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# Data reconciliation under fuzzy constraints applied to wood flows in Austria

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Abstract—Material flow analysis deals with gathering, harmonizing, and analyzing data about physical flows and stocks from different sources with varying quality in order to quantify the material turnover of a defined system. As data availability and quality is limited, there is uncertainty that the available data represent the actual value of interest. In the present study this degree of belief is expressed via fuzzy sets, which specify the possible range of values of the input data. The input data are forced to comply with the mass balance constraints given by the material flow model. As a result, possible ranges are calculated for each flow and consistency levels are determined to identify flows which are in good agreement with the model and flows which are hardly consistent. The method is illustrated using a sub-system of the Austrian wood flow model as a case study.

Keywords: Material flow analysis, Epistemic uncertainty, Uncertainty overdetermined, Possibility theory, Fuzzy sets, Wood budget

#### I. INTRODUCTION

Due to data limitations, material flow analysis (MFA) is confronted with uncertainties affecting the reliability of the results [3]. Using quantitative methods as a treatment for uncertainty by assuming that the flows within a system have specific density functions is typically not justified in situations of poor information [2]. Fuzzy set theory provides a framework to deal with scarce and imprecise input data arising rather from vagueness than due to randomness alone [1]. It enables to distinguish between the different types of data uncertainty in order to not confuse what is known with what is assumed. Membership functions are used to characterize the given information, allocating a certain positive "degree of belonging" to each value within the possible range of a flow belonging to the system. In this study a method for data reconciliation under fuzzy constraints is presented and applied to the wood flows in Austria in 2011 and in order to investigate the effect of different uncertainty characterization results, three different procedures to derive membership functions of flow input data are tested.

#### II. CASE STUDY ON AUSTRIAN WOOD FLOWS

Wood is a renewable resource with highly competing enduses. Material uses of wood as construction materials, in furniture or in other products conserve the resource and therefore (potentially) enable another use of wood at the end of the product lifetime, either via energy recovery or material recycling. However, the current understanding of wood flows in Austria does not allow for a reliable assessment of the resource efficiency of wood use. Therefore, it is an ideal resource for testing and using reconciliation procedures for fuzzy data to identify critical issues with respect to input data quality as well as wood management mechanisms. The major challenges for establishing the Austrian wood budget are, on the one hand, the data gaps in the life-cycle phases of wood processing and the management of waste wood flows, and on the other hand, the disparity of measures used for quantifying the amount of traded wood and wood-containing products. The



Fig. 1. Austrian wood balance system 2011 with highlighted observed sector.

focus of the case study is on a subsystem of the Austrian wood system (see Figure 1). In order to test the approach, we concentrate on 5 processes where wood is processed, namely the Sawing industry, the Boards industry, the Building timber and the Furniture industry as well as the Use-phase of wood products. All other related processes, which are linked to this system by flows, are defined to be outside of the system boundary and considered as import and export flows. There are no recycling loops considered in this subsystem. The major interest of the case study is in wood flows, historic stocks of wood are not investigated.

## III. UNCERTAINTY CHARACTERIZATION & BALANCING OF MODEL AND DATA

As a result of the data reconciliation procedure, consistency levels are determined for each flow of the reconciled model, indicating the agreement between the given data and the mass balance constraints defined in the model. On this basis, the reliability of the data for a specific flow is evaluated relative to the other data used for the balances. Uncertainty characterization always remains subjective to some degree. Reconciled fuzzy ranges could be wrong even though flow data and balance constraints are in perfect agreement with high consistencies. Therefore, three different procedures to derive membership functions of the wood flows are tested. In the base case, information fusion is used to merge competing input data to a mutual function. In the second case, the uncertainty ranges associated with the original input data are reduced, to highlight the effect of lower estimates for basic uncertainty on data reconciliation and the resulting consistency levels. In the third case, a disjunctive approach constituted through intersections of membership functions is used to characterize the uncertainty of the wood flows. The effects of the modified procedures on the wood flows inserted in the model and on the results of the reconciliation process are evaluated, resulting in a trade-off between the credibility assigned to input data and the calculated consistency levels. Conclusions, which are drawn out of these computational tests, are used to get a better understanding of the Austrian wood balance model with respect to the reliability of underlying data and the sensitivity of relevant wood resource management flows.

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