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# Secondary Materials in the Building Sector – Energy and Material Flows

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**Abstract**. The recycling of construction and demolition waste is an important step-stone towards the achievement of resource conservation and the reduction of environmental impacts through construction. To this end, the recycling of construction waste usually is considered from a mass perspective. But it is necessary to add an energy perspective to the production of secondary raw materials in order to develop environmental sound solutions and to reveal likely conflicts between environmental objectives. It is not yet clear how to implement such a combined analysis. Therefore, the aim is to develop an orientation framework that integrates the mass and energy perspective of recycling in the construction industry. The paper presents differences and specific particularities of building product groups and answers the following question: What is the energy expenditure associated with the sorting and processing of construction and demolition waste and what is a suitable basis for comparing the various options for the use of recycling materials?

## 1. Introduction

Studies on recycling in the construction sector usually examine which building materials can be easily recycled, which yield of secondary materials is possible and which material losses (waste for dumping) can be expected in the treatment processes [1]. Resource saving potentials by secondary materials are known for selected construction product groups in terms of mass (in tons) [1, 2, 3]. An assessment of resource saving potentials based solely on information in tons is problematic, because it does not take energy-related aspects into account. There are individual studies that focus on specific construction products with regard to the energy used in recycling [2]. However, there is no comprehensive overview for all important construction products. There is a lack of a common approach with which important building products can be presented synoptically and compared to each other in terms of their energy consumption during recycling.

The aim of the investigations is therefore to expand the mass and volume-oriented studies on resource saving potentials by energy considerations and to develop a synoptic research approach. Ten construction products are considered: concrete, bricks, limestone, plasterboard, timber, flat glass, mineral insulation, oil-based insulation materials, plastic profiles, and other plastics.[1] The production

[1] Timber and oil-based insulation materials dropped out of the further investigations because the energetic utilization is predominant.

and processing of secondary materials are examined taking into account the quality of the deconstruction material and the different future application variants in the construction sector. A comparison of the construction products reveals product-specific features and differences.

## 2. Methodology

The production of secondary materials is associated with expenditures, e.g. in terms of energy, labour, costs, and environmental pollution. At the same time, secondary materials can substitute and save primary materials and thus contribute environmental benefits and enhance resource efficiency. In order to realistically estimate the adverse effects of energy expenditure, it is necessary to think in "integrated" process chains from the deconstruction to the envisioned final use: From demolition, through the production to the secondary material and the further processing and conditioning in order to fit to the application variant.

Secondary materials can originate from demolition materials in quite different qualities, can be processed through a range of different process steps and can be used in different application variants. Therefore the range of possible process chains is considerably high. According to the final "destination" of the secondary material in a new building product the required quality and possible quantity of added secondary material in the new product differs. In order to cope with this complexity of possibilities, two to three possible process chains – starting from two to three deconstruction qualities and resulting in two to three application variants – were selected for each construction product group (figure 1).

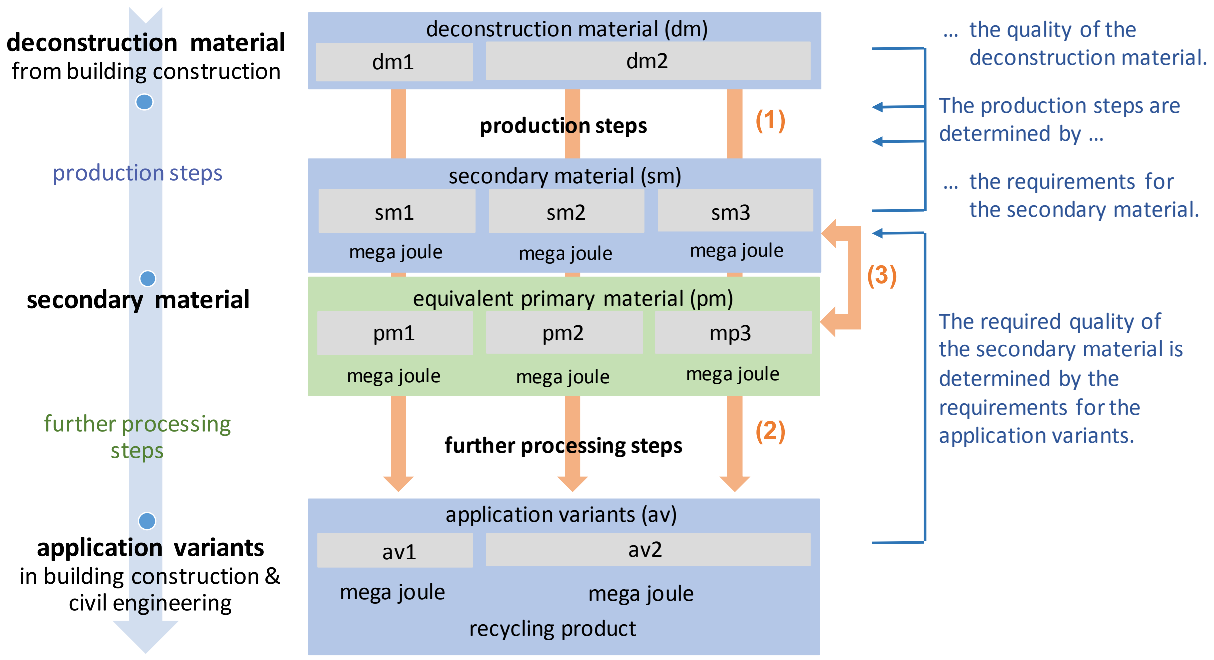


**Figure 1.** Analytical model

In order to be able to analyze and compare the energetic implications of the different process chains, a common balance sheet framework must be defined and terms must be clarified.

The clarification of terms is partly done under consideration of DIN EN 15804 [6]. Table 1 shows the definitions of the most important terms.

**Table 1.** Definitions of different terms used in this study

| Term | Definition |
|---|---|
| Deconstruction material | Deconstruction materials are available after demolition and have certain quality properties as starting material for recycling (e.g. sand-lime bricks with or without coarse adhesions). |
| Secondary material | In the disposal phase, the deconstruction material loses its waste properties through appropriate processing steps and becomes a secondary material (under consideration of DIN EN 15804). Preparation and processing steps are used to produce secondary materials from deconstruction materials, which can substitute primary materials. |
| Co-product | In one and the same process, the "target" product (secondary material) as well as co-products are produced. They are all considered equally for the analysis and must be distinguished from waste (under consideration of DIN EN 15804). |
| Waste | All materials that accumulate in a process and can no longer be used or recycled are waste. |
| Production of secondary material | The production of the secondary material comprises all processing and preparation steps that are necessary to produce the required quality of the secondary material. |
| Further processing of secondary material | In order to replace the primary material, the secondary material is further processed to obtain the necessary qualities with respect to particular application variants. Compared to the standard of primary material production, the further processing of the secondary material may include: modified process steps (e.g. lower melting temperatures), modified recipes (e.g. different additives and mixing ratios) and modified transport requirements (e.g. longer/shorter distances). |

The balance sheet framework is divided methodically into three steps (figure 1).

1. Production steps.
2. Further processing steps.
3. Comparison of energy expenditure for secondary material and equivalent primary material.

All process chains are analysed according to these steps.

### *2.1. Analysis of the production steps*

First, the process chain from deconstruction to the secondary material is analysed. Here, information about all necessary production steps are required. For example, for the secondary material “Recycling-gravel 2/16 type 1” (application variant: foundation concrete C20/25), the following preparation steps were calculated: comminution, metal separation, manual selection, classifications, recirculation and again comminution and classification. These steps are linked to average energy consumption by the technical components used for each of these steps (taken from energy fact sheets for machines, plants). These are added to a total value for the production of the secondary material.

### *2.2. Analysis of the further processing steps*

Now it is analysed whether the use of the secondary material, e.g. in the production of concrete C20/25 for use in foundations, results in production process changes compared to the use of primary material. Here it is of particular interest whether recipes change, whether process steps are obsolete or additional ones are necessary and whether additional transports occur. These potential additional and reduced expenditures were estimated based on results from workshops and targeted interviews with construction industry experts. They estimated these from an energy perspective in the form of percentage premiums and discounts. For example, there may be minor changes in the formulation of superplasticizer, admixture, cement and water. Experts estimate this to be a 1% increase in energy consumption. There are no modified process steps for this example. However, depending on the local situation, transport distances may be longer or shorter. The transport effects could not be estimated by the experts (there is a clear research gap).

### *2.3. Comparison of energy costs for the production of secondary materials and primary materials*

The premiums and discounts estimated by the experts are added to the secondary material's energy expenditure. This results in energy expenditure in MJ/kg that can now be compared with the energy expenditure of the primary material in MJ/kg (values for primary material were taken from the "Ökobaudat" database [7] or Environmental Product Declarations (for example [8])). The difference shows whether or not recycling is favourable from an energy perspective.

## 3. Results

Following the three analytical steps, the process chains of the individual construction product groups were defined and analysed. Although the investigations have not yet been fully completed, it is clear that the use of secondary materials can be a favourable alternative to the use of primary materials, as the examples of concrete and flat glass show (table 2).

**Table 2.** Comparative analysis of secondary material and equivalent primary material as standard (example: two possible process chains for concrete).

| | concrete<br>process chain: dm1 – sm1 – av1 | flat glass<br>process chain: dm1 – sm1 – av1 |
|---|---|---|
| deconstruction material (dm) | dm1: concrete breakage without coarse adhesions | dm1: flat glass from windows and doors |
| secondary material (sm) production | shredding; metal separation, manual selection; classification; repeated classification, recirculation, shredding | metal separation; classification, recirculation, shredding; separation of light materials; sorting out foreign shards/ foreign matter |
| co-products | 52 % co-products and waste | 15 % co-products and waste |
| secondary material (sm) | sm1: 48 % recycled aggregates 2/16 type 1 | sm1: 85 % recycled shards of glass |
| energy sm (production) | 0.0239 MJ/kg (own calculation) | 0.043 MJ/kg (own calculation) |
| further processing sm | <u>modified process steps</u>:<br>0,0239 MJ/kg ± 0 %,<br><u>modified transport distances</u>:<br>no information<br><u>modified recipe</u>:<br>0.0239 MJ/kg + 1 % (0.0002 MJ/kg; changed quantity of superplasticizer, admixture, cement, water) | <u>modified process steps</u>:<br>0.043 MJ/kg -25 % (0,011 MJ/kg; shards of glass: lower melting temperature),<br><u>modified transport distances</u>:<br>no information<br><u>modified recipe</u>:<br>0.043 MJ/kg ± 0 % |
| energy sm (production and further processing) | **0.0241 MJ/kg** (own calculation) | **0.032 MJ/kg** (own calculation) |
| primary material (pm) | pm1: aggregates of natural gravel (70 %) and chippings/gravel (30 %) | pm1: quartz sand |
| energy pm | **0.120 MJ/kg** (Ökobaudat [6]) | **0.049 MJ/kg** (Ökobaudat [6]) |
| application variant | av1: foundation concrete C20/25 | av1: toughened safety glass |

The energy required for the secondary material always depends on the quality to be achieved and the share of usable co-products (they shoulder a part of the energy input of the process). The analysis of the two process chains for concrete and flat glass make this clear. In the case of concrete (s1: aggregates 2/16, av1: foundation concrete C20/25) 52 % of the material is discharged. In the case of flat glass (s1: shards of glass, av2: toughened safety glass), this is only 15 %. According to these percentages, the energy required for the production steps is distributed between the target- and co-products (mass approach). This results in different energy expenditures for the production of the various secondary materials. Also in the further processing steps from the secondary material to the final application, energy increases or decreases may occur compared to standard processes due to modified process steps, transports or recipe changes. In the case of concrete, larger quantities of superplasticizer, cement and water may be required in the formulation under certain circumstances for quality assurance purposes. As shown above experts calculate this with an additional energy input of 1 %. In the case of flat glass, there are no recipe changes but changed process steps. The use of glass shards reduces the melting temperature and saves energy (-25 %). The approach of analysing the secondary material under consideration of its final application is therefore important and helps to identify energetic recycling differences between the building products.

## 4. Conclusions

Recycling of construction materials not only saves material masses in tons but also energy and thus $CO_2$ emissions (exception: in case of gypsum plasterboards this is questionable). There are also limits to recycling, as only a certain recycling admixture in percent is possible, depending on the construction product groups and application variants.

Recycling is regarded as a comprehensive process that should not be oriented at all costs to "high-quality" recycling (e.g.: from building construction to building construction). In general, it is important to keep materials in use at lowest possible energy input and to avoid landfill. For example, the use of brick aggregate as a gravel bearing layer should be regarded/evaluated as similarly positive as a use as vegetation layer for green roofs (the energy required to produce brick aggregate is lower than the production for vegetative layer).

In order to work out the special features of the individual construction product groups, clear material flow-oriented considerations are important. Within the framework of the investigations, comparisons of secondary material and primary material are meaningful at the material level. Here DIN EN 15804 is an orientation.

Transportation has a significant impact on energy consumption during recycling. However, up to now, only rough estimates have been possible. Further research is necessary.

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