SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Technology Position Paper

Solar Energy Buildings

Integrated solar energy supply concepts for climate-neutral buildings and communities for the "City of the Future”

January 2025

Technology Collaboration Programme
by iea

Contents

This document was prepared by Harald Drück, Institute of Building Energetics, Thermo-technology and Energy Storage (IGTE), University of Stuttgart, Germany, as Manager of *SHC Task 66 "Solar Energy Buildings"* of the Solar Heating and Cooling Technology Collaboration Programme with input from Elsabet Nielsen (DTU Denmark), Frank Späte (OTH Amberg-Weiden, Germany), Franziska Bockelmann (Steinbeis-Innovationszentrum energieplus, Germany), Michael Gumhalter (AEE INTEC, Austria) and Dominik Bestenlehner (Ritter Energie- und Umwelttechnik GmbH & Co. KG, Germany)

DOI: 10.18777/ieashc-task66-2025-0001

This position paper outlines the status of solar thermal and solar photovoltaic technologies for supplying Solar Energy Buildings with heat, cooling and electricity, outlining their importance, potential, and development. It addresses issues for policy- and decision-makers, other stakeholders, and influencers. It presents high-level information as a basis for the uptake and further development of technologies for Solar Energy Buildings. It concludes by highlighting existing challenges and the actions needed to best exploit the use of solar energy to cover the energy needs of the building sector.

1 Introduction and Relevance

On a global level, the operation of buildings accounts for 30% of final energy consumption and 26% of greenhouse gas emissions[1]. In Europe, buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions[2]. In China, buildings are responsible for 21% of the energy consumption and 22% of the CO_2 emissions[3]. Additionally, building construction materials embody large amounts of energy. In China, building material manufacturing is responsible for 28% of CO_2 emissions.

A significant reduction of the non-renewable energy consumption of buildings is an important goal of many countries and regions around the globe. For example, in Europe, the European Parliament and the Council agreed on the latest recast of the directive on the energy performance of buildings published in April 2024 (EPBD; Directive 2024/1275/EU[4]). According to this version of the European Building Directive, only zero emission buildings that meet specific requirements related to energy efficiency and the use of renewable energy sources may be erected from 2030 onwards. In China, according to the general mandatory code for energy efficiency and renewable energy application in buildings issued in 2022, energy consumption of new residential and public buildings must be 30% and 20% lower, respectively, than designing energy requirements in 2016. In many cases, a completely renewable central energy supply for cities will be impossible due to a lack of space for renewable energy production inside the city. For this reason, decentralized solutions will also be needed in the city of the future that interact with existing grid infrastructures in the best possible way.

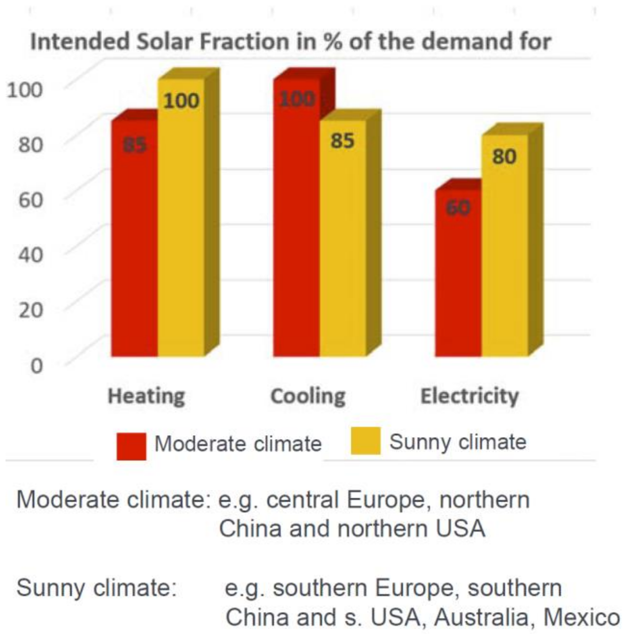

Figure 1. Intended solar fractions for heating, cooling, and electricity demand of Solar Energy Buildings in various climate zones, as defined in SHC Task 66.

What is a Solar Energy Building?

A Solar Energy Building is a building with a very high **solar fraction**. The solar fraction is the part of solar energy used in relation to the total energy consumption of the building, which is required for heating, cooling, and electricity. Considering economic and ecological aspects, the optimal solar fraction, as defined

1 https://www.iea.org/energy-system/buildings

2 https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

3 https://www.cabee.org/site/content/24420.html

4 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401275&pk_keyword=Energy&pk_content=Directive

in the context of IEA SHC Task 66, depends on the local climate conditions, as shown in Figure 1. In this context, the climate is predominately defined by the average ambient temperature and the available annual solar radiation. Solar Energy Buildings located in areas between sunny and moderate climates, for example Tibet, should be designed for a solar fraction between moderate and sunny climates.

2 Current Status

Today, solar technologies are used in the building sector to prepare heat for hot water production and space heating & cooling and to generate electricity.

In many countries, hot water preparation using solar thermal heating systems with different technologies, such as thermosiphon and forced circulation systems, is widely used in solar thermal applications. And using solar combisystems to provide hot water and space heating simultaneously is already a common practice in some countries. However, the solar fractions achieved with *typical* solar combisystems are around 20 to 30%, hence relatively low.

Using PV panels to produce electricity for different household appliances is common in many countries. Typical solar fractions are around 30% without and around 60% with electrical energy storage.

A relatively new technology is combined solar thermal and PV panels, or PVT collectors, to produce heat and electricity simultaneously. This technology is often combined with heat pumps. From 2018 to 2020, IEA SHC Task 60 focused on utilizing PVT collectors in heating systems with or without heat pumps. This work is continued by IEA SHC Task 73 on PVT heating systems, which started in January 2025.

To characterize the environmental and financial aspects appropriately, it is important to calculate the solar fractions based on short time intervals, e.g., 15 minutes, and not on an energy balance over one year. Using short time intervals to calculate the solar fraction is particularly important for electric systems because the electricity grid cannot store energy. Electricity fed into the grid is consumed immediately, and any excess photovoltaic energy generated in the summer cannot be stored for use in the winter. To cover electricity requirements in the winter, the grid must supply the electricity, which in many countries generally still contains a lot of electricity generated from fossil fuels. Calculating net values of the electricity consumption based on annual values results in significantly lower equivalent carbon emission values than in reality.

To contribute significantly to reducing greenhouse gas emissions, new buildings should be designed, and existing buildings should be energetically renovated so that high solar thermal and solar electrical fractions in the range of 60 up to 100% can be achieved - calculated on a 15-minute time interval.

Calculating the solar fraction using relatively short time intervals is especially relevant if the ratio of the storage capacity divided by the demand is smaller than the time interval used. In this case, the result strongly depends on the length of the time interval used. This is typically the case for grid-connected PV systems without electrical energy storage.

3 Potential

Several projects have shown that realizing economically and ecologically feasible solar energy supply concepts with high solar fractions for new and existing buildings and communities is possible.

Within SHC Task 66, twenty-one Solar Energy Building demonstration cases have been collected and analyzed. Solar Energy Buildings comprise single- and multi-family buildings as well as commercial buildings in different climate zones. These demonstration cases include buildings in district heating areas and individual buildings outside district heating areas. All demonstration cases, except one building in India, are connected to the electric grid. Solar Energy Buildings aim to achieve high self-sufficiency for heating, cooling, and electricity. The Solar Energy Building demonstration cases in Europe are in Austria, Germany, Poland, Portugal, and Denmark; in Asia, they are in China and India; and there is one in Australia (see Figure 2).

Figure 2. Location of Solar Energy Buildings demonstration sites.

A relatively extensive technology portfolio of Solar Energy Buildings is available. The investigation within SHC Task 66 has shown that the variability of technologies is more significant in European demonstration cases than in Asian ones (see Figure 3). While, on average, the thirteen European cases use five and the Australian case uses six different technologies to reach a high degree of self-sufficiency, the Asian average is three. This result is partly influenced by the fact that the Asian Solar Energy Buildings mainly do not require space heating.

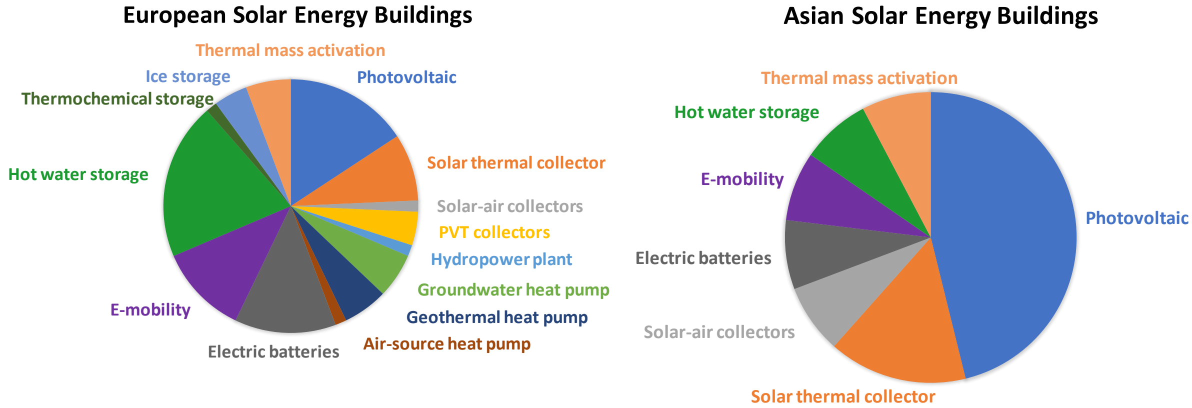

Figure 3: Technologies used in the investigated Solar Energy Buildings in Europe and Asia.

As a result of the survey, it was found that the use of the different technologies strongly depends on the region:

Europe:

- Solar thermal systems for hot water preparation and space heating
- Photovoltaic systems are often combined with batteries as electrical energy storage
- Photovoltaic-thermal (PVT) collectors and solar thermal air-brine collectors serve as heat sources for heat pumps. Solar thermal air-brine collectors are primarily used for melting ice storage but also provide an efficient heat source for heat pump systems.
- More than 60% of the Solar Energy Building projects use heat pumps in combination with solar thermal and photovoltaic systems.

Asia:

- Solar thermal systems for hot water preparation
- Photovoltaic systems are predominately used to provide electricity for cooling technologies
- In one particular case, in the high mountain region of the Himalayas, a solar air heating system is used for space heating and domestic hot water production.

Technology Radar

Within SHC Task 66, the motivation for realizing Solar Energy Buildings was investigated using a survey[5]. Figure 4 shows the factors that more than 80% of the survey participants across all countries considered important. These factors are mainly related to reducing CO_2 emissions and financial aspects.

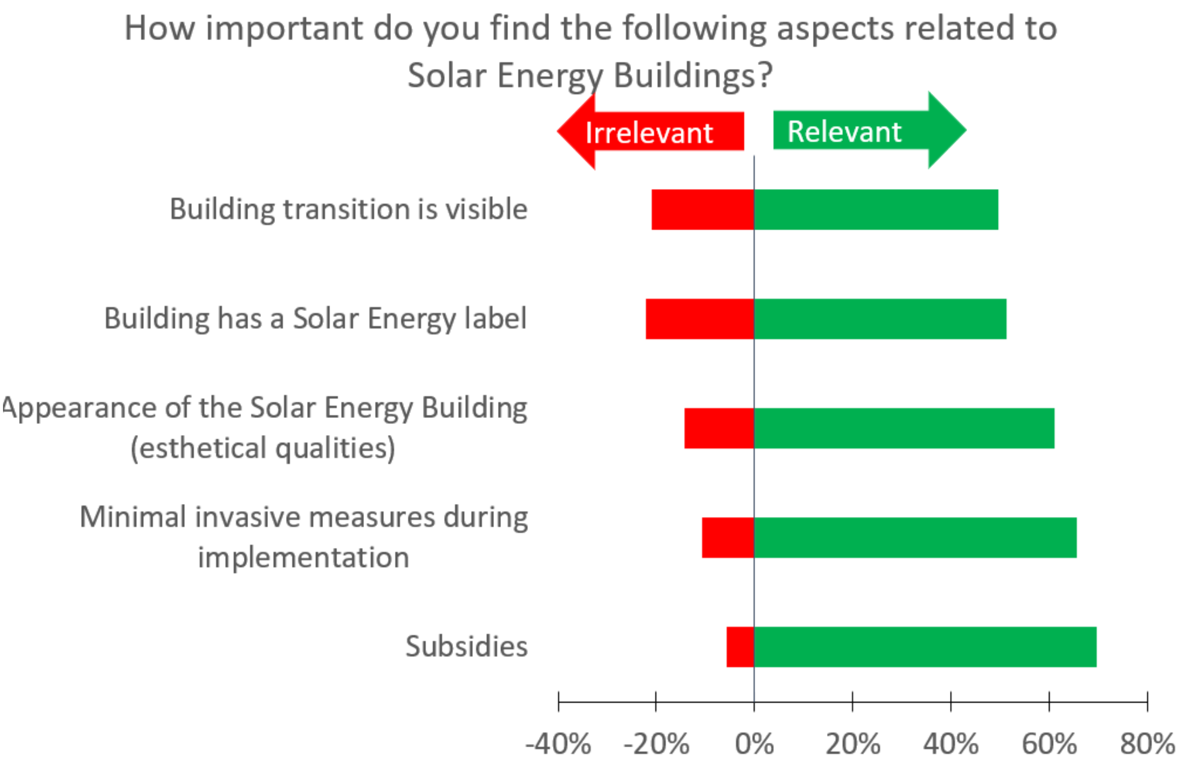

Figure 4. Most important factors: those that more than 80% of the participants indicated as “relevant” or “very relevant.”

[5] The survey was completed by 310 stakeholders, including academics (41%), consultants (20%), and participants from industry and public authorities, etc. The main countries of origin were Germany (104), China (101), Mexico (43), and Denmark (29).

Figure 5 shows an additional survey result. It is remarkable that besides subsidies, aesthetic aspects and the availability of a potential solar energy label for Solar Energy Buildings are highly relevant for many stakeholders.

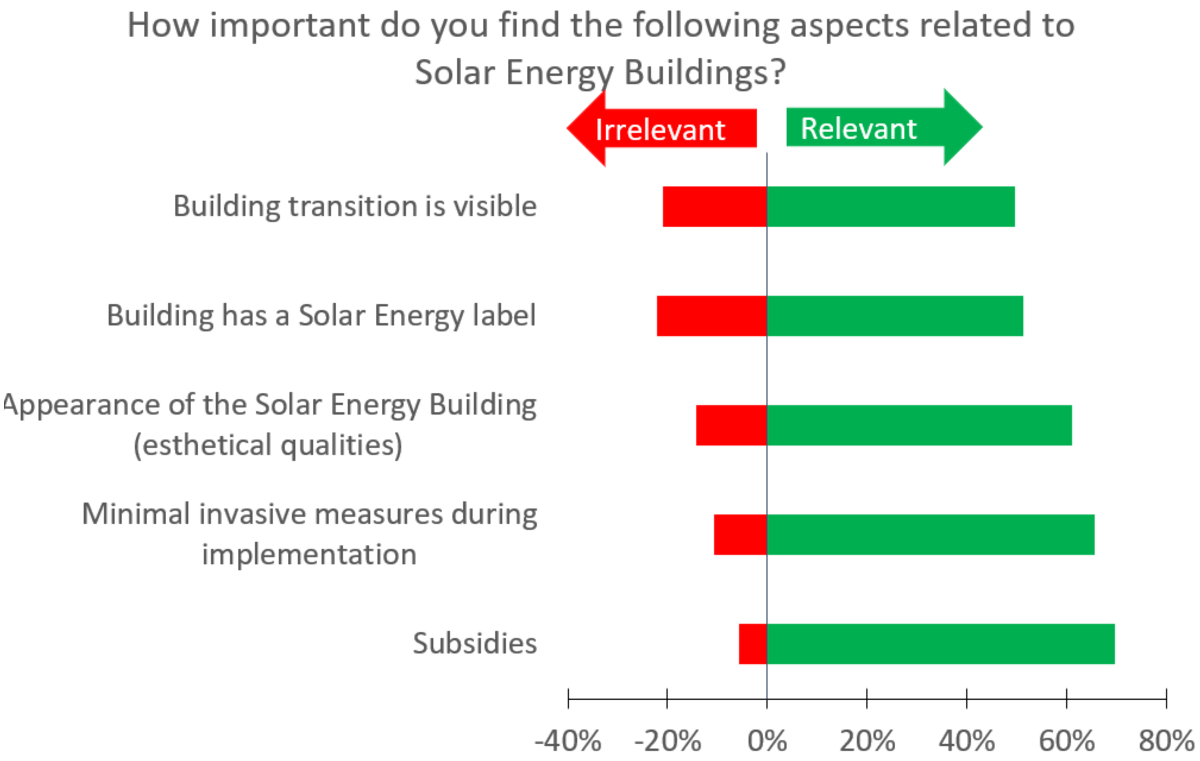

Figure 5. Less important factors: those that 50 to 70% of the participants indicated as "relevant" or "very relevant.

In addition to the results shown in Figures 4 and 5, a key survey result is that most respondents agreed there is a **huge potential for cost-effective Solar Energy Buildings with minimum CO_2 emissions.**

Concerning the potential of the various technologies for Solar Energy Buildings, the technology radar shown in Figure 6 was produced in SHC Task 66 based on a comprehensive technology review. The technology radar is divided into four main areas:

1. Generation
2. Storage
3. Thermal Grids
4. Buildings & Communities

In these four main areas, technological solutions, for example, energy facades and ice storage, are presented with their market potential for specific years by the size of the corresponding dot.

The technology radar in Figure 6 clearly shows **a high to middle market potential for many technologies, such as PVT collectors, heat pumps, and various types of energy storage, in the near future.**

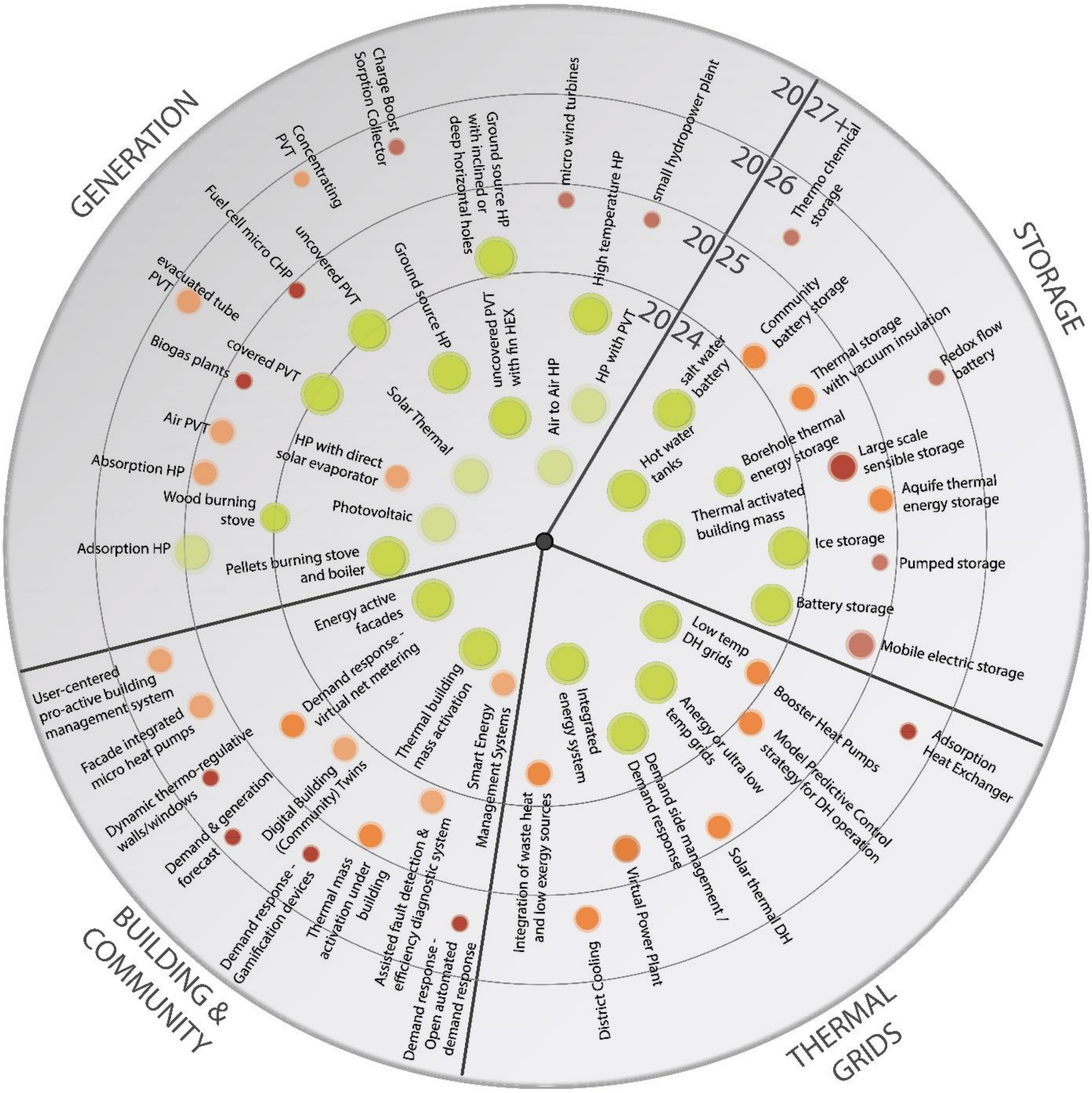

Figure 6. Technology Radar for Solar Energy Buildings.

4 Actions Needed

There is a huge potential for cost-effective Solar Energy Buildings with minimum CO_2 emissions. To benefit from this potential and implement Solar Energy Buildings as THE standard building technology in the near future, several challenges must be overcome. These challenges, the required actions, and related actors are listed in the following table.

Challenge	Action needed	Action by whom
Awareness raising for the benefits of Solar Energy Buildings	Promotion of the advantages of Solar Energy Buildings towards society, investors and politicians	• Industry and technology providers • Planners and architects • Energy consultants • Installation companies • Associations, NGOs, policy-makers, education sector • Environmental and consumer sectors
Provide financial incentives for Solar Energy Buildings	Subsidy programmes Tax reduction schemes Attractive financing instruments	• Policy-makers • Financial institutions and regulators
Establish standards and regulations beneficial for Solar Energy Buildings	Change of national building codes towards the requirement of zero energy buildings	• Policy-makers • Influencers (e.g., environmental and consumer NGOs)
Building Certification	Establish certification schemes for buildings exceeding requirements in building codes in a way that they are beneficial for Solar Energy Buildings	• Policy-makers • Certification bodies • Industry • Associations • Investors
Handbook and Software for designing Solar Energy Buildings	Used for training courses and provision of tools for stakeholders	• Industry • Investors • R&D institutions
R&D project for the further development of technologies for Solar Energy Buildings	Establishment of appropriate R&D funding schemes Applications for R&D projects	• Policy-makers • Industry • R&D community
Demonstration of Solar Energy Buildings	Dissemination of results of demonstration cases Establishment of local, climate zone specific demo cases	• Industry, R&D institutions • Municipalities • Politicians • Planners and architects
Dissemination of Solar Energy Building specific Know-How	Offer training courses of the design, construction and operation of Solar Energy Buildings	• Industry, R&D community • Education and training institutions • Associations, NGOs • Environmental and consumer sectors
Local production of technologies for Solar Energy Buildings	Establishment for local / regional production to create local jobs, to develop and keep Know-How, to increase resilience and to avoid unnecessary CO_2-emissions	• Policy-makers • Industry