Technology Scenarios, Economic Modelling and Life-Cycle Inventories

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**Abstract**

In a new EU project - PROSUITE - the assessment of technological innovation will be undertaken so as to address both the micro and the macro impacts of new technologies. The framework set up is designed to integrate the modelling of the value chains of product systems shaped by novel technologies and the modelling of the background economy through a hybrid of product-chain analysis and economic input-output modelling. The foreground system is defined as the parts of the value chain that are specific to the new technology investigated. The background system is the input-output system that is modelled on a generic basis common for many cases. The foreground system of new technologies as well as the background system will be specified for both current and future state scenarios. The challenge is put forward to make simple but reasonable predictions on economic structure and the links and feedback mechanisms between foreground and background system as they evolve over time.

**Keywords:** technology assessment, forecasting, hybrid input-output

# Introduction

Ample experience with life-cycle assessment (LCA) shows that two factors critically influence the amount of emissions caused during the life-cycle of a products: (a) The emissions and energy/resource use by the foreground system, that is the product system investigated, and (b) the emissions intensity of the background system which provides energy, materials, services and other inputs. The degree of responsibility of those two elements varies among different cases, but it is clear that both elements need to be considered. In a prospective assessment of economic activity and environmental impact caused by the future, large-scale application of (novel) technologies, both elements may change and they hence need to be specified.

In a new EU project - PROSUITE - the strategy is to integrate the modelling of the value chains of product systems shaped by novel technologies and the modelling of the background economy through a hybrid of product-chain analysis and economic input-output modelling. The foreground system is defined as the parts of the value chain that are specific to the case investigated. The background system is the system that is modelled on a generic basis common for many cases.

The technology performance and cost information will be used in scenario development. Scenarios for the evolution of the background economy will be developed. In these scenarios, a prospective future economy will be described in the form of an input-output table. The input-output table contains information on the requirements of energy, some materials and other environmentally important inputs to the economy, as well as information on economic activity and employment triggered by the demand for output from various sectors. There will be several scenarios describing different, alternative futures. Scenarios will be developed for the economy in 2020, potentially extended also to 2030, and taken from key existing models.

There is a need to further specify the break-down of the economic activity in the original IO tables on the more detailed aggregation level chosen for the specific technologies targeted in the modelling. Input from technology characterization will be used to this end:

a. A specification of important technologies which we should assume to have penetrated to significant degrees in 2020 or 2030, and a description of the degree of penetration.

b. A specification of the physical characteristics and costs of novel technologies that will have penetrated at a level significant for the performance or sustainability attributes of the overall economy. This specification should be in the form of a “production recipe” (intermediate input requirements – including capital and labor - and yield).

c. A specification of technological progress attained (decreased intermediate input or labor requirements, increased efficiencies) resulting from technology learning for important technologies.

In environmental assessments, the output of the scenario analysis will be used in the same manner as life-cycle inventory databases are used today: as background data to describe inputs of energy, materials, services and the like. These inputs can be utilized in conventional LCA software. But modelling of economic aspects and overall sustainability aspects may require an integration of the foreground technology scenario and the model of the total (background) economy. This implies that data on inputs, outputs and environmental interventions caused by the processes needs to be integrated into the model.

We conclude with a discussion of the challenges in integrating the foreground and background systems in a dynamic manner such that macro-variables of interest of the background system can be determined endogenously from the foreground system.

# Indicators and measures of economic impact

There is a fundamental distinction between the costs of a technology and the economic benefits it provides. Costs relate to the production of a good, while the benefits may relate to both production and use. From a microeconomic perspective, economic benefits relate to producer and consumer surplus and are the difference between the willingness to pay and the production costs. There are other benefits, however, including providing employment to unemployed or underemployed parts of the population, providing economic development and training of the work force, contributing to a redistribution of wealth in a desirable manner (e.g., 'cohesion' in the EU), increasing competitiveness (e.g., 'Lisbon agenda'), and producing positive or reducing negative externalities. From a macroeconomic perspective, the question is how technology influences economic growth. It is clear that economic costs are fundamental both to the determination of economic benefits of a technology and to the modelling of economic effects of the technology's full scale implementation. There is no consensus, however, on what measures or indicators of economic benefit or economic sustainability should be applied in the assessment of technologies.

Economic aspects of technology can be viewed from various perspectives. (1) The cost of technology, both in terms of required research and development, and expected market based costs; (2) The market for the technology and the profit for the company owning the technology; (3) Economic activity and employment generated by implementing a technology (the classical IO labour and economic input multipliers); (4) The question of whether a new technology provides for (a) strengthening national competitiveness compared to trading partners, and (b) stimulates overall economic growth (not at the expense of trading partners); (5) A new technology may alleviate some resource scarcity by reducing the resource input for a given function (efficiency gain) (6) The new technology may fulfil a function hereto unfulfilled, e.g. a new cure to disease. These potential impacts occur at different scales and not in all circumstances.

The cost of a technology is a very important factor affecting competitiveness, economic activity and employment. Cost, economic activity and employment under certain assumptions can hence be modelled within the project. Efficiency gains on the micro level and reductions in resource inputs for a certain function can be quantified and may be useful indicators. The effect of technology and efficiency gains on economic growth and resource scarcity alleviation are controversial. Making firm statements about the impact of a specific technology is difficult. Hence quantifying these impacts may not be straightforward, but qualitative assessment may still provide some guidance to potential impact.

|  |  |
| --- | --- |
| **Indicator** | **Scale** |
| Cost of technology |  |
| * Current | Micro |
| * Capital | Micro |
| * R&D | Micro |
| Market for technology |  |
| * Size/spread | Macro - domestic/global |
| * Forward linkages | Macro – domestic/global |
| Impact of technology |  |
| * Value added multiplier | Macro – domestic |
| * Labour income multiplier | Macro – domestic |
| Competitiveness |  |
| * Niche markets (local/global) * Competitive market (local/global) | Macro - domestic/global |
| Efficiency |  |
| * Economic gains/loss | Micro to Macro - domestic/global |
| * Resource gains/loss | Micro to Macro - domestic/global |

Table Economic indicators of interest and scales of application

Whilst an indicator of costs is relatively straightforward, we propose to use concentration indices (Soofi 1992) to measure the size/spread of a technology:

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

Where *N* is the number of economic sectors, **L** is the Leontief inverse, and **G** is the Ghoshian inverse.

Forward linkages according to the Ghosh inverse (see Lenzen 2003 for an overview):

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

Where **v** is value added.

Value added multiplier **mv** according to the basic Leontief inverse:

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

Where **x** is gross output and **A** is the technology matrix.

Labour income multiplier **mL** similarly:

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

Where **L** is compensation of employees by sector.

Efficiency measures can simply be taken as the total intermediate requirements:

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

Whereas resource efficiency would be calculated as the resource inputs **F** per unit of output **x**:

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

# Technology scenarios: current state

Certain environmental, economic and social impacts become relevant or apparent only if the technology reaches and exceeds a certain level of implementation. Current state technology scenarios concern the implementation of a new technology in the world-as-we-know-it. As such, we want to go beyond the technology based LCA to scale the technology to expected economic scale, and evaluate the effect of such a scaling on the economy. A novel combination of life cycle and input-output analysis will be developed to model the economy at a meso level and keep track of both physical and monetary aspects of technology introduction, drawing from the growing literature on hybrid IO-LCA (Moriguchi et al. 1993; Kondo and Nakamura 2004; Suh 2004; Suh and Huppes 2005; Nakamura et al. 2007; Strømman et al. 2009).

Figure Overview of process based system embedded within a broader economic system (from Strømman, pers. comm.)

In matrix format, when analysing unidirectional flows, this can be set up as the linking of a foreground system, to a background LCA database, to the broader economic activity. This is a tiered hybrid LCA set up (Equation 1).

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

|  |  |  |
| --- | --- | --- |
| Nomenclature: |  |  |
| Indices |  |  |
| *f* | Foreground processes, technology specific. |  |
| *p* | Background processes, LCA database. |  |
| *n* | Background commodities, IO database. |  |
| *i,j* |  |  |
| Matrices |  |  |
| *Aff* | Foreground process requirements |  |
| *App* | Background process requirements |  |
| *Ann* | Economic commodity requirements |  |
| *Apf* | Upstream inputs of background to foreground |  |
| *Anf* | Upstream inputs of economic commodities to foreground |  |
| *Afn* | Upstream inputs of foreground outputs to economic commodities |  |

More applicable to the case here, is the examination of both the requirements of a technology from the broader economy, as well as the impacts the technology will have on the broader economy. Such analysis needs to consider the flow on effects of introducing the technology, under the assumption that it will have a notable impact in the rest of the economy. Due to data limitations of using background LCA datasets in this way, the model is generally simplified into the framework of integrated hybrid LCA (Equation 2).

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

Different levels of technology adoption and technology alternatives are evaluated using comparative scenarios. Important factors are the costs, the potential market volume, the inputs to production, maintenance and disposal, and the effect of the utilization of the technology on the customer. The results of process-based life-cycle inventories for future technologies (undertaken elsewhere in the project) will be utilized here for the foreground matrix. Current state technology scenarios will be based on the estimation of the technology costs using engineering-economic cost estimation methods and learning curves. The potential market volume will be based on known applications given the current market size of those applications and assumptions about market penetration. Based on this market volume, a product system will be designed at the scale predicted. The inputs required to produce and operate the technology (cradle-to-gate) will be calculated, indicating the utilization of available production capacity, employment effect, and environmental effects. For this purpose, existing life-cycle data from the European Platform on Life-Cycle Assessment, standard databases such as EcoInvent, and case studies will be used. For the economic model, existing IO-models developed by NTNU and others, including the results from the ongoing EXIOPOL project, where NTNU is a core partner, will be utilised. Relevant effects of utilizing the technology are for example reductions in resource use and emissions due to the utilization of the technology, or gains such as cost reductions, safety or quality. The Current state approach is a comparative static analysis that does not account for technical and environmental changes in the background system (e.g., electricity mix, economic growth, efficiency gains) over time. Instead, it keeps the key values representing the background system (e.g. efficiency and specific CO2 emissions) at the level of the reference year.

# Technology scenarios: future state

New technologies will be implemented in the face of economic and demographic development, changes of and background technologies delivering inputs, and changes in regulatory requirements. The EU has outlined a climate that would substantially change the costs and environmental impacts of energy. The process of the implementation of Best Available Techniques through the IPPC will reduce the pollution from a number of industry sectors. Endogenous technological change and economies of scale will affect both costs and physical input requirements. The aim of this task is to develop an economic activity model for the year 2020, in order to model the output level of production processes required, associated costs, employment effects, and environmental pressures, that is the ‘inventory’ data needed for economic and environmental assessments. These scenarios for the “background economy” are to be utilized in scenario-based assessments of technologies set in an expected or desired future world. This approach utilizes story lines and outcomes of emissions scenarios developed by IIASA for the IPCC. The story line of a scenario explains the overall logic of developments and specifies external parameters such as population developments, economic development and equity, and social trends. Four storylines have been developed, and significant focus is placed on fuel mix and efficiency projections. Methods of inventory modelling using this background data will be illustrated on case studies, however, a simple illustrative case will be utilized in the process of method development and to illustrate the evaluation of potential rebound and ripple effects. We will develop the methods for implementing a single IPCC scenario (A2r) in the nearer future – the year 2020 which has become the new reference year for the next set of climate policies. The aim is to deliver background inventory data for at least two scenarios so that future economic and environmental impacts of technologies can be evaluated based on insights from scenario modelling and technological foresight. The idea being to develop scenarios for the background economy in 2020 in the form of a multiregional input-output model based on EXIOPOL sector/commodity classifications but a lower regional and sector resolution.

Basically, we are looking at forecasting an input-output technology matrix **A***nn* from an existing current technology matrix **A0***nn*, using a minimum entropy approach,

|  |  |  |
| --- | --- | --- |
| Equation |  |  |

with,

where

and

but scaling for expected final demand **y\***, economic output **x\***, value added **v**\*, and IPCC production scenarios on particular components of . Under known output, value added and final demand, this is essentially a RAS process (Stone and Brown 1962). Fixing components of *A*i,j essentially uses a modified RAS process (Lecomber 1975).

Based on the (separate) outcomes of the technology characterisation after the implementation of estimated learning curves, a second hybridisation of the forecasted economy is then undertaken.

# Challenges

Any economic forecasting is fraught with difficulties, especially when results are sought to be interpreted at the technological level. The dynamic nature of economies, and in particular, responses to changing government policy, makes it difficult to predict just how the structure of the economy will look either when a new technology is introduced, or 10 to 20 years into the future.

The scope of this project is not to cover the effect of integrated dynamic relationships in the economy. Instead, where existing data is available on expected economic structure, efficiency of production, volume of production, etc, it will be included under basic physical and economic equilibrium measures (total input/output balance).

At the level of individual technologies, learning rates provide a rather uncertain measure of just how successful the technology will become. Providing an adequate uncertainty analysis of the effect of these economies of scale both on the technology itself and on the technologies it seeks to replace will be an essential component of the overall analysis.

# Conclusion

The purpose of the PROSUITE project is to provide standardised and comprehensive measures of the expected sustainability outcomes of new technologies. A key component of this project is in providing comprehensive analysis on both the indirect requirements of new technologies and the expected flow on effects of the new technology in the broader economy.

Whilst hybrid IO-LCA provides a cornerstone method in which to link these new technologies to broader economic requirements, measuring the expected uptake of a new technology and the learning curves of a new technology over time introduces considerable uncertainty in global impacts.

Nevertheless, reasonable estimates of the overall sustainability picture of a prospective technology can and should be made before it is implemented in full, and it becomes too late to undo. Whilst we will never have the benefit of hindsight, we can at least provide clues to the future.

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