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Planning-oriented Material Flow Analysis to support the management of mineral resources extraction in Vietnam

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Abstract

In Vietnam, increased industrialization and the rising demand for infrastructures and buildings are creating great markets for the use of sand, gravel and crushed stone (aggregates), particularly in high growth urban areas like the Hanoi Metropolitan Region. A sustainable, application oriented and long term planning of mining activities depends largely on the quality of information about the expected demand for those materials. Dynamic material flow analysis (MFA) is a helpful tool to analyse the material stock in the built environment as well as the annual demand for raw materials. Particularly suitable is a bottom-up calculation approach, since it not only provides valuable information on the quantity of the required materials, but also on the required qualities.

The developed MFA model aims finally to better forecast the demand for mineral building materials and subsequently to foster a more sustainable long term mining and land use planning.

Key Words: Aggregates mining, material flow analysis (MFA), bottom-up calculation, mineral building materials, Vietnam.

1. Introduction

Vietnam is a fast developing country striving for economic growth, higher urbanization and more prosperity. By fostering extensive new construction activities for infrastructures and buildings through policy measurements, greater markets for the use of sand, gravel and crushed stone (aggregates), particularly in high growth urban areas like the Hanoi Metropolitan Region, emerge rapidly. Neighbouring provinces like Hoa Binh are responding quickly and with short term planning to the rising demand and are consequently experiencing a more and more severe threat to its natural environment due to increasing mining activities. In order to align mineral material planning as best as possible with the expected demand for mineral building materials, a planning oriented material flow analysis was conducted based on a stock-dynamic bottom-up approach for the case study area of Hoa Binh province and Hanoi.

MFA represents a possibility to analyse material flows between the biosphere and the anthroposphere and further between the entities within the economy according to qualitative, quantitative and spatial factors [1]. This study focus especially on the relation between mining of mineral building materials and their use in the built environment. Starting from the raw material development in Hoa Binh, a spatial framework is set up by analysing client relationships that exist almost exclusively between Hoa Binh and Hanoi and within Hoa Binh.

Based on the developed MFA model, sensitivity analysis will evaluate whether uncertainties regarding the assumptions and used parameters possess an impact on the results of the studies, and how material flow analysis depends on variations of those parameters.

The model aims finally to support forecast and to discuss influencing factors of the demand for mineral building materials and subsequently to foster a more sustainable long term mining and land use planning.

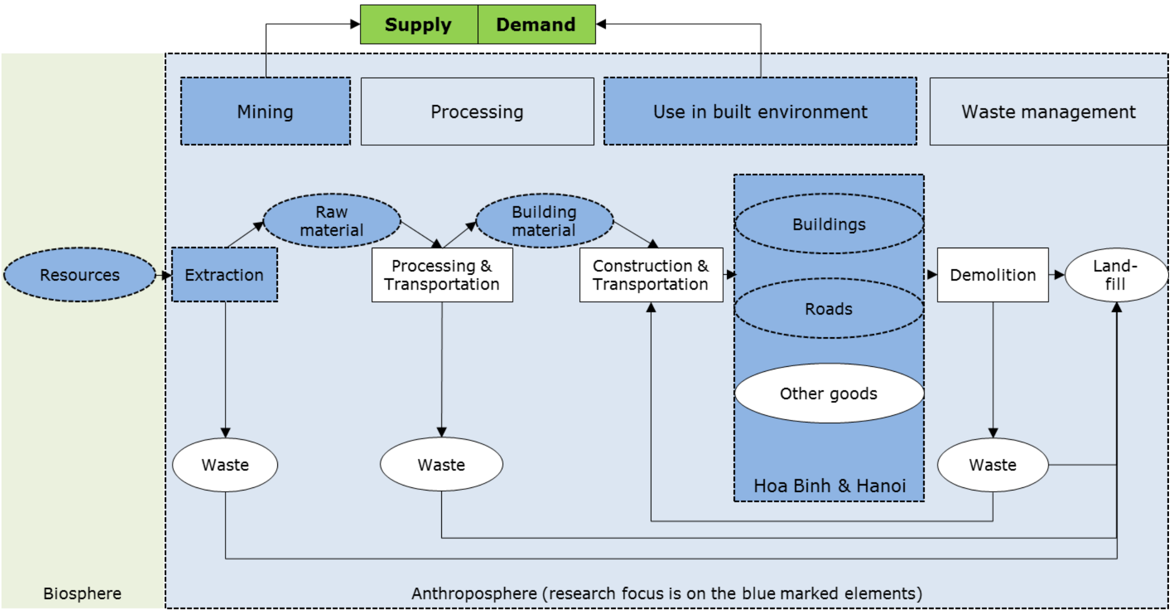

Figure 1: System boundaries and research foci (in blue, dotted lines)

2. Materials and Methods

The developed model is based on methods of dynamic material flow analysis (MFA) of mineral building materials, which is a frequently used method to assess past, present, and future stocks and flows of materials [2]. In this section, the method of a dynamic stock-driven bottom-up MFA approach for mineral building materials will be presented by considering the applied materials. Basically, all empirical and technical information was collected and analysed in close cooperation with Vietnamese researchers and experts. All statistical data is gained from the departments of transportation and construction in Hoa Binh and Hanoi. All applied materials are presented in detail in the following section.

2.1. System boundaries

Worldwide the main part of materials stocked in the built environment is used for buildings and roads. In Japan for example, nearly 43% of the in-use building materials are stocked in buildings and 26 % in roads [3]. Since the material composition as well as the stock dynamics of roads and buildings differ significantly, the two subsystems are calculated and analysed separately. Due to the spatial system boundaries of the case study area, the model is additionally divided into two further sub-systems, Hoa Binh Province and Hanoi, which are defined according to the administrative boundaries. The fixed system boundaries are shown in Figure 1.

2.2. Stock dynamic

Derived from [4] the model described in this article is developed based on a stock-driven approach. Herein it is assumed that the new construction activities and replacement of the existing stock (buildings and roads) drives the inflows and outflows of materials [5]. In order to make appropriate assumptions about the future behaviour of the in-use stock of building materials not only a prospective but also a retrospective analysis is carried out.

The dynamics of the dwelling stock is driven by population development, the change in consumed floor-space per person and inhabited building types and the renewal rates within the stock [6]. Figures about the past and forecasted population growth as well as the consumed floor space per capita and building type are given in official statistics [7].

Information about the road stock can be gained based on statistical data about the length of the road network, differentiated according to road classes (e.g., highways, district roads, etc.) and pavement types (e.g., concrete slab, crushed stone, etc.), and the width of the respective roads. Due to lacking data about the prospective development of the road network, the road stock is only analysed retrospectively. Scenarios about the future stock are based on assumptions concerning dependencies between the stock dynamics of buildings and roads. The calculation of these scenarios will be presented subsequently.

$$s_B(t) = p(t) * \frac{NFA}{pers.}(t) \quad (1)$$

$$s_R(t) = l_R(t) * w_R \quad (2)$$

with:

$s_B(t)$ stock of buildings [m²] in year t
$p(t)$ population [pers.] in year t
$\frac{NFA}{pers.}(t)$ net floor area per capita and building type [m²/pers.]
$s_R(t)$ stock of roads [m²] in year t
$l_R(t)$ length of roads [m] in year t
w_R width of road [m]

The indicator describing the building or road stock and its dynamic (e.g., number of buildings, floor area, road length or road surface) has to be defined according to the regional data situation. In the presented model this indicators are expressed as floor area [m²] for buildings and road surface [m²] for roads respectively [6].

2.3. Bottom up approach

Given the dynamic of the stock, a bottom-up approach can be used to calculate material flows by considering material composition indicators (MCI). This requires the definition of indicators to characterize material compositions of typical buildings which refer to the defined indicators describing the stock (e.g., tonnes per floor area [t/m²], tonnes per road surface [t/m²]). Aggregate material flows can then be determined by multiplying the MCIs by the sum total of physical changes in the stock (e.g., [8], [9], [10]). On the basis of these principles and derived from [6], a dynamic stock model for Vietnam is established as shown in equation (3) and (4).

$$c_B(t) = s_B(t) * (1 + r_B(t)) - s_B(t-1) \quad (3)$$

$$c_R(t) = s_R(t) * (1 + r_R(t)) - s_B(t-1) \quad (4)$$

with:

$c_B(t)$ constructed buildings [m²] in year t

$c_R(t)$ constructed roads [m²] in year t

$s_B(t-1)$ stock of buildings [m²] in year t-1

$r(t)$ renewal rate in year t

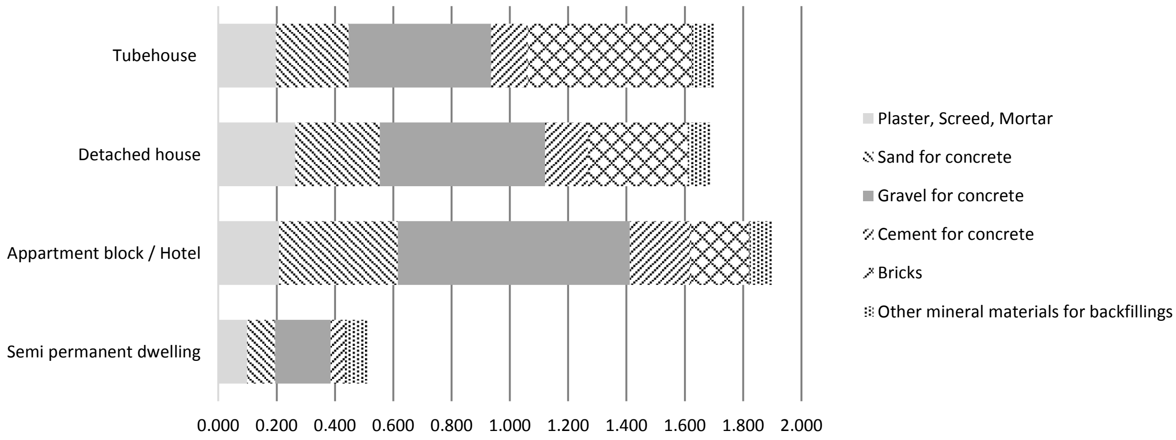

Figure 2: Compositions of mineral building materials in typical building types in Vietnam based on metric tonnes per floor space (own calculation based on empirical data)

Using equation (5), the regionalized annual material input flows in buildings can be calculated. The same applies to annual material input flows in roads.

$$m_{B,in}(t) = \sum(MCI_{B,i} * c_B(i,t) \quad (5)$$

with:

$m_{B,in}(t)$ total input in buildings [t] in year t

$MCI_{B,i}$ material composition indicator for building type i [t/m²]

$c_B(i,t)$ constructed buildings [m²] of type i in year t

Figure 2 gives some examples for the mineral material compositions (MCIs) of typical Vietnamese buildings. All developed MCIs, for buildings as well as for roads, are elaborated based on [9]. In the course of excursions with professionals working in the construction sector in Hoa Binh and Hanoi, empirical data were obtained and subsequently analysed in close cooperation with Vietnamese researchers and experts.

3. Results

In this section, the results of an application of the MFA model to estimate quantities and qualities of mineral materials demanded from the built environment in Hoa Binh and Hanoi.

3.1. Planning challenges regarding quantities of mineral materials

In order to establish a sustainable mining planning, the demand for building materials has to be estimated in the long term by responsible authorities for raw material supply planning. The analysis of planning data suggests that the current strategic planning of mining activities is not sufficiently geared to the demand for building materials of Hoa Binh Province itself and of Hanoi. Thus, it is difficult for the responsible authorities to plan the allocation of licences long term and based on spatially differentiated quantitative data.

In the currently valid mining master plans ([11], [12]) of Hoa Binh Province three calculation methods are presented to assess the demand for building materials within the province. The choice of the method in order the material demand of Hoa Binh is justified by the fact that a calculation according to the growth rate in consumption of building materials corresponds most to the real situation in the past period. The projected demand for building materials in Hanoi is mentioned, but neither further discussed nor analysed.

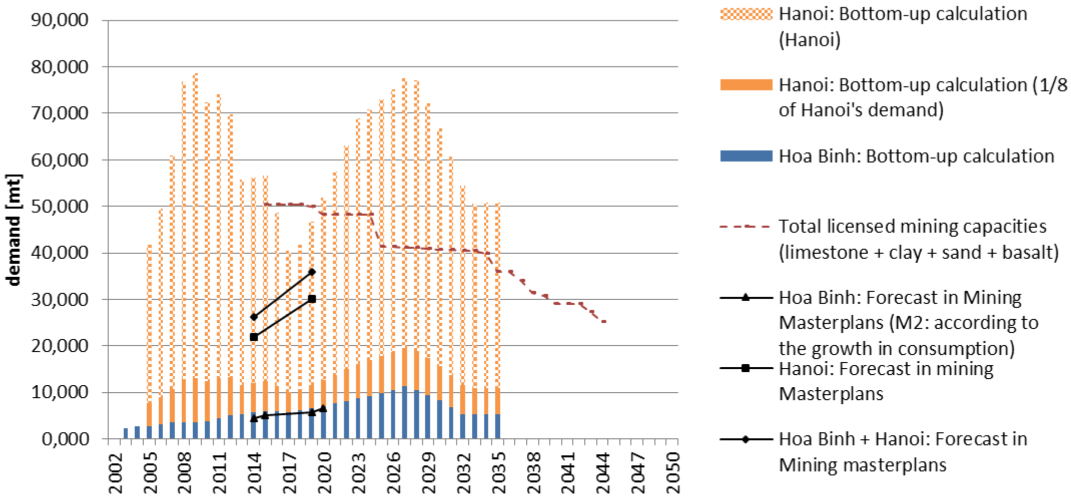

Figure 3: Annual demand (Hoa Binh & Hanoi) and supply (Hoa Binh) of mineral building materials

Figure 3 shows the material demand of Hoa Binh and Hanoi forecasted by official mining masterplans of the province (black), the sum of licenced mining capacities (state 2015, red) and the results of a bottom up estimation of the material demand of Hoa Binh and Hanoi (blue and orange). Assumed that each neighbouring province of Hanoi and Hanoi itself covers 1/8 of its demand for mineral building (filled out orange areas), it can be estimated how much material Hoa Binh should provide annually to meet the demand.

According to the Figure 3, the regional demand for mineral building materials is significantly below the annually available and licensed mining capacities. Since in praxis only the demanded quantity is actually mined, there is an annual supply surplus. This surplus will be available as an additional still unused capacity in the next few years, so that available future mining capacities will increase without requiring new licenses. Thus, an actual development of the mining capacities can be expected, which runs counter to the red dashed line in Figure 3.

3.2. *Planning Challenges regarding qualities of mineral materials*

Application-oriented raw material planning can not only take place at the general level of mineral building materials. It is necessary to differentiate quantities according to kinds of material groups (basalt, limestone, clay, sand). The demand for the individual materials depends on the intended use. Buildings and roads, e.g., require different materials. Building and roadwork activities are not in line with the same dynamic. In addition to that construction methods with regard to both, buildings and roadworks may change over time.

All of them is influenced by settlement and construction policies.

Figure 4: Production of aggregates for different applications in the construction industry

The rather rough and short term top-down estimation of the demand for building materials, which is carried out for planning mining activities and the granting of mining licenses in Hoa Binh, has no relation to the components (buildings, roads) of the built environment.

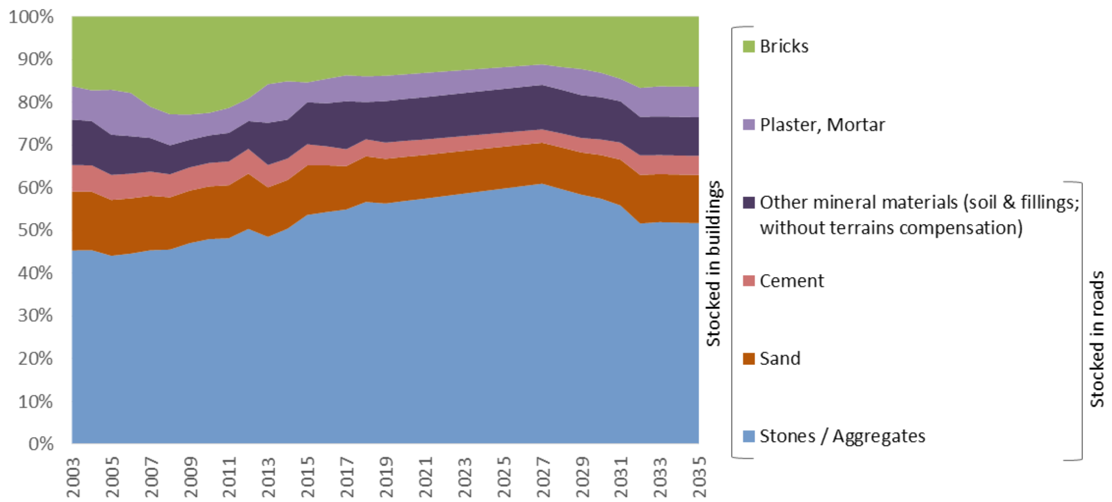

Figure 5: Percentage distribution of required mineral building materials in Hoa Binh Province

For this reason, a long term estimation of mineral material supply on the level of specific materials is very difficult. The proposed solution is a bottom-up calculation approach, which is characterized in particular by the fact that the built environment is described and examined up to the level of building materials. Furthermore, changing dynamics and future development of consumption patterns can be taken into account. A top-down calculation approach does hardly allow any further distinction between the individual components of the built environment, but merely a continuation of the demand estimation, which depends on very few socio-economic factors.

An application of the model is illustrated in Figure 5, taking Hoa Binh province as an example. With regard to urban development policies and in particular the housing development program of Hoa Binh it is assumed, that especially the urban population continues to increase. Thus, the demand for buildings in general will further rise and a shift from semi-permanent buildings to permanent buildings is to be expected in the next future.

On the other hand, the road network, which can be regarded as a prerequisite for an urbanization, will continue to grow. From a certain infrastructure development onwards, however, the new construction will diminish. If the two opposing dynamic developments of the road and building stock are brought together, it is to be expected that a shift in the shares of buildings and roads will take place in the upcoming decades.

By combining the development trends of the percentage distribution of residential buildings (RB), non-residential buildings (NRB) and roads with empirically gained information about the respective material composition a dynamic change of the required mineral building materials is discernible, as shown in Figure 5.

By using a bottom-up MFA approach and based on this model, the material requirements can be calculated and differentiated according to building material groups for various scenarios, e.g. for a change in the construction of roads and buildings. Thus, a differentiated and more application-oriented raw material planning can be achieved. The planning is supposed to be based on a detailed knowledge of a possible future development of the regional demand for materials, in which not only quantitative but above all also qualitative aspects of the foreseeable flow of materials into the built environment play an important role.

4. Conclusions

The results derived by MFA modelling indicates a significant mismatch between already licensed mining capacities and long-term demand for building materials, marked by an over-supply of building material minerals in terms of overall quantity. At the same time the model indicates a shift in the demand in terms of specific building materials due to different dynamics in building construction and road construction and due to potential changes in construction methods.

Considering these aspects it is advisable to overthink existing mining planning and to prove possibilities to combine prosperity oriented mining planning with aspects of nature and landscape protection. There seem to be potentials for removing sensitive areas from the mining planning, not only in order to bring demand and supply into line, but also to foster the protection of areas and ecosystems.

Since experts from the mining and construction industry cannot unconditionally confirm a tendency to over-supply, it is assumed that other or more aspects have to be taken into account by calculating the demand of building materials. A further need for research is therefore to develop additional scenarios considering the specific Vietnamese condition and situation on the basis of expert assessments. and thus to represent the development of the material demand as accurately as possible and yet sufficiently abstract.

In addition to that it is worth to consider options to influence the demand for building materials by integration resource efficiency aspects in terms of materials into construction-, settlement- and infrastructure policies. MFA models provide an approach to quantify effects of specific measurements on potential changes of the future demand of building materials. Based on this a substantiated integrated planning can be supported towards a proactive and responsible management of sustainable mining.

Acknowledgments

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References

[1] Hashimoto, S., Tanikawa, H., Moriguchi, Y., 2007. Where will large amounts of materials accumulated within the economy go? - A material flow analysis of construction minerals for Japan. Waste Management, Volume 27, Issue 12, 1725-1738. http://dx.doi.org/10.1016/j.wasman.2006.10.009.

[2] Müller, E., Hilty, L. M., Widmer, R., Schluep, M., Faulstich, M., 2014. Modeling Metal Stocks and Flows: A Review of Dynamic Material Flow Analysis Methods. Environmental Science & Technology 2014 48 (4), 2102-2113; DOI: 10.1021/es403506a

[3] Tanikawa, H., Fishman, T., Okuoka, K., Sugimoto, K., 2015. The weight of society over time and space: A comprehensive account of the construction material stock of Japan, 1945–2010. Journal of Industrial Ecology.

[4] Müller, D. B., 2006. Stock dynamics for forecasting material flows-Case study for housing in the Netherlands. Ecological Economics 59(1): 142–156.

[5] Pauliuk, S., Müller, D. B, 2014. The role of in-use stocks in the social metabolism and in climate change mitigation. Global Environmental Change 24: 132–142.

[6] Schiller, G., Gruhler, K., Ortlepp, R., 2017. Continuous material flow analysis approach for bulk nonmetallic mineral building materials applied to the German building sector. Journal of Industrial Ecology 21 (2017) 3, 673-688; http://dx.doi.org/10.1111/jiec.12595 (Online First 2017)

[7] Thuong, P. D., 2011. Report of housing development program for Hoa Binh province until 2020 and vision to 2030 (Báo cáo chương trình phát triển nhà ở tỉnh Hòa Bình đến năm 2020, tầm nhìn đến năm 2030).

[8] Bergsdal, H., Bohne, R. A., Brattebø, H., 2007. Projection of Construction and Demolition Waste in Norway. Journal of Industrial Ecology, 11: 27–39. doi:10.1162/jiec.2007.1149.

[9] Ortlepp, R., Gruhler, K., Schiller, G., 2016. Material stocks in Germany’s non-domestic buildings: a new quantification method. Building Research & Information 44 (2016) 8, S. 840-862. http://dx.doi.org/10.1080/09613218.2016.1112096

[10] UNEP (United Nations Environment Program) International Panel for Sustainable Resource Management; Working Group on the Global Metal Flows, 2010. Metal stocks in society: Scientific synthesis. Paris: UNEP DTIE. www.unep.org/resourcepanel/ Portals/24102/

[11] MOC, 2011. Development plan of construction materials in Hoa Binh province until 2020. Hoa Binh.

[12] MOC, 2013. Exploration and exploitation planning and use of three kinds of minerals as common building materials: Stones and sand for construction materials, clay for brick in Hoa Binh province, period 2014-2019, with a vision to 2024. Hoa Binh.

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