UNIVERSITY OF APPLIED SCIENCES UPPER AUSTRIA

Research Group Smart Mechatronics Engineering

EcoMechatronics: A (new) paradigm supporting sustainability

Peter Hehenberger

EnerMan
Energy Efficient Manufacturing System Management

AGIP
Société d'Automatique, de Génie Industriel et de Productique

gdr macs

cnrs

GT SYSME (Systèmes Mécatroniques):
„mécatronique et industrie du futur“
ENIT Tarbes, 30.9.2022

RC LOWCAP
Research Centre for Low CO_2 Special Powertrain

Research Areas

EcoMechatronics

- Life Cycle Assessment and Engineering
- Eco Design
- Sustainability by Design
- Energy Efficiency Awareness in Production
- Energy-flexible Factory
- Smart Production
- Circular Economy
- Design for Recycling

Sustainability in Development and Production of Mechatronic Systems

- CAx-Systems
- Product Data Management PDM
- Cyber Physical (Production) System
- Internet of Things IoT
- Product-Service System
- Hierarchical Modelling of Systems
- Digital Twin
- Virtual Commissioning

Digital Transformation (Selected Topics)

Engineering Processes

- Advanced Systems Engineering
- MBSE
- Requirements Engineering
- Agile Transformation

- Product/Production System Co-Design
- Product Lifecycle Management
- Mechatronic System Design

Engineering Design | **Mechatronic Systems** | **Production** | **Product Lifecycle Management**

EnerMan

H2020-Projekt ENERMAN **"ENERgy-efficient manufacturing system MANagement"** (2021-2023)

RC LOWCAP

"CO2 Life Cycle Analysis in early stage design phase" Project within the COMET-Project "Research Center for Low Carbon Special Powertrain" (2018-2023)

NaKuRe - HoKu

"Holistic LCA-based Consideration of Lifecycle of Plastics" Project within the FTI-Project "NaKuRe" (2022-2025)

SUNISWELL

upper austria

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Motivation

The 2030 Agenda for Sustainable Development, 17 Sustainable Development Goals (SDGs) @ sdgs.un.org/goals

The European Green Deal is about **improving the well-being of people**. Making Europe climate-neutral and protecting our natural habitat will be good for people, planet and economy. No one will be left behind.

The EU will:

- Become climate-neutral by 2050
- Protect human life, animals and plants, by cutting pollution
- Help companies become world leaders in clean products and technologies
- Help ensure a just and inclusive transition

"The European Green Deal is our new growth strategy. It will help us cut emissions while creating jobs."

Ursula von der Leyen, President of the European Commission

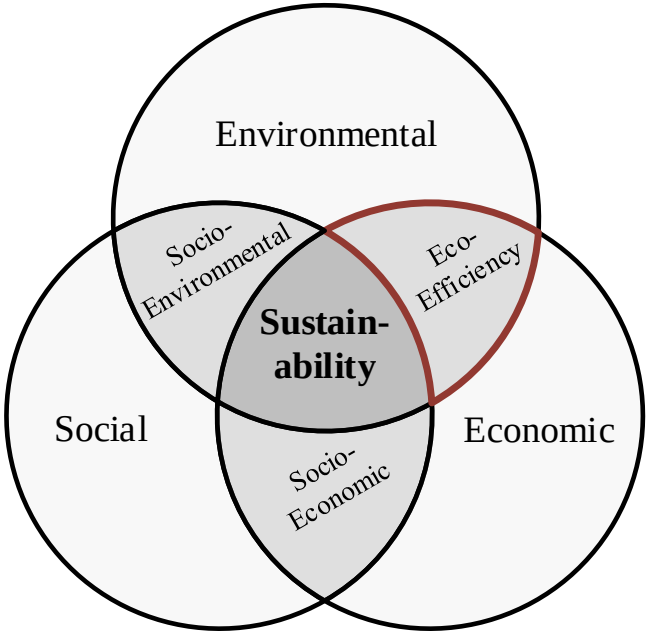
"We propose a green and inclusive transition to help improve people's well-being and secure a healthy planet for generations to come."

Frans Timmermans, Executive Vice-President of the European Commission

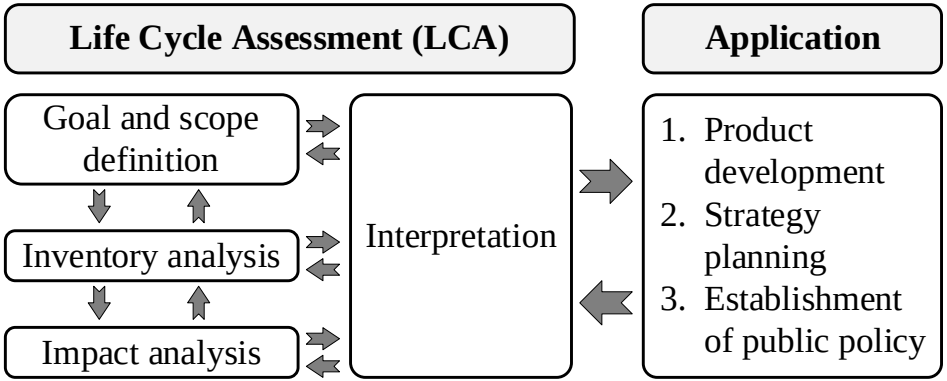
https://ec.europa.eu/commission/presscorner/api/files/attachment/859152/What_is_the_European_Green_Deal_en.pdf.pdf

Background: Sustainability

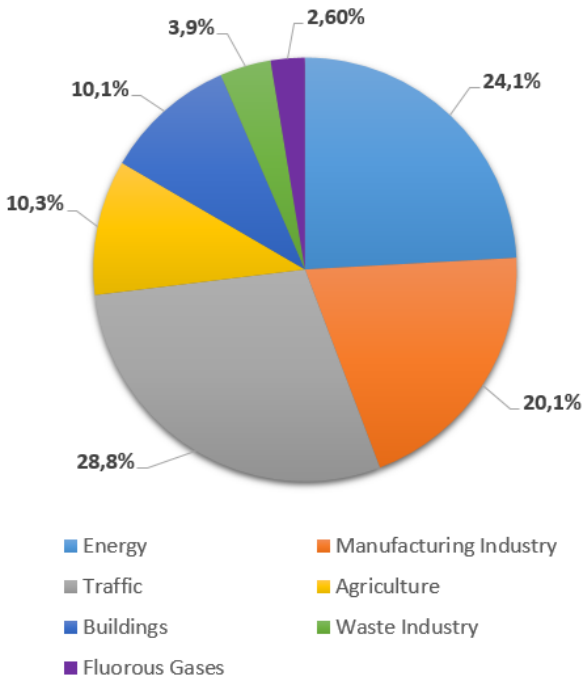
- Three dimensions of sustainability



- Life Cycle Assessment



Background: Global greenhouse gas emissions by sector



Greenhouse gas emissions in Austria (2016)
http://www.umweltbundesamt.at/aktuell/publikationen

- Global climate change
- Legislative regulations force the industry to reduce CO_2-emissions
- **Manufacturing Industry** and **Traffic** => 50% of CO_2-emissions in Austria => high potential for optimization

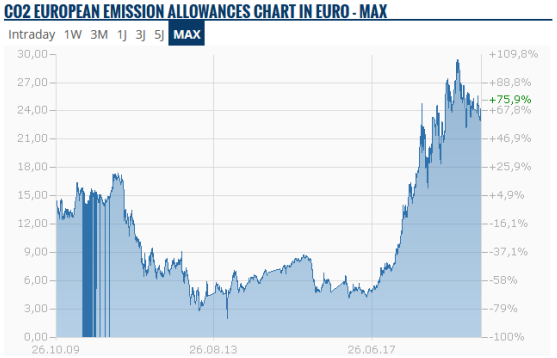
Background: Environmental Indicators

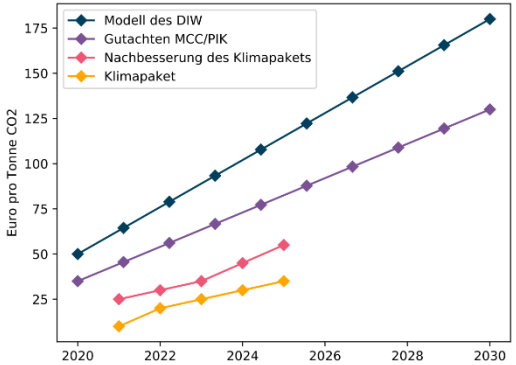
WHAT YOU CAN'T MEASURE; YOU CAN'T MANAGE !!

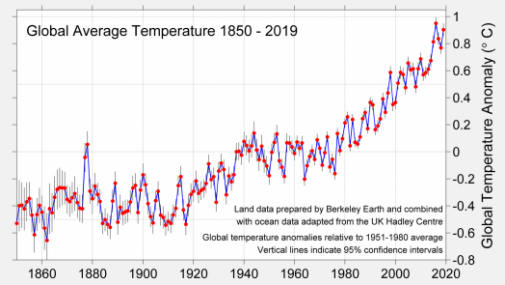
- An environmental indicator is a numerical value that helps provide insight into the state of the environment or human health.
- A wide range of different environmental indicators is available.

Examples:

GHG emissions
Air pollution
Ozone depletion
Land use change
Land degradation
Soil pollution
Water pollution
Environmental water scarcity



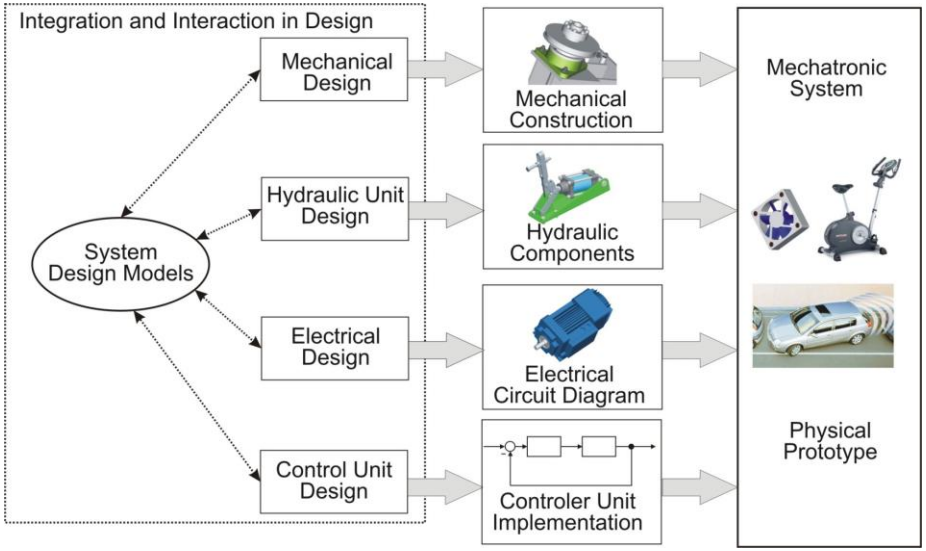




Source: http://berkeleyearth.org/2019-temperatures/

Paradigmn EcoMechatronics 1

Mechatronics is centred on the **synergy of multidimensional and multifaceted knowledge**, facilitated by tools and methodologies that support the implementation of smart and sustainable systems while promoting cleaner futures that reduce ecological impact while improving sustainability and quality of life.

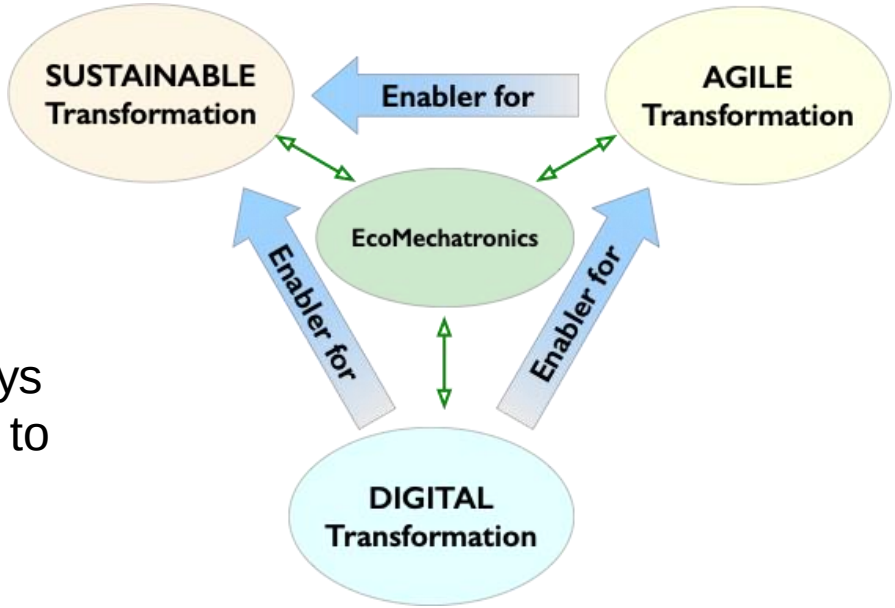


Paradigmn EcoMechatronics 2

The vision of EcoMechatronics is that improving

- human behaviour and
- quality of life while moving towards more sustainable lifestyles.

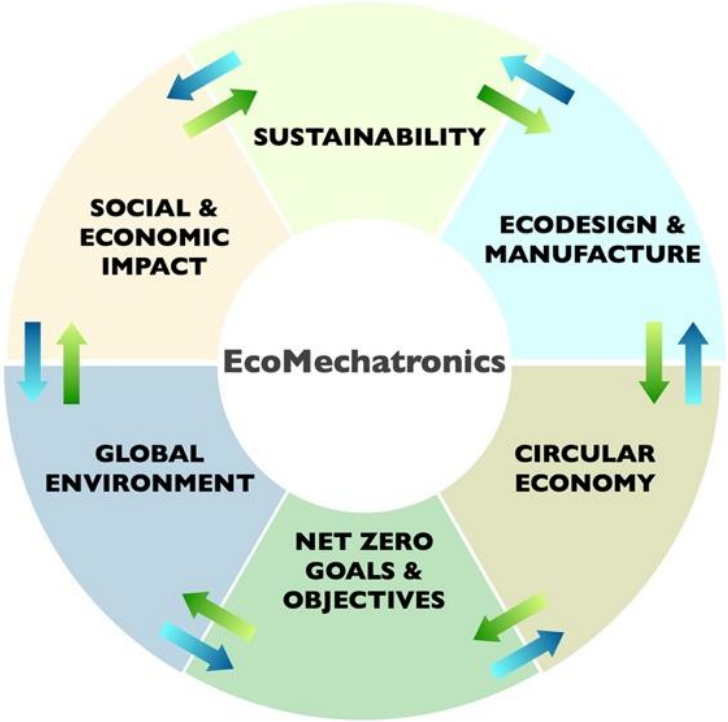
In doing so, it must address the interdisciplinary challenges presented to support a synergy of experience and ways of working, technologies and knowledge to optimize the design and development processes and to maximize functionality while providing efficient and economic ways of utilizing resources.



Paradigmn EcoMechatronics 3

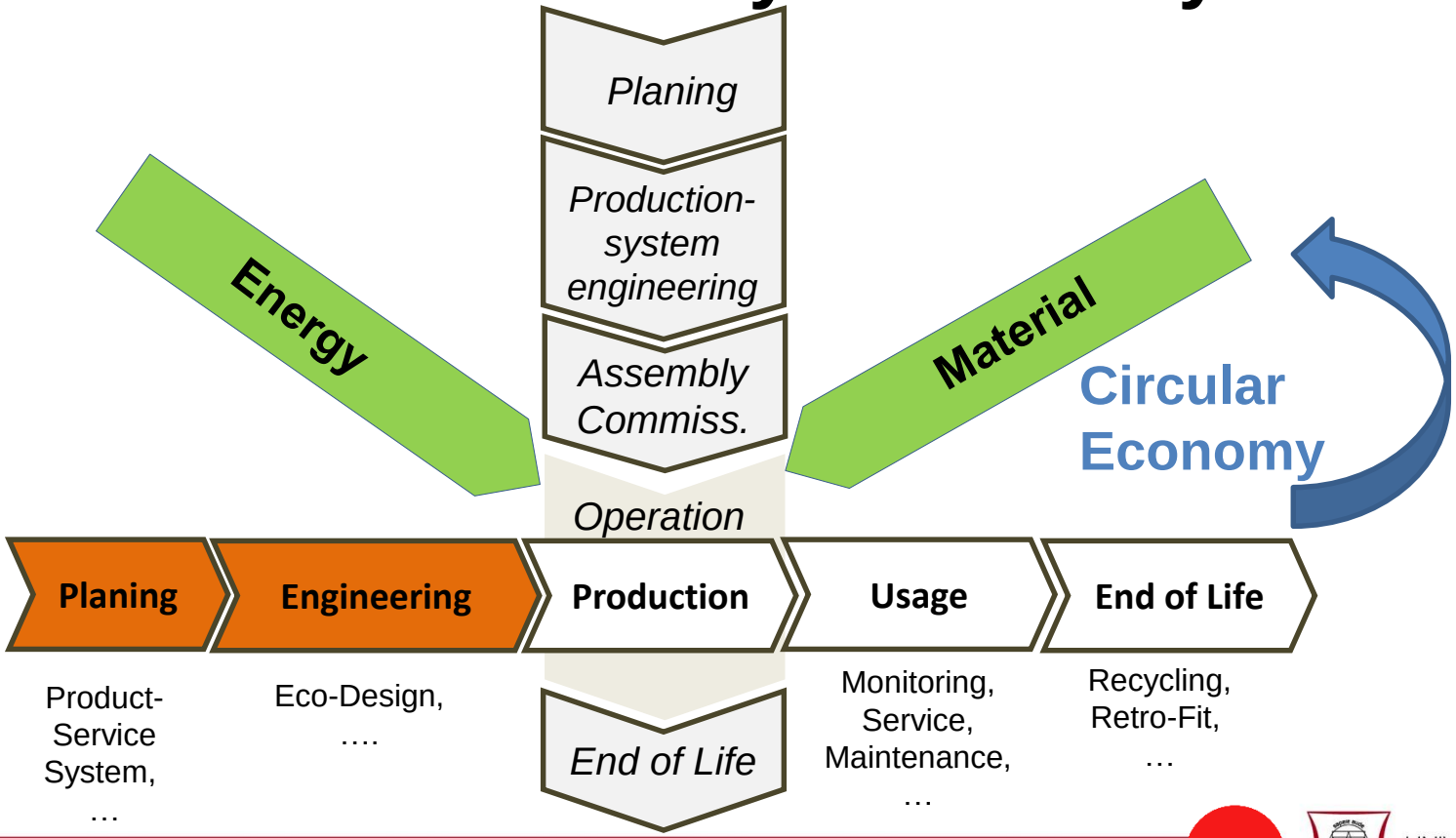
Ecologically sustainable design represents an environmentally aware and motivated design process that integrates ecologically sustainable features.

Mechatronics has the potential to represent a synergy of ecologically sustainable design that harmonizes solutions to modern problems, and challenges along with the need for an effective and creative sustainable model for the design of environmentally friendly **products, processes and systems**.

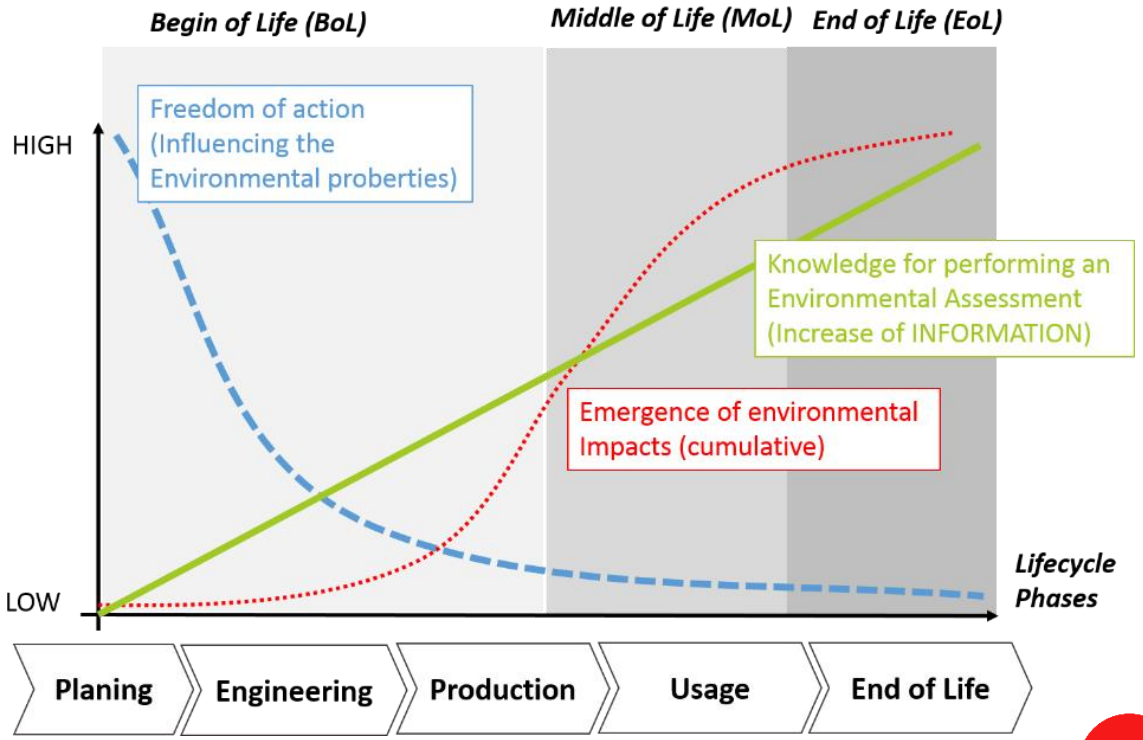


EcoMechatronics

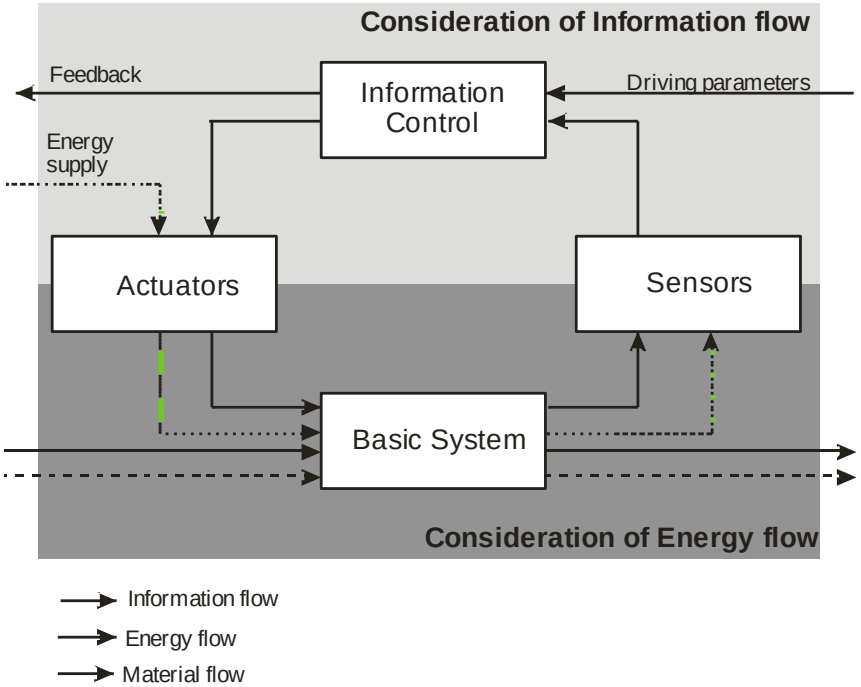
Product - Productionsystem Lifecycle



Relevance of Engineering Phase Holistic View



From Mechatronic Systems to SoS (1)



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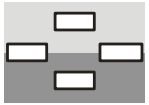
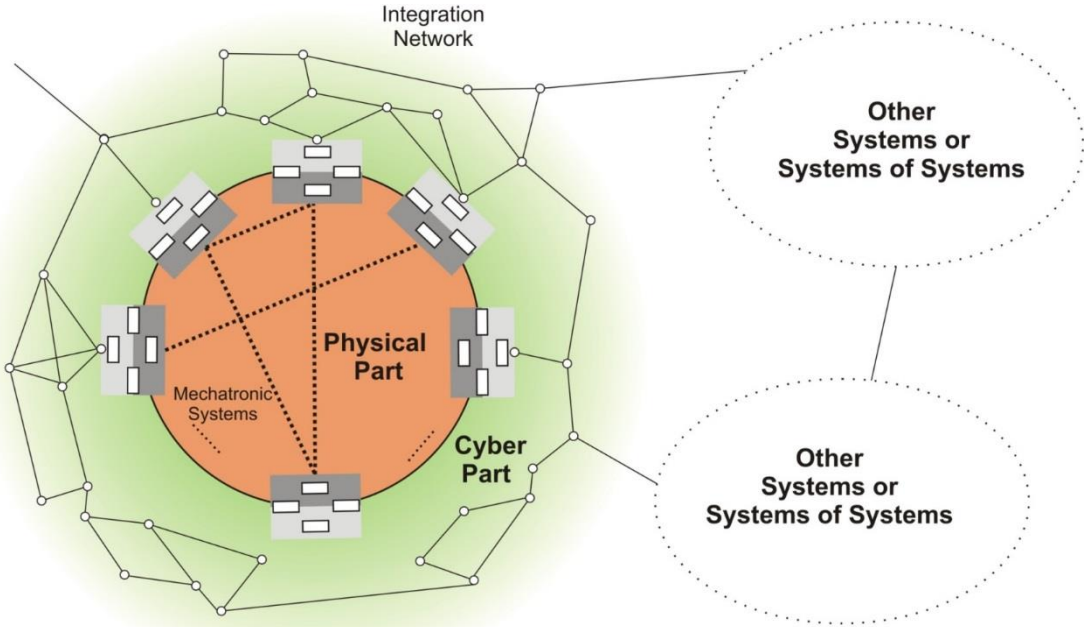
Simplified Symbol



From Mechatronic Systems to SoS (2)

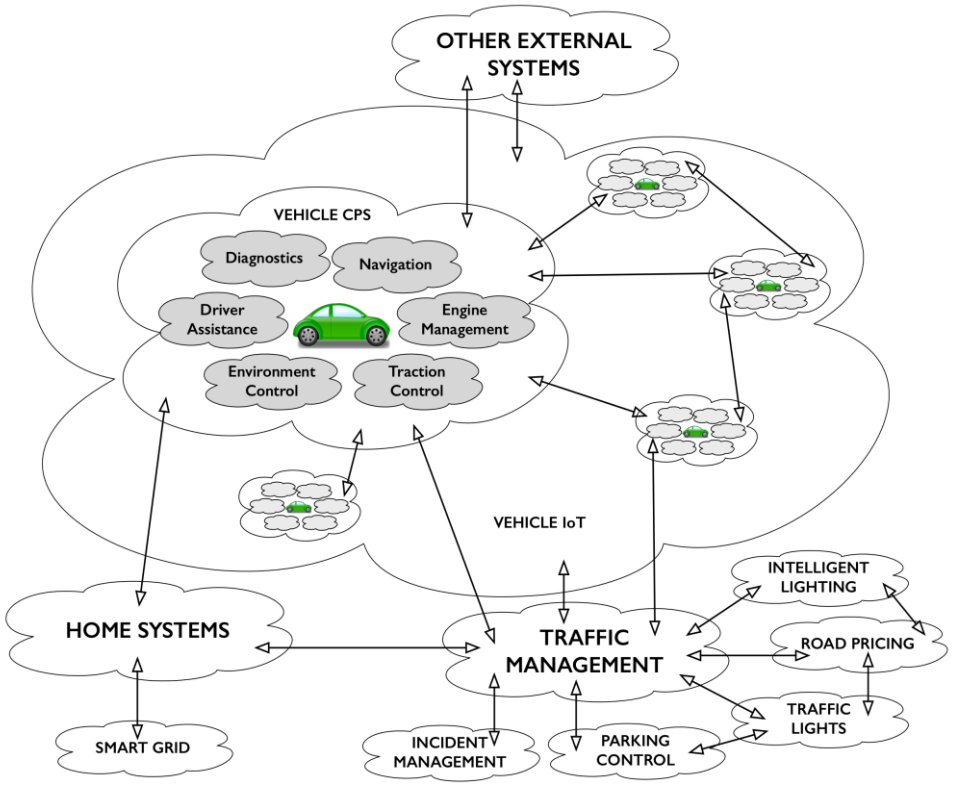


[Lee2008]
Cyber-Physical Systems (CPS) are integrations of computation with physical processes.
Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa.

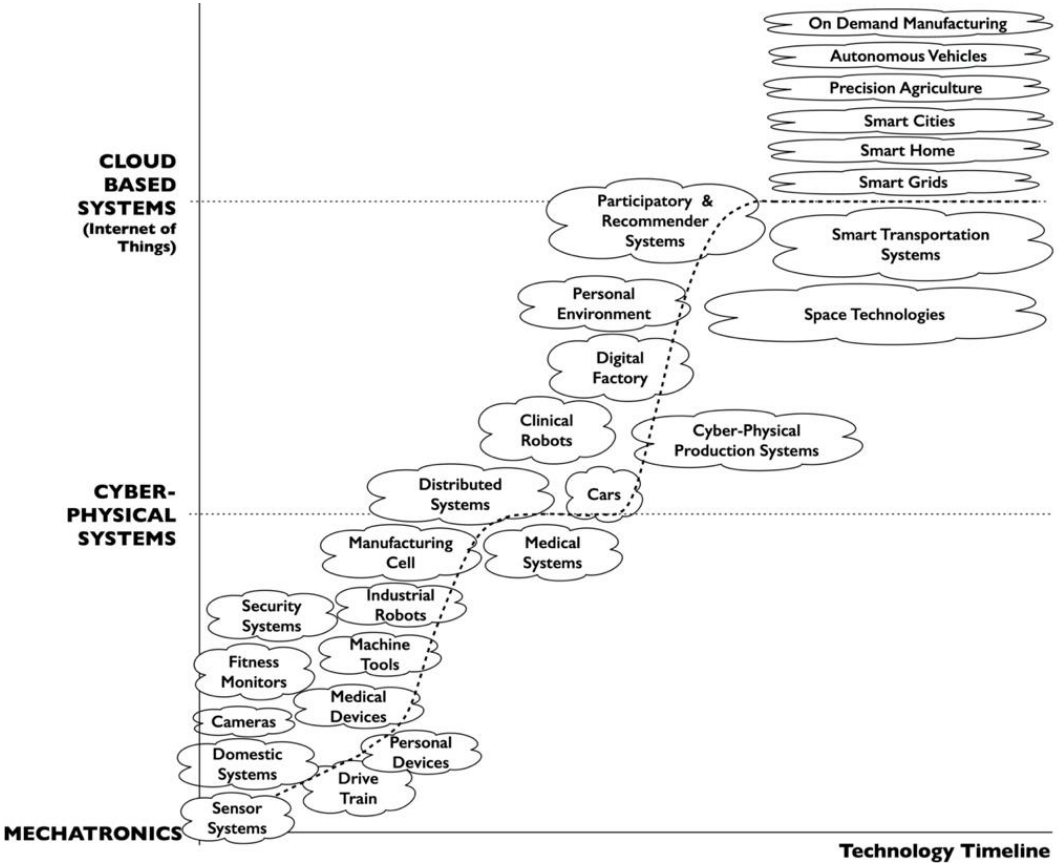
Reference:
Hehenberger P., Bradley D. (2016): „Mechatronic Futures – Challenges and Solutions for future Mechatronic Systems and Designers“, ISBN 978-3-319-32154-7, Springer London, Berlin Heidelberg.

Use Case

- In Downtown San Francisco, 20% to 30% of traffic congestion is caused by people looking for a parking place!
- On average, finding a parking place in a German city requires about 4.5 km of driving which for a vehicle emitting around 140 grams of CO2/km will generate at least 630 grams of unnecessary CO2.



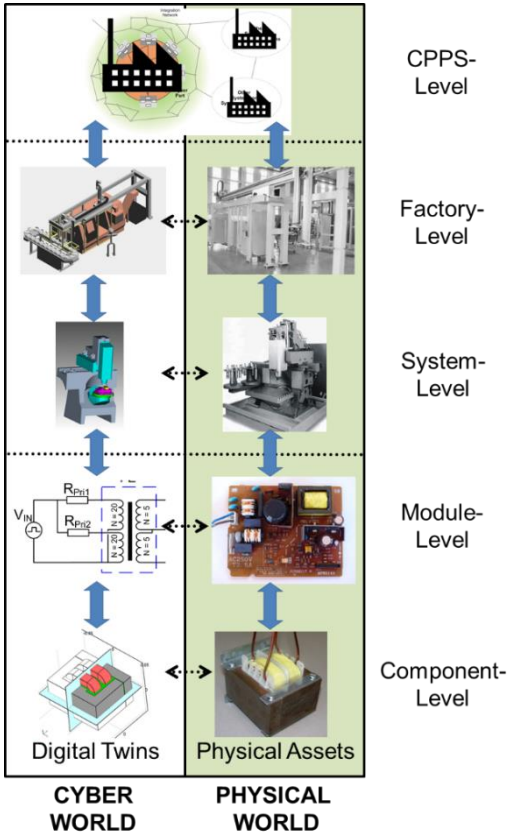
The evolution of EcoMechatronics related to applications



Hierarchical Modelling Techniques for „Digital Twins“

In order to achieve an accurate efficient sustainability estimation/prediction of the overall system, we define the needed models to achieve that at a different abstraction level.

This abstraction of the multi-physically coupled reality can be understood as a balance between the accuracy of the prediction of the system properties and the duration of the simulation.



Energy Efficient Manufacturing System Management

20/21

HORIZON2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement **No 958478**

EnerMan

Main Goals

BACKGROUND

- Manufacturing industry stake for energy sustainability
- Energy Consumption monitoring, control, forecast
- Industrial production in Europe consumes large amounts of energy (27.8% of the total energy consumption in Germany, 21% in France)
- Machine Lifecycle Analysis: 60-90% CO_{2e} in operation

OPPORTUNITIES

- Digital Transformation
- Need for automation and flexibility
- Involving large investments, plant re-design

Factories of the Future (FoF)

- need to restate the approach they have on using energy and
- move from purely energy optimization model to an energy sustainability model that has a
- holistic view on energy consumption

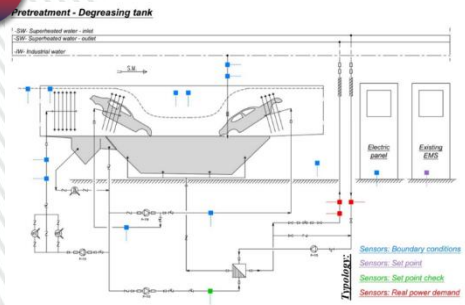
Energy Sustainability *as a three aspect combination:*

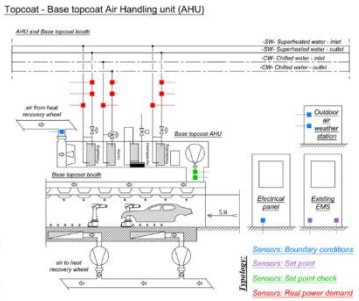
- *Energy consumption,*
- *Energy cost due to the power grid electricity price and*
- *CO2 emissions (environmental impact) due to the production process of the consumed energy.*

Goals

- ENERMAN envisions the factory as a **living organism** that can manage its energy consumption in an **autonomous way**.
- The ENERMAN digital twin will predict the economic cost of the consumed energy based on the collected and predicted Energy Peak load tariff, Renewable Energy System self-production, the variations in demand response, possible virtual generation and prosumer aggregation.
- Finally, ENERMAN considers the operators actions within the production chain as part of a factory's energy fingerprint since their activity within the factory impacts the various production lines.

CRF

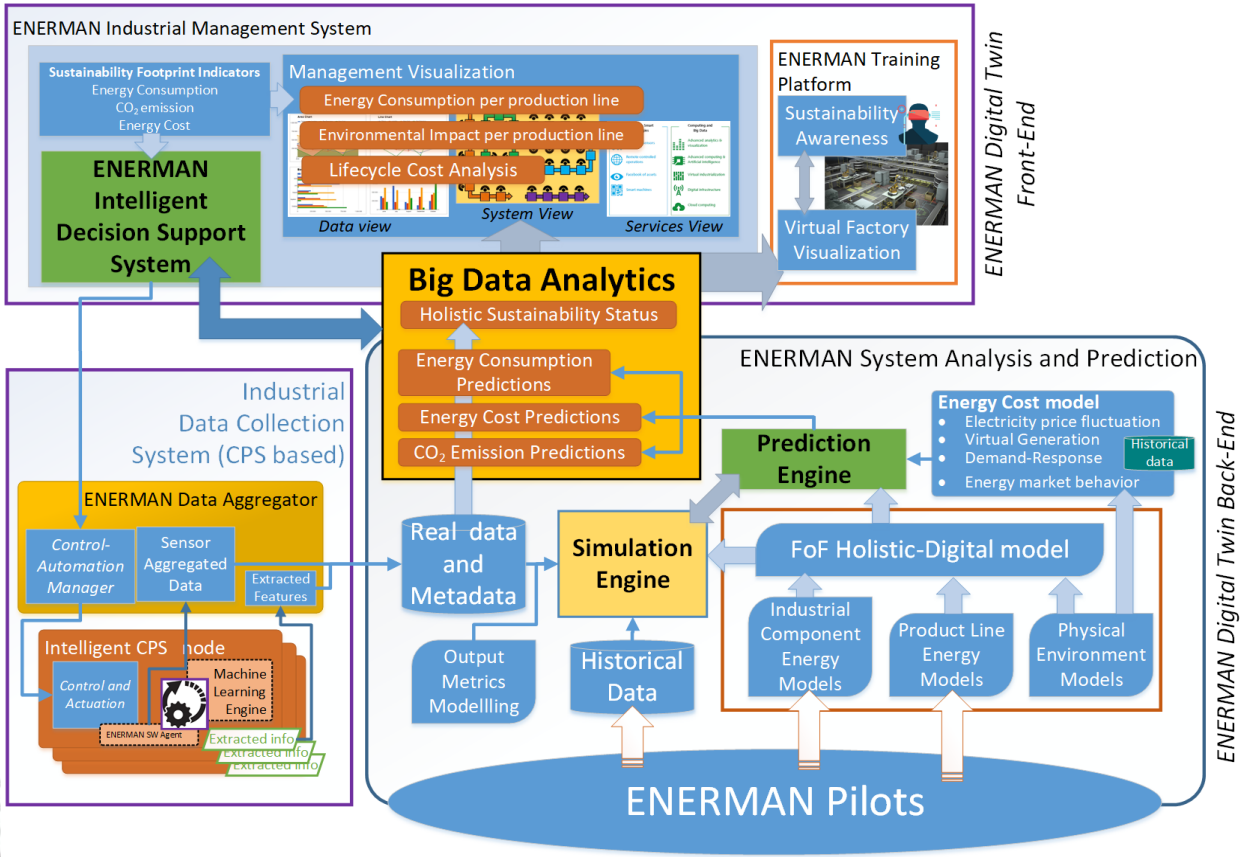




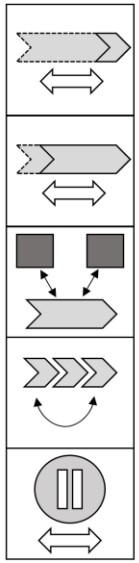
AVL

https://enerman-h2020.eu/

Approach


ENERMAN Industrial Management System
Sustainability Footprint Indicators
Energy Consumption
CO_2 emission
Energy Cost
ENERMAN Intelligent Decision Support System
Management Visualization
Energy Consumption per production line
Environmental Impact per production line
Lifecycle Cost Analysis
Data view
System View
Services View
ENERMAN Training Platform
Sustainability Awareness
Virtual Factory Visualization
ENERMAN Digital Twin Front-End
Big Data Analytics
Holistic Sustainability Status
Energy Consumption Predictions
Energy Cost Predictions
CO_2 Emission Predictions
ENERMAN System Analysis and Prediction
Industrial Data Collection System (CPS based)
ENERMAN Data Aggregator
Control-Automation Manager
Sensor Aggregated Data
Extracted Features
Intelligent CPS node
Control and Actuation
Machine Learning Engine
ENERMAN SW Agent
Extracted info
Real data and Metadata
Output Metrics Modellling
Simulation Engine
Historical Data
Prediction Engine
Energy Cost model
Electricity price fluctuation
Virtual Generation
Demand-Response
Energy market behavior
Historical data
FoF Holistic-Digital model
Industrial Component Energy Models
Product Line Energy Models
Physical Environment Models
ENERMAN Digital Twin Back-End
ENERMAN Pilots

Hierarchical Modelling Techniques for „Digital Twins“



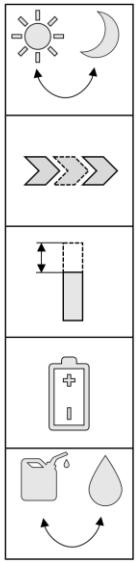
Adjustment of process starts (short-term)

Adaptation of process starts (medium term)

Adjustment of the machine occupancy

Adjustment of the job sequence

Adjustment of break times



Adjustment of shift times

Interruption of processes

Adaptation of process parameters

Storage of energy

Changing the energy source

In order to achieve an accurate efficient sustainability estimation/prediction of the overall system, we define the needed models to achieve that at a different abstraction level.

This abstraction of the multi-physically coupled reality can be understood as a balance between the accuracy of the prediction of the system properties and the duration of the simulation.

Merschak S., Hehenberger P., Witters M., Gadeyne K. (2018): “A Hierarchical Meta-Model for the Design of Cyber-Physical Production Systems”, 19th International Conference on Research and Education in Mechatronics (REM), June 7-8, 2018, Delft, The Netherlands

M. Graßl, Bewertung der Energieflexibilität in der Produktion. München: Utz, 2015.

"CO_2 Life Cycle Analysis in early stage design phase"

Merschak, Hehenberger

Research Centre for Low Carbon Special Powertrain (Dec. 18 – Nov. 22)

- Scientific partners: 4
- Industry partners: 9

Main research topics:

- Use of CO_2 neutral fuels
- Reduction of CO_2 emission by hybridization and electrification
- Further minimization of pollutant emissions
- **Assessment of CO_2 emission over the whole life cycle in the early phase of product design**

Area	Tools	Personal Mobility	Transport
Fuels	F1 LOC-Tool	F2 LOC-Pers	F3 LOC-Trans
Hybrid	HE1 HE-Tool	H2 HE-Pers	H3 HE-Trans
Cross	X1 Cross-Sens	X2 Cross-LCA	X3 Cross-Fuels

Source: https://www.stihl.at

Source: https://at.brp.com

Source: https://www.bmw-motorrad.at

Source: https://www.stihl.at

XLCA – Topics at a Glance

Product Ideas
Evaluation, Eco-Design

Early Phase
Lifecycle Assessment

Existing Product
Calculation and Optimization

classical
lifecycle assessment

Goals
Support of Decisions in the Conceptual Design Phase regarding Carbon-Footprint

(A) Product Lifecycle Phases

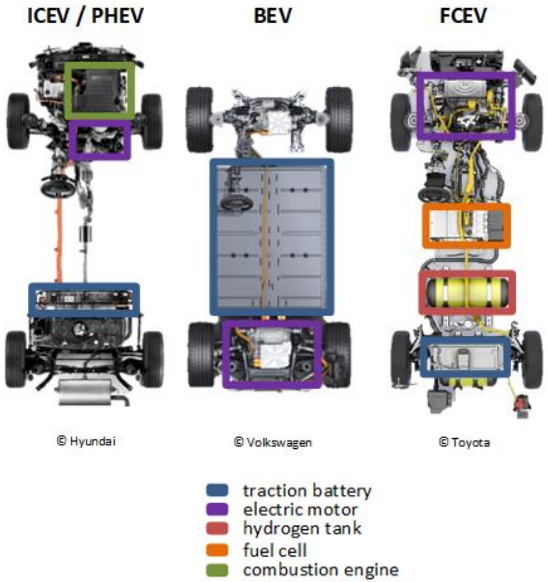
Project focus

(B) Development Process

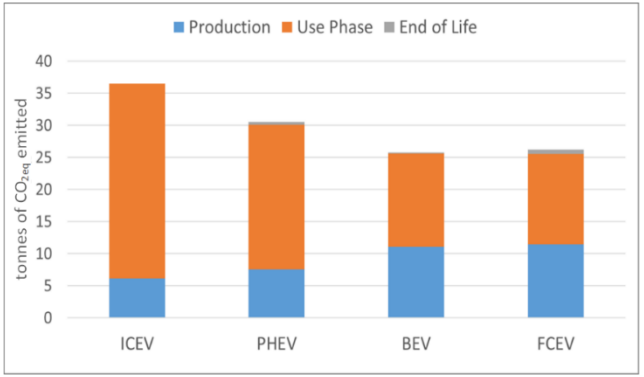
(C) System – Component Level

Background

- Powertrain concepts



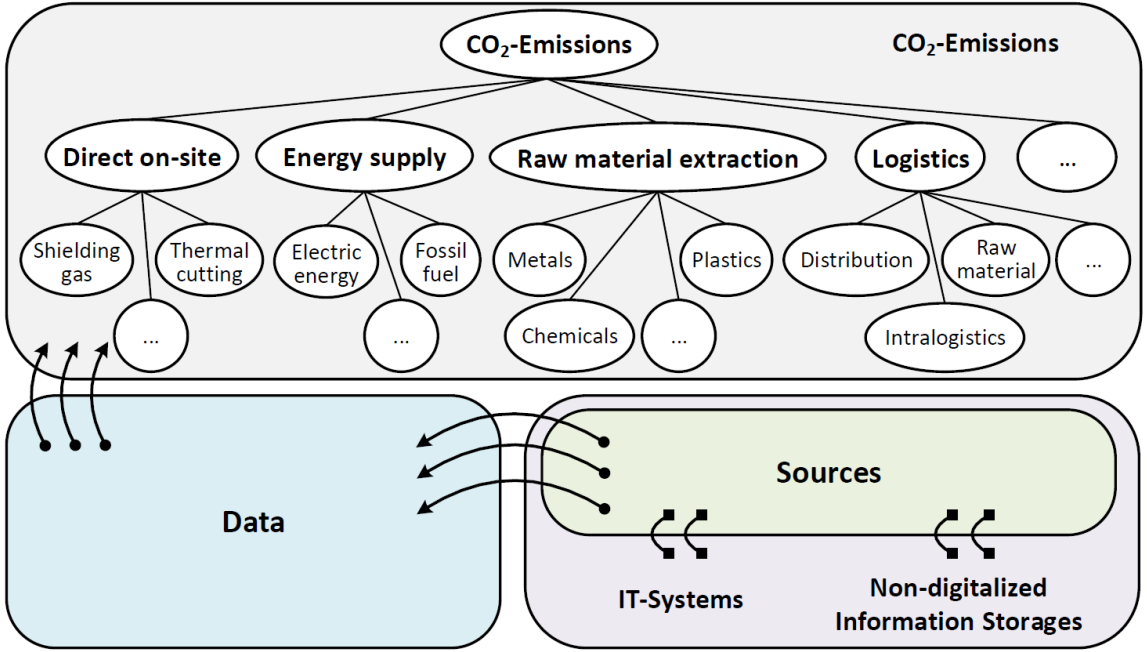
- CO_2 emissions of different powertrain concepts and life cycle phases



Mean CO_{2eq} values of 82 analyzed studies

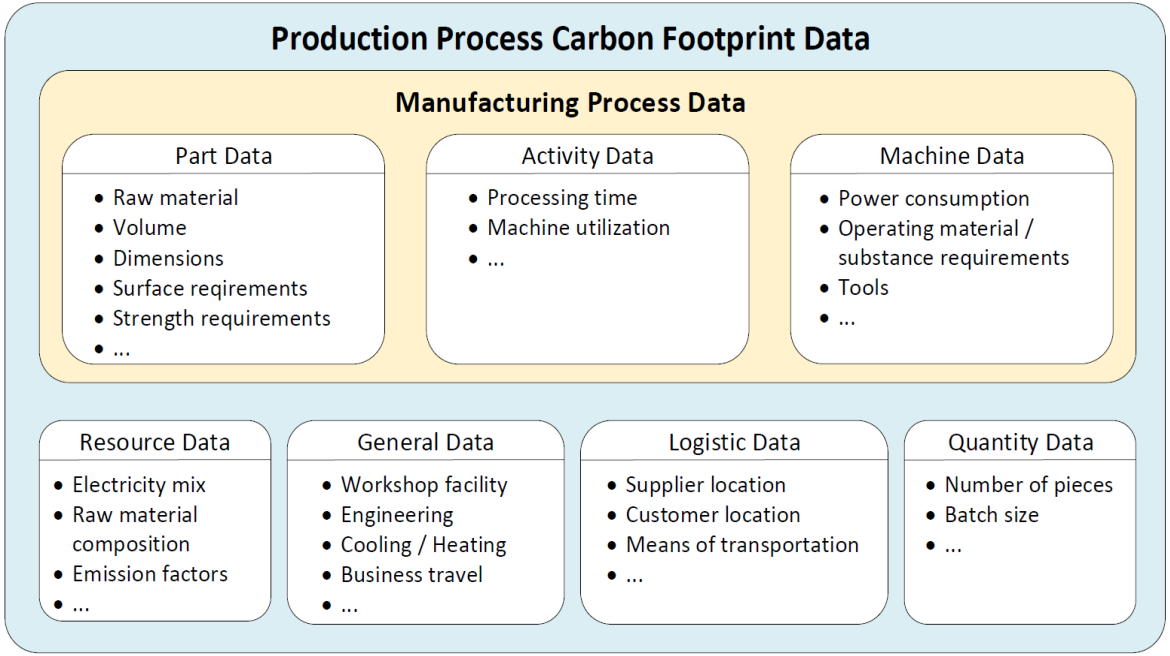
Challenges regarding data for CO_2-footprint calculation

- Identify required data
- Find suitable data sources:
  - Not all required data is digital available
  - Different IT-systems have to be integrated
  - Interfaces are required



Generic data structure for CO_2-footprint calculation

- Manufacturing Process Data
  - Part data
  - Activity data
  - Machine data
- Production Process Carbon Footprint Data



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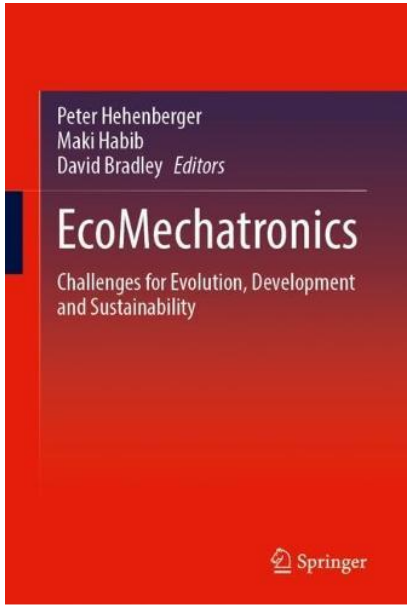
There are many ways to influence sustainable product creation !



Thank you for your attention!

Contact: peter.hehenberger@fh-wels.at

Hehenberger P, Habib M., Bradley D. (2022): „EcoMechatronics: Challenges for Evolution, Development and Sustainability", Springer Berlin Heidelberg, https://link.springer.com/book/9783031075544