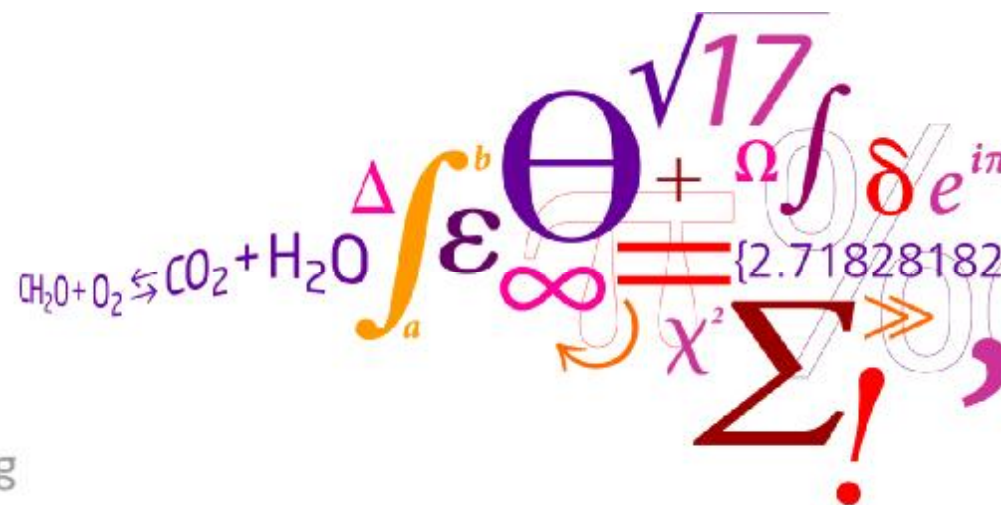


# Waste Prevention: Life Cycle Costing of Food Waste Management

Thomas F. Astrup



# Related studies: Life Cycle Costing (LCC) principles and assessment of food waste



## Life cycle costing of waste management systems: Overview, calculation principles and case studies

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**ABSTRACT**

This paper provides a detailed and comprehensive cost model for the economic assessment of solid waste management systems. The model was based on the principles of Life Cycle Costing (LCC) and followed a bottom-up calculation approach providing detailed cost items for all key technologies within modern waste systems. All technologies were defined per source of waste input, and each cost item within a technology was characterized by both a technical and an economic parameter (for example amount and cost of fuel related to waste collection, to ensure transparency, applicability and reproducibility). Cost items were classified as: (1) budget costs, (2) variable (for example taxes, subsidies and fees) and (3) externality costs (for example damage or abatement costs related to emissions and dissemination). Technology costs were obtained as the sum of all cost items of the same type within a specific technology, while scenario costs were the sum of all technologies involved in a scenario. The cost model allows for the comparison of three types of LCC: a conventional LCC for the assessment of financial costs, an Environmental LCC for the assessment of financial costs where results are complemented by a Life Cycle Assessment (LCA) for the same system, and a Social LCC for socio-economic assessments. Conventional and Environmental LCCs include budget costs and taxes/fees, while Social LCCs include budget and externality costs. Critical aspects were found in the existing literature regarding the cost assessment of waste management, namely: system boundary methodology, accounting for temporally distributed emissions and impacts, inclusion of taxes, the internalization of environmental impacts and the coverage of shadow prices, and there was also significant confusion regarding terminology. The presented cost model was implemented in two case study scenarios assessing the costs involved in the source segregation of organic waste from 100,000 Danish households and the subsequent co-digestion of organic waste with animal manure. Overall, source-segregation resulted in higher financial costs than the alternative of including the organic waste with the residual waste: 1.0 M€/year, of which 0.9 M€/year was costs for extra bins and bags used by the households, 1.8 M€/year for extra collection and -0.3 M€/year saved on incineration.

### 1. Introduction

Over the past decade, increasingly rigorous and systematic documentation of societal consequences related to solid waste management has been required by authorities, technology developers and other stakeholders. This has placed increasing emphasis on the holistic assessment of waste management, in particular on environmental impacts. Meanwhile, the Life Cycle Assessment (LCA) of waste management systems has matured significantly [Larsen et al., 2014a,b; Friis et al., 2009], and it is now

regularly accepted as a useful source of support for overall decision-making in many countries [Larsen et al., 2005]. While waste LCA provides a systematic framework for accounting for environmental impacts associated with waste management, cost decisions related to the real-life implementation of waste technologies in modern societies are affected by economic constraints. For decision-makers, the lack of a balanced economic assessment alongside traditional LCA results therefore limits the value of the LCA itself, as economic priorities are then determined from environmental aspects.

The economic characteristics of waste management have been addressed in the literature, related either to specific waste management technologies [for example Virjes et al., 2012; Tonini et al., 2012; De Feo and Malvarra, 2012; Corbett and He, 2010,

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## Life-Cycle Costing of Food Waste Management in Denmark: Importance of Indirect Effects

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Supporting Information

**ABSTRACT:** Prevention has been suggested as the preferred food waste management solution compared to alternatives such as conversion to animal fodder or to energy. In this study we used societal life-cycle costing, as a welfare economic assessment, and environmental life-cycle costing, as a financial assessment combined with life-cycle assessment, to evaluate food waste management. Both life-cycle costing assessments included direct and indirect effects. The latter are related to income effects, accounting for the marginal consumption induced when alternative scenarios lead to different household expenses, and the land-use-changes effect, associated with food production. The results highlighted that prevention, while providing the highest welfare gains as more services/goods could be consumed with the same income, could also incur the highest environmental impacts if the monetary savings from un-purchased food commodities were spent as goods/services with a more environmentally damaging production than that of the (prevented) food. This was not the case when savings were used, e.g., for health care, education, and insurance. This study demonstrates that income effects, although uncertain, should be included whenever alternative scenarios incur different financial costs. Furthermore, it highlights that food prevention measures should not only denote the purchase of unconsumed food but also promote a low-impact use of the savings generated.

### INTRODUCTION

One-third of food produced globally for human consumption is wasted (i.e., 1.3 billion Mg of food per year),<sup>1</sup> corresponding to an average food waste per capita of 190–200 kg per year in Europe and North America. Food waste management practices proposed in Europe and United States highlight landfilling as the least preferred option, followed by incineration and later by (anaerobic) digestion. Strategies involving utilization of food waste in other industrial sectors, such as the animal fodder industry, are instead favored, which changes in consumer behavior are considered the most desirable (i.e., prevention of food waste).<sup>2,3</sup>

Economic and environmental performance in relation to food waste management, from production to waste management, has been assessed by different authors. For example, losses associated with food waste corresponded to 0.8% gross domestic product (GDP) in South Africa,<sup>4</sup> \$390 per capita per year in the United States,<sup>5</sup> and the global warming equivalent of 7 million cars per year in the United Kingdom. Life-cycle assessment (LCA) has often been used to compare the environmental performance of alternative food waste management strategies. For example, anaerobic digestion was found to be environmentally preferable to landfilling or comparable with incineration.<sup>6–12</sup> In addition, selecting

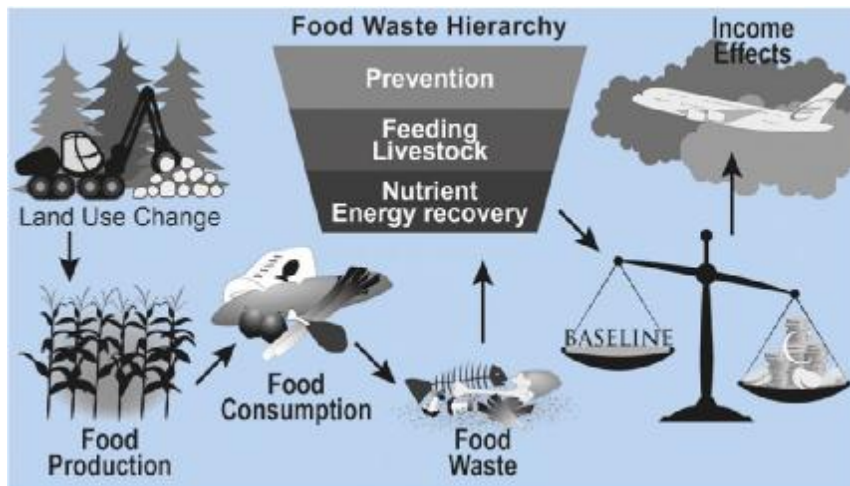
level waste for use as animal fodder provided better environmental performance than anaerobic digestion, on the basis of an energy LCA,<sup>13</sup> while a potential reduction in greenhouse gas (GHG) emissions on the order of 800–1400 kg of CO<sub>2</sub> equiv Mg<sup>-1</sup> of food waste was estimated following prevention of avoidable food waste.<sup>14</sup>

While a number of LCA studies assessing food waste management strategies can be found in the literature, none of them consider two distinct indirect effects. The first is the income effect (also called the “rebound effect” in energy economics),<sup>15,16</sup> associated with the marginal consumption induced or reduced when there is a difference in costs to consumers between alternative scenarios providing the same service.<sup>17</sup> For example, the economic savings generated by preventing food waste (avoiding food purchases) may be spent on purchasing other goods/services associated with environmental impacts. The second effect relates to indirect land-use changes (ILUC) induced by production of food commodities (i.e., upstream impacts associated with changes in land demand).

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# Background and focus



- § One-third of food production is lost as waste
- § Associated GW impacts correspond to 7 M cars in the UK
- § Considerable economic losses
- § Food Waste Hierarchy suggests alternatives

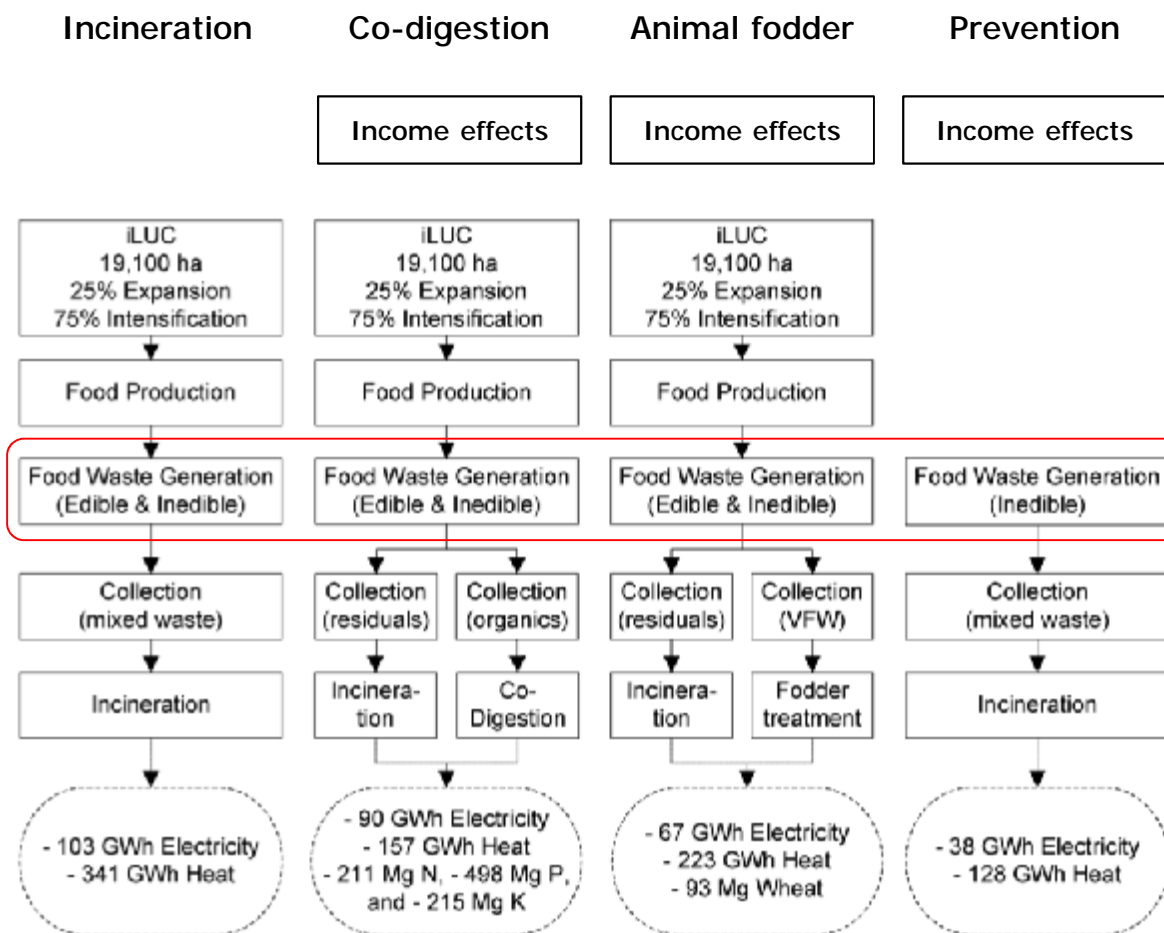
Food waste may support circular economy solutions:

- § Very few studies offering consistent assessment
- § Typically focus on direct effects
- § Indirect effects may be significant

Food waste management may affect:

- § Expenses in households
- § Marginal consumption (indirect, welfare change)
- § Emissions in society (indirect, welfare loss)
- § Land-use-changes and ecosystem losses (indirect, welfare loss)

# Four management scenarios



**Income Effects Distribution**

- 31 % Housing
- 22 % Communication
- 16 % Leisure
- 13 % Meals
- 6 % Clothing
- 5 % Security
- 3 % Education
- 2 % Health Care
- 1 % Hygiene

**Food Waste (FW) Generation**

- 206,416 Mg Inedible
- 251,671 Mg Edible

**Edible FW Composition:**

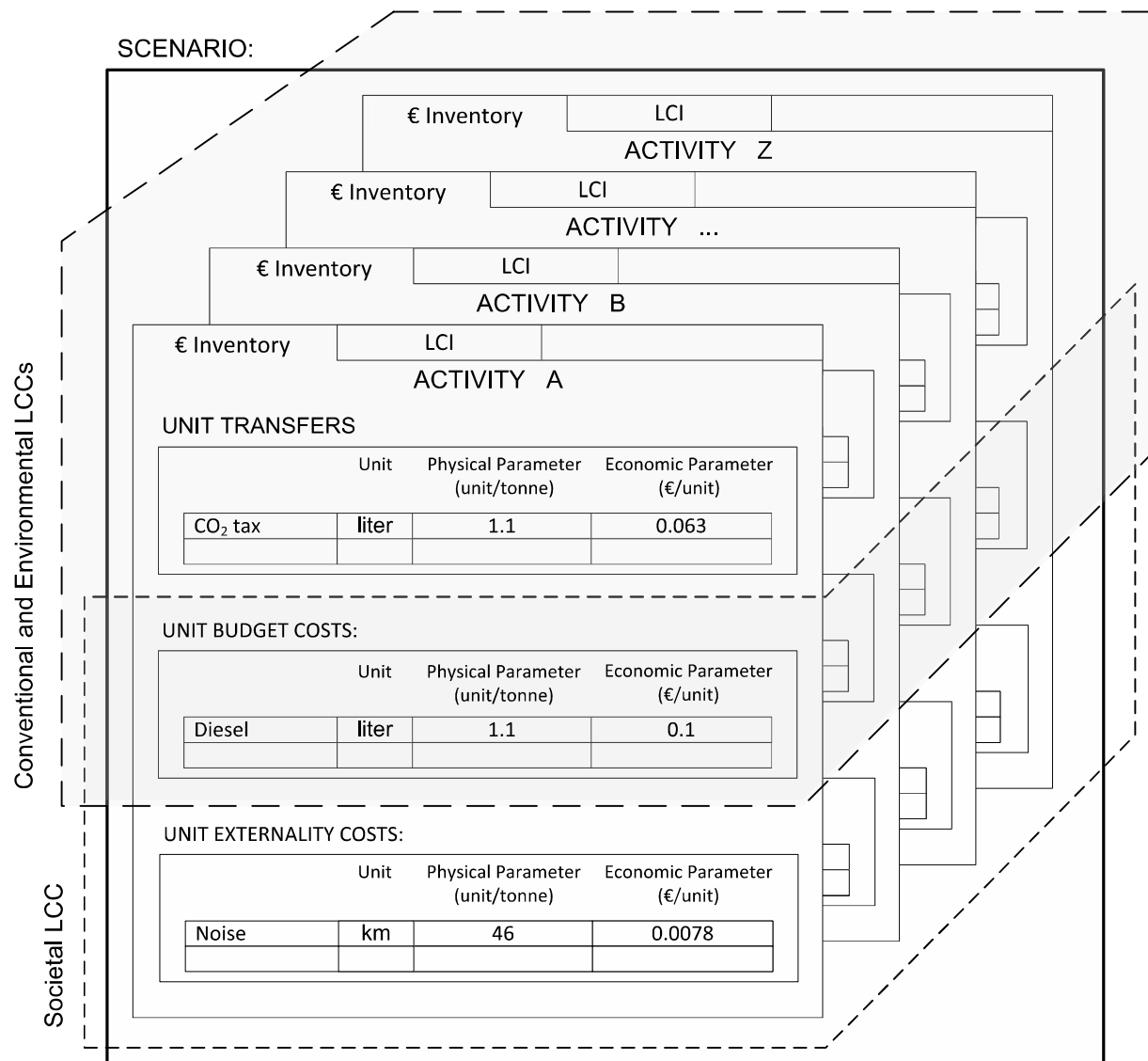
- 27% Vegetable FW (VFW)
- 73% Animal-Derived FW (AFW)

<b>VFW:</b>	<b>AFW:</b>
30% Bread	32% Milk
16% Carrots	24% Butter
13% Tomatoes	10% Beef
9% Cabbage	8% Yoghurt
5% Rice	8% Pork
5% Pasta	7% Eggs
5% Orange	4% Cheese
4% Apple	4% Chicken
4% Potatoes	1% Fish
3% Banana	
3% Grapes	
2% Kiwi	

# Life cycle costing: methodology

	Conventional	Environmental	Societal
Type	Financial assessment of marketed goods and services	Conventional + Life Cycle Assessment	Conventional + Externalities
Example	<ul style="list-style-type: none"> <li>§ Budget costs</li> <li>§ Transfers</li> </ul>	<ul style="list-style-type: none"> <li>§ Budget costs</li> <li>§ Transfers</li> <li>§ LCA</li> </ul>	<ul style="list-style-type: none"> <li>§ Budget costs</li> <li>§ Externality costs</li> </ul>
Focus	An individual stakeholder: Internal costs	All affected stakeholders: Internal and external costs	All affected stakeholders: Internal and externality costs

# Cost types and modeling (EASETECH)

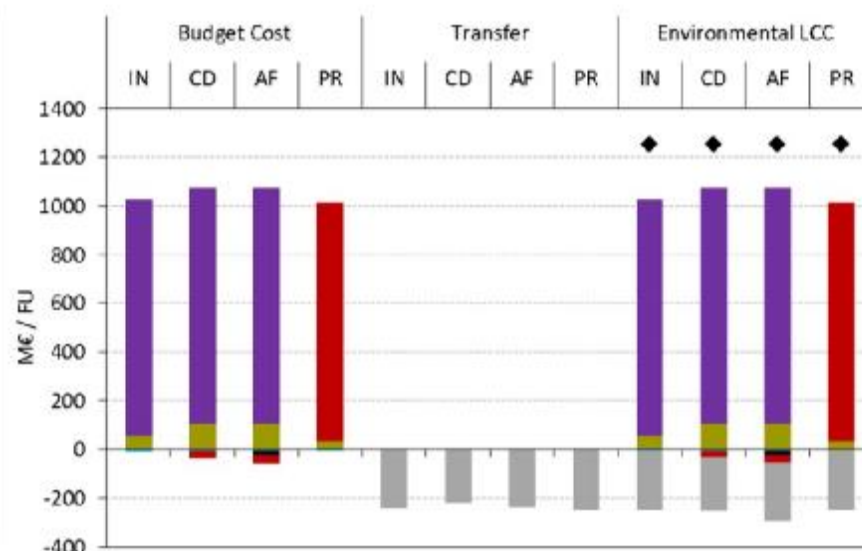


# Financial assessment

## Direct effects



## Direct + indirect effects

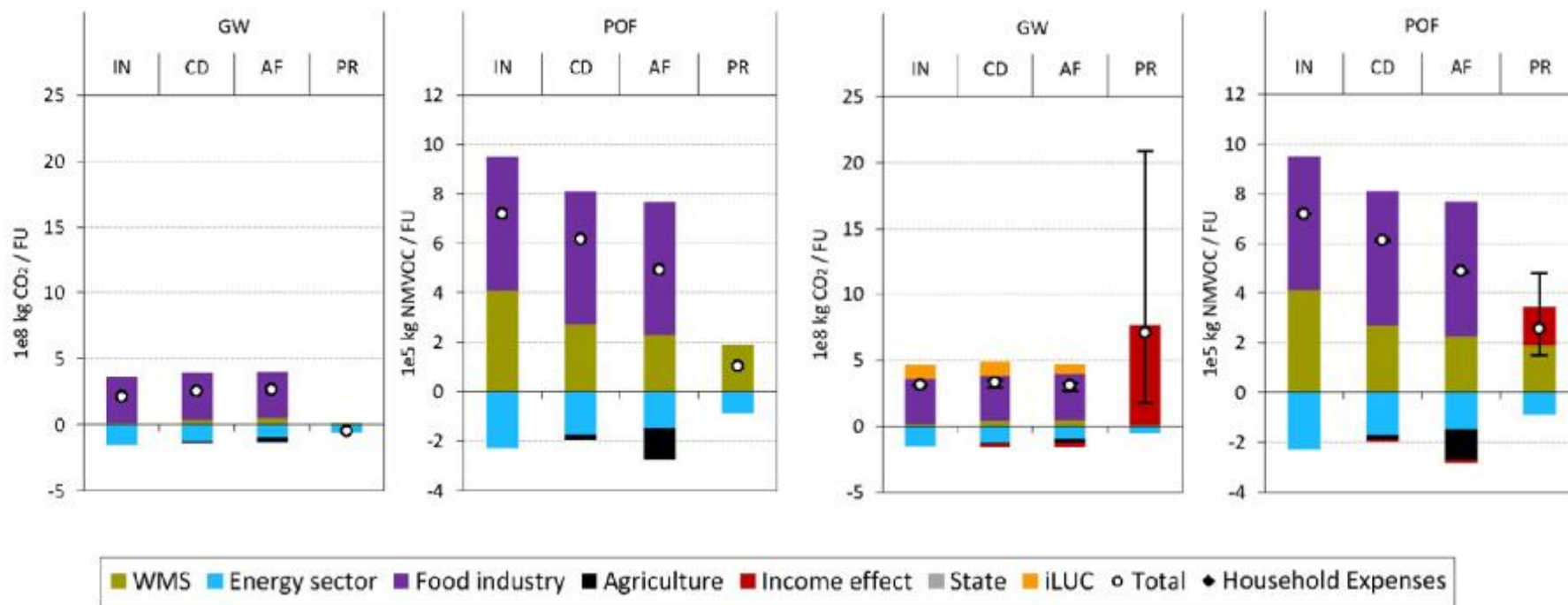


■ WMS 
 ■ Energy sector 
 ■ Food industry 
 ■ Agriculture 
 ■ Income effect 
 ■ State 
 ■ iLUC 
 ○ Total 
 ◆ Household Expenses

# Life cycle assessment

Direct effects

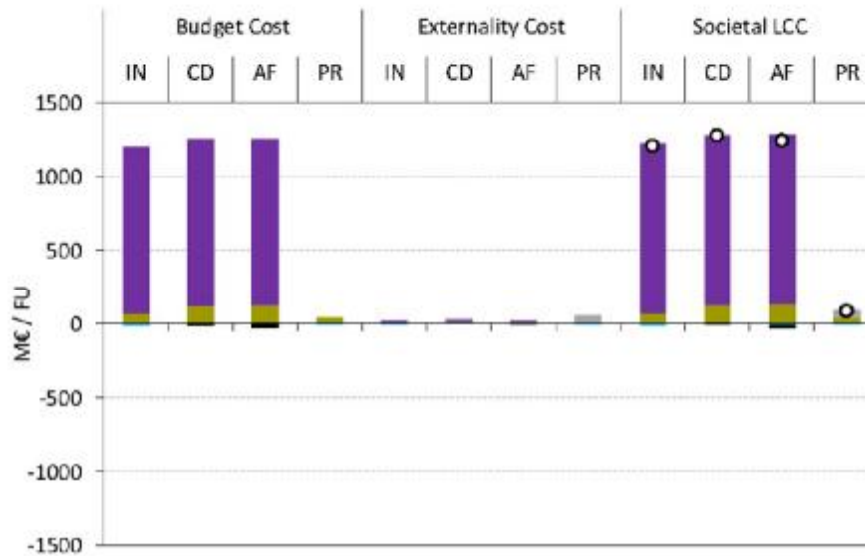
Direct + indirect effects





# Welfare economic assessment

## Direct effects



## Direct + indirect effects



■ WMS 
 ■ Energy sector 
 ■ Food industry 
 ■ Agriculture 
 ■ Income effect 
 ■ State 
 ■ iLUC 
 ○ Total 
 ◆ Household Expenses

## Summary

- § Including only direct effects (without income effects), waste prevention *is* beneficial
- § Including additional indirect effects (income effects), waste prevention *may* be environmentally beneficial
- § Waste prevention initiatives *could* facilitate significant reduction in household expenses (welfare gain)
- § LCAs of waste prevention and circular economy solutions may need to address economic consequences
- § Cost assessments, however uncertain and limited, may be useful in this context
- § Indirect effects from land-use-changes do not appear critical for cost assessments