods

**B.4. Report on energy-saving & GHG
reduction methods along with current
and future trends**

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Deliverable

Subtask B. Thermosyphon Systems

B.4. Report on energy-saving & GHG reduction methods along with current and future trends

This is a report from SHC Task 69: Solar Hot Water for 2030 and work performed in Subtask A: State-of-the-art and operating environments in different regions and Subtask B: Thermosyphon hot water systems

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1 Executive Summary

This report provides a comprehensive analysis of four primary methodologies for quantifying carbon emissions reduction in solar water heating (SWH) systems: the Clean Development Mechanism (CDM), Life Cycle Assessment (LCA), project-level technical specifications, and White Certification schemes. The CDM methodology, established under the Kyoto Protocol, offers a standardized framework for certifying emission reductions (CERs) through rigorous baseline scenario determination, project emission monitoring, and third-party verification. It has proven particularly effective in developing countries like China and India, where abundant solar resources and strong hot water demand create ideal conditions for SWH deployment. By displacing conventional energy sources (e.g., electricity, coal, or gas), CDM-compliant SWH projects demonstrate measurable GHG reductions, with transparency ensured through certified monitoring plans and UNFCCC-approved calculation formulas. For instance, baseline emissions are calculated using regional grid emission factors or IPCC fuel coefficients, while project emissions account for auxiliary energy consumption, ensuring accurate quantification of net carbon mitigation. This methodology not only supports global climate goals but also generates economic benefits through carbon credit trading, making it a cornerstone for international carbon mitigation projects.

Complementing project-based approaches, Life Cycle Assessment (LCA) adopts a holistic cradle-to-grave perspective to evaluate the environmental impact of SWH systems. Governed by ISO 14040/44 standards, LCA quantifies embodied emissions from raw material extraction (e.g., aluminum, glass, copper) and manufacturing, operational energy savings, and end-of-life recycling credits. Functional units such as "per kWh of delivered heat" enable direct comparison with fossil fuel-based systems, revealing that initial production-related emissions are typically offset within a short payback period due to long-term operational savings. Key insights highlight the dominance of metal and glass production in embodied emissions, the role of auxiliary electricity during use, and the significant GHG reductions achievable through metal recycling. For example, sensitivity analyses show that regional electricity mixes and system longevity critically influence overall carbon balances. By integrating LCA into design optimization and policy decisions, stakeholders can identify material substitution strategies and maximize sustainability outcomes, ensuring SWH technologies contribute effectively to circular economy principles.

At the project level, technical specifications for GHG reduction assessments provide granular guidance for solar thermal applications, including hot water supply, heating, cooling, and industrial processes. This methodology outlines detailed procedures for boundary definition, baseline scenario selection (e.g., grid electricity or gas-fired boilers), and emission calculation using standardized formulas. For instance, baseline emissions incorporate energy consumption for heating and distribution, while project emissions monitor solar fraction and auxiliary usage. The assessment process emphasizes adaptability to regional conditions, with specific rules for new, retrofitted, or expanded projects. A structured workflow—from scenario identification to data quality management—ensures consistency and reliability, supported by visual tools like flowcharts for clarity. By aligning with local policies and technological realities, this approach enables accurate, context-sensitive carbon accounting, facilitating the scaling of solar thermal solutions across diverse sectors and geographies.

White Certification schemes, exemplified by Australia's state-level programs (e.g., Victorian Energy Upgrades and NSW Energy Savings Scheme), leverage market mechanisms to incentivize SWH adoption. These programs set energy-saving thresholds (e.g., $\geq 60\%$ efficiency gains) and issue tradable certificates for verified reductions, directly lowering consumer costs through rebates or discounts. By integrating with federal incentives like Small-scale Technology Certificates (STCs), white certificates create a multi-layered support system that accelerates market penetration. Rigorous performance standards (e.g., AS/NZS 4234) and climate-zone modeling ensure credibility, while statutory targets for energy retailers sustain demand for certificates. This model demonstrates how policy-driven economic incentives can transform environmental benefits into tangible financial returns, offering a replicable template for other regions seeking to decarbonize residential and commercial heating sectors.

Collectively, these methodologies underscore the critical role of solar water heating in global decarbonization efforts. From international carbon trading (CDM) to full lifecycle analysis (LCA) and market-based incentives (White Certificates), each approach provides unique strengths for quantifying, verifying, and incentivizing GHG reductions. By adopting tailored combinations of these frameworks, policymakers and industry stakeholders can accelerate the transition to sustainable heating, leveraging solar energy's vast potential to meet climate targets while delivering economic and social co-benefits.

2 Introduction

Solar water heating (SWH) systems represent a mature and scalable technology for reducing greenhouse gas (GHG) emissions in residential, commercial, and industrial sectors. By harnessing solar energy to displace fossil fuels for thermal energy needs, SWH systems offer a direct path to decarbonizing heating processes, which accounts for a sizeable portion of global energy consumption. For instance, in regions with high solar insolation, such as China, India, and Australia, SWH technologies have demonstrated capacity to reduce carbon emissions by 50–75% compared to conventional electric or gas-fired water heaters. This introduction explores the methodological frameworks, technical foundations, and real-world applications that underpin the carbon mitigation potential of SWH systems, drawing on diverse approaches from international standards to regional case studies.

The Clean Development Mechanism (CDM) provides a robust regulatory foundation for quantifying and certifying emission reductions from SWH projects. Under CDM methodologies, baseline scenarios are rigorously defined to reflect fossil fuel-based heating systems that would otherwise be used, with emissions calculated using region-specific factors (e.g., grid electricity carbon intensity or IPCC fuel coefficients). Project emissions, in contrast, are monitored based on auxiliary energy consumption, allowing for precise measurement of net GHG reductions. For example, in a typical CDM-registered SWH project in China, annual emission reductions can reach 2–4 tons of CO₂ equivalent per household, depending on local energy sources and system efficiency. The involvement of designated operational entities (DOEs) for verification adds a layer of credibility, ensuring that carbon credits generated (Certified Emission Reductions, or CERs) are both real and additional. This framework not only facilitates carbon trading but also promotes technology transfer and sustainable development in emerging economies.

Life Cycle Assessment (LCA) expands the evaluation scope beyond operational emissions to include embodied carbon from manufacturing, transportation, and end-of-life phases. Using standardized ISO 14040/44 protocols, LCA reveals that while SWH systems require energy-intensive materials like aluminum and glass, their lifetime carbon footprint is substantially lower than that of conventional systems. For instance, a cradle-to-grave LCA of a flat plate collector system in Europe shows a carbon payback period of less than two years, with net savings of 200–400 kg CO₂e/m² over a 20-year lifespan. Key to this outcome are design innovations that minimize material use (e.g., polymer composites) and maximize recycling potential at end-of-life. By highlighting hotspots in the supply chain, LCA guides manufacturers toward more sustainable practices and helps policymakers prioritize support for low-carbon technologies.

At the project level, technical specifications for GHG reduction assessments offer practical guidelines for implementing and evaluating SWH systems. These specifications detail procedures for defining system boundaries, selecting baseline technologies (e.g., electric boilers or gas heaters), and calculating emissions using standardized formulas. For example, in solar heating projects, baseline emissions account for energy losses in distribution and control systems, while project emissions include only auxiliary power consumption. The methodology emphasizes adaptability, allowing for customization based on project scale (e.g., single household vs. district heating) and local conditions. Tools such as software interfaces for carbon calculation streamline the process, enabling developers to simulate energy savings and GHG reductions during the planning phase. This approach ensures that projects are not only technically feasible but also aligned with carbon accountability standards.

White Certification schemes, such as those in Australia, demonstrate how market-based incentives can drive SWH adoption. Programs like the Victorian Energy Upgrades (VEU) and NSW Energy Savings Scheme (ESS) issue tradable certificates for verified energy savings, effectively subsidizing the cost of high-efficiency SWH systems for consumers. For instance, a household installing a thermosiphon SWH system may receive certificates equivalent to 60–80% of the upfront cost, making solar thermal technology economically competitive with conventional options. These schemes are reinforced by stringent performance standards (e.g., climate-zone-specific testing under AS/NZS 4234) and complementary federal policies, creating a cohesive ecosystem for carbon reduction. By translating environmental benefits into financial value, white certificates bridge the gap between consumer affordability and climate goals.

Regional case studies highlight the contextual factors influencing SWH carbon reduction potential. In China, which hosts over 70% of global installed solar thermal capacity, research by institutions like CABR and Sunrain has quantified average GHG reductions at 284 kg CO₂e/m² annually. However, performance varies significantly with climate: systems in high-insolation regions like Lhasa achieve reductions exceeding 400 kg CO₂e/m², while those in cloudier areas like Chongqing may save closer to 150 kg CO₂e/m². Such disparities underscore the need for localized design and assessment tools, as exemplified by China's carbon reduction calculation software and testing fields. These efforts not only validate methodologies but also provide data-driven insights for optimizing system performance under real-world conditions.

3 Energy-saving & GHG Reduction Methods

3.1 Method 1: CDM Methodology

3.1.1 Introduction

The Clean Development Mechanism (CDM), established under the Kyoto Protocol, is one of its three key flexible implementation mechanisms. Centered on the trading of certified emission reductions, CDM facilitates international cooperation by providing financial and technological support to developing countries for the implementation of emission reduction projects. In turn, it offers cost-effective compliance options for developed countries to meet their carbon mitigation targets. This mechanism effectively aligns the emission reduction compliance needs of developed nations with the sustainable development objectives of developing countries.

In accordance with decisions made by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP), the CDM Executive Board (CDM EB) has developed and operates the CDM Registry—a standardized electronic database designed to accurately track the issuance, holding, and transfer of Certified Emission Reductions (CERs).

3.1.2 CDM Methodology in Solar Water Heaters

The CDM methodology defines key elements such as project boundaries, baseline scenarios, project emissions, and monitoring plans, forming a critical foundation for generating carbon emission reductions. Solar water heater projects under the CDM are developed based on methodologies approved by the Executive Board of the United Nations Framework Convention on Climate Change (UNFCCC).

CDM methodology in solar water heaters

3.1.2.1 Baseline Scenario Determination

The baseline scenario describes the greenhouse gas emissions that would have occurred under existing practices without the project, while delivering the same level of hot water service. Key steps include defining project boundaries and service parameters (water volume, temperature, supply schedule), identifying the energy sources and equipment that would otherwise be used to provide hot water, and collecting verifiable data (e.g., electricity or gas bills, historical operational records). The energy consumption is disaggregated by type (electricity, natural gas, liquefied petroleum gas, etc.), and baseline emissions are calculated using approved emission factors corresponding to each energy source, as specified in formula (1). The baseline may also consider regional and technological specificities to better reflect local conditions.

$$BE_y = \sum_i E_{i,y} \times EF_i \quad (1)$$

Here, $E_{i,y}$ is the benchmark consumption of energy i in year y , and EF_i is its emission factor. In terms of electricity, the value of EF_i can refer to the regional grid emission factor database published by the UNFCCC, or the annual grid average emission factor published by relevant government departments in the region. For fuels such as natural gas and coal, the value of EF_i can refer to the carbon emission coefficients of different fuels in *IPCC 2006 Guidelines, Volume 2 Energy*.

3.1.2.2 Project Scenario Determination

The project scenario reflects actual emissions from operating the solar water heating system while maintaining the same service level. A detailed description of the system is required, including collector type and area, heat storage capacity, control strategies (e.g., thermostat settings, pump operation), auxiliary heating arrangements, and the expected solar fraction. Continuous metering of auxiliary energy use (electricity or fossil fuels) is essential for quantifying remaining non-renewable energy consumption. PE_y are calculated based on formula (2), incorporating actual monitored data where applicable.

$$PE_y = \sum_j F_{i,y} \times EF_j \quad (2)$$

Here, $F_{i,y}$ is the actual consumption of energy j in year y , and EF_j is its emission factor. In CDM accounting, the emission factor for solar power generation is usually set to 0, because the operating phase does not involve fossil fuel consumption (Reference to *UNFCCC ACM0002: Grid connected electricity generation from renewable sources*).

3.1.2.3 Emission Reduction Calculation

The certified emission reductions for a given year y are calculated as the difference between baseline emissions and project emissions, considering any leakage effects, though these are typically minimal in solar thermal projects. The result represents the net GHG mitigation achieved through the displacement of conventional energy by solar thermal energy. Formula (3) is applied under a conservative approach to ensure environmental integrity.

$$ER_y = BE_y - PE_y - LE_y \quad (3)$$

Here, LE_y is the leakage emission amount, which refers to the additional emissions caused by the implementation of the project outside the boundary.

3.1.2.4 Monitoring and Verification

A robust monitoring plan is essential to ensure that emission reductions are measurable, reportable, and verifiable. Parameters such as solar radiation, hot water output, auxiliary energy consumption, and system performance must be regularly recorded. After each monitoring period, an independent third-party Designated Operational Entity validates and verifies the results according to the approved methodology and monitoring plan. A verification report is submitted to the UNFCCC Executive Board, and upon approval, the corresponding Certified Emission Reductions for the monitoring period are issued.

3.1.3 Application situation

During the first commitment period of the Kyoto Protocol (2005–2012), the Clean Development Mechanism (CDM) experienced rapid expansion, with solar water heater (SWH) projects emerging as a widely adopted small-scale renewable energy technology. Due to their operational consistency and reliability across diverse settings, SWH projects demonstrated strong implementation potential and significant emission reduction effects. Countries such as China, India, South Africa, and Brazil registered and implemented a notable number of SWH-based CDM projects, among which China accounted for a substantial share. This was largely attributable to its vast market demand, abundant solar resources, and proactive government policies.

As a representative renewable energy technology, solar water heating exhibits considerable emission reduction potential, broad applicability, and favorable cost-effectiveness under the CDM framework:

(1) Emission Reduction Mechanism

SWH systems use solar radiation as the primary energy source, effectively displacing conventional energy (e.g., electricity, coal, or gas) for water heating. The resulting reduction in greenhouse gas emissions is quantified by monitoring the actual fossil fuel or electricity consumption replaced, which is then converted into CO₂ equivalent reductions. This forms the core of emission accounting within CDM projects.

(2) Versatile Application Scenarios

Solar water heaters are suitable for a wide range of settings with stable and continuous hot water demand, including residential buildings, hotels, schools, and hospitals. These sites ensure consistent and efficient long-term operation of SWH systems. Particularly in urban clusters or large institutions, centralized deployment and management further enhance operational efficiency, forming scaled clean energy utilization models. Such setups not only improve emission reduction outcomes but also facilitate centralized monitoring and verification under the CDM, reducing transaction and regulatory costs.

Developing countries such as China and India—endowed with abundant solar irradiation, large populations, and strong hot water demand—provide ideal conditions for SWH dissemination. Growing household demand for hot water, coupled with supportive government policies for energy conservation and clean energy, has created a favorable environment for the adoption of SWH technology. Within the CDM framework, these projects not only contribute to national sustainable development goals but also generate certified emission reductions (CERs) that can be acquired by developed countries, creating a mutually beneficial outcome.

(3) Clear Carbon Accounting and Co-Benefits

The emission reductions achieved by SWH projects are directly measurable through displaced conventional energy use. The straightforward accounting method enhances transparency and credibility. Project operators benefit from reduced energy costs and additional revenue streams through the sale of carbon credits under the CDM. This dual advantage has established SWH as an attractive and widely implemented technology pathway within the CDM system.

3.2 Method 2: LCA Calculations

3.2.1 Introduction

Life Cycle Assessment (LCA) is a standardized method (ISO 14040/44) used to quantify the environmental performance of technologies such as solar hot water systems. In the context of Task 69, LCA serves as a complementary approach to project-based monitoring and technical specifications. It provides a structured way to assess greenhouse gas (GHG) reductions, energy savings, and broader sustainability indicators by looking at all relevant stages of a system's life cycle.

3.2.2 System Boundary

Depending on the goal and scope of the assessment, different system boundaries can be applied:

- Cradle-to-Gate: from raw material extraction up to the finished product at the factory gate, focusing on embodied emissions.
- Cradle-to-Grave: including installation, operation, maintenance, and end-of-life treatment (recycling or disposal).

The functional unit is usually defined as 1 m² of collector area or 1 kWh of useful heat delivered, ensuring comparability with conventional baseline systems.

3.2.3 Calculation Method

The calculation is based on three main steps:

1. Inventory Analysis: Collection of data on materials (aluminum, glass, copper, polymers) and energy requirements for production, transport, and operation.
2. Impact Assessment: Conversion of material and energy flows into environmental impacts using established characterization factors (e.g., GWP100 for climate change).
3. Result Aggregation and Interpretation: Comparison of solar systems with baseline fossil-based systems, and identification of key drivers such as material efficiency, system lifetime, and recycling potential.

Results are expressed either per unit of collector area or per kWh of thermal energy, and can be complemented with sensitivity analyses (e.g., influence of regional electricity mixes, lifetime assumptions).

3.2.4 Interpretation of Results and Impact Assessment

LCA results show that while solar thermal systems require energy and materials for production, these initial impacts are typically offset within a short payback period. Over the system's lifetime, significant GHG savings can be achieved compared to electric or gas-based water heating.

Key insights include:

- Embodied emissions: Metals (aluminum, copper) and glass dominate production-related impacts.
- Use phase: Auxiliary electricity and component replacement are secondary but relevant contributions.

- End-of-life: Recycling of metals can provide substantial credits, improving the overall balance.

Overall, LCA calculations complement monitoring-based approaches by providing a transparent framework to evaluate both direct and indirect effects of solar hot water systems. They are essential for design optimization, material substitution strategies, and policy-level comparisons.

3.3 Method 3: Technical Specification at The Project Level for Assessment of GHG Reductions—Solar Thermal Applications

3.3.1 Assessment Procedures

This method guides the assessment of greenhouse gas emission reductions during the operation phase of solar thermal utilization projects by specifying the content, evaluation procedures, scenario determination, identification of greenhouse gas sources, emission reduction calculation, monitoring, data quality management, and preparation of emission reduction assessment reports. It provides guidance for projects that use solar energy to supply hot water, heating, heat driven cooling, and industrial heat, as well as for projects that combine two or more of the forms. At the same time, this method is also applicable to the assessment of greenhouse gas emission reduction during the operation phase of solar thermal utilization in comprehensive energy utilization projects.

The project evaluation includes the determination of greenhouse gas types, scenario identification and greenhouse gas source identification, emission reduction calculation, monitoring, and data quality management, as well as the preparation of emission reduction assessment reports. For implemented projects, greenhouse gas emission reductions should be evaluated during the stable operation of the project; For projects that have not yet been implemented, greenhouse gas emission reductions should be evaluated during the project planning phase. The greenhouse gas emission reduction assessment procedure for the project is shown in Figure 1.

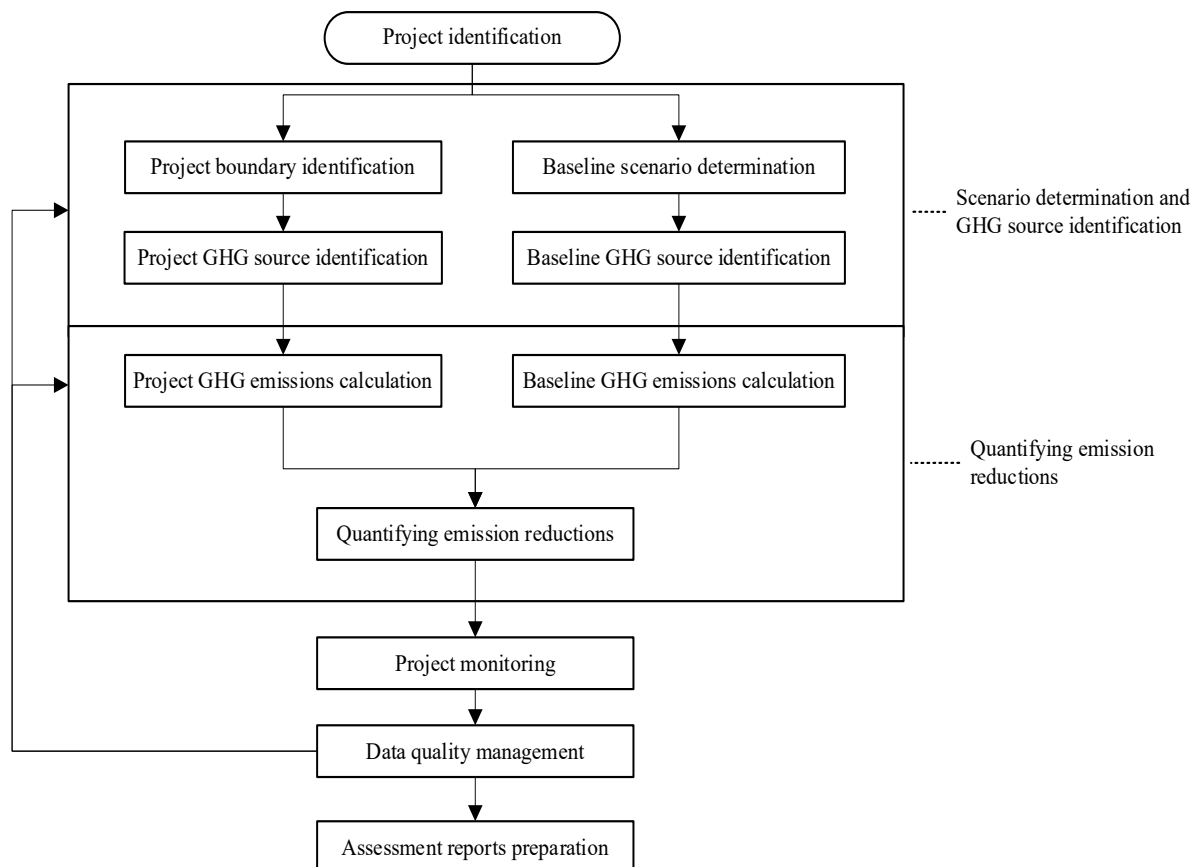


Figure 1: Diagram of The Project-Based GHG Emission Reduction Assessment Procedures.

3.3.2 Baseline Scenario

New projects should adopt the technology specified by national policies as the baseline scenario. When there are no regulations, the baseline scenario for new construction projects should be determined based on the mainstream technology and energy supply situation adopted in the project location, using the following alternative methods.

a) Using solar energy to supply hot water:

1) The centralized collection solar hot water project can choose to obtain electricity from the power grid and use electric hot water boilers to supply water or use natural gas and gas hot water boilers to supply water as the baseline scenario.

2) The decentralized solar heating water project can choose to obtain electricity from the power grid and use electric water heaters to supply hot water or use natural gas and gas water heaters to supply hot water as the baseline scenario.

b) Using solar energy for heating:

1) The heating target is a single building or household solar heating project in a building, which can choose to obtain electricity from the power grid and use electric heating equipment, or use natural gas and use gas heating furnaces for heating as the baseline scenario.

2) The heating target is a solar district heating project for multiple buildings or areas, which can choose coal-fired boilers or use natural gas and gas boilers for heating as the baseline scenario.

c) Using solar thermal energy to drive refrigeration:

Based on the energy supply conditions of the project location, the baseline scenario can be selected as obtaining electricity from the power grid and using electric refrigeration equipment or using natural gas and using thermal energy to drive refrigeration equipment for cooling.

d) Using solar energy to provide industrial heat:

Based on the temperature and power requirements of the heating process, the baseline scenario can be selected as obtaining electricity from the power grid and using industrial electric boilers, using natural gas, and using gas boilers, or using coal-fired boilers to provide industrial heat.

The renovation project should select a baseline scenario based on the specific situation before the implementation of the renovation project. Expansion projects should determine baseline scenarios based on the needs of target users, using either renovation or new construction methods. Please refer to Table 1 for specific details.

Table 1: Main Project and Baseline Scenarios.

Project scenarios		Possible baseline scenarios		Examples (including but not limited)
No.	Scenario	No.	Scenario	
P1	Supplying hot water with solar energy	B1	Supplying hot water with electric boilers or electric water heaters powered by electricity from the grid	Centralized Solar Water Heating Project Distributed Solar Water Heating Project
		B2	Supplying hot water with gas boilers or gas fired heating and hot water combi-boilers powered by natural gas	
P2	Supplying space heating with solar energy	B3	Supplying space heating with electric heaters powered by electricity from the grid	Household Solar Heating Projects Solar district heating projects
		B4	Supplying space heating with coal-fired boilers	
		B5	Supplying space heating with gas boilers or gas fired heating and hot water combi-boilers powered by natural gas	
P3	Supplying cooling with heat-driven refrigeration	B6	Supplying cooling with electricity-driven refrigeration equipment powered by electricity from the grid	Solar Air Conditioning Project Centralized Solar Cooling Project

		B7	Supplying cooling with heat-driven refrigeration equipment powered by natural gas	
P4	Providing industrial heating with solar energy	B8	Providing industrial heating with electric boilers powered by electricity from the grid	Industrial Solar Heating Project
		B9	Providing industrial heating with coal-fired boilers	
		B10	Providing industrial heating with gas boilers powered by natural gas	
Note: For solar desalination projects and projects providing process heating for agriculture, scenarios in Table 1 for providing industrial heating with solar energy could be used as reference.				

The project boundary generally includes solar energy collection, storage, transmission and distribution, and control systems. When using solar thermal energy to drive refrigeration, thermal energy driven refrigeration equipment should also be included. The baseline boundary should include heating and cooling equipment, transmission and distribution, control systems, etc. powered by the power grid, as well as heating and cooling equipment using other energy sources.

The emission sources of the project generally include greenhouse gas emissions generated by the collection, storage, transmission and distribution, and control systems using grid electricity within the boundary; The baseline emission sources generally include greenhouse gas emissions generated by equipment within the boundary due to the use of grid electricity, coal, gas, or other fuels, as well as greenhouse gas emissions generated by the use of refrigerants when using electrically driven refrigeration units.

The boundary and emission source for projects supplying hot water with solar energy and the baseline scenario are shown in Table 2.

Table 2: Boundary and Emission Source for Projects Supplying Hot Water with Solar Energy and The Baseline Scenario.

Boundary/Emission sources		Projects and baseline scenarios	
		P1-B1	P1-B2
Projects	Boundary	Solar collectors, thermal storage, transmission and distribution, control systems, etc.	
	Emission sources	GHG emissions from the grid electricity used by equipment within the boundary	
Baseline	Boundary	Electricity grid: electric boilers or electric water heaters, transmission and distribution system, etc.	Heating equipment: gas boilers or gas fired heating and hot water combi-boilers Electricity grid: Transmission and distribution systems, etc.
	Emission sources	GHG emissions from the grid electricity to meet the demand for heating, transmission and distribution, control, etc.	GHG emissions from gas boilers or gas fired heating and hot water combi-boilers; GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.

The boundary and emission source for projects supplying space heating with solar energy and the baseline scenario are shown in Table 3.

Table 3: Boundary and Emission Source for Projects Supplying Space Heating with Solar Energy and The Baseline Scenario.

Boundary/Emission sources		Projects and baseline scenarios		
		P2-B3	P2-B4	P2-B5
Projects	Boundary	Solar collectors, thermal storage, transmission and distribution, control systems, etc.		
	Emission sources	GHG emissions from the grid electricity used by equipment within the boundary		
Baseline	Boundary	Electricity grid: electric heaters, transmission	Heating equipment: coal-fired boilers	Heating equipment: gas boiler or gas fired heating and hot water combi-boilers

		and distribution system, etc.	Electricity grid: transmission and distribution system, etc.	Electricity grid: transmission and distribution system, etc.
	Emission sources	GHG emissions from the grid electricity to meet the demand for heating, transmission and distribution, control, etc., as well as GHG emissions from the refrigerants	GHG emissions from coal-fired boilers; GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.	GHG emissions from gas boilers or gas fired heating and hot water combi-boilers; GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.

The boundary and emission source for projects supplying cooling with heat-driven refrigeration and the baseline scenario are shown in Table 4.

Table 4: Boundary and Emission Source for Projects Supplying Cooling with Heat-Driven Refrigeration and The Baseline Scenario.

Boundary/Emission sources		Projects and baseline scenarios	
		P3-B6	P3-B7
Projects	Boundary	Solar collectors, thermal storage, transmission and distribution, control systems, etc., as well as heat-driven refrigeration equipment	
	Emission sources	GHG emissions from the grid electricity used by equipment within the boundary	
Baseline	Boundary	Electricity grid: electricity-driven refrigeration equipment, transmission and distribution system, etc.	Heat-driven refrigeration equipment: direct-fired absorption chiller Electricity grid: cooling towers and other equipment, as well as transmission and distribution system, etc.
	Emission sources	GHG emissions from grid electricity to meet the demand for cooling, transmission and distribution, control, etc.	GHG emissions from gas for cooling; GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.

The boundary and emission source for projects Providing industrial heating with solar energy and the baseline scenario are shown in Table 5.

Table 5: Boundary and Emission Source for Projects Providing Industrial Heating with Solar Energy and The Baseline Scenario.

Boundary/Emission sources		Projects and baseline scenarios		
		P4-B8	P4-B9	P4-B10
Projects	Boundary	Solar collectors, thermal storage, transmission and distribution, control systems, etc.		
	Emission sources	GHG emissions from the grid electricity used by equipment within the boundary		
Baseline	Boundary	Electricity grid: electric boilers, transmission and distribution system, etc.	Heating equipment: coal-fired boilers Electricity grid: transmission and distribution system, etc.	Heating equipment: gas boilers Electricity grid: transmission and distribution system, etc.
	Emission sources	GHG emissions from the grid to meet electricity demand for heating, transmission, distribution, control and other processes	GHG emissions from coal-fired boilers; GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.	GHG emissions from gas for heating; GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.

3.3.3 Calculation of Emission Reductions and Data Sources

The GHG emission reductions generated by the project over a certain period shall be calculated by formula (4):

$$ER = BE - PE \dots\dots\dots (4)$$

In Eq:



ER—GHG emission reduction from the project over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e).

BE—GHG emissions of the baseline scenario over the same period, in tonnes of carbon dioxide equivalent (tCO₂e).

PE—GHG emissions of the project scenario over the same period, in tonnes of carbon dioxide equivalent (tCO₂e).

For projects covering two or more scenarios, baseline scenarios shall be adopted separately according to energy supplying forms, and the GHG emission reductions shall be calculated by adding them up.

The calculation of baseline GHG emissions is detailed in Table 6.

Table 6: Calculation of Baseline GHG Emissions.

Baseline Scenarios	Methods for calculating GHG emissions
B1	<p>Baseline emissions shall include GHG emissions from the grid electricity to meet the demand for heating, transmission and distribution, control, etc.:</p> $BE = BE_{EL} = (EC_P + EC_C + EH) \times EF_e = \left(EC_P + EC_C + \frac{Q_{HW}}{\eta_r \eta_{HW}} \right) \times EF_e$ <p>In Eq:</p> <ul style="list-style-type: none"> <i>BE</i>— GHG emissions of the baseline scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e); <i>BE_{EL}</i>— During the same period, GHG emissions of the baseline scenario from electricity consumption for heating, transmission, distribution, control, etc., in tonnes of carbon dioxide equivalent (tCO₂e); <i>EC_P</i>— During the same period, electricity consumed for transmission and distribution in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h); <i>EC_C</i>— During the same period, electricity consumed by control system in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h); <i>EH</i>— During the same period, electricity consumed for hot water heating in the baseline scenario, in megawatt hours (MW·h); <i>EF_e</i>— CO₂ emission factor for electricity, same as the project scenario, in tonnes of carbon dioxide equivalent per megawatt hour (tCO₂e/MW·h); <i>Q_{HW}</i>— During the same period, DHW heating energy at the user side, which shall be same as the project scenario, in megawatt hours (MW·h); <i>η_r</i>— DHW distribution efficiency considering heat losses, in percentage (%); <i>η_{HW}</i>— The efficiency of electric boilers or electric water heaters, dimensionless, could be taken as 0.90.
B2	<p>Baseline emissions shall include GHG emissions from gas boilers or gas fired heating and hot water combi-boilers, as well as GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.:</p> $BE = BE_{EL} + BE_F = (EC_P + EC_C) \times EF_e + \frac{Q_{HW} \times 3.6}{\eta_r \eta_{HW}} \times EF_j$

	<p>In Eq:</p> <p>BE — GHG emissions of the baseline scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>BE_{EL} — During the same period, GHG emissions of the baseline scenario from electricity consumption for transmission, distribution, control, etc., in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>BE_F — During the same period, GHG emissions of the baseline scenario from fuel consumption for heating, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>EC_P — During the same period, electricity consumed for transmission and distribution in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p>EC_C — During the same period, electricity consumed by control system in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p>EF_e — CO₂ emission factor for electricity, same as the project scenario, in tonnes of carbon dioxide equivalent per megawatt hour (tCO₂e/MW·h);</p> <p>Q_{HW} — During the same period, DHW heating energy at the user side, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p>η_r — DHW distribution efficiency considering heat losses, in percentage (%);</p> <p>η_{HW} — The efficiency of gas boilers or gas fired heating and hot water combi-boilers, in percentage (%), could be taken as 86%.</p> <p>EF_j — CO₂ emission factor for the j th fuel, in tonnes of carbon dioxide equivalent per gigajoule (tCO₂e/GJ). It shall be the latest national or local recognized data, when no data available, the default values in Table D.1 could be adopted.</p>
B3	<p>Baseline emissions shall include GHG emissions from the grid electricity to meet the demand for heating, transmission and distribution, control, etc.:</p> $BE = BE_{EL} = (EC_P + EC_C + EH) \times EF_e = \left(EC_P + EC_C + \frac{Q_H}{COP_{sys}} \right) \times EF_e$ <p>In Eq:</p> <p>BE — GHG emissions of the baseline scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>BE_{EL} — During the same period, GHG emissions of the baseline scenario from electricity consumption for heating, transmission, distribution, control, etc., in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>EC_P — During the same period, electricity consumed for transmission and distribution in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p>EC_C — During the same period, electricity consumed by control system in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p>EH — During the same period, electricity consumed for space heating in the baseline scenario, in megawatt hours (MW·h);</p> <p>EF_e — CO₂ emission factor for electricity, same as the project scenario, in tonnes of carbon dioxide equivalent per megawatt hour (tCO₂e/MW·h);</p> <p>Q_H — The space heating energy during the same period, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p>COP_{sys} — System COP when using air-source heat pump system heating, dimensionless, its value could refer to GB/T 50801.</p>

<p style="text-align: center;">B4 B5</p>	<p>Baseline emissions shall include GHG emissions from coal-fired boilers, gas boilers or gas fired heating and hot water combi-boilers, as well as GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.:</p> $BE = BE_{EL} + BE_F = (EC_P + EC_C) \times EF_e + \frac{Q_H \times 3.6}{\eta_H} \times EF_j$ <p>In Eq:</p> <p><i>BE</i>—— GHG emissions of the baseline scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p><i>BE_{EL}</i>—— During the same period, GHG emissions of the baseline scenario from electricity consumption for transmission, distribution, control, etc., in tonnes of carbon dioxide equivalent (tCO₂e);</p> <hr/> <p><i>BE_F</i>—— During the same period, GHG emissions of the baseline scenario from fuel consumption for heating, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p><i>EC_P</i>—— During the same period, electricity consumed for transmission and distribution in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p><i>EC_C</i>—— During the same period, electricity consumed by control system in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p><i>EF_e</i>—— CO₂ emission factor for electricity, same as the project scenario, in tonnes of carbon dioxide equivalent per megawatt hour (tCO₂e/MW·h);</p> <p><i>Q_H</i>—— The space heating energy during the same period, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p><i>η_H</i>—— The heating efficiency of coal-fired boilers, gas boilers or gas boilers or gas fired heating and hot water combi-boilers, in percentage (%), its value could be taken as 82% for coal-fired boilers, 92% for gas boilers and 86% for gas fired heating and hot water combi-boilers;</p> <p><i>EF_j</i>—— CO₂ emission factor for the <i>j</i> th fuel, in tonnes of carbon dioxide equivalent per gigajoule (tCO₂e/GJ). It shall be the latest national or local recognized data, when no data available, the default values in Table D.1 could be adopted.</p>
<p style="text-align: center;">B6</p>	<p>Baseline emissions shall include GHG emissions from the grid electricity to meet the demand for electricity-driven refrigeration equipment, cooling towers, transmission, and distribution system, etc., as well as GHG emissions from the refrigerants:</p> $BE = BE_{EL} + BE_R = \left(EC_P + EC_C + \frac{Q_C}{\eta_C} \right) \times EF_e + m_R y_R GWP_R / 1000$ <p>In Eq:</p> <p><i>BE</i>—— GHG emissions of the baseline scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p><i>BE_{EL}</i>—— During the same period, GHG emissions of the baseline scenario from electricity consumption for cooling, transmission, distribution, control, etc., in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p><i>BE_R</i>—— During the same period, GHG emissions due to refrigerant used, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p><i>EC_P</i>—— During the same period, electricity consumed for transmission and distribution in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <hr/> <p><i>EC_C</i>—— During the same period, electricity consumed by control system in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p><i>Q_C</i>—— The cooling energy during the same period, which shall be same as the project scenario, in megawatt hours (MW·h);</p> <p><i>η_C</i>—— The cooling efficiency of electricity-driven chiller, its value could be taken as 3.50;</p>

	<p>EF_e— CO₂ emission factor for electricity, same as the project scenario, in tonnes of carbon dioxide equivalent per megawatt hour (tCO₂e/MW•h);</p> <p>m_R— Refrigerant charging amount of electricity-driven chiller, in kilograms per time (kg/time);</p> <p>y_R— Number of refrigerant charges for electricity-driven chiller in the same period, in time (time);</p> <p>GWP_R— GWP values for refrigerants used, in tonnes of carbon dioxide equivalent per tonne (tCO₂e/t).</p>
B7	<p>Baseline emissions shall include GHG emissions from gas for cooling, as well as GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.:</p> $BE = BE_{EL} + BE_F = (EC_P + EC_C) \times EF_e + \frac{Q_C \times 3.6}{\eta_C} \times EF_G$ <p>In Eq:</p> <p>BE— GHG emissions of the baseline scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>BE_{EL}— During the same period, GHG emissions of the baseline scenario from electricity consumption for cooling tower, transmission, distribution, control, etc., in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>BE_F— During the same period, GHG emissions of the baseline scenario from fuel consumption for cooling, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>EC_P— During the same period, electricity consumed for transmission and distribution in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW•h);</p> <p>EC_C— During the same period, electricity consumed by control system in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW•h);</p> <p>EF_e— CO₂ emission factor for electricity, same as the project scenario, in tonnes of carbon dioxide equivalent per megawatt hour (tCO₂e/MW•h);</p> <p>Q_C— The cooling energy during the same period, which shall be same as the project scenario, in megawatt hours (MW•h);</p> <hr/> <p>η_C— The cooling efficiency of direct-fired absorption chiller, its value could be taken as 1.10;</p> <p>EF_G— CO₂ emission factor for natural gas, in tonnes of carbon dioxide equivalent per gigajoule (tCO₂e/GJ). It shall be the latest national or local recognized data, when no data available, the default values in Table D.1 could be adopted.</p>
B8	<p>Baseline emissions shall include GHG emissions from the grid electricity to meet the demand for heating, transmission and distribution, control, etc.:</p> $BE = BE_{EL} = (EC_P + EC_C + EC_I) \times EF_e = \left(EC_P + EC_C + \frac{Q_I}{\eta_I} \right) \times EF_e$ <p>In Eq:</p> <p>BE— GHG emissions of the baseline scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>BE_{EL}— During the same period, GHG emissions of the baseline scenario from electricity consumption for transmission, distribution, control, etc., in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>EC_P— During the same period, electricity consumed for transmission and distribution in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW•h);</p>

	<p>EC_C— During the same period, electricity consumed by control system in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW•h);</p> <p>EC_I— During the same period, GHG emissions of the baseline scenario from electricity consumption by electric heating equipment, such as industrial electric boilers, in megawatt hours (MW•h);</p> <p>EF_e— CO₂ emission factor for electricity, same as the project scenario, in tonnes of carbon dioxide equivalent per megawatt hour (tCO₂e/MW•h);</p> <p>Q_I— The industrial heating energy supplied during the same period, which shall be same as the project scenario, in megawatt hours (MW•h);</p> <p>η_I— Industrial electric boiler efficiency, dimensionless, could take 0.90.</p>
B9 B10	<p>Baseline emissions shall include GHG emissions from coal-fired boilers or gas boilers, as well as GHG emissions from the grid electricity to meet the demand for transmission and distribution, control, etc.:</p> $BE = BE_{EL} + BE_F = (EC_P + EC_C) \times EF_e + \frac{Q_I \times 3.6}{\eta_H} \times EF_j$ <p>In Eq:</p> <p>BE— GHG emissions of the baseline scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>BE_{EL}— During the same period, GHG emissions of the baseline scenario from electricity consumption for transmission, distribution, control, etc., in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>BE_F— During the same period, GHG emissions of the baseline scenario from fuel consumption for heating, in tonnes of carbon dioxide equivalent (tCO₂e);</p> <p>EC_P— During the same period, electricity consumed for transmission and distribution in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW•h);</p> <p>EC_C— During the same period, electricity consumed by control system in the baseline scenario, which shall be same as the project scenario, in megawatt hours (MW•h);</p> <p>EF_e— CO₂ emission factor for electricity, same as the project scenario, in tonnes of carbon dioxide equivalent per megawatt hour (tCO₂e/MW•h);</p> <p>Q_I— The industrial heating energy supplied during the same period, which shall be same as the project scenario, in megawatt hours (MW•h);</p> <p>η_H— The heating efficiency of coal-fired boilers or gas boilers, in percentage (%), its value could be taken as 82% for coal-fired boilers and 92% for gas boilers;</p> <p>EF_j— CO₂ emission factor for the j th fuel, in tonnes of carbon dioxide equivalent per gigajoule (tCO₂e/GJ). It shall be the latest national or local recognized data, when no data available, the default values in Table D.1 could be adopted.</p>

The calculation of project GHG emissions is detailed in Table 7.

Table 7: Calculation of Project GHG Emissions.

Scenarios	Methodologies for calculating GHG emissions and monitoring content
Project scenario	<p>Project emissions shall include GHG emissions from the grid electricity used by solar collectors, thermal storage, transmission and distribution, control systems, etc. within the boundary. The heat-driven refrigeration equipment shall also be included for solar cooling projects:</p> $PE = \left(EC_P + EC_C + \sum_i EC_i \right) \times EF_e$ <p>In Eq:</p>

	PE —	GHG emissions of the project scenario over a certain period, in tonnes of carbon dioxide equivalent (tCO ₂ e);			
	EC_P —	During the same period, the electricity consumed by transmission and distribution system of the project, in megawatt hours (MW•h). When the project shares transmission and distribution system with auxiliary energy or other energy systems, this part is shared according to the proportion of solar heating/cooling energy transmitted or distributed; when the project does not have transmission and distribution equipment, such as heating/cooling pumps or fans, it is equal to 0;			
	EC_C —	During the same period, the electricity consumed by control system of the project, in megawatt hours (MW•h). When the project shares control system with auxiliary energy or other energy systems, this part is shared according to the proportion of solar heating/cooling energy transmitted or distributed; when the control system is difficult to measure separately, or integrated in heat collection, thermal storage, transmission and distribution systems, it could not be counted separately;			
	EC_i —	During the same period, the electricity consumed by the rest of the equipment i , other than the transmission, distribution and control system, in megawatt hours (MW•h);			
	EF_e —	The CO ₂ emission factor for electricity, in tonnes of carbon dioxide equivalent per megawatt hour (tCO ₂ e/MW•h), shall be the latest national or competent department recognized data.			
Monitoring parameters	P1	EC_P	EC_C	EC_i	Q_{HW}
	P2	EC_P	EC_C	EC_i	Q_H
	P3	EC_P	EC_C	EC_i	Q_C
	P4	EC_P	EC_C	EC_i	Q_I

The requirements for obtaining data on domestic hot water heating, heating, cooling, industrial heating, and equipment power consumption for calculating project emissions and baseline emissions are as follows:

- a) For implemented projects, monitoring procedures should be selected or established to regularly monitor or estimate relevant operational data; When the project cannot be monitored or the monitoring data cannot meet the requirements and the evaluation time is a whole year, the methods specified in relevant standards can be used to calculate the heating capacity of domestic hot water, heating capacity, cooling capacity, and industrial heating capacity;
- b) For projects that have not yet been implemented, data related to domestic hot water heating, heating, cooling, industrial heating, and equipment power consumption should be obtained based on the feasibility study report or other relevant materials, and their sources should be explained. After that, the emission reduction should be calculated according to the methods specified in this document.

3.4 Method 4: Policies Implemented by Australian State

Source: Ken Guthrie AM, Australian Representative on IEA SHC Executive Committee, Former - Chair Australian Standards Committee CS028.

3.4.1 Introduction

State based white certificate schemes are energy efficiency policies implemented by Australian state and territory governments, centred on incentivizing households and businesses to install high-efficiency equipment through market mechanisms to reduce energy consumption.

By leveraging market forces, white certificate schemes effectively lower the cost for consumers to purchase high-efficiency hot water systems, such as thermosyphon SWH and heat pump systems, while simultaneously driving overall improvements in energy efficiency and reductions in carbon emissions. These schemes complement the Small-scale renewable energy systems scheme, collectively forming Australia's multi-tiered incentive system supporting the clean energy transition.

3.4.2 Key Components of State Plans

(1) Victorian Energy Upgrades (VEU)

VEU aims to establish a trading platform centered around energy certificates and offers discounts on a range of energy-efficient products, from water heaters and lighting to space heating and cooling systems. Replacing outdated, energy-intensive gas or electric water heating systems with efficient solar or heat pump water heating systems is one of the most common and heavily subsidized activities under the VEU program.

(2) NSW Energy Savings Scheme (ESS)

ESS requires relevant enterprises (primarily energy retailers) to achieve specific annual energy-saving targets. Energy-saving measures (such as installing high-efficiency hot water systems) generate Energy Savings Certificates upon certification. Businesses can fulfil their compliance obligations by purchasing these certificates.

In addition to solar and heat pump water heaters, ESS also encompasses a wide range of energy-saving upgrades for lighting, motors, air conditioning systems, and other applications in commercial and industrial settings.

Similar schemes are replicated in South Australia and the Australian Capital Territory.

3.4.3 Main Method

(1) Economic Incentives

Providing direct financial incentives is the most direct and effective approach. When a household installs a certified thermosiphon solar water heater, it generates a white certificate representing “achieved energy savings.” These certificates can be sold on the market to energy retailers with compliance obligations, with the proceeds returned to consumers as discounts or rebates. This significantly reduces the initial installation cost of the equipment. Such direct financial subsidies are a key factor motivating many households to make this choice.

(2) Thresholds and Evaluation Criteria

To ensure subsidies are directed toward products with high performance and significant emission reduction benefits, the white certificate program will establish stringent eligibility criteria. For example, thermosiphon solar water heating systems must demonstrate at least 60% energy savings to qualify for the program.

The system's performance evaluation is based on standards such as AS/NZS 4234 and incorporates modelling for Australia's diverse climate zones (seen as Figure. 2). This ensures accurate assessment of the actual energy savings and emissions reductions achieved by thermosiphon solar water heaters in specific regions, thereby maintaining market confidence.

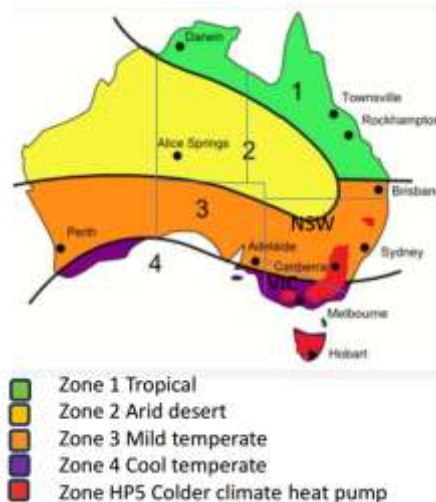


Figure 2: Australia's Diverse Climate Zones.

(3) Market-driven mechanism

The state government establishes statutory energy-saving targets for responsible entities such as energy retailers, compelling them to fulfil their obligations by purchasing white certificates. This creates a sustained market demand for energy-saving certificates, including those generated by installing thermosiphon solar water heaters. This market mechanism ensures that the incentive to promote efficient technologies like thermosiphon solar water heaters remains viable over the long term.

(4) Policy Complementarity

State-level white certificate programs operate in parallel with and complement the federal government's Small Technology Credit (STC) program. A qualified solar thermal water heater project may qualify for both STCs and white certificates, thereby receiving dual economic incentives. This significantly accelerates the market penetration of the technology and the process of carbon reduction.

3.4.4 Conclusion

In summary, Australia's state-based white label program employs a market-driven approach to directly translate the environmental benefits (carbon emissions reduction) of thermosiphon solar water heaters into tangible economic advantages for consumers. By skilfully leveraging economic incentives, this initiative has significantly accelerated the adoption of this technology, making a substantial contribution toward achieving regional and national carbon reduction targets.

4 Research on Greenhouse Gas Emissions Reduction from Solar Water Heating Systems in China

Research on Greenhouse Gas Emissions Reduction from Solar Water Heating Systems in China As the global climate change problem becomes increasingly serious, achieving carbon peak and carbon neutrality has become an urgent task for the global response to climate change. Under such conditions, solar thermal application is a promised way to realize carbon neutral in building sector. According to IEA, China accounts 73.1% of world's total installed solar collectors, making it the world's largest market, producer, and exporter of solar thermal products. Solar thermal projects are making significant contributions to energy saving and carbon reduction.

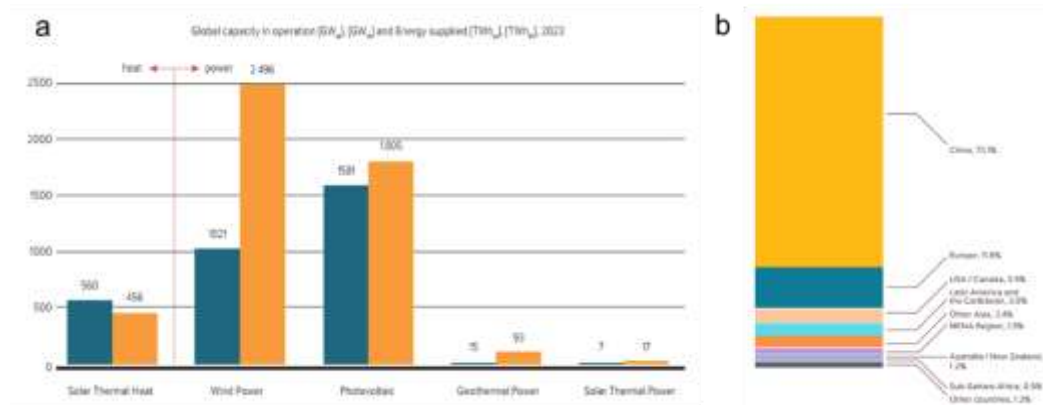
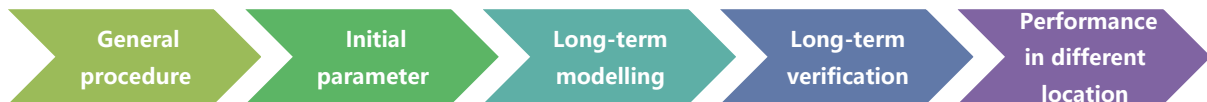


Figure 3: a) Global Capacity in Operation 2023 and Annual Energy Yields b) Share of The Total Installed Capacity in Operation by Economic Region in 2022.

Source: Solar Heat Worldwide (2024 Edition).

However, differences between China and Europe causes differences in the GHG reduction potential. Thus, other countries' experience may not be quite suitable for GHG reduction evaluation in China. To give an assessment method on GHG emission reduction of SHW system under China's climate resources and usage conditions, CABR and Sunrain together conducted series research on that topic includes:



- General procedure: Generate a procedure to evaluate long-term GHG reduction performance of solar hot water system.
- Initial parameters: According to ISO 9459-2 and GB/T 18708-2002, give a method to get initial parameters.
- Long-term modelling: Build up a model to calculated annual energy saving and carbon reduction.
- Long-term verification: Verify the model and improve methods with different types of systems' long-term operation data.
- Performance in different location: Simulate GHG reduction of solar hot water systems in different cities in China.

4.1 Research Process

In the Initial parameters testing process, four samples of solar hot water systems (Table 8) were evaluated to get initial performance parameter.



Figure 4: Compact System with ETC (left) and Closed System with FPC (right).

Table 8: Samples in Lab Testing.

Sample	Type	Collector Area (m ²)	Tank Volume (L)	Avg. Daily Heat Gain (MJ/ m ²)	Avg. Daily GHG Reduction (kg/ m ²)
1	ETC 45°	2.25	140	3.62	0.58
2	ETC 45°	3.75	255	3.18	0.51
14	FPC 90°	1.73	80	0.86	0.14
15	FPC 70°	1.73	100	1.76	0.28

Through daily calculation, method is similar to ISO 9459-2, and a software was developed to make it easier.



Figure 5: Annual Carbon Emission Reduction Calculation Software Interface.

For verification, a carbon reduction testing field was established in Jiangsu province. The test was conducted in the Clean Thermal Energy Carbon Emission Test Center of the Solareast Group. And 15 types of solar thermal system have been installed for a long-term testing.



Figure 6: Test Filed in The Clean Thermal Energy Carbon Emission Test Center.

As shown in Figure 7, 15 sets of solar water heating systems were selected for the experiment, including 10 sets of compact (open) systems and 5 sets of pressurised (closed) systems. The outdoor operating conditions of each system were recorded throughout the day during the experiment.



Figure 7: Tested Samples.

The outdoor operating conditions of each system were recorded throughout the day during the experiment. The parameters required for daily experiments include the daily solar radiation on the collector's lighting surface, the average ambient temperature during the day, the daily cold water temperature, the end of heat collection water temperature, the average drainage temperature, the starting water temperature of the hot water storage tank, the end of water filling water tank temperature, the start and end time of daily drainage, and the daily hot water consumption. And based on this, calculate the daily heat gain and carbon dioxide emission reduction of the system. The daily heat gain and GHG reduction of compact (open) systems and pressured (closed) systems are shown in Table 9 and Table 10, respectively.

Table 9: Compact (Open) System.

Sample	Type	Collector Area (m ²)	Tank Volume (L)	Avg. Daily Heat Gain (MJ/ m ²)	Avg. Daily GHG Reduction (kg/ m ²)
1	ETC 45°	2.25	140	3.62	0.58
2	ETC 45°	3.75	255	3.18	0.51
3	ETC 45°	2.32	158	4.63	0.75
4	ETC 45°	3.75	220	3.10	0.50
5	ETC 45°	2.25	160	4.05	0.65
6	ETC 20°	8.80	320	2.06	0.33
7	ETC 45°	3.90	256	3.92	0.63
8	ETC 40°	3.00	200	2.66	0.43
9	ETC 45°	2.50	150	3.40	0.55
10	ETC+HP 45°	3.75	240	3.04	0.49

Table 10: Pressured (Closed) System.

Sample	Type	Collector Area (m ²)	Tank Volume (L)	Avg. Daily Heat Gain (MJ/ m ²)	Avg. Daily GHG Reduction (kg/ m ²)
11	FPC 45°	2.78	80	3.63	0.59
12	UFPC 90°	1.37	80	2.23	0.36
13	UFPC 90°	1.37	80	1.13	0.18

14	FPC 90°	1.73	80	0.86	0.14
15	FPC 70°	1.73	100	1.76	0.28

For compact (open) system, the average daily GHG reduction is about 0.33~0.75 kg/m². For pressured (closed) system, the average daily GHG reduction is about 0.14~0.50 kg/m². And display the statistical data of daily heat gain and GHG reduction of compact (open) systems and pressured (closed) systems in Figure 8.

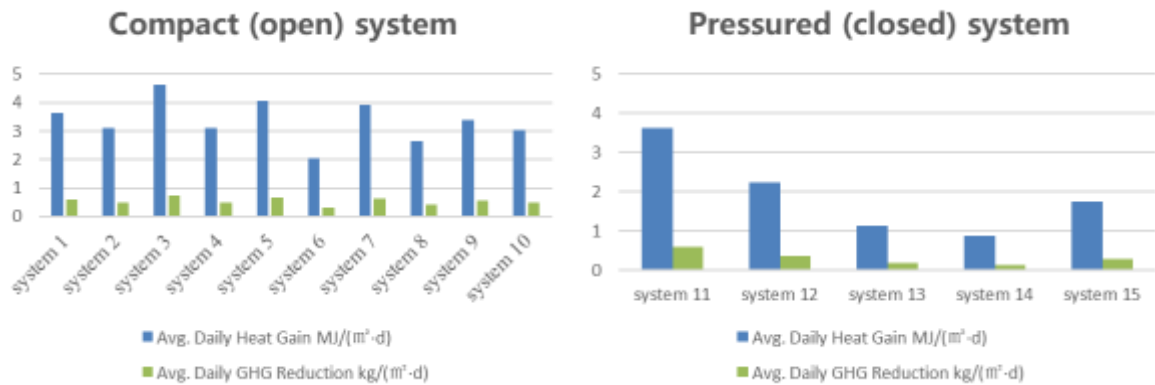


Figure 8: Long-Term Testing Results.

4.2 Results

By comparing the simulated and tested average daily heat gain, the deviation is within 12%. The accuracy of software calculations was verified.

Table 11: The Comparison of Simulated and Tested average Daily Heat Gain.

Type	Sample	Testing Results		Calculated Result		Deviation
		Avg. Daily Heat Gain MJ/(m ² ·d)	Avg. Daily GHG Reduction kg/(m ² ·d)	Daily Heat Gain MJ/(m ² ·d)	Avg. Daily GHG Reduction kg/(m ² ·d)	
Compact (open) system	1	3.62	0.58	3.19	0.52	11.9%
	2	3.18	0.51	2.97	0.48	6.6%
Pressured (closed) system	14	0.86	0.14	0.84	0.14	1.2%
	15	1.76	0.28	1.71	0.28	2.8%

GHG reduction have significant difference in different cities. Based on the developed carbon reduction calculation software, 14 cities with different solar energy resource have been used to analyse its application effect. The performance analysis is shown in Table 12.

Table 12: Annual Heat Gain and GHG Reduction in 14 Typical Cities.

Cities	Classification of solar energy resource	Slope	Total horizontal radiation (MJ/m ²)	Solar irradiation on title surface (MJ/m ²)	Annual Heat Gain (MJ/m ²)	Annual Heat Gain (kWh/m ²)	Annual GHG Reduction (kg/m ²)
Lhasa	I	30°	7200	8200	2800	780	460
Golmud		35°	7000	8300	2800	790	460
LinZhi	II	30°	6300	7100	2300	640	370
Hohhot		40°	5800	7200	2400	660	380
Xining		35°	5700	6600	1800	510	300
Guangzhou		25°	5000	5200	1900	540	310
Luoyang	III	35°	4800	5200	1700	470	270
Shanghai		30°	4700	5000	1600	450	260
Harbin		45°	4700	5800	1400	380	220
Beijing		40°	4700	5500	1700	460	270
Nanjing		30°	4400	4600	1500	420	240
Chengdu		30°	4100	4100	1200	330	190
Guiyang		IV	25°	3600	3700	860	240
Chongqing	30°		3200	3100	870	240	140

To obtain the national average operating effect, average GHG reduction is weighted according to the population of each region. The average heat gain is 490 kWh/m² and the average GHG Reduction is 280 kg/m². Based on these studies, a technical specification more suited to China's climate and usage conditions has been developed, titled technical specification at the project level for assessment of greenhouse gas emission reduction-Solar thermal applications.

According to Solar Heat Worldwide 2024, the total installed collector in China 545 million m². If they are all solar hot water systems, then the annual GHG reduction will be 155 million ton. Solar thermal technology has shown enormous potential in reducing carbon emissions.

5 Conclusion and Recommendations

Solar water heating systems stand as a proven, scalable solution for reducing carbon emissions in the heating sector. Methodologies like CDM, LCA, project-level specifications, and White Certification provide complementary frameworks for quantifying, verifying, and incentivizing these reductions. By integrating technical rigor with economic and policy support, stakeholders can unlock the full potential of SWH technology—contributing to global climate targets while fostering energy independence and sustainable development. As innovations in materials, design, and digital monitoring continue to emerge, SWH systems are poised to play an even greater role in the transition to a low-carbon future.

However, the current evaluation system still faces challenges in regional applicability, data standardization, and policy coordination. Particularly in developing countries and regions with significant climate diversity—such as China, where solar resource variations between cities are pronounced—directly applying internationally standardized methods may lead to evaluation results that deviate from reality. Therefore, it is recommended to further advance the localization and refinement of assessment methodologies in the future. This includes strengthening field verification of system performance under typical regional climatic conditions and building corresponding databases, while developing user-friendly computational tools to enhance the accuracy and scalability of evaluations. Concurrently, integrating comprehensive environmental assessment methods like LCA into product standards and green building certification systems should be encouraged to guide the industrial chain toward low-carbon materials and circular design.

At the policy and market mechanism level, countries can draw on Australia's “white certificate” model to explore pathways for converting carbon emission reduction benefits into economic incentives for consumers. This can be achieved by reducing users' initial investment costs through certificate trading, tax breaks, and installation subsidies. Additionally, international mutual recognition and alignment of methodologies should be strengthened to promote the establishment of cross-regional carbon emission reduction accounting platforms. This will enhance the liquidity of solar water heating systems in global carbon markets, further attract private sector investment, and expand project scale.

In summary, solar water heating systems are not only a key technology for decarbonizing building and industrial heating, but their emissions reduction assessment methods also serve as a vital bridge connecting technology, policy, and market. Future efforts should continue to strengthen methodological innovation, data support, and policy coordination to establish a comprehensive, multi-scenario, high-precision evaluation and incentive mechanism covering the entire project lifecycle. This will accelerate the large-scale deployment of solar thermal utilization technologies, providing robust support for global climate governance and green recovery.

6 Appendix

6.1 Abbreviations

SWH	Solar Water Heating
CDM	Clean Development Mechanism
LCA	Life Cycle Assessment
GHG	Greenhouse Gas
CERs	Certified Emission Reductions
UNFCCC	United Nations Framework Convention on Climate Change
ICCP	Impressed Current Cathodic Protection
STCs	Small-scale Technology Certificates
DOEs	Designated Operational Entities
VEU	Victorian Energy Upgrades
ESS	Energy Savings Scheme
CMP	Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol
CDM EB	CDM Executive Board
IEA	International Energy Agency

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6.4 References

- [1] Ken Guthrie AM, Australian Representative on IEA SHC Executive Committee, Former - Chair Australian Standards Committee CS028.