nova Institute for Ecology and Innovation

nova paper #5 on bio-based economy 2014-11

New nova Methodology for Techno-Economic Evaluations of Innovative Industrial Processes (nTEE)

– with a case study applied to a lignocellulosic biorefinery concept (BIOCORE)

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New nova Methodology for Techno-Economic Evaluations of Innovative Industrial Processes (nTEE)

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1 Introduction

For the techno-economic evaluation of innovative industrial processes, often limited data can be made use of. In particular, this concerns equipment sizing which is required in standard approaches for determining investment and operating costs (see e.g. Towler and Sinnott 2008, Dimian 2003).

This paper presents a new methodology for conducting techno-economic evaluations in those cases where energy and material flows from process simulation models form the principal data source available. In these cases, at best the number and type of required equipment is known, but no more detailed specifications as needed for an equipment sizing.

Therefore, a model is needed which could lead to satisfactory estimates of techno-economic parameters even with such a limited database. The description of such a model is at the core of this paper.

We have applied this model in the framework of the European research project BIOCORE (BIOCOmmodity REfinery)[1], which conceptualized an industrial-scale lignocellulosic biorefinery. However, the principles of our model could equally well be applied to other industrial processes.

2 Methodology

The economic evaluation of an investment project for an industrial process includes the estimation of capital expenditures (CAPEX), annual operating expenditures (OPEX), revenues, profits and further indicators of economic sustainability. In the following, we first describe the methodologies we developed for estimating CAPEX and OPEX before we briefly touch upon indicators of evaluating the economic viability of an investment project.

2.1 CAPEX

The total investment needed for a project, also called Capital Expenditues (CAPEX), can be roughly divided into the sum of the fixed capital investment (FCI) and working capital investment (WCI).

According to Towler and Sinnott 2008 (p. 299), the FCI is the total cost of the plant ready for start-up. It includes the cost of:

1. Design, and other engineering and construction supervision,
2. All items of equipment and their installation,
3. All piping, instrumentation and control systems,
4. Buildings and structures,
5. Auxiliary facilities, such as utilities, land and civil engineering work.

The FCI is a once-only cost that is not recovered at the end of the project life, other than the scrap value. The FCI includes the complete construction cost of the plant with all its processing and handling equipment as well as its ground preparation and non-process structures and equipment.

FCI would also include the investment for purchasing land to build the plant on. However, at the early stages of process development, neither the total ground surface nor the unit costs of land, which is very much location-dependant, can be reasonably approximated. We therefore leave the cost of land out of our analysis. Land is the only part of the FCI that is not depreciable so that the remainder constitutes the depreciable FCI.

The WCI includes the initial cost of resources, such as feedstock and catalyst, as well as money required for labour and services required to start operation of the plant. WCI is the additional investment needed, over and above the fixed capital, to start up the plant and operate it to the point when income is earned. It includes the cost of:

1. Start-up,
2. Initial catalyst charges,
3. Raw materials and intermediates in the process,
4. Finished product inventories,
5. Funds to cover outstanding accounts from customers.

According to Peters and Timmerhaus 1991, typical values for the WCI are between 15–20% of the FCI, i.e. about 13–17% of the total investment. However, this estimate has been made for conventional chemical plants. For biorefineries, the estimate of the WCI may be different. For example, Humbird et al. 2011 chose an estimate of 5% of the FCI for their lignocellulosic biomass to ethanol production plant (Humbird et al. 2011, p. 68).

1 FP7-241566

There exist several methods for rapidly estimating total investment costs based on limited data (see e.g. Towler and Sinnott 2008, p. 306ff. for an overview). From these methodologies, an approach first presented by Lange 2001 is particularly appealing since it is entirely based on the sum of energy transfer duties of all process segments, roughly equivalent to the sum of the rated power of all process equipment. In this study, Lange suggested a correlation between the fixed capital investment (FCI) of a petrochemical plant and the sum of the rated power of all equipment parts expressed in megawatts (MW). The original equation proposed by Lange 2001 was:

$$\text{FCI [Mill. USD 1993]} = 2.9 * \text{Rated Power [MW]}^{0.55} \quad (1)$$

In order to validate this FCI-estimation model also for bio-based industrial processes, we sought for actual data on investment and rated power for different bio-based processes. Although data on rated power are typically not published and also not readily available from other sources, a number of data points could still be added to the graph (shown in Figure 1 – the data points shown in light blue are those originally found by Lange 2001). In order to apply this model to this new data, currency conversions and inflation adjustment were performed.

First, actual business data for a starch plant were obtained (see the yellow data point in the graph). Then, respective data was found for an investment to convert an ethanol to a butanol plant (Larsson et al. 2008; see the red data points). Finally, data was used from BIOCORE partner Energy Research Centre of the Netherlands (ECN) for their ethanol-based organosolv process (see the blue data point).

As can be seen from these data entries, the proposed correlation appears to fit well for these selected bio-based processes. Although further analyses are not possible with such a small number of data points, it appears that the bio-based processes tend to lie above the curve, meaning that their FCI is higher at the same rated power compared to petrochemical processes. Note that this does not say anything about differences in production costs.

Applying this model thus leads to estimates for the fixed capital investment for an industrial plant. Total CAPEX can then be calculated by adding an estimate for the working capital investment (WCI).

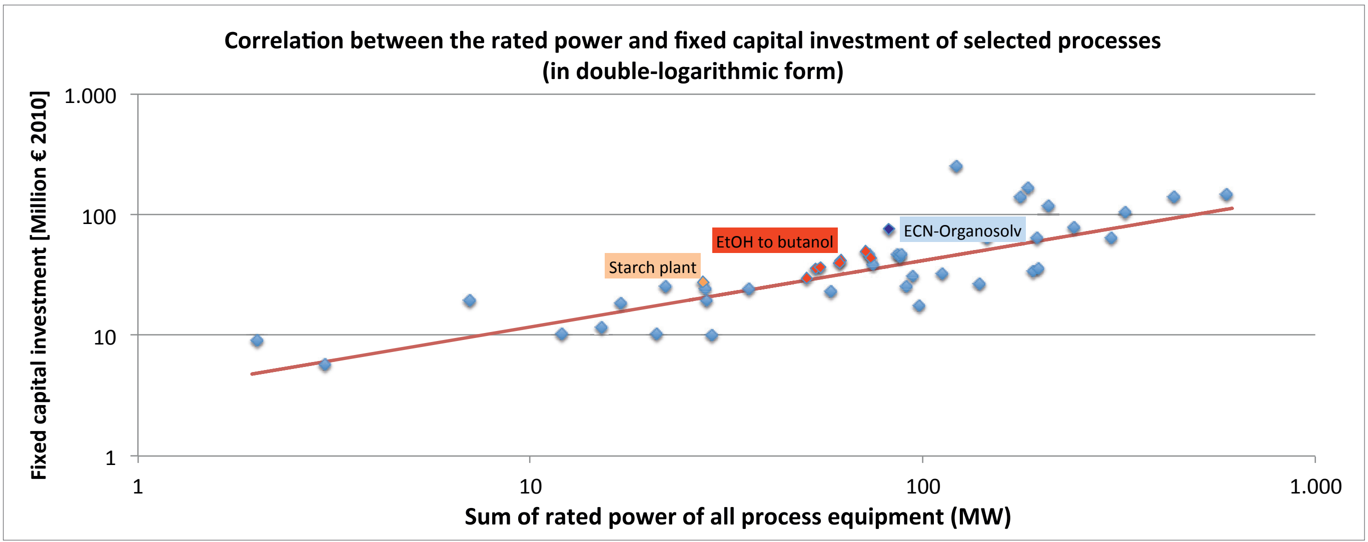

Figure 1: Validation of the model for estimating CAPEX

2.2 OPEX

For estimating the annual operating expenditures (OPEX), typically some amount of data, especially raw material and utility costs, can be retrieved based on process simulation models. Other data, such as for operating labour and different kinds of fixed and general costs, are, however, often not available and need to be estimated. For this purpose, standard models exist for different industries based on experience. We have therefore applied a model described by Turton et al. 2012 which is tailored to industrial chemical processes.

According to Turton et al. 2012, the annual OPEX are the sum of direct or variable manufacturing costs (DMC), fixed manufacturing costs (FMC) and general expenses (GE):

$$OPEX = DMC + FMC + GE \qquad (2)$$

Table 1 shows the types of cost items as grouped into these categories.

DMC	FMC	GE
Raw materials	Depreciation	Administration costs
Utilities	Local taxes and insurance	Distribution and selling costs
Operating labour	Plant overhead costs	Research and development
Direct supervisory & clerical labour		
Maintenance and repairs		
Operating supplies		
Laboratory charges		
Patents and royalties		

Table 1: Cost items included in DMC, FMC and GE
Source: Turton et al. 2012

According to Turton et al. 2012, total OPEX can be determined when the following costs are known or can be estimated:

1. Fixed capital investment (FCI)
2. Cost of operating labour (C_{OL})
3. Cost of utilities (C_{UT})
4. Cost of raw materials (C_{RM})

This result follows from the assumption, as described in Turton et al. 2012, that all other cost items are fixed factors of these four cost components shown above. The assumed relations for each cost item are shown in Table 2.

Cost item	Calculation, resp. estimation
Direct manufacturing costs (DMC) are the sum of:	
Raw materials (C_{RM})	Actual prices
Utilities (C_{UT})	Actual prices
Operating labour (C_{OL})	Based on equipment types
Direct supervisory and clerical labour	*Fixed factor of C_{OL}*
Maintenance and repairs	*Fixed factor of FCI*
Operating supplies	*Fixed factor of FCI*
Laboratory charges	*Fixed factor of C_{OL}*
Patents and royalties	*Fixed factor of OPEX*
Fixed manufacturing costs (FMC) are the sum of:	
Depreciation	*Fixed factor of FCI*
Local taxes and insurance	*Fixed factor of FCI*
Plant overhead costs	*Fixed factor of C_{OL} and FCI*
General expenses (GE) are the sum of:	
Administration costs	*Fixed factor of C_{OL} and FCI*
Distribution and selling costs	*Fixed factor of OPEX*
Research and development	*Fixed factor of OPEX*

Table 2: Cost items and their calculation, resp. estimation procedure according to Turton et al. 2012

Given that all of the cost items written in italics in Table are assumed to be estimable as fixed factors of either C_{OL}, FCI or OPEX, solving the equation (2) for OPEX and factoring out leads to an equation in which only C_{OL}, FCI, C_{UT} and C_{RM} appear on the right side, each of them with a specific multiplier (Fx):

$$OPEX = F_1*FCI + F_2*C_{OL} + F3*(C_{UT} + C_{RM}) \qquad (3)$$

Annual operating expenditures can therefore be estimated using figures for FCI, C_{OL}, C_{UT} and C_{RM}. The procedure for estimating FCI was explained in section 2.1 and the quantities of utilities and raw materials needed for a process could be obtained directly from mass and energy balances and unit prices can be obtained from market research. Thus, also C_{UT} and C_{RM} are calculable. For the costs of operating labour, different estimation methods are possible. In a situation where the number and types of major equipment (e.g. reactors, columns, heat exchangers) is known from the flowsheet models, a procedure can be applied which links each type of equipment to the number of working units needed for operation (Dimian 2003, p. 592). Wage rates can obtained from statistical databases for the region under study.

Overall, the model therefore provides a robust and transparent means for estimating both CAPEX and OPEX with limited data.

2.3 Evaluating economic sustainability

Often, different process scenarios need to be compared in economic terms. For this purpose, suitable performance figures are needed. A very popular metric for evaluating investment projects is the Internal Rate of Return (IRR), which is defined as the discount rate at which the net present value (NPV) of an investment is equal to zero (DeFusco et al. 2011). The higher the IRR, the more favourable the investment project appears, because it implies that future cash flows could be discounted at a higher discount rate until the NPV equals zero.

An IRR of 25% is usually considered "as the threshold for securing capital investment in new processing technology" (Brown et al. 2012, p. 82) in the chemical industry. This threshold can therefore be used as a benchmark which the process under study would have to achieve in order to become attractive for investors.

Apart from CAPEX and OPEX, estimates regarding revenues as well the project lifetime are needed for a calculation of the IRR. For a calculation of revenues, product quantities from flow sheets are needed as well as product prices from market research. This further requires an evaluation of the potential for GreenPremium for selected products[2].

Although the IRR is very popular, the concept is often not well understood. In particular, it should be noted that the benchmark of an IRR of 25% is not equivalent to an annual interest rate of 25%. To make the difference clear and to put the IRR of 25% into perspective, a simple comparison can be made. Instead of investing the original capital into a biorefinery, it could be put into a bank account and earn annual interest. Then, the interest rate that would result in the same future value at the end of the project lifetime, e.g. 15 years, could be determined. In the case of an IRR of 25%, the equivalent interest rate lies at about 7% p. a.

2.4 Summary of the parameters needed

The following list summarizes all parameters that are finally needed for an application of the proposed model for a techno-economic evaluation. This list is formulated in more general terms in order serve as a guideline for future applications of the model.

1. Capital expenditures (CAPEX)

The model requires an estimate of the rated power of all equipment parts, expressed in MW. According to the model, the rated power is linked to the fixed capital investment (FCI) through a positive correlation. For an estimate of the total CAPEX, the model further requires an estimate of the share of working capital investment (WCI) in total CAPEX.

2. Annual operating expenditures (OPEX)

The model assumes that all other elements of the OPEX are either linked through fixed multiplication factors to the total OPEX or the following four cost items:

1. Fixed capital investment (FCI)
2. Cost of operating labour (C_{OL})
3. Cost of utilities (C_{UT})
4. Cost of raw materials (C_{RM})

Thus, OPEX can be estimated once these four elements are known or approximated. According to the model, an estimate for FCI has already been derived in step 1. For the other three elements of OPEX, the following procedures are proposed:

Cost of operating labour:
Numbers for the workforce needed (if possible differentiated by qualifications) can either be obtained directly from expert judgement or through an estimation based on the number and type of equipment.

Wage rates can either be obtained from statistical databases for the study region or from expert judgment.

Cost of utilities:
Quantities of utilities needed are obtained from the energy and material flow data. Utility prices are obtained from market research.

Cost of raw materials:
Quantities of raw materials (feedstock and operating materials) needed are obtained from the material flow data. Raw material prices are obtained from market research.

3. Revenues

For a calculation of revenues, product quantities from flow sheets are needed as well as product prices from market research. This further requires an evaluation of the potential for GreenPremium for selected products.

4. Estimates of economic sustainability

As the main indicator for economic sustainability, the model proposes the Internal Rate of Return (IRR). The calculation of the IRR requires an assumption regarding the project lifetime in years.

2 GreenPremium can be understood as the extra amount actors are willing to pay for a product for the fact that it is "green", or in our specific case, "bio-based" (=derived from biomass) (Carus et al. 2014).

3 Case study: The BIOCORE project

In the following, the application of the model described above to the BIOCORE project is presented. First, we introduce the BIOCORE project.

The BIOCORE (BIOCOmmodity REfinery) project (FP7-241566) managed by the French National Institute for Agricultural Research (Institute national de la recherche agronomique – INRA), aimed at conceiving and demonstrating the industrial feasibility of a biorefinery concept that allows the conversion of cereal by-products (straws), forestry residues and short rotation woody crops into a wide spectrum of products, including chemical intermediates, polymers and materials as well as second generation biofuels. At the heart of the concept is a patented organosolv technology to fractionate lignocellulosic biomass into the main components cellulose, hemicellulose and lignin, which was developed by the French company CIMV *(Compagnie Industrielle de la Matière Végétale)*.

BIOCORE brought together 24 partners who collaborated over a 48-month period (March 2010 to February 2014). Among its European partners, BIOCORE counted 10 companies, of which five were SMEs (among these the nova-Institute), one NGO and 12 public R&D organizations (i.e. universities, etc.). In addition, BIOCORE counted TERI, the world-class Indian R&D institute from New Delhi, among its partners. The BIOCORE project benefited from a budget of €20.3 million, of which €13.9 million consisted of aid from the European Union through FP7. For more information on the project, please visit *www.biocore-europe.org*.

The techno-economic evaluation described in the following covers selected BIOCORE biorefinery scenarios. The data available for this evaluation mainly consisted of energy and material flow data from modelling software, supplemented by expert knowledge from project partners. This type of data therefore proved to be suitable for an application of the model described in the first part of this paper.

The full public report on the environmental, economic, social and legal sustainability assessment of the BIOCORE biorefining system, together with general information about the project, can also be found at *www.biocore-europe.org*.

3.1 Description of the dataset

The dataset used for the economic assessment consists of scenarios that depict possible mature, industrial scale implementations of the BIOCORE biorefinery concept in 2025. This dataset was also used by our project partner, the Institut für Energie- und Umweltforschung (*The Institute for Energy and Environmental Research* – IFEU) for the environmental assessment, ensuring comparability between the environmental and economic sustainability assessment (Rettenmaier et al. 2013).

As mentioned above, the patented organosolv fractionation technology produces cellulose, but also partially depolymerised hemicelluloses and sulphur-free, low molecular weight lignins.

After the fractionation process has finished, BIOCORE combines the development of biotechnologies and chemical processes in order to create smart transformation itineraries that allow the production of resins, polymers (and their intermediates), surfactants and food/feed ingredients and second generation biofuel. It therefore valorises all three main biomass components.

There is a second benefit to this technology, in that it tolerates a wide variety of biomass feedstocks. Therefore, BIOCORE uses several types of biomass resources, including cereal by-products (straws, etc.), forestry residues and short rotation woody crops.

The evaluated concepts consist of selected combinations of feedstocks and products. Four main scenarios were defined based on wheat straw and produced combinations of two or three out of four main products: xylitol from the C5 fraction, itaconic acid from the C6 fraction, ethanol from both the C5 and C6 fraction and unmodified lignin (Table 3).

From these main scenarios, a total number of 13 variations were assessed with modifications concerning the type of feedstock (rice straw, hardwood, miscanthus or SRC poplar) or product portfolio. Furthermore, apart from standard scenarios in terms of process conditions, two sub-scenarios termed "favourable" and "less favourable" have been defined for some of these in order to reflect the wide range of possible future implementation conditions. The "favourable" sub-scenario for example depicts an implementation with very efficient energy integration, low amounts of material inputs, high conversion efficiencies and at the same time less by-products for energy generation. Comprehensive energy and material flow data was available for all scenarios.

All scenarios are based on European conditions, except the rice straw scenario which is based on conditions in India. Furthermore, all scenarios only consider feedstock from domestic production, i.e. imported biomass is excluded. Apart from these framework conditions, the scenarios are generic in the sense that they do not assume an implementation at a specific location or in a specific business environment.

Scenario short name[3]	Feedstock	Products			Sub-scenarios?[4]
		C5	C6	Lignin	
Main scenarios					
Xyl/IA	Wheat straw	Xylitol (Biotech)	Itaconic acid	Unmodified lignin	Yes
Xyl/Eth	Wheat straw	Xylitol (Biotech)	Ethanol	Unmodified lignin	Yes
Eth/IA	Wheat straw	Ethanol	Itaconic acid	Unmodified lignin	Yes
SHF[5] Eth	Wheat straw	SHF ethanol			
Variation: Catalytic xylitol production (Xyl Cat.)					
Xyl Cat./IA	Straw	Xylitol (Catalytic)	Itaconic acid	Unmodified lignin	No
Variation: Ethanol process					
Eth/Eth	Straw	Ethanol	Ethanol	Unmodified lignin	Yes
SSF[6] Eth	Straw	SSF ethanol		Unmodified lignin	No
PVC[7]	Straw	Ethylene		Unmodified lignin	No
Variation: Recycling of itaconic acid (IA Rec.)					
Xyl/IA Rec.	Straw	Xylitol (Biotech)	Itaconic acid (high purity, incl. recycling)	Unmodified lignin	No
Variation: Different feedstocks					
Xyl/IA hardw.	Hardwood	Xylitol (Biotech)	Itaconic acid	Unmodified lignin	Yes
Xyl/IA rice	Rice straw	Xylitol (Biotech)	Itaconic acid	Unmodified lignin	Yes
Xyl/IA misc.	Miscanthus	Xylitol (Biotech)	Itaconic acid	Unmodified lignin	Yes
Xyl/IA pop.	SRC poplar	Xylitol (Biotech)	Itaconic acid	Unmodified lignin	Yes
Variation: Use of lignin for energy (lig. en.)[8]					
Xyl/IA lig. en.	Straw	Xylitol (Biotech)	Itaconic acid	Crude lignin (energy)	No
SHF Eth/lig. en.	Straw	SHF ethanol		Crude lignin (energy)	No
Variation: Use of straw for energy (straw en.)[9]					
Xyl/IA straw en.	Straw	Xylitol (Biotech)	Itaconic acid	Unmodified lignin	No
Variation: Fallback (FB) product portfolio					
FB	Straw	Feed (sugars in syrup)	Paper pulp	Crude lignin (fuel)	No

Table 3: Table 3: Biorefinery scenarios

3 In most cases, the scenario short names indicate two main products from the C5 and C6 fraction in abbreviated form; in almost every case, unmodified lignin is produced from the lignin fraction.

4 Sub-scenarios “favourable” and “less favourable”

5 SHF: separate hydrolysis and fermentation

6 SSF: simultaneous saccharification and fermentation

7 PVC: the ethylene in this scenario is intended to be processed further into PVC. The PVC production itself, however, is not part of the scenario.

8 Where lignin is used for energy instead, this is indicated as “lig. en.” in the scenario short name.

9 Where additional wheat straw is used for energy, this is indicated as “straw en.”

3.2 Results

3.2.1 CAPEX

For an application of the CAPEX model, we first converted the original equation as presented above. Converting this formula into euros in 2010 gives the following equation:

$$FCI\ [Mill.\ EUR\ 2010] = 3.3 * Rated\ Power\ [MW]^{0.55} \qquad (4)$$

For the estimation of total CAPEX, we assumed WCI to amount to 4% of the fixed capital investment in each of the scenarios.

The estimation results for CAPEX for the standard scenarios are displayed in Figure 2. The estimates lie between about €123 million for the fallback option and €161 million for the value chain that produces ethylene for the further conversion into PVC. Both these lower and upper bounds of CAPEX estimates lie in a realistic range. It is comprehensible that investment costs for the fallback option are lowest since less equipment is needed than for the more complex product portfolios. Conversely, investment costs for the ethylene chain are highest since one further production step is needed after the ethanol production. Overall, the CAPEX model in this case thus leads to acceptable results.

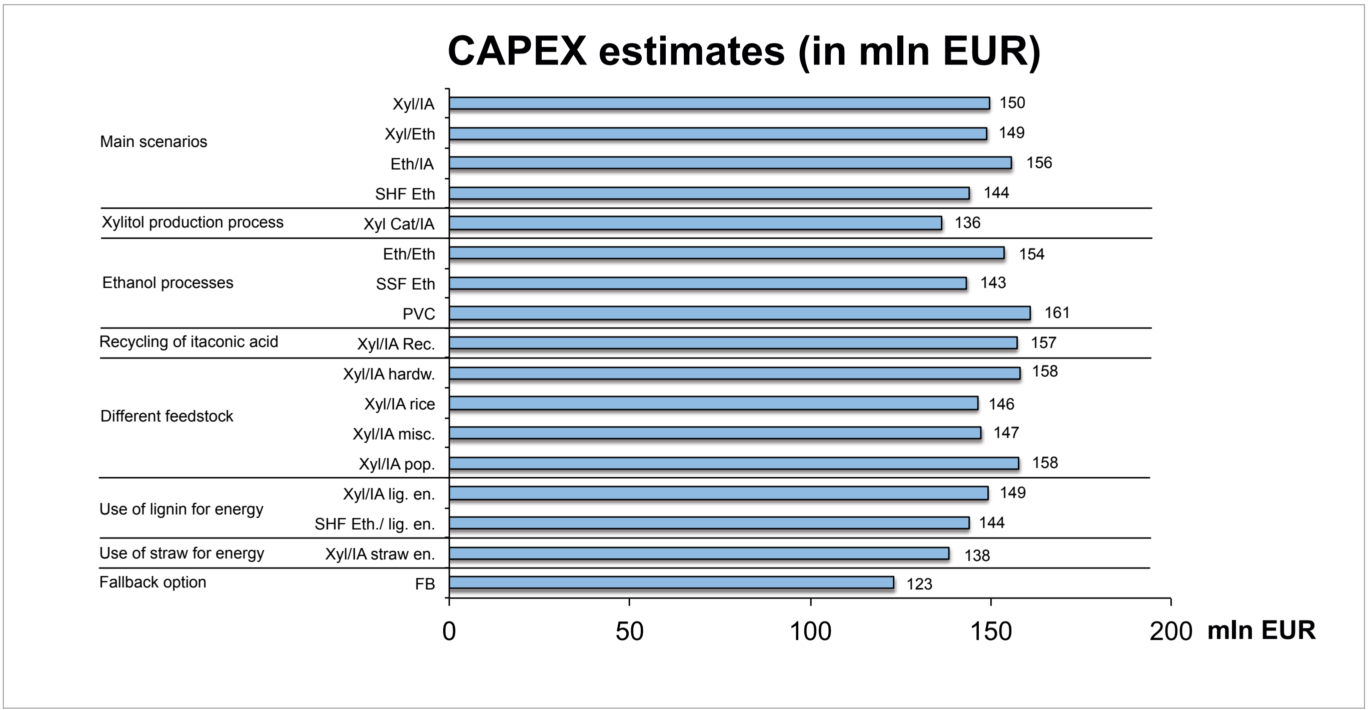

Figure 2: Overall results for CAPEX

3.2.2 OPEX

After applying multiplication factors from literature and expert judgement (Turton et al. 2012 as well as personal communication with BIOCORE partners), the final estimation procedure for DMC, FMC and GE is as follows:

Cost item	Calculation, resp. estimation
Direct manufacturing costs (DMC) are the sum of:	
Raw materials (C_{RM})	Actual prices
Utilities (C_{UT})	Actual prices
Operating labour (C_{OL})	Based on equipment types
Direct supervisory and clerical labour	$0.18*C_{OL}$
Maintenance and repairs	0.02*FCI
Operating supplies	0.003*FCI
Laboratory charges	$0.15*C_{OL}$
Patents and royalties	0.03*OPEX
Fixed manufacturing costs (FMC) are the sum of:	
Depreciation	0.067*FCI
Local taxes and insurance	0.02*FCI
Plant overhead costs	$0.708*C_{OL}$+ 0.036*FCI
General expenses (GE) are the sum of:	
Administration costs	$0.177*C_{OL}$+ 0.003*FCI
Distribution and selling costs	0.11*OPEX
Research and development	0.05*OPEX

Table 4: Cost items and their calculation, resp. estimation procedure for the BIOCORE case study

Then, as explained in section 2.2, solving equation (2) for OPEX and factoring out leads to the following equation for OPEX:

$$OPEX = 0.184*FCI + 2.735*C_{OL} + 1.235*(C_{UT} + C_{RM}) \qquad (5)$$

Figure 3 shows the results for the operating expenditures for the standard scenarios, split between biomass, operating labour, operating materials, utilities (natural gas, electricity and tap water), other DMC, GE and FMC. On average across all scenarios, both operating materials and utilities account for about 20% of manufacturing costs each. The other DMC, FMC and GE combined account for about 40%. Biomass accounts for about 15% and operating labour for 5%. Also these results lie in realistic ranges, so that also the OPEX model leads to viable results. Note, however, that the multiplication factors should be critically reviewed before applying them in new studies since these may be very project-specific.

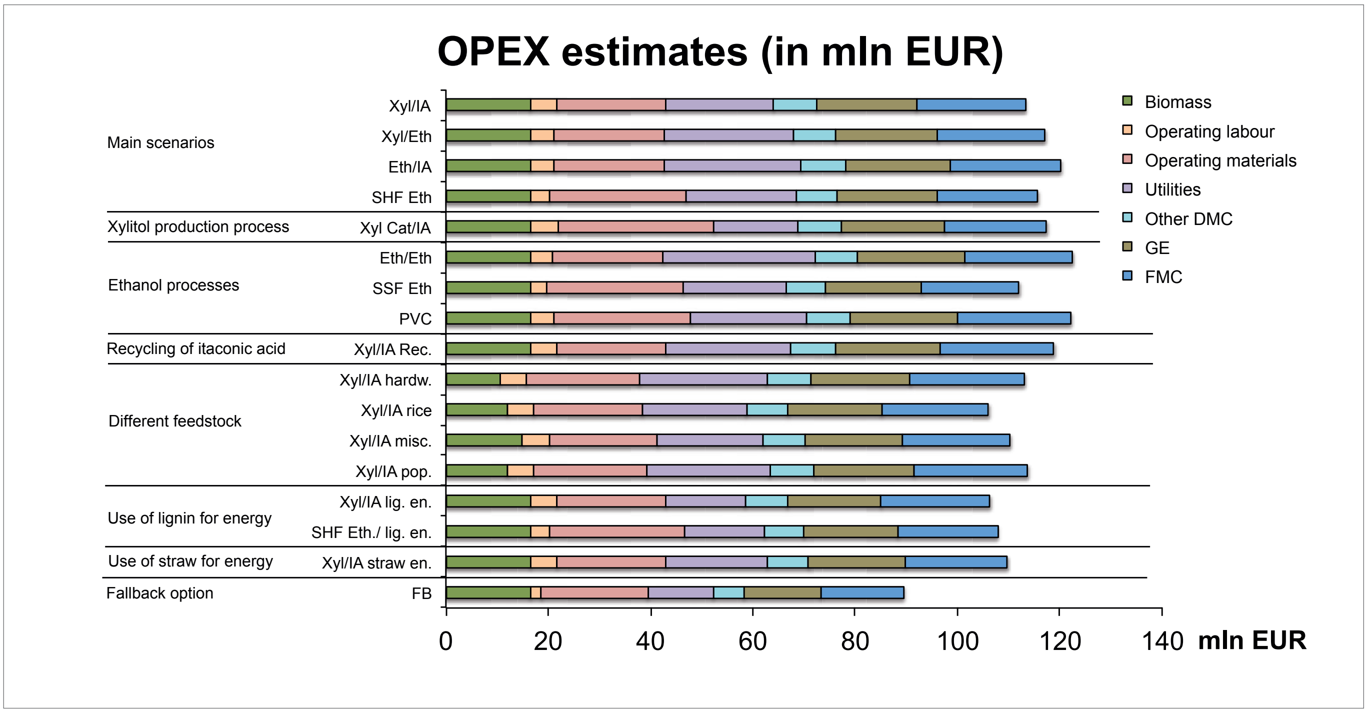

Figure 3: Overall results for OPEX

3.2.3 Economic sustainability

The results show that most of these biorefinery schemes would make annual losses under standard conditions. Only a few would make a profit, but it would not be sufficient to achieve an IRR of 25%. In order to reach this IRR target, and to make investment without favourable implementation conditions viable, these schemes would need a support mechanism.

One possible support mechanism would be direct price support on the sold production of the biorefinery. In a first instance, we assume that all sold products would be supported by a certain percentage added to the assessed market prices without GreenPremium.

The results in Figure 4 clearly show that the first main scenario (Xyl/IA) and all of its variations would need the lowest overall price support in order to reach the target of 25% IRR. In the favourable sub-scenarios (indicated in green), the Xyl/IA scenarios based on wheat straw, hardwood, poplar, miscanthus and rice straw would be able to achieve an IRR above 25% without any support. The dotted vertical lines in Figure 4 indicate actual current price support levels for biodiesel and bioethanol in Europe and Germany. These lie between about 45% in the case of average European support levels for biodiesel and 70% in the case of bioethanol support in Germany. This comparison shows clearly that the necessary price support for some of the selected biorefinery schemes could be moderate compared with the support for biofuels currently in place.

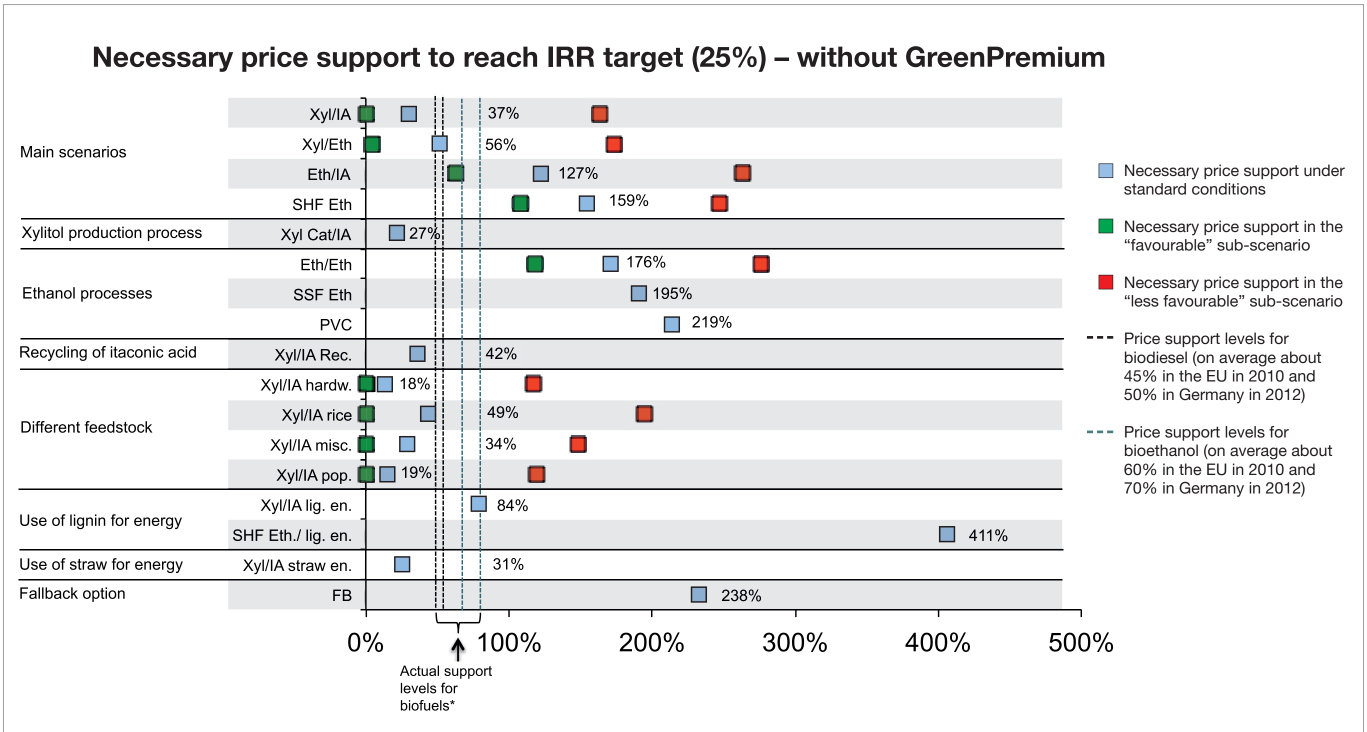

Figure 4: Necessary price support to reach an IRR of 25% without GreenPremium

Note: For an explanation of the scenarios, please see Table 3

These results significantly improve if GreenPremium prices are taken into account. Market research indicates that both itaconic acid and ethylene could be marketed for GreenPremium prices. For an assessment of the impact of this price premium, we assume a GreenPremium of 50% for itaconic acid and a GreenPremium of 30% for ethylene.

As Figure 5 shows, the GreenPremium for itaconic acid could cut the remaining necessary price support down further so that even the standard sub-scenarios of Xyl/IA based on hardwood and poplar could come close to profitability without any further support. The GreenPremium for ethylene, however, could not bring the PVC scenario anywhere near profitability.

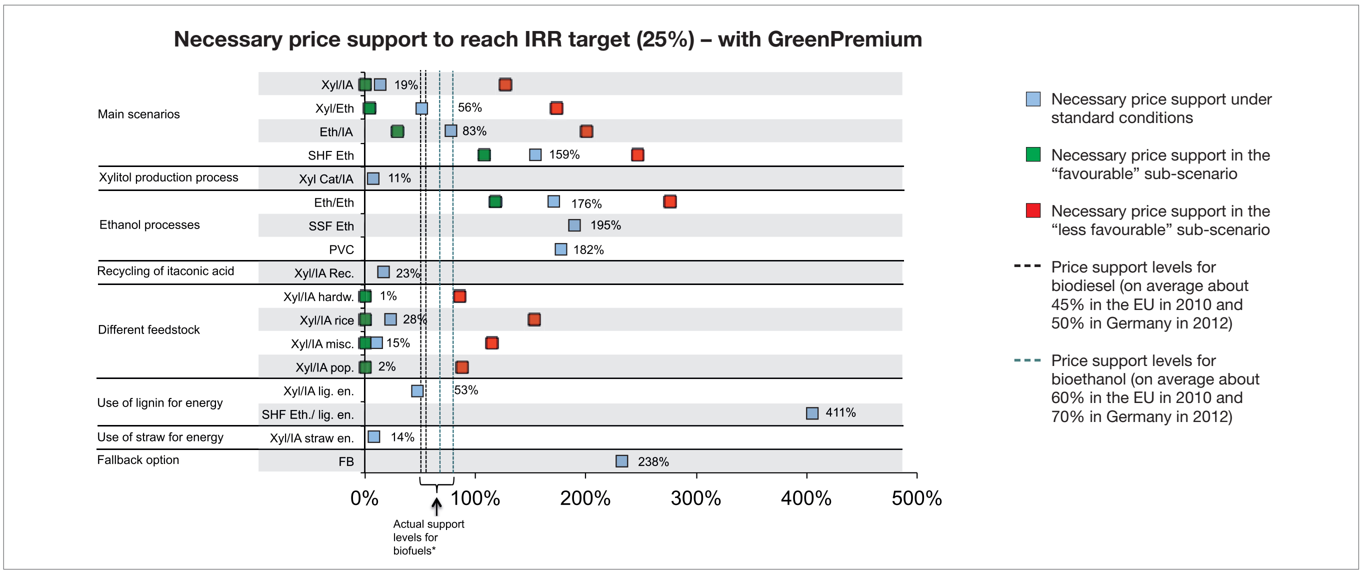

Figure 5: Price support needed to reach an IRR of 25% with GreenPremium

An alternative support instrument resulting in a CAPEX cut was also assessed. This support instrument was developed within the framework of the European Bioeconomy by DG Research & Innovation and the BBI. According to this policy, it will be possible to receive financial support for demonstration plants (on average 40%) and for flagship plants (on average 15%). In combination with other programmes, e.g. regional development or Member States support, capital investment could in some cases be reduced by a total of 50%.

Figure 6 shows the effects of such a 50% reduction of CAPEX on the remaining necessary price support (with GreenPremium). With this CAPEX reduction, the standard sub-scenarios of the first main scenario Xyl/IA based on hardwood, miscanthus and poplar as well as the scenario with catalytic xylitol production could now reach the target of an IRR of 25% without any further subsidies. However, other scenarios remain unprofitable.

In particular, all of the BIOCORE processes that are focused on ethanol proved to be energy intensive and generate – without incentives – low revenues. Policies targeted at bioethanol production therefore apparently set wrong incentives; policies should be directed towards value-adding chemicals and polymers.

Furthermore, scenarios with material use of lignin fare better than those which merely exploit its energy content.

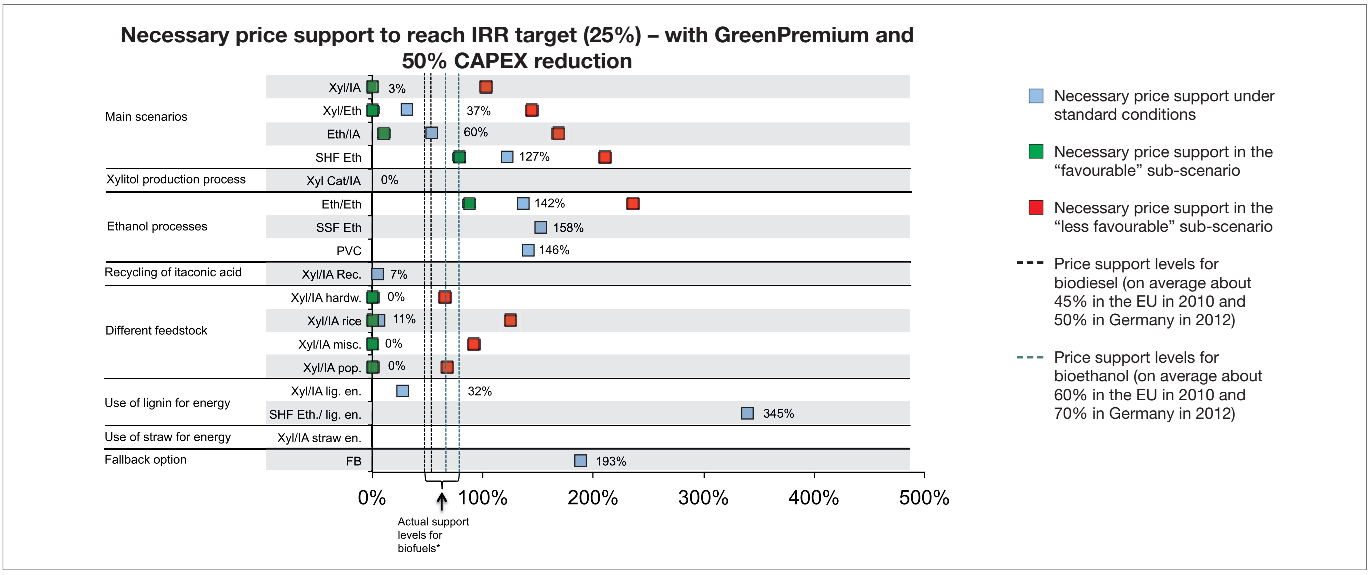

Figure 6: Necessary price support to reach an IRR of 25% with GreenPremium and 50% CAPEX reduction

4 Summary and outlook

This report first presented a newly developed model for a TEE of industrial processes in a situation of limited data availability, especially where no equipment sizing is possible.

The starting point of the analysis was the estimation of capital expenditures (CAPEX) based on the calculated rated power of all equipment of the whole plant. This estimation procedure was first proposed by Lange 2001 for petrochemical plants. However, a first testing of the proposed correlation for selected bio-based processes shows that it does not appear to be valid only for petrochemicals.

Furthermore, an estimation procedure for the annual operating expenses (OPEX) was presented. This procedure partly relies on data that could be retrieved from flowsheet models (types and amount of raw materials, utilities and equipment) and partly on assumptions regarding multiplication factors for those elements of the OPEX that cannot be estimated directly.

Finally, the overall economic viability of a process can be evaluated by calculating performance indicators such as the Internal Rate of Return (IRR), which requires estimates of revenues as well as the project lifetime.

Applied to the dataset that formed the basis for the sustainability assessment in the BIOCORE project, this model achieved reasonably good and coherent results, notwithstanding the limited data available. This encourages an evaluation of the model also for other early-stage processes in order to test its general applicability.

The results from the application to the BIOCORE project showed that especially those scenarios which produce high-value chemicals could come close to profitability with limited support mechanisms or GreenPremium. Conversely, scenarios with a focus on lignocellulosic ethanol production and energy use of lignin fare much poorer.

5 Literature

Brown, T.R., Zhang, Y., Hu, G., Brown, R.C. 2012: Techno-economic analysis of biobased chemicals production via integrated catalytic processsing, Biofuels, Bioproducts & Biorefining 6 (2012), pp. 73–87.

Carus, M., Eder, A., and Beckmann, J. 2014: Industry Reports - GreenPremium Prices Along the Value Chain of Biobased Products, Industrial Biotechnology 10(2), April, 2014, pp. 83-88.

De Fusco, R.A., McLeavey, D.W., Pinto, J.E. and Runkle, D.E. 2001: Quantitative Investment Analysis, John Wiley & Sons, UK.

Dimian, A.C. 2003: Integrated design and simulation of chemical processes, Elsevier, Amsterdam, The Netherlands.

Humbird, D., Davis, R., Tao, L., Kinchin, C., Hsu, D. and Aden, A. 2011: Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol. Technical report (2011), *www.nrel.gov/biomass/pdfs/47764.pdf.*

Lange, J.-P. 2001: Fuels and chemicals manufacturing: Guidelines for understanding and minimizing the production costs, Cattech, 5 (2), pp. 82–95.

Larsson, E., Max-Hansen, M., Pålsson, A., and Studeny, R. 2008: A feasibility study on conversion of an ethanol plant to a butanol plant, KET050 Feasibility Studies on Industrial Plants, Dept of Chemical Engineering, Lund Institute of Technology, Sweden.

Peters, M.S. and Timmerhaus, K.D. 1991: Plant Design and Economics for Chemical Engineers, McGraw-Hill, New York, USA.

Rettenmaier, N. et al. 2013: Environmental sustainability assessment of the BIOCORE biorefinery concept. Stable URL: *www.biocore-europe.org/file/D7_5%20Environmental%20sustainability%20assessment%20of%20the%20BIOCORE%20biorefinery%20concept.pdf.*

Towler, G. and Sinnott, R. 2008: Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design, Second Edition, Elsevier, Oxford, UK.

Turton, R., Bailie, R.C., Whiting, W.B., Shaeiwitz, J.A., and Bhattacharyya, D. 2012: Analysis, Synthesis, and Design of Chemical Processes, Fourth Edition, Prentice Hall, New Jersey, USA.

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nova paper #4: Proposals for a Reform of the Renewable Energy Directive to a Renewable Energy and Materials Directive (REMD). 2014-05.

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Dr. Stephan Piotrowski has broad international experience in the economics of value chain management in the agricultural and silvicultural sector. He conducts research on land use competition, the techno-economic evaluation of novel processes and biorefineries as well as market research for fossil and renewable raw materials and bio-based products.

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Physicist, from 1983 to 1994, he worked for the IT industry, environmental institutes and the solar industry. In 1994, he co-founded nova-Institute and has been functioning as owner and Managing Director since then. More than 15 years experience in the field of bio-based economy, including work on biomass feedstocks, industrial biotechnology and all kinds of biobased materials. His work focuses on market analysis, techno-economic and ecological evaluation and creating a suitable political and economic framework for bio-based processes and applications.

Michael Carus is member of the Technical Committee, CEN/TC 411 “Bio-based products”, member of the “Expert Group on Bio-based Products” of the European Commission, member of the Thematic Working Groups “Biomass supply” and “Market-making” of the “Bioeconomy Panel” of the European Commission, as well as member of the SCAR Foresight experts group “Sustainable Bioresources for a Growing Bioeconomy”.

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Achim Raschka studied biology with a focus on ecology and zoology at the Free University of Berlin and finished his diploma in biology in 2002. Before this, he completed an industrial training as a physics laboratory assistant at the Hella KG Hueck & Co. in Lippstadt, a component supplier for the automotive industry. After his studies, Mr Raschka worked at the public relations office of the German Human Genome Project in Berlin and later as a publisher at the Directmedia Publishing GmbH. Since 2008 he has been a staff scientist at the nova-Institute and has been responsible for biomass and biotechnology topics. For several projects, he has worked on the methodology of data collection and statistics on the use of biomass in Germany, the EU and worldwide. Since December 2012, he has been leading the department of technology.

Citation of the paper

Piotrowski, S., Carus, M., Sibilla, F., Raschka, A.: New nova Methodology for Techno-Economic Evaluations of Innovative industrial Processes (nTEE).– with a case study applied to a lignocellulosic biorefinery concept (BIOCORE) nova paper #5 on bio-based economy, Hürth 2014-11. Download at *www.bio-based.eu/policy*

Imprint

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