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Significance of fixed assets in life cycle assessments

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ABSTRACT

Accounting for fixed assets in life cycle assessments is often ignored. Fixed assets represent machinery, equipment and constructions, which are utilized in the life cycle of products to enable their production and use. Subject matter is the set-up of an input–output model to implement fixed assets, followed by a methodological analysis of the approach and structural analysis of the determined coefficients. The study is based on an input–output model in hybrid units, which measures nine energetic transactions in energetic units and 64 other transactions in monetary units. An environmental extension takes renewable energies and greenhouse gases into account. Specific cumulative energy demands and emissions are determined. Fixed assets are implemented by either the augmentation method or the matrix flow method. Energetic and ecologic coefficients rise by 20–30 % on average, and in particular for services, if fixed assets are considered. Applying these coefficients to a life cycle assessment of an offshore wind farm indicates about 12% higher values for the energy demand and emissions. The augmentation method is easy to implement and delivers approximately the same energetic coefficients for fixed assets, compared to the matrix flow method. For a holistic analysis, the significant additional energy demand and emissions for fixed assets have to be included in life cycle assessments. In particular, the indirect share and especially machinery and equipment have to be considered. Recommendations on the modeling, as well as coefficients for fixed assets, to be implemented in future life cycle assessments, are delivered.

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1. Introduction and problem

Life cycle assessments enable the evaluation of the ecological sustainability of products. A holistic analysis from cradle-to-grave takes the complete life cycle of the product, which can be goods or services, into account. Both the cumulative energy demand and cumulative mass and emission flows for the entire life cycle can be split into the direct, process specific fraction and into the indirect fraction for conditioning the production process environment. In particular, production materials, consumables and especially *fixed assets*, which operate the direct process, belong to the indirect fraction. With aid of the *consumption of fixed capital*, the fixed assets, e.g. buildings, machines, production or transport facilities, can be allocated to the final product. (DIN EN ISO 14040; DIN EN ISO 14044; VDI 4600).

A predominant majority of contemporary life cycle assessments ignore especially these fixed assets, although they show for their part direct demands and emissions, as well as indirect. Fixed assets must not be ignored in principle, even if the direct applied fixed assets are not crucial. The importance of fixed assets in life cycle assessments has not been investigated sufficiently. On the one hand, especially the influence of fixed assets of upstream process stages of higher-order has not been investigated. On the other hand, a methodological analysis of the approach and a structural analysis of the resulting coefficients have not been performed. The dissertation “Input–Output Ansatz zur Berücksichtigung von Anlagegütern in Ökobilanzen – angewendet für einen Offshore-Windpark” published in (Eickelkamp, 2013) focuses on these questions, which is the basis for this article and contains more detailed results, approaches and background information.

1.1. Current state of research

There are three basic methodologies: the *process chain analysis*, the *material balance analysis* and the *environmentally extended input–output analysis* (explained in SubSection 2.1). Compared to the first two methodologies, the latter enables the consideration of fixed assets by an implementation process, the endogenization of

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Nomenclature

$a_{i,j}$	Input-coefficients; intermediate direct inputs of products of the product group i for production of one unit of value of products of the product group j
A	Direct input coefficient matrix (normalized by total outlays)
b	Cumulative ecologic output (for respective final demand)
$c_{i,j}$	Leontief coefficients; total – direct and indirect – intermediate input of products of the product group i for production of one unit of value of products of the product group j
C	Leontief inverse matrix
D	Matrix of ecological coefficients
E	Matrix of ecological parameters
f	Relative deviation
i	Row index
I	Identity matrix
j	Column index
M	Matrix of ecological commodity inputs
N	Matrix of ecological commodity outputs
v	Primary input
W	Matrix of the consumption of fixed capital (distinguishes the consumption of fixed capital for each product group between different kinds of fixed assets)
x	Total output vector
Y	Final demand matrix
$z_{i,j}$	Intermediate inputs of products of the product group i for production of products of the production group j
Z	Inter-industry transaction matrix
ˆ	Diagonal matrix with elements of the vector in the principal diagonal and all other elements equal zero
—	Augmented
*	In hybrid units
'	Row vector or transposed matrix

the consumption of fixed capital. Thereby, the two methods, *augmentation method* and *matrix flow method*, can be performed to account for fixed assets.

Preceding input–output studies covering the cumulative energy demand of fixed assets, collected in Table 1 and (Eickelkamp, 2013), show up to 5% additional cumulative values for fixed assets for products in the primary and processing industry, up to 20% for other products of the secondary industry and up to 60% for products of the tertiary industry.

As well, the topic has been analyzed by means of other methodologies, e.g. (Brogaard et al., 2013; Frischknecht et al., 2007). If material balance studies take fixed assets into account, they often focus on the directly utilized fixed assets, e.g. in (Brogaard et al., 2013) buildings and machinery installed in incineration plants are analyzed. Necessary for life cycle assessments is a holistic analysis of fixed assets including the fixed assets in upstream process chains of all utilized products. In (Frischknecht et al., 2007) an analysis is performed relying on a matrix calculation approach combining a large number of gate-to-gate unit processes including and excluding fixed assets to account for the share of cumulative fixed assets. The outcome is, that it is reasonable to include fixed assets by default for practical reasons. Assumptions and educated guesses can be uses in some case, depending on the utilized product and environmental impact category.

Using the input–output analysis as the predestinated calculation method for this study results in the advantage of not cutting off any process chain. After implementing fixed assets, the input–output analysis accounts holistically for fixed asset within the upstream process stages of any intermediate consumption. This includes first of all the upstream process chains of fixed assets themselves, second the fixed assets used in every upstream process stage of utilized goods and services and third the fixed assets used for the production of utilized fixed assets. On the one hand, the input–output approach enables the accounting for all different products within a national economy, categorized in product groups according to (Cpa, 2002). On the other hand the input–output analysis is based on a consistent and conceptual matched framework for accounting and input data (Esa, 1995; Oecd, 2001). Another advantage is, that this methodology enables deeper insights, as described in the following subsection.

Table 1
Overview of the methods used in selected input–output studies.

Study	Method (balancing boundaries)	Considered coefficients	Endogenization
(Bullard et al., 1978)	Hybrid unit IOM (USA, 1967)	Primary energy	No detailed description
(Casler, 1983)	Monetary IOM (USA, 1972)	Energy	Matrix flow method
(Drake, 1996)	Hybrid unit IOM (Germany, 1987)	Primary energy, energy-induced carbon dioxide, other energy-induced greenhouse gases	Augmentation method
(Wenzel and Pick, 1997)	Monetary IOM (Germany, 1993)	Primary energy	Matrix flow method
(Lenzen and Treloar, 2005)	Monetary IOM (Australia, 1996/97)	Energy, carbon dioxide, water consumption	Methodological comparison of the augmentation and matrix flow method
(Defra, 2009)	Multiregional monetary IOM (United Kingdom, 1992–2004)	Greenhouse gases	Matrix flow method (augmentation method only described)
(Minx et al., 2011)	Monetary IOM (China, 1992, 1997, 2002, 2007)	Carbon dioxide	Augmentation method
(Benders et al., 2012)	Dynamic monetary IOM of (Idenburg and Wilting, 2000) (the Netherlands, 1980–1997)	Energy, methane, nitrous oxide, sulfur oxides, nitrogen oxides, ammonia, NMVOC, nitrates, phosphates, and other	No endogenization (consideration of costs for the consumption of fixed capital as a fraction of the basic price)

IOM = Input-output model; NMVOC = Non methane volatile organic compounds.

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