RESOURCE EFFICIENCY WITH BUILDING INTEGRATED PV IN CONSTRUCTION

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ABSTRACT: The growing, intensive and unsustainable use of resources at local, regional and global level causes direct and indirect environmental problems such as climate change, soil and water degradation, land consumption, water shortage or biodiversity loss. Measures to reduce resource consumption are measures to reduce greenhouse gas emissions and thus contribute indirectly to climate protection. In the long term, the current use of resources endangers the basis of life for all people. At present, German policy makers are increasingly focusing on resource efficiency (efficiency gains), but this approach alone will not lead to a fair use of resources within the planetary boundaries, taking into account rebound effects. The debate about resource consumption does not stop at consumers. Public discourses clearly show that the way of life to date and one's own consumption patterns are being increasingly questioned, especially in the industrialized nations. Increasingly, consumers feel insecure in their purchasing decisions. At the same time, politics and business are being criticized by consumers. LCA as a tool must therefore be reconsidered. Building-integrated PV is capable of saving large quantities of non-mineral building materials.
Keywords: BIPV, CO_2-Emissions, Resource Efficiency, Green Building certification, LCA

1 INTRODUCTION

At over 90 billion tonnes, global material use has more than tripled compared to the 1970s. According to current UN estimates, this trend will continue. Forecasts expect a doubling to 180 billion tonnes by 2050 [1,2]

Resource consumption is not only a direct cost factor, but a key driver of major global environmental problems [1] Through the accompanying degradation of ecosystems and biodiversity and the acceleration of climate change, resource consumption is already having a negative impact on our livelihoods. The link between climate change and resource consumption is becoming increasingly apparent in society and the call for a resource transition is growing louder [3]. Its goal is to ensure equitable resource use within the limited capacities of our planet [4,5,6,7].

For example, a standardised procedure has been established through eco-balancing in accordance with ISO 14040/44 (1), but strategic control is lost in the complex presentation of input-output analyses.

Life cycle assessments need to be redefined and reconsidered.

2 LCA A1-A3, THE MOST IMPORTANT VALUES

2.1 Background:

German and European legislation on climate and resource protection in buildings is limited to improving energy efficiency during building use. Systems for assessing the sustainability of buildings such as German Sustainable Building Council (DGNB)(2), Assessment System for Sustainable Building (BNB) (3), Leed or Breeam, on the other hand, use an unmanageable number of indicators and are complex and expensive. At the same time, they do not address three major challenges of the 21st century in a concise and communicable way: climate protection, resource and energy transition.

So far, the systematic improvement of the environmental performance of buildings and settlements in Germany and Europe has been limited to increasing energy efficiency. In Germany, this was started very successfully in the late 1970s with the first Thermal Insulation Ordinance. To date, the specific energy consumption for heating buildings and supplying hot water has been reduced from more than 350 kWh/m^2/a to around 50 kWh/m^2/a with the current Energy Saving Ordinance. This corresponds to about 7/8 of what is theoretically possible. A further increase in energy efficiency is hardly possible, as the expected marginal expenditure of further measures necessary for this often exceeds the achievable marginal benefit.

In Europe, the Performance of Buildings Directive and the Energy Efficiency Directive also focus exclusively on energy consumption during building use.

Greenhouse gases and mass flows - and thus also the recycling of raw materials - have not been considered so far.

Systems for assessing the sustainability of buildings such as DGNB (2), BNB(1), Leed or Breeam use a variety of indicators. The DGNB (2) system for residential or office buildings, with its 139 criteria and sub-criteria, is more a comprehensive assessment system for the quality of buildings than for their environmental performance. An assessment according to these systems is comparatively costly and hardly economically feasible, especially for smaller or medium-sized buildings, and therefore only reaches a niche market. Moreover, indicators on mass flows and greenhouse gases - if available at all - only account for a negligible share of the overall assessment.

For the challenges of the energy transition, climate neutrality and the resource transition away from the linear economy based on non-renewable, mineral and metallic raw materials towards a cycle-oriented economy relying more and more on renewable raw materials, the existing certification system do not offer any outstanding, easily recognizable and well communicable criteria.

In addition, credits are possible in the life cycle assessment of the building, which are justified by a recycling of a building material after deconstruction. However, this is highly controversial. It is completely unclear whether and when a building will be deconstructed. One example of this is the completely deconstructible showroom of a furniture manufacturer in Baden-Württemberg, which was built in 2022 by Ludloff Ludloff Architects. This multi-award-winning building was simply demolished in 2025 due to a change of ownership. If you now calculate the life cycle assessment for the three-year lifetime, including the thermal recycling of the wooden components, you get a disastrous result in contrast to the LCA that was created when construction was completed. Only the PV system on the roof was reused. Furthermore, it is hardly possible to seriously estimate which disposal technology will be available in 50, 80 or more years and what resource demands will then be associated with it. It is equally unclear whether in 50 or 80 years there will be an interest in secondary raw materials that could be extracted from the deconstructed building.

Even more serious, however, is the fact that a CO_2 molecule released into the atmosphere with the production of the building materials will remain there for at least 1500 years. A CO_2 credit for a recycling that hypothetically takes place at the end of the building's useful life does not reduce this entry of greenhouse gases into the atmosphere. The same applies to the damage to ecosystem services as a result of raw material extraction. If credits are applied for any recycling that may take place at a later date, the sum of the greenhouse gases actually released into the atmosphere as a result of the construction and operation of a building does not match the amount of greenhouse gases indicated by the life cycle assessment according to DGNB (2).

2.2 Methodology

Focusing on CO_2 emissions in life cycles A1-A3 allows real emissions to be considered. In addition, these also accurately reflect the use of recycled building materials and biogenic building materials, as these emit significantly fewer emissions.

A distinction should also be made between active and inactive components. Inactive components are all non-renewable energy-generating components, while active components generate renewable energy.

In the case of building-integrated PV in particular, this allows the emissions avoided by not installing non-metallic building materials to be represented.

Below, we present the potential emissions that could be avoided in Germany through the use of roof-integrated PV.

3 SAMPLE CALCULATION:

The German Brick Association [9] states that around 90% of roofs in Germany are pitched roofs. 600 million bricks are produced annually. From this, the following assumption could be outlined:

- if bricks are used evenly in all directions in renovation or new construction (assumption)
- 25% each for south, west, east, and north roofs
- South, west, and east would be interesting for PV
- Approximately 75% of the 600 million roof tiles could potentially be replaced with PV roof tiles
- If we subtract areas where this is not structurally possible or where there are similar obstacles, we could assume a potential of 60%, for example
- This means that 60% of the 600 million tiles could be replaced.

3.1 Component layer analysis

Given the above requirements for increasing sustainability ambitions and classifying the relevance of modules A1-A3 of the classic life cycle phases according to DIN EN 15978:2012-10, there is a need to reduce potential material flows in order to minimize the amount of emissions caused during the construction of buildings. While classic optimization approaches for reducing GWP values are limited to changing building materials (e.g., concrete to wood) or the use of recycled building materials, the consideration of envelope-integrated PV surfaces reveals the potential to eliminate classic facades or roof coverings in the overall structure, thereby actively dispensing with building materials in the construction.

Within a classic roof structure, the following roof structure is usually created for a pitched roof.

Reference – sample roof cladding structure:

Interior:

Sloping roof structure (material according to structural and fire protection properties)

- Between-rafter insulation or above-rafter insulation
- Integration of various membranes for sealing and air regulation
- Roof covering substructure (1)
- Roof covering made of tiles or metal roofing (2)
- Substructure for photovoltaic system (1)
- Photovoltaic system

Exterior

Individual market participants are primarily promoting the development of roofing with photovoltaic-integrated energy generation potential in the roofing sector. The spectrum ranges from individual roof tile-like PV modules to bundled PV elements that can be integrated into a roof tile system and do not require any additional sealing.

Integrating this potential into the model structure outlined above offers the potential to reduce the substructure (1) by one substructure and, at the same time, to minimize the area of necessary roof covering (2) by the area of the PV-integrated materials. This integration enables the promotion of self-sufficiency through self-generated electricity and, at the same time, the reduction of emission-intensive materials such as fired roof tiles, which, similar to bricks, have a high energy and thus GWP impact on the overall construction due to the production process.

In a sample comparison, ÖkoBauDat 2023 and the ELCA Baustoffe tool were used to outline materials that can be eliminated from the building construction with a PV-integrated solution.

Facade:

1. Facing bricks: A1-A3 GWP = 60.78 kg CO2 equiv. / m^2
2. Fiber cement: A1-A3 GWP = 14.05 kg CO2 equiv. / m^2
3. Artificial stone: A1-A3 GWP = 28.35 kg CO2 equiv. / m^2
4. Sheet metal: A1-A3 GWP = 12.94 kg CO2 equiv. / m^2

Roof covering:

1. Roof tiles: A1-A3 GWP = 15.38 kg CO2 equiv. / m^2
2. Sheet metal: A1-A3 GWP = 12.94 kg CO2 equiv. / m^2
3. Slate: A1-A3 GWP = 9.57 kg CO2 equiv. / m^2

If we take a classic single-family home measuring 10 x 10 m with a roof pitch of 45% as a prime example, the potential roof area for a gable roof is around 140.00 m^2. Assuming a west-east orientation, which allows both roof surfaces to be used for solar energy, and assuming that half of the area is used for PV, this results in around 70.00 m^2 of roof area that can be used for PV-integrated modules. This leads to the elimination and savings of the following idealized GWP values:

Roof covering:
1. Roof tiles: A1-A3 GWP = 15.38 kg CO2 equiv. / m^2 x 70 m^2 = 1,076.6 kg CO2 equiv. savings

2. Sheet metal: A1-A3 GWP = 12.94 kg CO2 equiv. / m^2 x 70 m^2 = 905.8 kg CO2 equiv. Savings

3. Slate: A1-A3 GWP = 9.57 kg CO2 equiv. / m^2 x 70 sqm = 669.9 kg CO2 equiv. Savings

For classic roofing with fired clay tiles, the use of roof-integrated PV elements results in a reduction of around 1 ton of CO_2 equivalent, which is achieved by not using the building material.

4 OUTLOOK AND POTENTIAL

If the reference values outlined above are scaled up to an entire country, despite the relatively small-scale analysis, there is considerable potential to be gained from the sensible combination of PV-integrated solutions and the elimination of additional building materials.
Taking Germany as an example and referring to information from the brick industry that around 90% of roofs in Germany are pitched roofs and 600 million roof tiles are produced each year, this results in a potential saving of 300,000 tons of CO_2 equivalent [9].

A:
600,000,000 (roof tiles per year) / approx. 11 tiles per m²
= approx. 54,000,000 m² (cover area)

B:
approx. 54,000,000 m² (cover area)/ 4 (cardinal direction) x3 (cardinal direction with PV potential)
= approx. 40,900,000 m²

Implementation of 50% of approx. 40,900,000 m² as PV-integrated area instead of roof tiles plus PV system.

20,450,000 m^2 x 15kg CO_2 equiv. /m^2 (roof tiles according to ÖkoBauDat) = approx. 300,000,000 kg CO_2 equiv

Corresponds to approx. **300,000 tons** CO_2 equiv.

This assumption is based on the space requirement of around 11 tiles per square meter of roof area, which, with a requirement of 600 million roof tiles, would enable a potential coverage of around 54 million square meters of roof area.

Assuming that the roof areas are evenly distributed across the cardinal directions north, south, east, and west, this results in a potential PV usable area of 75%, which is primarily suitable for solar use (west, east, south). This means that there is a remaining area of around 40 million square meters that is suitable for PV-integrated modules in new buildings or renovations.

Under a conservative assumption that only 50% of this potential area will be used, there remains around 20 million square meters of tile surface that can be replaced by PV-integrated modules. In this case, the PV system is not installed directly on the roof tiles, but replaces this building material in the overall construction. Based on an estimate of 15.38 kg CO_2 equivalent per m^2 of roof tile and a usable area of 20 million m^2 of roof space, this would result in a conceptual reduction of around 300,000 tons of CO_2 equivalent in newly produced roof tiles that would no longer need to be installed due to PV integration. This does not take into account metal substructures, which are required in many areas for PV integration on roof surfaces in order to attach the large-area modules.

A similar potential and methodology can be derived for the facade area, which is primarily limited to curtain walls. This typology is mostly used in standardized buildings and could reveal new potential for industrial buildings.

In summary, it can be outlined that the consideration of A1-A3 building materials also offers short-term reduction potential in the small-scale area in order to actively reduce current emissions in pursuit of climate targets.

A reliable determination of emission savings requires further detailed basic research and varies depending on the country and industrial orientation. The dependence here is on building typology, regional material selection, and roof orientation, which must be determined.

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6 LOGO

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