Life Cycle Engineering and Evaluation of Hybrid Products and Manufacturing Processes

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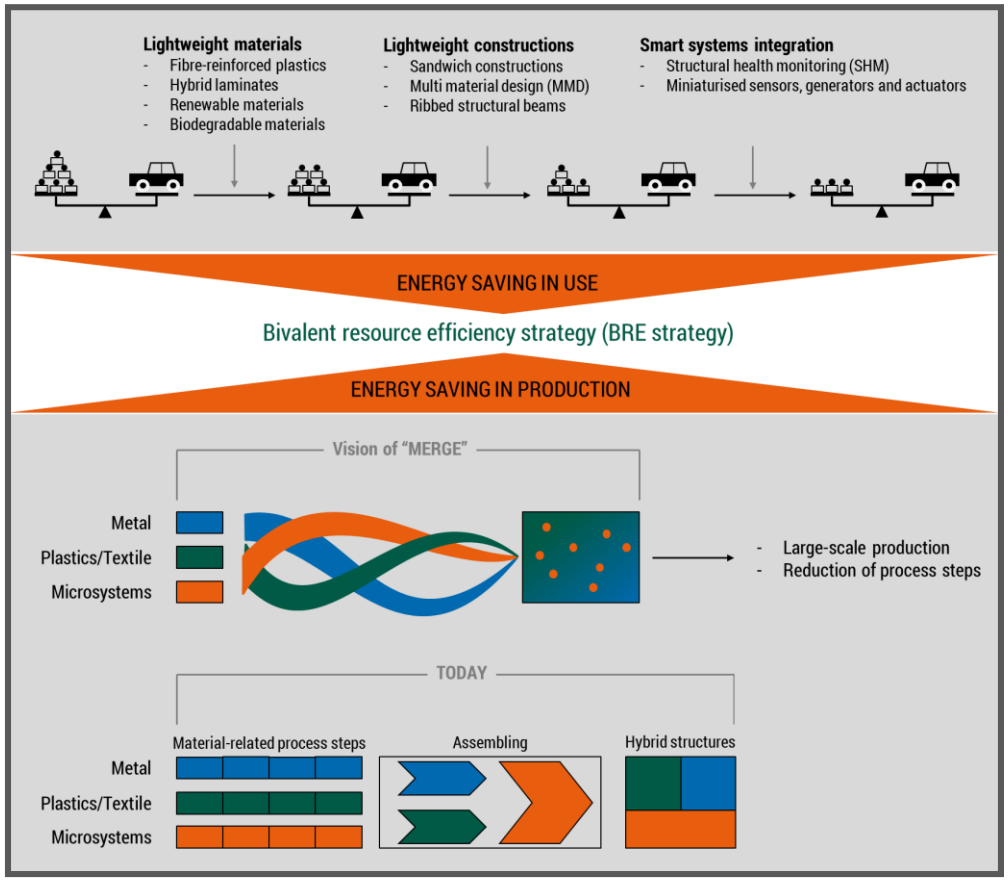
1. Motivation

MERGE Technologies for Multifunctional Lightweight Structures

Cluster of Excellence | EXC 1075



MERGE – Mission statement [1]

Motivation: Contributing to economic and ecological sustainability and cleaner production by life cycle-wide resource savings

Approach: Merging materials and material-specific processes for manufacturing hybrid lightweight structures → "hybrid" production

Objectives:

- Enabling large-scale production of lightweight structures by hybrid processes
- Fostering the usage of hybrid structures/products

1. Motivation

Life Cycle Engineering – Role of Evaluation

Relevance for

- Decision making in design processes
- Proof of contribution to sustainability

Challenges

- Multiple target criteria and various alternatives
- Life cycle-wide effects and influences
- High uncertainty

Need of a sophisticated life cycle-related

evaluation methodology

applicable in early design phase

Agenda

1. Motivation
2. Hybrid Production
3. Life Cycle Engineering and Evaluation
4. Case Study: Manufacturing of a Hybrid Component
5. Conclusion and Outlook

2. Hybrid Production

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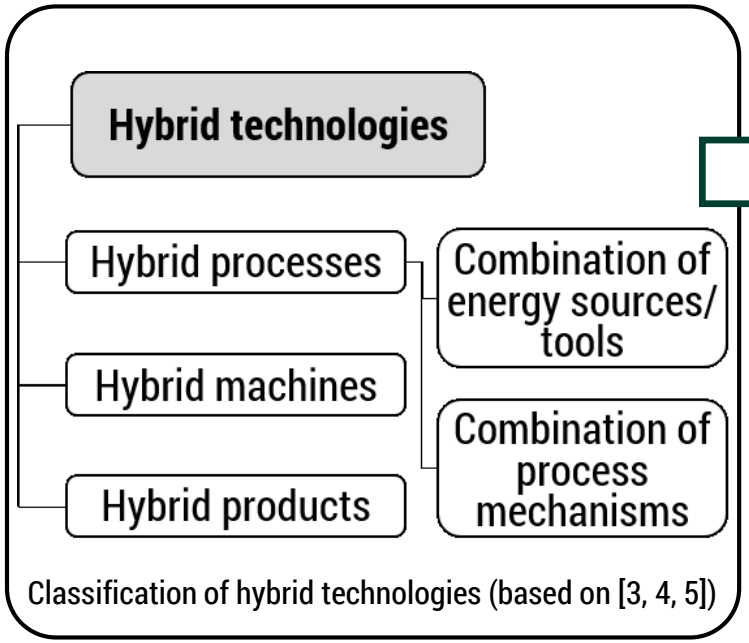
Hybrid production: combining processes/machines for more efficient and productive manufacturing of parts [3]



Classification of hybrid technologies (based on [3, 4, 5])

Potential benefits, e. g.: [4]

- Shortening of process chain → potential advantages with regard to processing and lead times, setup times, required resource inputs, manufacturing costs etc.
- Enhancement of flexibility of means of production
- Enabling of new product features

Challenges:

- Relative high investment costs [4]
- Selective design of processes, machines and products

Need of an early sophisticated life cycle-related evaluation

Hybrid production in the Cluster of Excellence MERGE:

- Manufacturing of hybrid lightweight structures
- Merging of basic process technologies for manufacturing such hybrid structures

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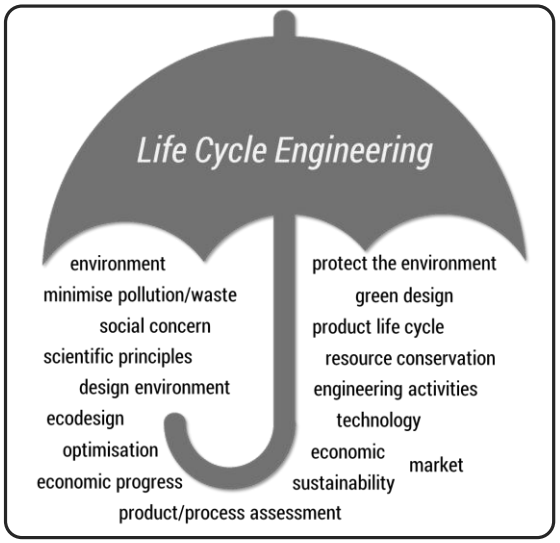
Selected Life Cycle-Related Engineering and Evaluation Approaches

- Design for/to X (manufacturing, maintenance, recycling ...)
- Life Cycle Costing, Total Cost of Ownership, Life Cycle Assessment etc.
- Life Cycle Engineering (LCE)

LCE: "Engineering activities which include: the application of technological and scientific principles to the design and the manufacture of products, with the goal of protecting the environment and conserving resources, while encouraging economic progress, keeping in mind the need for sustainability, and at the same time optimizing the product life cycle and minimizing pollution and waste" [6]



Keywords of Life Cycle Engineering (slightly modified adopted from [6])

→ Various approaches with common characteristics:

- Life cycle-orientation
- Focus on engineering decisions
- Target dimensions: ecological, economic, (technical)

→ Need of evaluation and a sophisticated evaluation methodology

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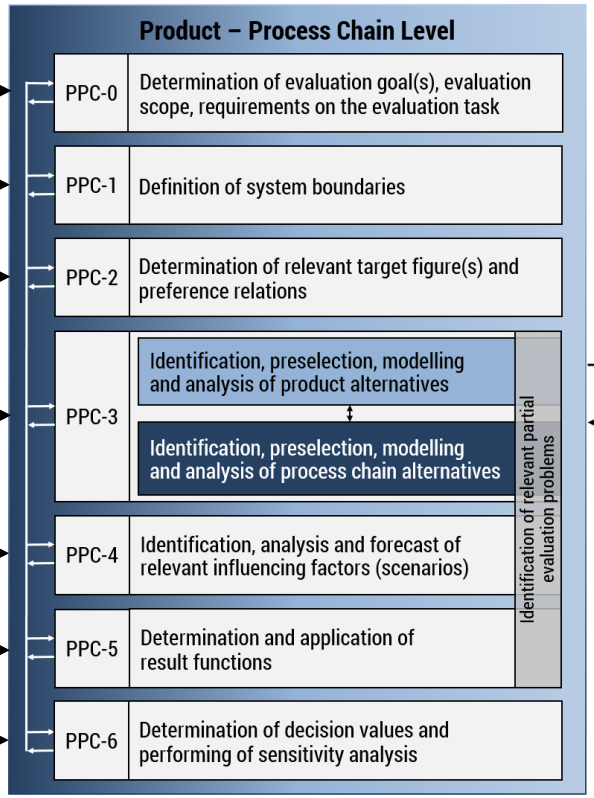
Procedure Model – Core Element of the Evaluation Approach

Main Characteristics of the Procedure Model

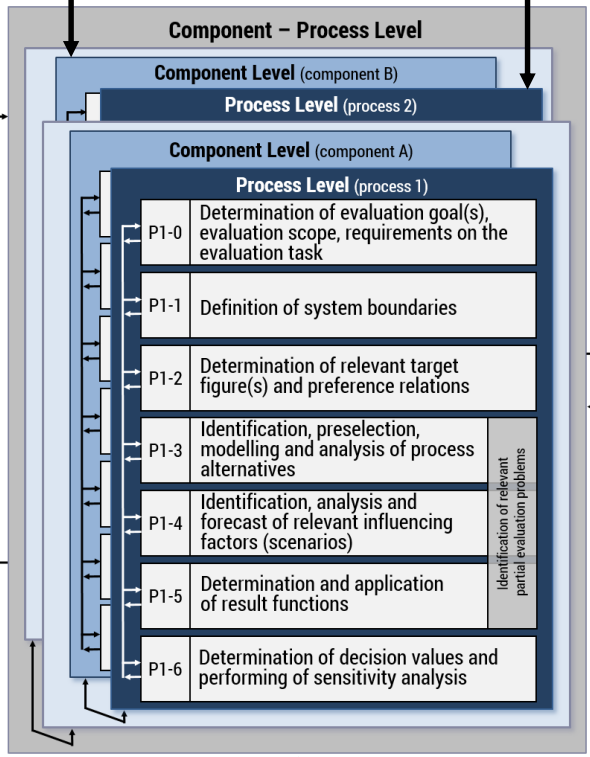
Several steps

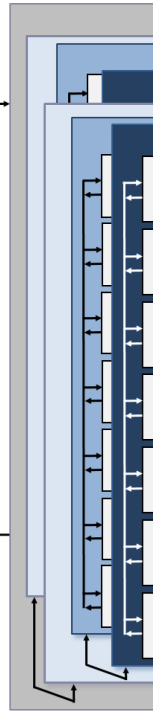
… referring to basic elements of decision models:

- target figures and preference relations
- alternatives
- environmental factors
- result functions



Different dimensions of alternatives





Procedure model for process chain and product evaluation [7]

Means of communication

Frame for the integrated use of evaluation methods

Hierarchic levels

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4. Case Study: Manufacturing of a Hybrid Component

Introduction to the Case

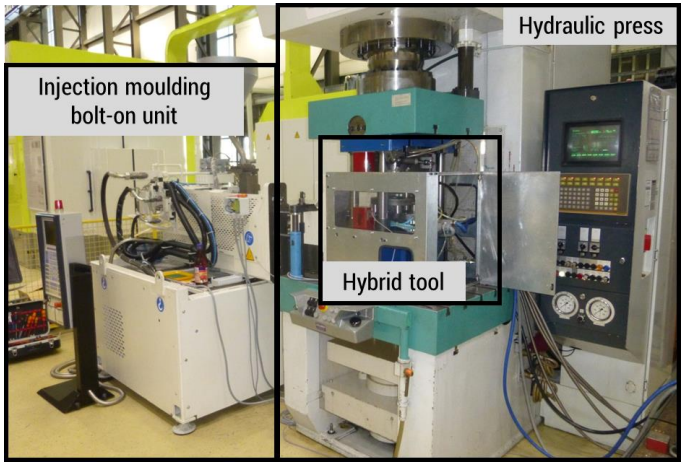
Manufacturing of a metal/plastic (hybrid) component

- Innovative process chain is characterised by:
  - Integrating different manufacturing processes (deep-drawing and injection moulding with active media-based forming)
  - Using only one single tool (hybrid tool)

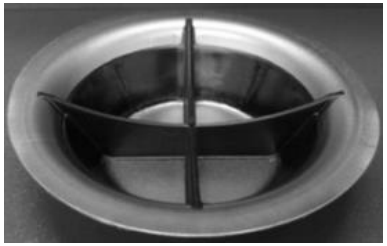
  ➔ Hybrid process chain

  ➔ Potential to enhance (resource) efficiency and economic as well as ecological sustainability of hybrids

- Demonstrator: cup-shaped metal/plastic (hybrid) component



Experimental setup of hybrid process chain [2]



Cup-shaped metal/plastic (hybrid) component [2]

4. Case Study: Manufacturing of a Hybrid Component

Introduction to the Case

Manufacturing phase of component/product – usage/service phase of process chain

Hybrid process chain

Hybrid process comprising deep drawing, injection moulding and media-based forming

[2]

Deep drawing → Storage and transport → Injection moulding + media-based forming

[2]

Conventional process chain

Reduced number of processes and process steps by hybrid process chain

Potential for energy, time and costs savings

4. Case Study: Manufacturing of a Hybrid Component

Evaluation – Application of the Procedure Model

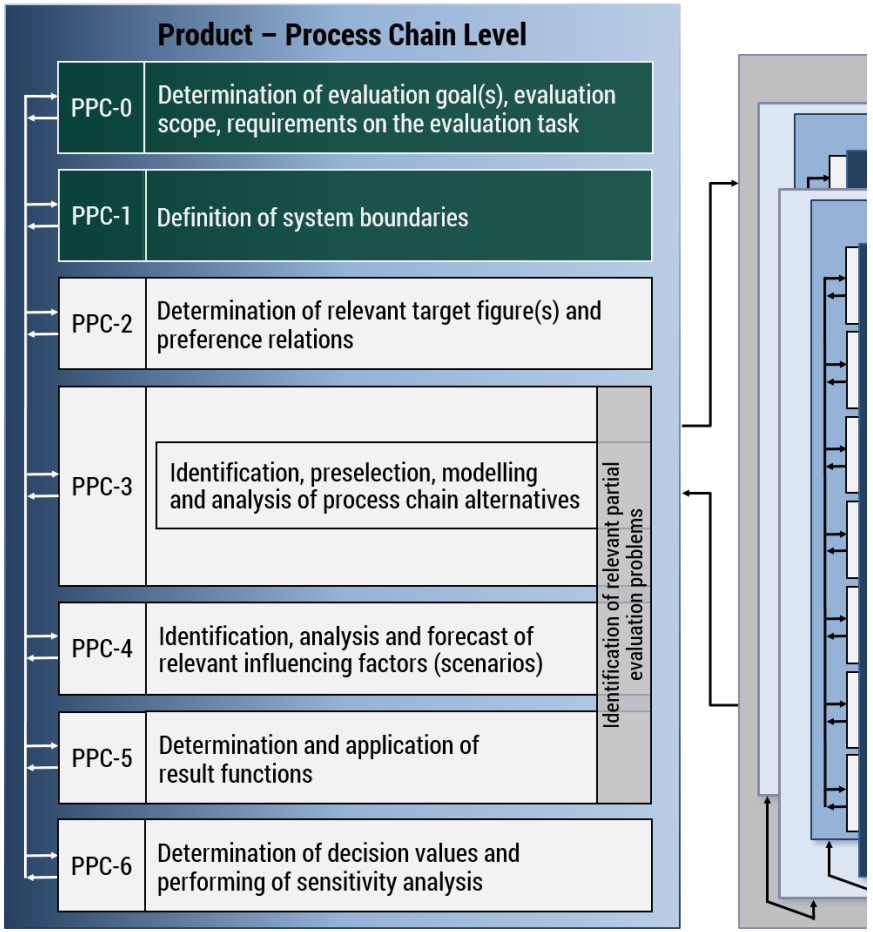
Basis for evaluation

PPC-0: Evaluation goal(s), evaluation scope, requirements on the evaluation task

- Goal: Comparison of hybrid vs. conventional process chain
- Scope: economic effects, manufacturing phase of component/product and usage/service phase of process chain
- Requirements: significance, transparency, efficiency …

PPC-1: System boundaries

- Alternatives: process chain (boundaries: inserting of blank in tool – removal of hybrid component of tool)
- Effects: economic
- Time: economic lifes of machines and tools, life cycle of component



Procedure model for process chain and product evaluation [7]

4. Case Study: Manufacturing of a Hybrid Component

Evaluation – Application of the Procedure Model

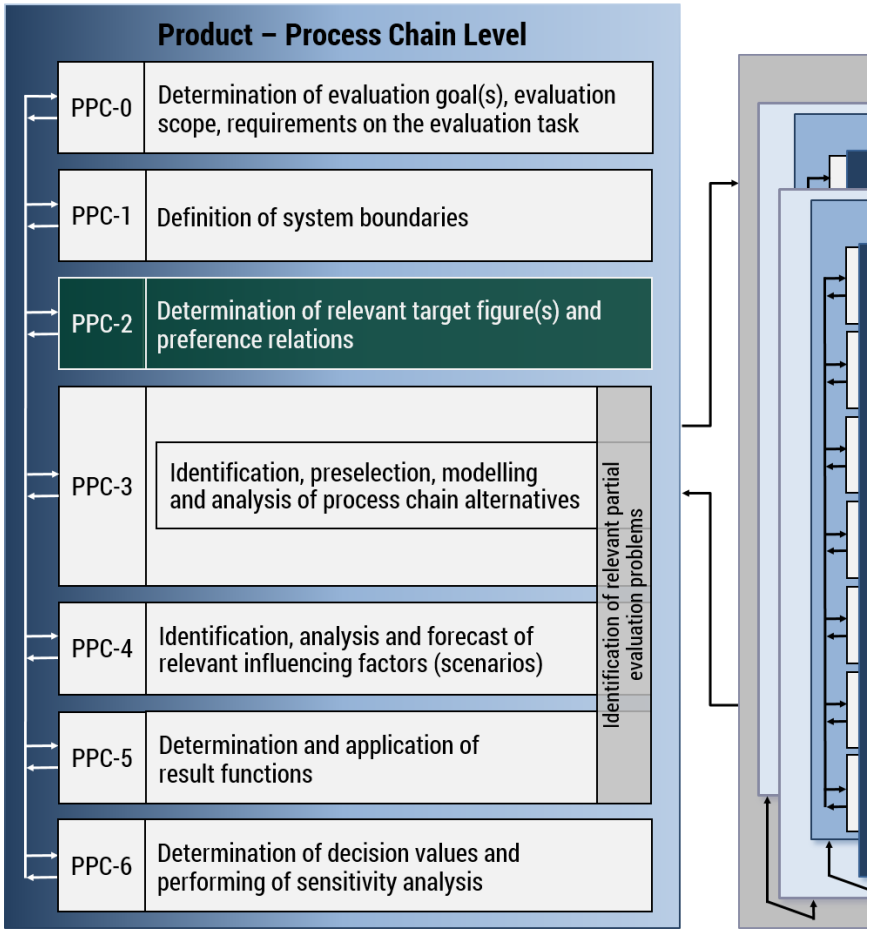
Target figure(s)

PPC-2: Target figure(s) and preference relations

- Economic target figure: (relevant) costs of the process chain

Direct material costs
+ Material overhead costs
= **Material costs of the process chain**
+
Direct manufacturing costs of process 1
+ Direct manufacturing costs of process 2
+ …
+ Direct manufacturing costs of process n
= *Total direct manufacturing costs of the process chain*
Machine-dependent indirect manufacturing costs of process 1
+ Machine-dependent indirect manufacturing costs of process 2
+ …
+ Machine-dependent indirect manufacturing costs of process n
= *Total machine-dependent indirect production costs of the process chain*
+ Specific direct costs of manufacturing (process chain-relevant and traceable)
+ Residual indirect manufacturing costs
= **Manufacturing costs of the process chain**
=
Costs of the process chain

Calculation scheme for costs of the process chain [8, 9]



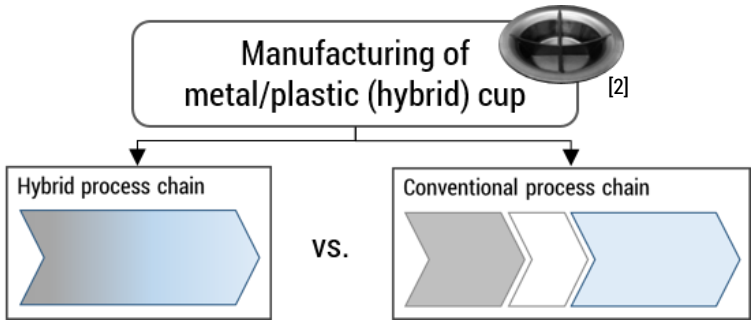
Procedure model for process chain and product evaluation [7]

4. Case Study: Manufacturing of a Hybrid Component

Evaluation – Application of the Procedure Model

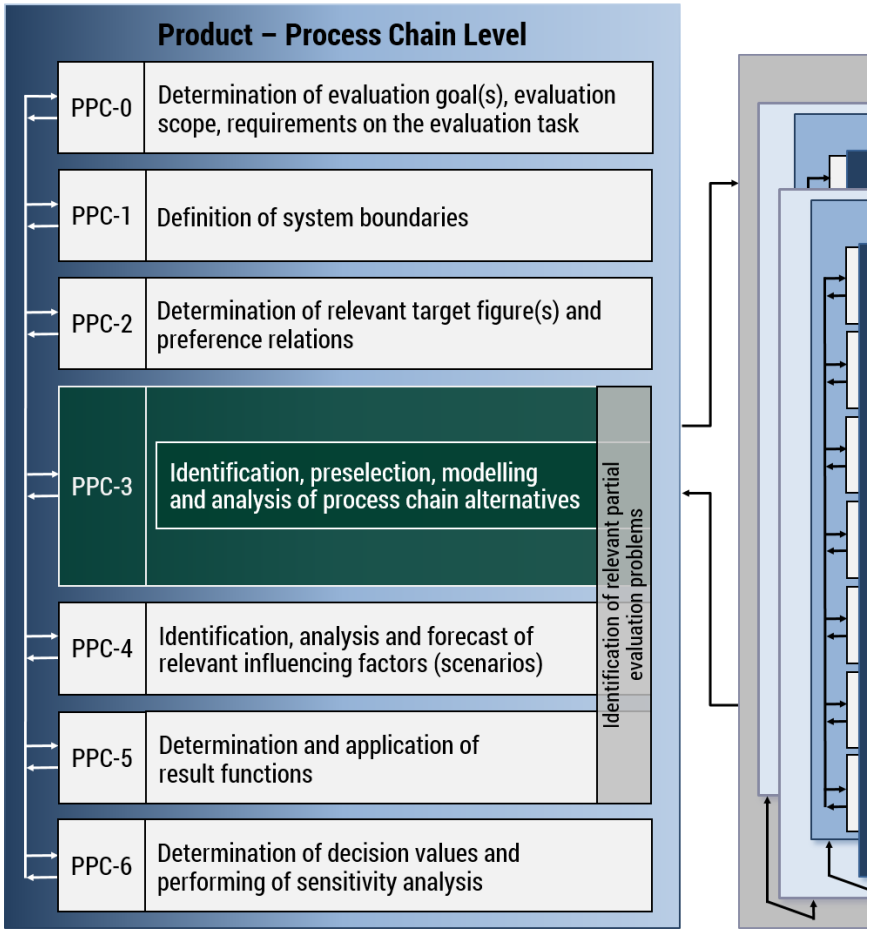
Analysis of alternatives

PPC-3: Process chain alternatives



- Input-Throughput-Output (I-T-O) models:
  - Used for modelling and analysis
  - Basis for identification of relevant input, throughput and output variables and parameters → derivation and calculation of relevant cost items

→ At subordinated levels: evaluation of relevant sub-alternatives



Procedure model for process chain and product evaluation [7]

4. Case Study: Manufacturing of a Hybrid Component

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Evaluation – Application of the Procedure Model

Analysis of alternatives

I-T-O model of hybrid process chain

Input

Material:
- DC04 metal sheet coated with bonding agent Vestamelt® X113
- Polyamid granulate PA6 GF 60

Machines/Tools:
- 1 Hydraulic press
- 1 Injection moulding bolt-on unit
- 1 Hybrid tool

Energy/Media/Labour:
- Electrical
- Water
- 1 worker (technician)

Throughput

Insert blank → Close press/hybrid tool – Deep drawing → Injection moulding and media-based forming → Plasticize and cooling → Cooling → Open hybrid tool → Remove metal/plastic (hybrid) cup

Hybrid process

Output

Product:
- Metal/plastic (hybrid) cup

[2]

Emission/Waste:
- Heat
- Polyamid PA6 GF60

I-T-O model of conventional process chain

Input

Material:
- DC04 metal sheet coated with bonding agent Vestamelt® X113
- Polyamid granulate PA6 GF 60

Machines/Tools:
- 2 Hydraulic press
- 1 Injection moulding bolt-on unit
- 1 Deep drawing tool
- 1 Moulding tool
- 1 Container

Energy/Media/Labour:
- Electrical
- Water
- 2 workers (technician)

Throughput

Insert blank → Close press/deep drawing tool – Deep drawing → Open press/deep drawing tool → Remove preformed blank → Insert preformed blank in container → Storage and transport

Deep drawing process

...

Remove preformed blank of container → Insert preformed blank in moulding tool → Looking of moulding tool → Injection moulding and media-based forming → Plasticize and cooling → Cooling → Open moulding tool → Remove metal/plastic (hybrid) cup

Injection moulding and media-based forming process

Output

Product:
- Metal/plastic (hybrid) cup

[2]

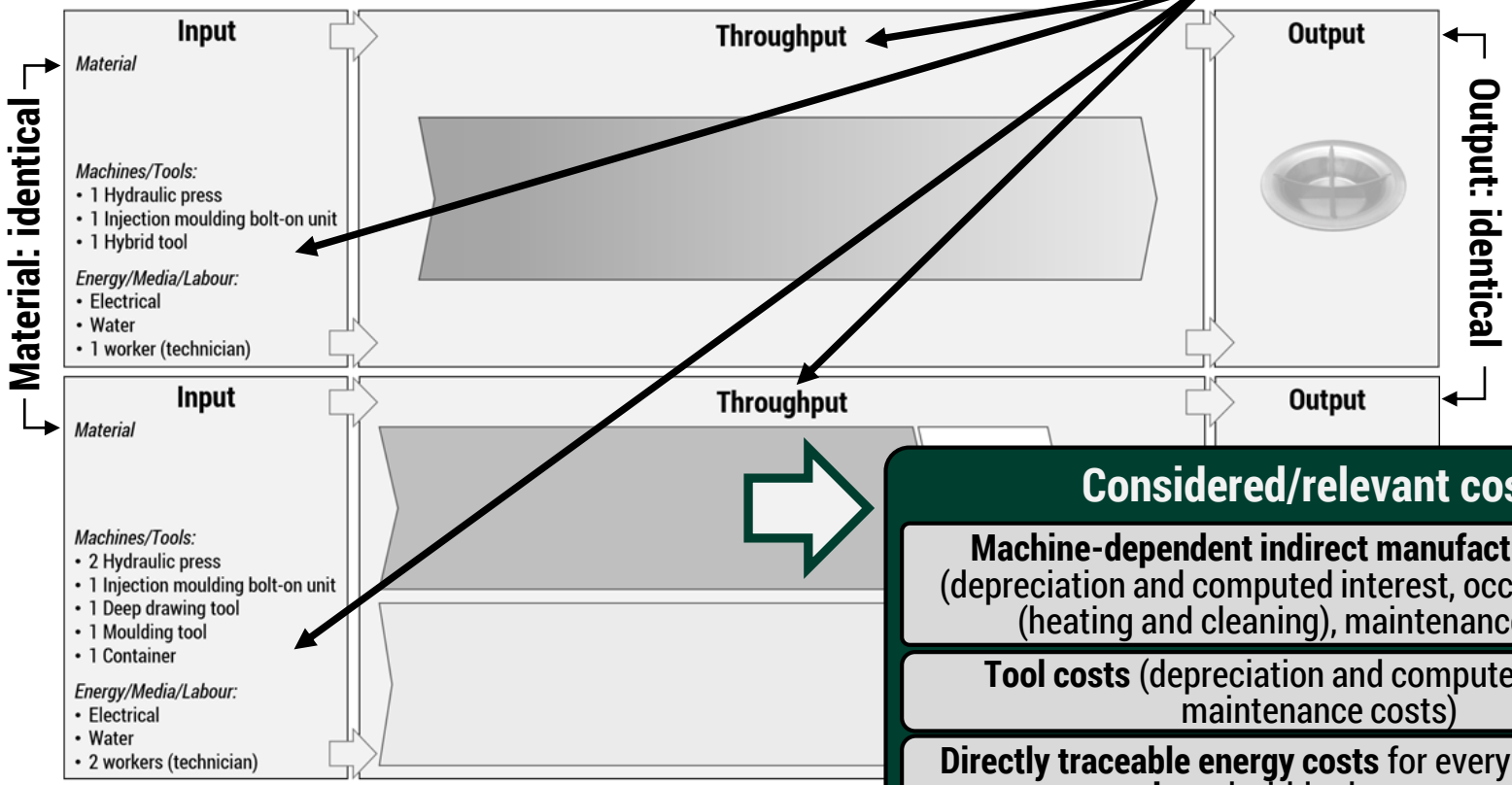
Emission/Waste:
- Heat
- Polyamid PA6 GF60

4. Case Study: Manufacturing of a Hybrid Component

Evaluation – Application of the Procedure Model

Analysis of alternatives

Main differences between alternative process chains



Considered/relevant costs

- **Machine-dependent indirect manufacturing costs** (depreciation and computed interest, occupancy costs (heating and cleaning), maintenance costs)
- **Tool costs** (depreciation and computed interest, maintenance costs)
- **Directly traceable energy costs** for every **machine** and **tool** used within the processes
- **Labour costs** (direct manufacturing costs)

4. Case Study: Manufacturing of a Hybrid Component

Evaluation – Application of the Procedure Model

Analysis of alternatives

PPC-4: Influencing factors

- Internal and external factors (e. g. prices of input factors, output quantity) determined by information systems, forecast methods etc.

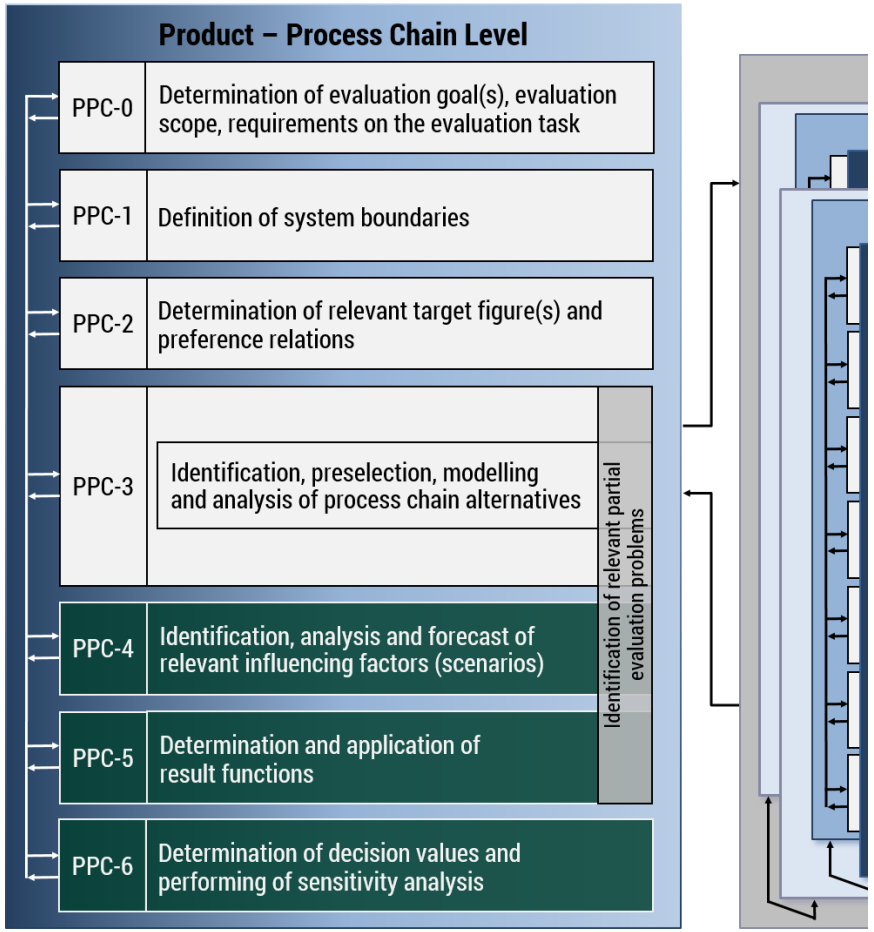
PPC-5: Result functions

- Capture relationship between characteristics of alternatives – outcomes of environmental factors – elements of target figure, e. g. result function for *energy costs = energy consumption * energy price*
- Basis for determining cost items
- Supporting methods: I-T-O models, development-concurrent calculation, cost accounting etc.

Evaluation and decision making

PPC-6: Decision values and sensitivity analysis

- Decision making based on decision values: here relevant costs of the alternative process chains



Procedure model for process chain and product evaluation [7]

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Evaluation – Application of the Procedure Model

Evaluation and decision making

Assumptions for evaluation

- Values of production volume, factor prices and process times: acceptably safe
- Material and types of machines: identical types and volumes
- Manually: insertion and removal of blank, preformed blank and hybrid cup
- Neglected:
  - Differences of the acquisition costs of the moulding tool and the hybrid tool
  - Costs and times for intermediate storage and transport of preformed blank (conventional process chain)
- Free capacities of machines and working force: used for other production purposes
- …

Initial data

Production volume [cups/year]	36,900
Machine hours [h/year]	1,950.00
Working hours (1 shift) [h/year]	1,950.00
Wage rate [€/h]	37.00
Interest rate [%]	10
Energy price [€/kWh]	0.15
Useful life time [years]	5 (hydraulic press) 13 (injection moulding bolt-on unit) 8 (tools)

4. Case Study: Manufacturing of a Hybrid Component

Evaluation – Application of the Procedure Model

Evaluation and decision making based on modified data

	Hybrid process chain		Conventional process chain		
	Hybrid process		Deep drawing process	Injection moulding + media-based forming process	
Direct manufacturing costs [€/cup]	0.77		0.34	0.76	
	Hydraulic Press	*Injection moulding bolt-on unit*	*Hydraulic Press*	*Hydraulic Press*	*Injection moulding bolt-on unit*
Machine-dependent indirect manufacturing costs [€/cup]	1.30	0.39	0.57	1.28	0,38
Directly traceable energy costs [€/cup]	0.09	0.03	0.02	0.09	0.03
	Hybrid tool		*Deep drawing tool*	*Moulding tool*	
Specific direct costs of manufacturing [€/cup]	0.34		0.06	0.34	
Directly traceable energy costs of tool [€/cup]	0.02		0.00	0.02	
(Relevant) costs of the process chain [€/cup]	2.94		3.89		

Evaluation and decision making

Costs saving potential of hybrid process chain

Note:
- Restricted availability and quality of data
- Simplifying assumptions

→ Corresponding high uncertainty

⇨ Careful interpretation of results and performing of sensitivity analyses

4. Case Study: Manufacturing of a Hybrid Component

Evaluation – Application of the Procedure Model

Evaluation and decision making based on modified data

	Hybrid process chain		Conventional process chain		
	Hybrid process		Deep drawing process	Injection moulding + media-based forming process	
Direct manufacturing costs [€/cup]	**0.77**		**0.34**	**0.76**	
	Hydraulic Press	*Injection moulding bolt-on unit*	*Hydraulic Press*	*Hydraulic Press*	*Injection moulding bolt-on unit*
Depreciation [€/year]	68,485.97	13,023.62	68,485.97	68,485.97	13,023.62
Interest rate [€/year]	17,121.49	8,465.35	17,121.49	17,121.49	8,465.35
Occupancy costs (heating and cleaning) [€/year]	602.08	787.72	602.08	602.08	787.72
Maintenance costs [€/year]	17,121.49	8,465.35	17,121.49	17,121.49	8,465.35
Machine hour rate [€/h]	62.34	18.55	62.34	62.34	18.55
Machine-dependent indirect manufacturing costs [€/cup]	**1.30**	**0.39**	**0.57**	**1.28**	**0,38**
Directly traceable energy costs [€/cup]	**0.09**	**0.03**	**0.02**	**0.09**	**0.03**
	Hybrid tool		*Deep drawing tool*	*Moulding tool*	
Depreciation [€/cup]	0.26		0.05	0.26	
Interest rate [€/cup]	0.01		0.002	0.01	
Maintenance costs [€/cup]	0.07		0.01	0.07	
Specific direct costs of manufacturing [€/cup]	**0.34**		**0.06**	**0.34**	
Directly traceable energy costs of tool [€/cup]	**0.02**		**0.00**	**0.02**	
(Relevant) costs of the process chain [€/cup]	**2.94**		**3.89**		

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Conclusion

- **Hybrid production:** bears a significant potential for more sustainability and cleaner production in a couple of fields (as indicated in the case from MERGE (despite the limitations of evaluation))
- **Life Cycle Engineering:** is a promising approach (family) for a sustainability-oriented design of production factors, processes and products
- **Evaluation method:** is suitable for a structured evaluation of complex, life cycle-related and sustainability-oriented alternatives of hybrid technologies in early life cycle phases

Outlook

- **Hybrid production:** needs intensive R&D activities and further successful application cases to become contemporarily an established way of (cleaner) production
- **Life Cycle Engineering:** should be systematised, elaborated and integrated with related engineering and evaluation concepts
- **Evaluation method:** has to be refined with regard to its applicability in early design phases, the different target dimensions of sustainability, different life cycle phases etc. and validated in use cases

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- Since 1997 full professor – Professorship of Management Accounting and Control (Faculty of Economics and Business Administration) at the Technische Universität Chemnitz
- Since 1998 Editor of Journal of Planning/Journal of Management Control (JoMaC)
- Various lectures in study courses for Business Administration (Bachelor/Master) and Business Administration and Engineering (Bachelor/Master)

- Participation in various research projects e. g. in the:
  - Cluster of Excellence “Merge Technologies for Multifunctional Lightweight Structures”
  - "Collaborative Research Centre 692 – High-strength aluminium-based lightweight materials for safety components“
  - Cluster of Excellence "Energy-efficient Product and Process Innovations in Production Engineering"

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Procedure Model as a Frame for the Integrated Use of Evaluation Methods – Overview

Steps \ Target figures	*Technical*	*Economic*	*Ecological*	*Social*
Determination of evaluation goal(s), evaluation scope, requirements on the evaluation task	...			
Definition of system boundaries	...			
Determination of relevant target figure(s) and reference relations	• Multi-criteria decision making methods (e. g. utility value analysis, Analytic Hierarchy Process, PROMETHEE) • Investment theory/appraisal • ...			
Identification, preselection, modelling and analysis of alternatives	• Generic product and process models • Product- and process-related analysis instruments (e. g. FMEA, FEM, value analysis, material flow analysis) • ...			
Identification, analysis and forecast of relevant influencing factors (scenarios)	• Sales/distribution, production and procurement plans • Analytical and intuitive forecast methods • Scenario technique • ...			
Determination and application of result functions	• Empirical investigations (measures, statistical analyses) • Input-Throughput-Output models • Simulations • Approaches of production theory incl. production functions • ...			
	• Check lists • Expert judgements • Utility value analysis • ...	• Traditional cost accounting • Discounted cash flow methods, life cycle costing (net present value method) • ...	• Environmental life cycle assessment (e. g. cumulated energy demand)	• Social (life cycle) assessment • Ergonomic methods • ...
	• Methods of development-concurrent calculation			
Determination of decision values and performing of sensitivity analysis	• Multi-criteria decision making methods • Engineering scientific approaches • ...			

Selection of instruments for analysing and evaluating product and process chain combinations (slightly modified adopted from [B1])

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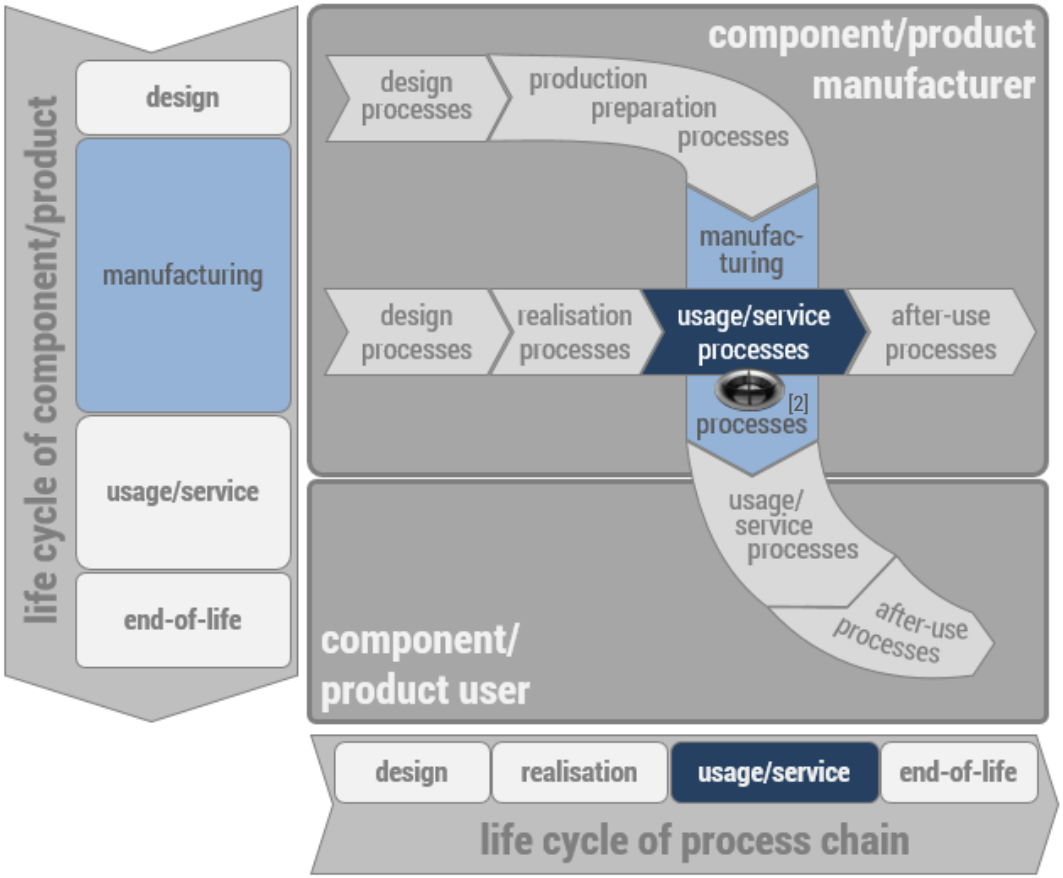
Life cycles of process chain and component/product



Actors and processes in the life cycles of process chain and component/product (based on: [B2, B3])

Backup – References

[B1] Götze U. et al.: Zur Analyse und Bewertung von Produkt-Prozessketten-Kombinationen der hybriden Produktion. In: Neugebauer, R. et al. (eds.): Energetisch-wirtschaftliche Bilanzierung – Diskussion der Ergebnisse des Spitzentechnologieclusters eniProd, 3. Methodenband der Querschnittsarbeits-gruppe „Energetisch-wirtschaftliche Bilanzierung“ des Spitzentechnologieclusters eniProd, Verlag Wiss. Scripten, Auerbach, 2014, pp. 21-32

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