Environmental Footprints as a Tool to Progress to the Circular Economy

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The Route
United Kingdom → Hungary → Czech Republic
UMIST – Pioneering Pinch Analysis

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University of Pannonia, Veszprem Hungary
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- Green/sustainable engineering
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- Biomass
- Energy use and consumption
- Waste minimisation
- Pollution reduction
- Renewable energy
- Environmental assessment
- Emergy/exergy analyses
- LCA of product and process
- Footprints and other assessment types
- Supply chains (modelling, mathematical, and engineering)
- Eco-industrial parks
- Energy-water nexus

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Circular Economy

Scarcity to extract natural resources

Increase in raw material price and volatility
Overview of Circular Economy

Transition from linear to circular economy

<aspenpartnerships.com/what-is-the-circular-economy/> accessed 20/3/2018
Market Drivers

• Win-win situation, create value

• Risk management - raw material shortage, disruption in the supply chain

• Environmental efficiency

• Innovation and brand image
The Advantages

Environmental win
- Reduced virgin material and energy input
- Virgin inputs are predominantly / to the extent possible renewable from productive ecosystems

Economic win
- Reduced raw material and energy costs
- The value in resources is used many times, not only once
- The use of costly scarce resources is minimized
- Reduced costs that arise from environmental legislation, taxes and insurance
- Image, responsible and green market potential

Social win
- New employment opportunities through new uses of the value embedded in resources
- Increased sense of community, cooperation and participation through the sharing economy
- User groups share the function and service of a physical product instead of individuals owning and consuming the physical product

Environmental win
- Reduced wastes and emissions
- Resources in production-consumption systems are used many times, not only once
- Renewables are CO₂ neutral fuels and their wastes are nutrients that can be used by nature

Circular Measurement Model

- Takes into account all five pillars of Circular Economy, applied by using a number of sub-indicators
- Defines a single circularity index. Calculate based on flow circularity and usage circularity
- To evaluate the success and effectiveness of the circular economy

Energy Efficiency

How much energy is required to operate a circular economy?
Challenges in CE

- **Thermodynamic limits**
  - Cyclical systems consume resources and create waste and emissions

- **System boundary limits**
  - Spatial: problems are shifted along the product life cycle
  - Temporal: short term non-renewables used to build long-term renewable infrastructure

- **Limits posed by physical scale of the economy**
  - Rebound effect, Jevon's paradox, boomerang effect

- **Limits posed by path-dependency and lock-in**
  - First technologies retain their market position despite of in-efficiency

- **Limits of governance and management**
  - Intra-organizational and intra-sectoral management of inter-organizational and inter-sectoral physical flows of materials and energy

- **Limits of social and cultural definitions**
  - The concept of waste has a strong influence on its handling, management and utilisation
  - The concept is culturally and socially constructed
  - The concept of waste is always constructed in a certain cultural, social and temporal context and this context is dynamic and changing

Environmental Footprints

Circular economy practices led to low-carbon emission footprint and the other benefits (low N footprint, water footprint etc)
Footprint is a quantitative measure showing the appropriation of natural resources by human beings (Hoekstra, 2008).

Footprints:
- Carbon emissions footprint (CFP) – GHG Footprint
- Nitrogen footprint (NFP)
- Water footprint (WFP)
- Energy footprint (EFP)
- Ecological footprint (ECOFP)
- Land footprint (LFP)
- Social footprint (SFP)
- etc.


The Total Annual Anthropogenic GHG Emissions

(FOLU - Forestry and Other Land Use, F-Gases = Fluorinated Gases)

IPCC (Intergovernmental Panel on Climate Change), Developed from Climate Change 2014: Synthesis Report, Report Graphic, IPCC Secretariat, World Meteorological Organization, Geneva, Switzerland
Virtual GHGs Emissions Flows in the International Trade

1. China to US (Quéré et al, 2014)
2. China to EU (Carbon Trust, 2011)
3. China to Rest of Asia (Carbon Trust, 2011)
4. Rest of Asia to EU (Peters et al, 2012)
5. Russian Federation to EU (Peters et al, 2012)
6. China to Japan (Carbon Trust, 2011)
7. Africa to EU (Peters et al, 2012)
8. US to EU (Peters et al, 2012)
9. Canada to EU (Petar et al, 2012)
10. EU to US (Petar et al, 2012)
Proposal of a New Footprint

SMOG/HAZE FOOTPRINT

• Over the past few years, the concern of anthropogenic emission has been focused on the greenhouse gases than the air pollutants, e.g. SO\textsubscript{x}, NO\textsubscript{x}, VOC, Particulate Matter (PM) that causing air pollution and poses an instantaneous impact to human health.

• GHG (climate change) and the air pollutants share some of the components, but the evaluation perspective is different.
Smog and Haze Footprints

Has Become a Gas Chamber

Flights temporarily suspends

India to spray water over Delhi amid pollution emergency

Schools closed

Equivalent to smoking 44 cigarettes a day

Blanketed in Toxic Haze

threatening residents with concentrations of dust 12 times the acceptable level

smog-choked Indian capital Delhi

Mortality and Burden of Disease from Air Pollution

Air pollution attributable to atmospheric emissions

Worldwide, ambient air pollution contributes to **5.4% of all deaths**

Low Carbon?!  
Zero Carbon?!  
Carbon-free?!  

**Carbon is an ASSET**

Design with the natural cycle in mind to ensure the carbon end ups in the right place, right dose & right duration

“It is we who made carbon toxic”

Carbon World: The Good

• Every living organism on the planet is a carbon based life form
• Climate change is a design failure
• CO₂ in the atmosphere is a liability but in the soil it is an asset

<blogs.scientificamerican.com/observations/new-view-carbon-is-not-the-enemy/>
The New Language

• **Fugitive Carbon (BAD)** - ended up somewhere unwanted and can be toxic as emissions (e.g. atmosphere)

• **Durable Carbon** - Locked in stable solids that are used and reused (e.g. soil)

• **Living Carbon** - Organic, flowing in biological cycles, providing fresh food, healthy forests and fertile soil

<www.nature.com/news/carbon-is-not-the-enemy-1.20976> accessed 28/10/2017
Circular Economy in Energy
A Sankey Diagram for the Electricity Generation and Use in the US in 2014

Projected Energy Mix

In 2040, the projected energy mix will be:

- Oil: 32%
- Nat Gas: 25%
- Nuclear: 7%
- Coal: 20%
- Wind, Solar & Biofuels: 4%
- Other: 12%

ExxonMobil <corporate.exxonmobil.com/en/energy/energy-outlook/highlights/> accessed 26 July 2017
Renewable Share

Renewables share of power generation

Shares of renewable power growth

Energy Storage

- **100 MWh** lithium ion battery
- Stores considerable amounts of energy from renewable sources and funnels it out to the grid when usage is high

Tesla’s giant Powerpack battery in Australia

In successful operation for about 6 months now

Rapid, accurate, cheaper and with low emissions

Reduced the cost of the grid service that it performs by 90%

Effect of Energy Saving Measures

Study: Multifamily residential buildings in Slovakia

- Impact of energy renovation: CO$_2$ concentration higher, air exchange rates is lower, formaldehyde concentration increased.
- Energy saving measures can lead to insufficient ventilation rates
- Energy retrofitting efforts should be complemented with improved ventilation to avoid adverse effect on indoor air quality

Biomass Energy

Why it is consider as Renewable Energy?
• Plant at least as many trees as you burn (a seedling/50 y tree)
• Biomass waste but not uncontrolled logging
What goes wrong?

Inappropriate Practice

- **Whole trees** from forest instead of wood scrap/ residue (waste)
- **Shipping** of wood pellets/ transporting

What goes wrong?

Inappropriate Assessment

• Take **several decades to fully compensate for the CO$_2$ emitted** during plant operation (for a tree to grow)

• Low efficiency (trees contain water, which means less potential energy per unit of C emissions in biomass energy than in fossil fuels)

• Emission: Release **more NOx, VOC, PM and CO** than a modern coal/gas fired plant.

• Degrades the C emissions sinks

• Biodiversity issues
Methane Fluxes from Coastal Sediments

THE ROLES OF MACROFAUNA

- Macrofauna contributes to GHG production and that the extent is dependent on lineage.
- It may play an important but overlooked role in regulating GHG production and exchange in coastal sediment ecosystems.

Methane Fluxes from Coastal Sediments

• **Eutrophication** a principal driver for the enhanced GHG flux from aquatic environments.

• Shallow aquatic systems contribute \(~10\%\) of global N\(_2\)O emissions.

• The contribution of these environments to the global CH\(_4\) emission because **source magnitude and variability remain highly uncertain**.

• However, up to 30–40\% of the methane emissions due to methane produced in sediments of aquatic ecosystems.

• The role of **coastal benthic macrofauna** in mediating gas release is still debated as the mechanisms regulating production and transport of gases are largely unknown.

• **Bivalves isolated from coastal sediments** were shown to be strong emitters of N\(_2\)O.

Circular Economy in Waste Treatment
Landfill

- GHGs EMISSION
- WATER POLLUTION
- UNPLEASANT SMELL
- HEALTH & SAFETY ISSUES
Municipal Solid Waste

MSW

- Organic Material (Food & Plants)
- Paper
- Construction Materials
- Plastic
- Metal
- Glass
Top 10 GHG Emission Contributors and the Contribution of Food Waste

- 4,400 Mt CO₂ eq. (3rd largest GHG emitter, if food waste is a country)
- Share of Global GHG Emission= 8.2 % (More than the share of Aviation= 1.4 % and Iron and Steel= 3.3 %, comparable with road transport= 10 %) (WRI, 2015)

*The comparison is to illustrate the impact of food waste. It is not a country or a sector. Food waste emissions include from various lifecycle stages (e.g. road transport). It should not be viewed as a country or sector to avoid double counting.

Food Waste

- About 1/3 of the food produced in the world for human consumption every year is wasted/lost (~1.3x $10^9$ t).
- Cost: US$ 680*10^9 in industrialized countries and US$ 310*10^9 in developing countries.
- Fruits and vegetables, plus roots and tubers—highest wastage rates

Per capita food losses and waste (kg/y)

Food waste- in the year of 2020

<table>
<thead>
<tr>
<th>Waste amount in EU27 (t/y)</th>
<th>GHG Emission (CO₂ eq/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>126,000,000 t/y</td>
<td>240</td>
</tr>
</tbody>
</table>

European Commission (DG ENV-Directorate C), Final report- preparatory study on food waste, 10/2010; calculated based on EUROSTAT data, national sources and ETC/SCP working paper

Waste Prevention/ Reduction

Before waste production

Products and Packaging

• Design- minimise packaging, design for recycling, durable
• The materials use- recyclable/ compostable, easy to clean (e.g. food packaging)
• Process- maximise the utilisation, innovative use e.g. orange (juice, flesh, peel)

Reuse after the first cycle
• E.g. waste water, waste heat
Embedding Circular Economy Thinking in Waste Management

Regenerated and constantly flow around a “closed loop” system, rather than being used once and discard

Before waste production
1. Waste prevention/reduction

After waste production
2. Resources (waste to wealth) management
Circular Economy Strategies in Europe

• Recycling of minimum 65 % of all MSW by 2030

• Maximum 10 % of MSW landfilling by 2030

• Promoting industrial symbiosis

• Encouraging eco-design

Waste to Wealth

After waste production

- Reusing
- Waste separation-recycling
- Waste to energy (biogas-electricity, heat; biofuel etc)
- Waste to nutrient for soil (fertiliser, digestate, biochar etc)

Treatment Options

- Composting
- Anaerobic digestion
- Incineration
- Sanitary landfill
- Landfill
- MBT¹

¹Mechanical Biological Treatment: integration of sorting facility with biological treatment such as composting, anaerobic digestion and materials recovery facilities.
Composting & Anaerobic Digestion (AD)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Composting</th>
<th>Anaerobic Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant capacity</td>
<td>Scalable</td>
<td>Only medium to large</td>
</tr>
<tr>
<td>Technology and process</td>
<td>Simple</td>
<td>Complex</td>
</tr>
<tr>
<td>Need of working surface</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Investment cost</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Output product</td>
<td>Solid</td>
<td>Liquid (semi solid)+ biogas</td>
</tr>
</tbody>
</table>

**Compost:**
Humified plant matter, organic matter, plant nutrients and microbes

**Digestate:**
Less stable carbon, more readily available nutrient
Compost-Limitation

• Does not degrade inorganic it only reduces their availability for plant uptake
• Itself may release some metallic contaminants
  ❖ Accumulation of hazardous substances in soil and plants
  ❖ Biomagnifications though the food chain: human health and environment concerns.
• Most of the EU countries do not consider mixed waste for composting. In Denmark, only green waste is utilised.
• Compost goes though MBT is not allowed for agricultural purpose
Heavy Metal Reduction Techniques

• Implementation of at source waste segregation
• **Selection of feedstock** (input materials)
• Addition of chemicals (natural zeolite, red mud, lime, sodium sulfide, bamboo charcoal and bamboo vinegar, etc.)
• Biological agent (eg Phanerochaete chrysosaurium-remove lead; earthworm)
Is Current Practice Sustainable?! 

Good business (source = waste) but in ENVIRONMENT PERSPECTIVE?

• **Incineration:** Importing garbage/waste from the other city/country (E.g. Sweden)

• **MBT plant:** Discourage waste separation at source, centralised (transport issues)

• **AD plant:** Planting of energy crop (similar issues as BIOMASS ENERGY)

• **Composting:** Open process (emission, leachate) without energy recovered, heavy metal issues

ASSESSMENT & IMPROVEMENT IS NEEDED
Relationship between Environment, WTE and Circular Economy System

Circular Economy in Agriculture
Animal Agriculture

Responsible for **18 %** GHGs (more than combined exhaust from all transportation)

Livestock is responsible for **65 %** of all human-related emissions of N\textsubscript{2}O

Livestock and their by products account for at least **32,000 Mt** of CO\textsubscript{2}eq/y

Example: Agri-food Sector

- Nitrogen footprint
- GHG footprint
- Water footprint
- Biodiversity footprint (land usage change)

<www.agrocycle.eu/> accessed 20/3/2018
Example: Dairy Sector

Carbon emission footprint

Nitrogen footprint

Water footprint

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CIRCULAR DAIRY VISION

- **Zero or negative GHG emissions**: Net greenhouse gas emissions, including carbon sequestration, across a full dairy value chain are zero, or even negative.
- **Closed soil nutrient cycles**: Nutrients extracted from the soil are returned to the same soils, without leakage to the environment, and nutrient levels are carefully optimised to reduce the use of artificial fertilisers.
- **Zero waste generation**: There is no waste from dairy operations and all waste streams are treated and reused or recycled to maximise value recovery.
- **Water recovery and reuse**: Dairy cows do not prohibit renewable freshwater availability for human food production.
- **Soil and land preservation**: Dairy farming does not constrain available arable land for human food production, does not drive land use change and deforestation and has positive impact on the resilience of agriculture landscapes.
- **Biodiversity in business model**: Soil, landscape and natural biodiversity are prioritised and incorporated in the farm’s business model.

Circular Economy in Transportation

Circular economy in transport: electric cars, recuperation/recharging energy
## Vehicle Technologies

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Initial cost (kUSD)</th>
<th>Power plant to wheel efficiency</th>
<th>Commercial availability</th>
<th>Main challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>20</td>
<td>High (&gt;50%)</td>
<td>Now</td>
<td>Chemical sustainability, battery cost, reprocessing</td>
</tr>
<tr>
<td>Hybrid electric</td>
<td>23</td>
<td>Moderate (≤50%)</td>
<td>Now</td>
<td>Chemical sustainability, battery cost, reprocessing</td>
</tr>
<tr>
<td>Hydrogen internal combustion engine</td>
<td>18 + H₂ Storage</td>
<td>Low (&lt;25%)</td>
<td>In 2–3 y ??</td>
<td>Lack of infrastructure</td>
</tr>
<tr>
<td>Fuel-Cell</td>
<td>40</td>
<td>Low (&lt;25%)</td>
<td>In 2–3 y ??</td>
<td>Lack of infrastructure, high cost</td>
</tr>
<tr>
<td>Biofuels</td>
<td>17.1</td>
<td>Low (&lt;25%)</td>
<td>Now</td>
<td>CO₂ fixation, NOx, responsible farming</td>
</tr>
</tbody>
</table>

The Main Part of E-car

- **CONTROLLER**: regulates the amount of power to the electric motor from the battery.
- **RECHARGEABLE BATTERY**: on-board storage of electric energy.
- **ELECTRIC MOTOR/GENERATOR**: The electric motor uses electrical energy to power the vehicle. When acting as a generator, it provides electricity to the battery by recapturing energy from the vehicle momentum when slowing.
- **PLUG**: allows for charging.
- **PUMP**: refueling station for conventional engines.
- **TANK**: conventional fuel storage.
- **REGENARATIVE BRAKES**: recover energy when braking, to recharge the battery.
- **COMBUSTION ENGINE**: uses conventional fuel to power the vehicle.

**Conventional vehicle**

Conventional vehicles use an internal combustion engine (petrol/diesel) to provide vehicle power.

**ADVANTAGES**

- Choice of different models
- Many refueling stations

**DISADVANTAGES**

- Exhaust emissions
- Fossil fuel dependency
- Higher engine noise
- Low energy efficiency

Charging Time to Provide 100 km of Driving

<table>
<thead>
<tr>
<th>POWER, CURRENT, MODE</th>
<th>TIME</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 kW DC (mode 4)</td>
<td>10 MINUTES</td>
<td>Motorway service area or dedicated charging stations in urban areas (future standard)</td>
</tr>
<tr>
<td>50 kW DC (mode 4)</td>
<td>20-30 MINUTES</td>
<td>Motorway service area or dedicated charging stations in urban areas (current standard)</td>
</tr>
<tr>
<td>22 kW AC, three-phase (mode 3)</td>
<td>1-2 HOURS</td>
<td>Most public charging poles</td>
</tr>
<tr>
<td>10 kW AC, three-phase (mode 3)</td>
<td>2-3 HOURS</td>
<td>Household, workplace wall box</td>
</tr>
<tr>
<td>10 kW AC, three-phase (mode 3)</td>
<td>2-3 HOURS</td>
<td>Household, workplace wall box</td>
</tr>
<tr>
<td>7.4 kW AC, single-phase (mode 1 or mode 2)</td>
<td>3-4 HOURS</td>
<td>Public charging poles</td>
</tr>
<tr>
<td>2.3 kW AC, single-phase (mode 1 or mode 2)</td>
<td>6-8 HOURS</td>
<td>Household, workplace wall box</td>
</tr>
</tbody>
</table>

Source: E-Mobility NSR, 2013.

Smart Cities in CE

• The smart city concept goes beyond the use of ICT for better resource use and less emissions.

• It means smarter urban transport networks, upgraded water supply and waste disposal facilities, and more efficient ways to light and heat buildings.

• Encompasses a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.
Cyber & IT for healthy living in smart cities – Climate Monitoring

Fig. 1: The proposed VSN architecture for micro-climate monitoring.

VSN= Vehicular wireless sensor network

Specifics of the Description of the Spread of Pollutants

- **Current field**
  - Heavily influenced by the terrain and vegetation coverage of the neighbourhood
  - Large differences in local speeds in the area

- **Sources of pollution**
  - A limited number of significant line sources
  - Great importance of background resources
  - Significant local sources from small furnaces

Need for a detailed solution

Pospíšil J, Huzlík J, Ličbinský R, Chaloupeck P. Spread of pollutants from line sources in small settlements. Center for Transport Research, Brno University of Technology, 10.11.2014
Appropriate / Inappropriate CFD Applications

Dynamics of contamination at junction space

1s 10s 20s 30s

Jiří Pospíšil, Jiří Huzlík, Roman Ličbinský, Pavel Chaloupecký. Spread of pollutants from line sources in small settlements. Center for Transport Research, Brno University of Technology. 10.11.2014


Transportation Emission Modelling in NYC

Traffic Behaviour Before (simulation)

Traffic Behaviour After (simulation)

Footprints from Shipping

Ideally

• Consuming less oil and releasing fewer pollutant for each unit of goods carried

However

• Low grade marine fuel (3,500 times more S than road diesel). In Europe ships contributed 18% of NO\textsubscript{x}, 18% of SO\textsubscript{x} and 11% of PM\textsubscript{2.5}.

• Ship scrapping - asbestos, heavy metals and oils are toxic

• Improper management (human activities)

<www.nature.com/news/pollution-three-steps-to-a-green-shipping-industry-1.19369> accessed 20.06.2017
Cruising and International trade

AIR POLLUTION

<en.nabu.de/issues/traffic/cruiseships.html>

THE DIRTY TEN
Particulate matter less than 2.5 micrometres (PM$_{2.5}$) emitted from dirty marine fuel oil causes poor air quality along shipping lanes. Emissions-control zones omit the ten largest container ports, which contribute an estimated 20% of worldwide port emissions of nitrogen oxides and sulfur oxides.

<www.nature.com/news/pollution-three-steps-to-a-green-shipping-industry-1.19369> accessed 05.06.2017
Circular Economy in Industry
Global Energy Consumption by Sector (year 2015)

Total Final Consumption 49%

Industry = 2,712 Mtoe

Transport = 2,704 Mtoe
Other = 3,132 Mtoe

Non-energy use = 836 Mtoe

Integrating Renewable Energy Sources into Extended Total Sites

Perry, Klemeš, Bulatov, Chemical Engineering Transactions, 12, 2007, 593-598
Perry, Klemeš, Bulatov, Energy, 33, 1489-1497, 2008
Conclusion

• More **development is needed** to secure that the actual environmental impacts of circular economy work toward sustainability

• Improve the **efficiency/design of waste minimisation, management and treatment**

• Rather than having circularity as an ultimate goal, a more pragmatic vision for a material future would be **aim to meet human needs (demand) while minimising the environmental impact**.
What Can We Do

• Use energy efficient light bulbs and appliances
• Walk, bicycle
• Live where you work
• Drive less, and drive fuel efficient vehicles
• Eat less meat, change the diet
• Do not over-heat or over-cool, Increasing thermostat by 1° in the summer & Decreasing it by 1° in the winter (save 10% of energy consumption),
• Wear a sweater
• Reuse, reuse (shopping bag, bottles, packaging)
• Reduce your waste (incl. food waste), separation, composting
• Insulate your house etc:
• Use biofuels (?) – target biowaste
• Use a clothesline
• Vote!

Trenberth K E, NCAR, Extreme weather and the changing climate, <www.cgd.ucar.edu/staff/trenbert/presentations.html> 2/7/2018
Large moisture fluxes from a “red hot” ocean fuel the hurricane and its heavy rains.
The Need of Action and Appropriate Implementation
Acknowledgement

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Future Special Session: SDEWES 2018 Palermo
Proposed Special Session: SDEWES 2019 Dubrovnik

Energy, Water and Resource Efficiency for Sustainable Future: Contribution to Circular Economy

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22nd Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction

20–23 October 2019
Crete, Greece

IMPORTANT DATES
30 November 2018, Abstract due
31 January 2019, Notification of abstract acceptance
16 March 2019, Full text submission due
30 April 2019, Full text revisions and final acceptance completed

<conferencepres.com>  |  <pres2019.cperi.certh.gr>
<table>
<thead>
<tr>
<th></th>
<th>Book Title</th>
<th>Editors</th>
<th>Publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Handbook of water and energy management in food processing (English and Chinese version)</td>
<td>Jiří Klemeš, Robin Smith and Jin-Kuk Kim</td>
<td>Woodhead Publishing Ltd / Elsevier [中国轻工业出版社]</td>
</tr>
<tr>
<td>3</td>
<td>Sustainability in the process industry</td>
<td>Jiří Klemeš, Ferenc Friedler, Igor Bulatov, Petar Varbanov</td>
<td>McGraw-Hill Professional</td>
</tr>
<tr>
<td>4</td>
<td>Process integration and intensification</td>
<td>Jiří Jaromír Klemeš, Petar Varbanov, Sharifah Rafidah Wan Wan Alwi, Zainuddin Abdul</td>
<td>De Gruyter</td>
</tr>
<tr>
<td>5</td>
<td>Assessing and Measuring Environmental Impact and Sustainability</td>
<td>Jiří Jaromír Klemeš</td>
<td>Butterworth-Heinemann/Elsevier</td>
</tr>
<tr>
<td>6</td>
<td>Compact heat exchangers for energy transfer intensification: Low grade heat and fouling mitigation</td>
<td>Jiří Jaromír Klemeš, Olga Arsenyeva Petro Kapustenko, Leonid Tovazhnyanskyy</td>
<td>CRC Press/ Taylor and Francis Group</td>
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Thank you, comments welcome
感谢倾听，请多指导