BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF MECHANICAL ENGINEERING

NETME Centre

SPIL

Lecture 1

SPIL Introduction – Main Issues and Problems of Pollution and Resource Depletion

Prof Dr Jiří Jaromír Klemeš, DSC

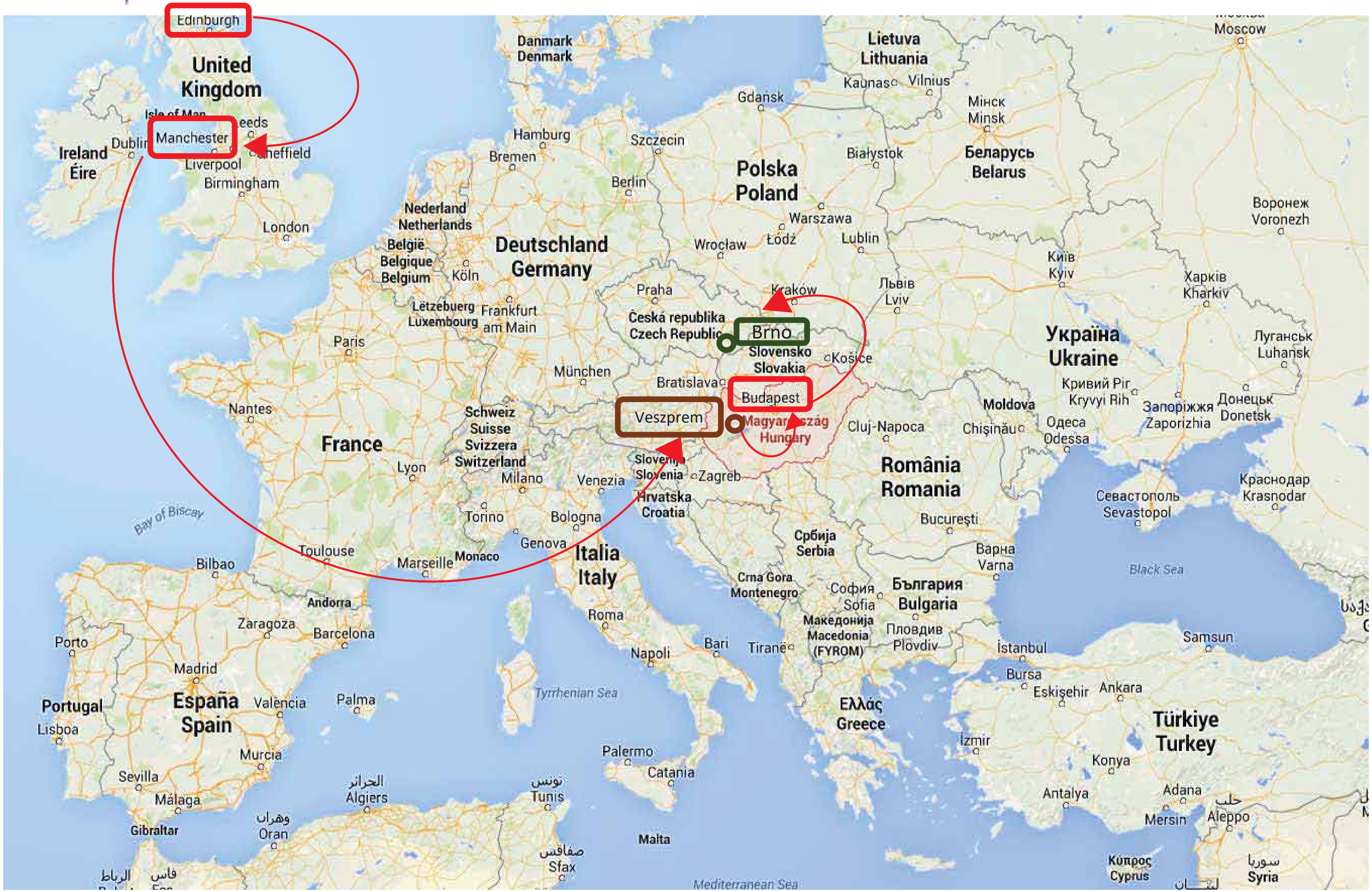
Prof Dr Petar Sabev Varbanov

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research, Development and Education

MŠMT
MINISTRY OF EDUCATION, YOUTH AND SPORTS

The route: Czechoslovakia

United Kingdom→ Hungary → Czech Republic



UMIST – Pioneering Pinch Analysis

Department of Process Integration at UMIST 1990 – 2004

Brno

The second largest city of Czech Republic


Brno


Mahen Theatre


Old Town Hall + Information centre


Morzart Statue and Reduta theatre


Jošt horse statue

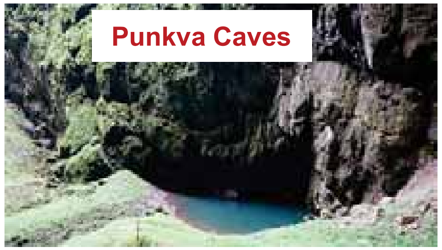
Hody
Traditional Moravian Celebration

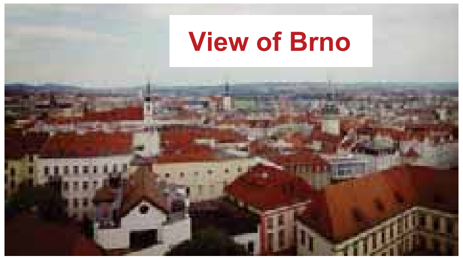

Freedom Square


Vegetable Market


Spilberk Castle

Tramvaj-Christmas market


Punkva Caves


View of Brno


Petrov

Brno University of Technology

- Public university founded in **1899**
- The **second oldest and the largest** technical university in the Czech Republic
- 3,000 employees, ~23,000 students at **8 faculties**.
- 26 study programmes are offered in a foreign language
- One of the current **top priorities** is to achieve a **high quality of research and development**
- Cooperation with industry (e.g. Škoda Auto, IBM, ABB, ČEZ, Siemens, Zetor, ŽĎAS, Honeywell and many others)

NETME Centre
Faculty of Mechanical Engineering

Main Building of FME

- Founded in 2010
- One of the two public centres focused on advanced mechanical engineering technologies, alongside the Regional Technological Institute of the University of West Bohemia, Pilsen.
- Supports horizontal mobility of research workers not only among national and foreign R&D organisations but also between BUT and the application sector
- The centre cooperates with leading universities and companies. 40 % contracted research is from international companies.

NETME Centre

NETME Centre

BRNO UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

Description of Scientific Project

- Principal aim - to achieve unique and practically **applicable knowledge** that would **contribute to increased efficiency of process and energy industry**

- Focused on **minimising** the **greenhouse gases, NOx, energy and water footprints** searching for a complex solution in the area of energy savings.

Research Agenda

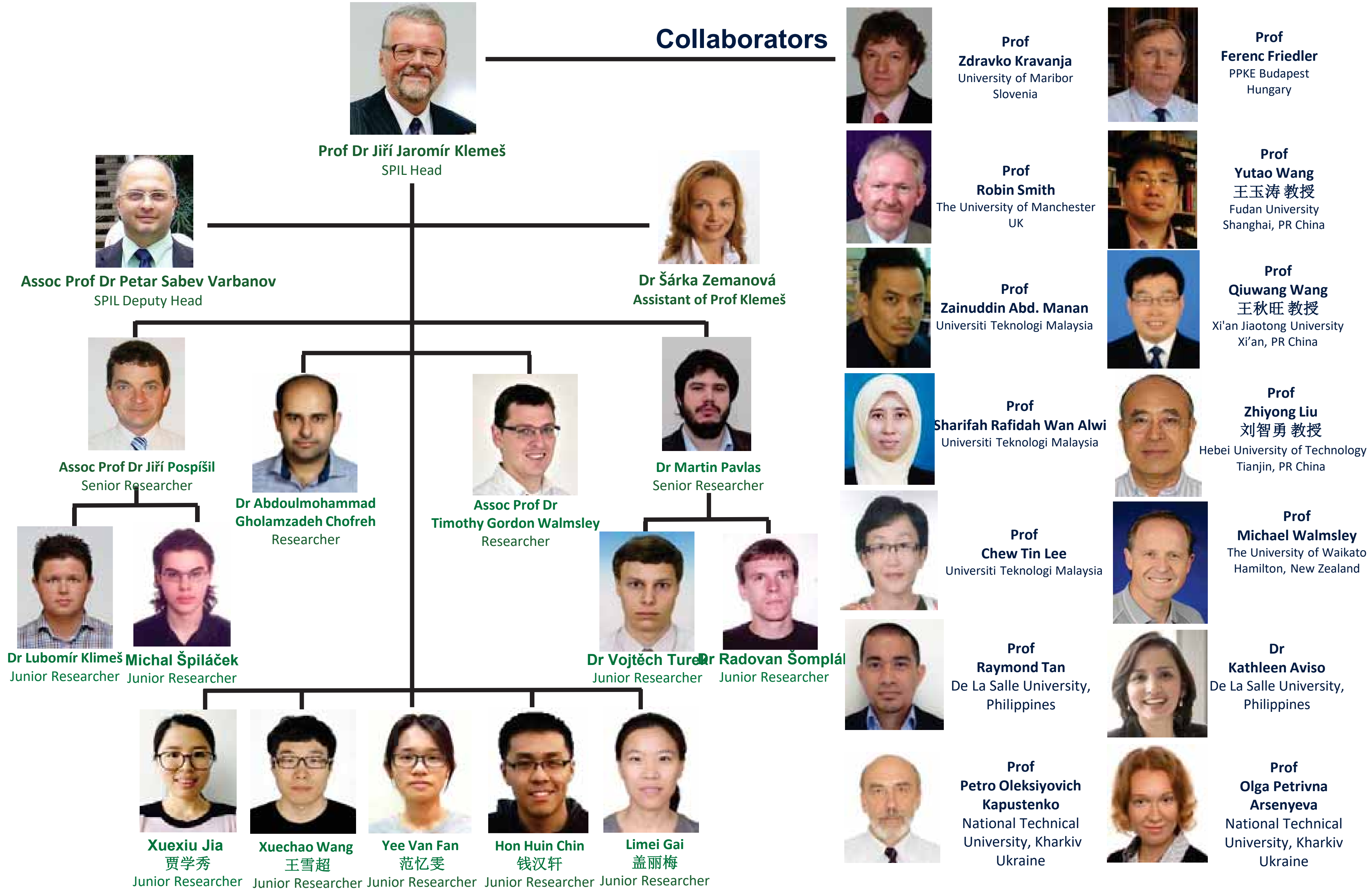
The 12 Main Objectives

1. A comprehensive **state-of-the-art analysis** in the following areas and their combinations.
2. Extending and developing an advanced methodology for Total Site and regional integration methodology for **thermal energy**.
3. Extending the methodology for **water and waste water** minimisation and **water and energy** minimisation.
4. Extending the methodology into **power (electricity)** Total Site and Regional Integration.
5. Development of the methodology for further minimisation of **Greenhouse gas footprints** (including the carbon footprints).
6. Development of the methodology for minimisation of **Nitrogen footprints**.

Research Agenda

7. Development of the methodology for minimisation of **Water footprints** (specified as blue, green, and grey footprints).
8. Study and suggestions for minimisation of **virtual footprints** – including GHG, Nitrogen, and Water footprints.
9. Study and suggestions for reduction of the environmental impact of **energy and water flows**.
10. Extending and developing **advanced procedures and tools**.
11. Resource (energy, water, etc.) improvement **road-mapping**
12. **Knowledge transfer and dissemination**, with user feedback.

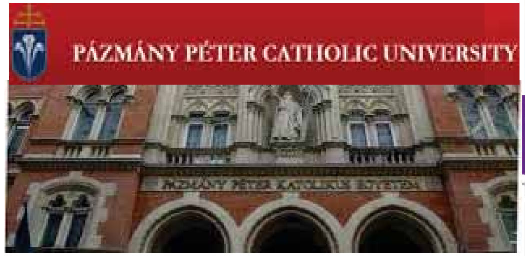
Sustainable Process Integration Laboratory (SPIL)



Collaborators Top World Universities

SLOVENIA

HUNGARY

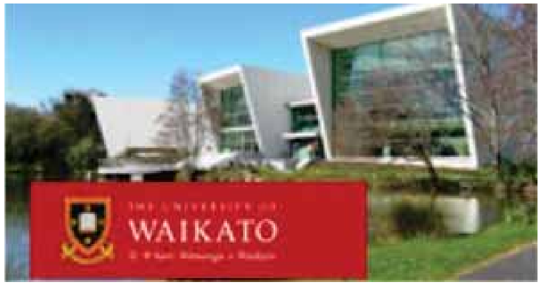


UK

PHILIPPINES

MALAYSIA

NEW ZEALAND



CHINA (Hebei, Tianjin)

CHINA (Jiaotong, Xi'an)

CHINA (Fundan, Shanghai)

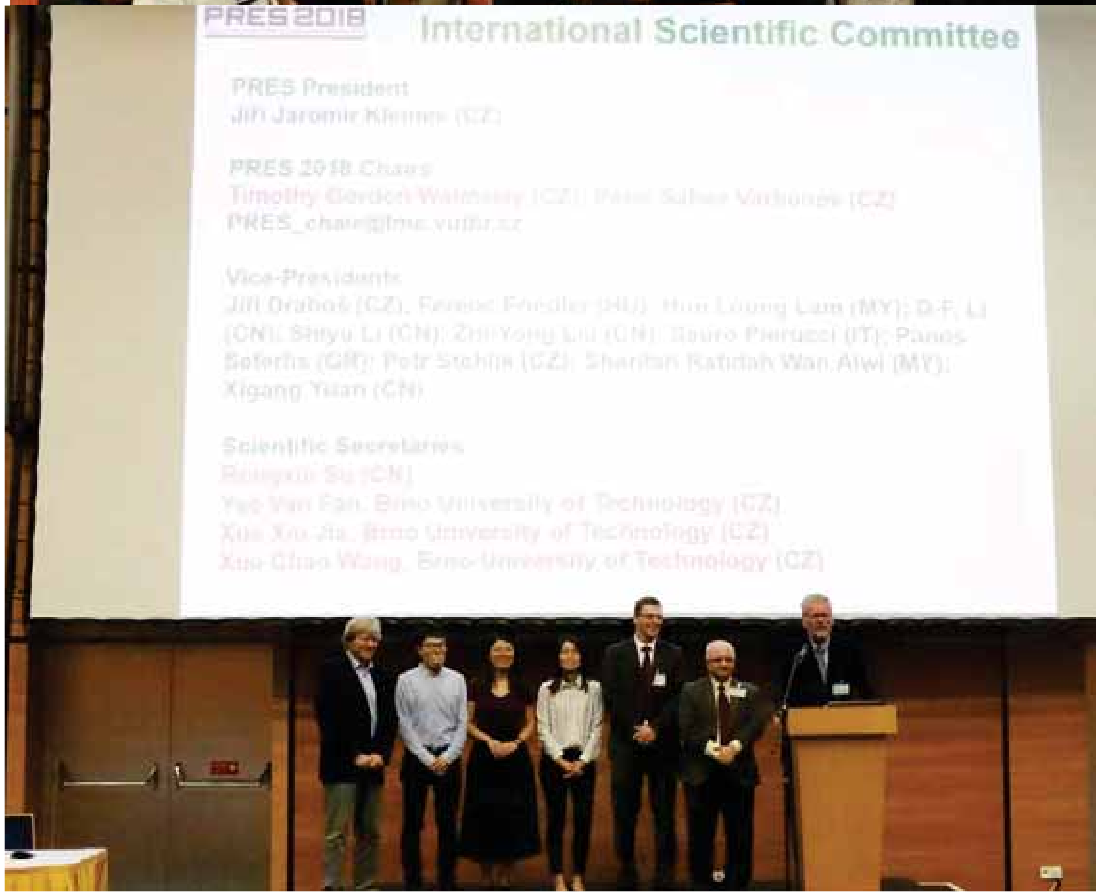
UKRAINE

Conferences - SPIL Team

SPIL in ICCHMT 2018, Kraków, Poland, 2018

Conferences - SPIL Team

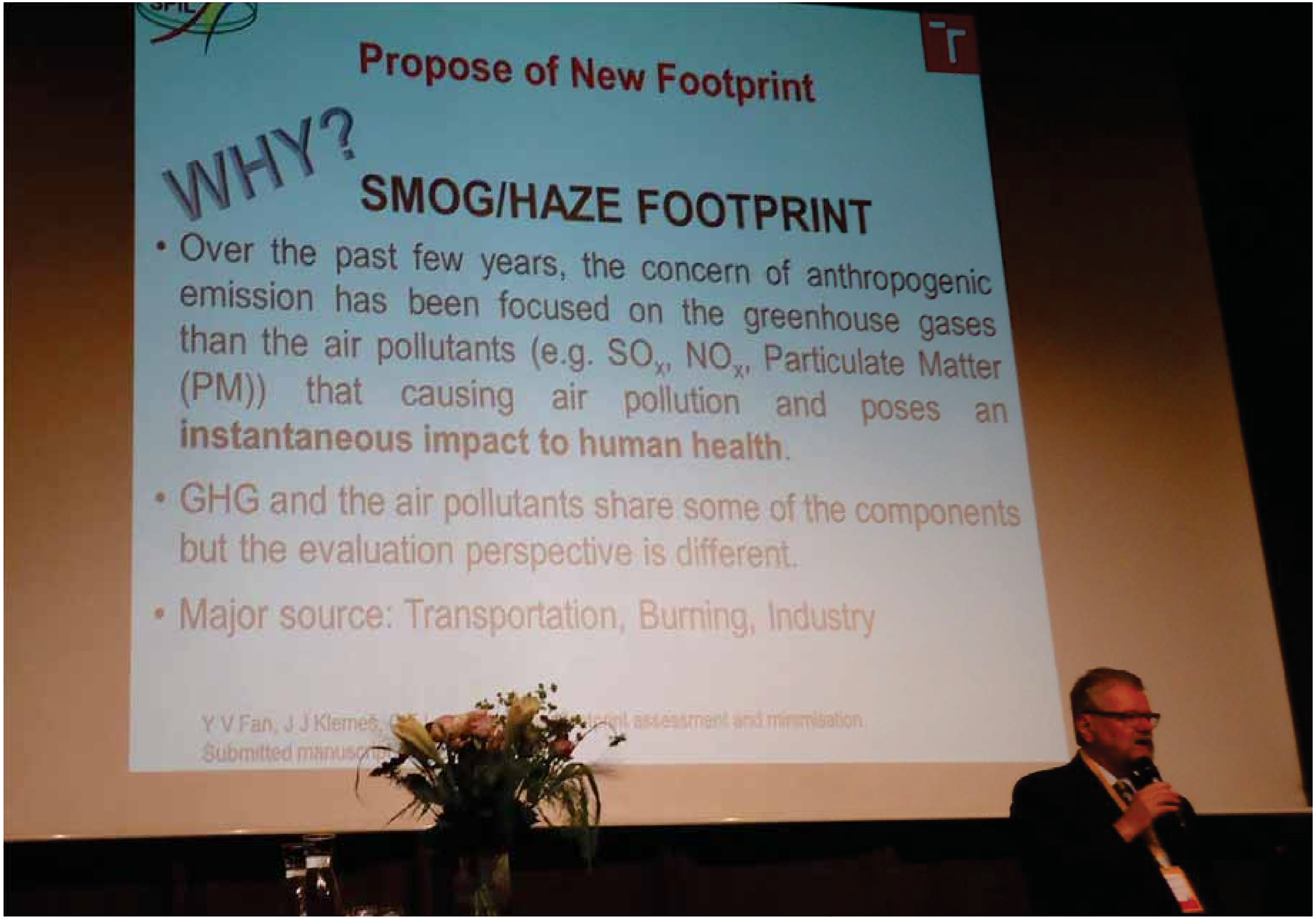
SPIL Symposium PRES 2018, Prague



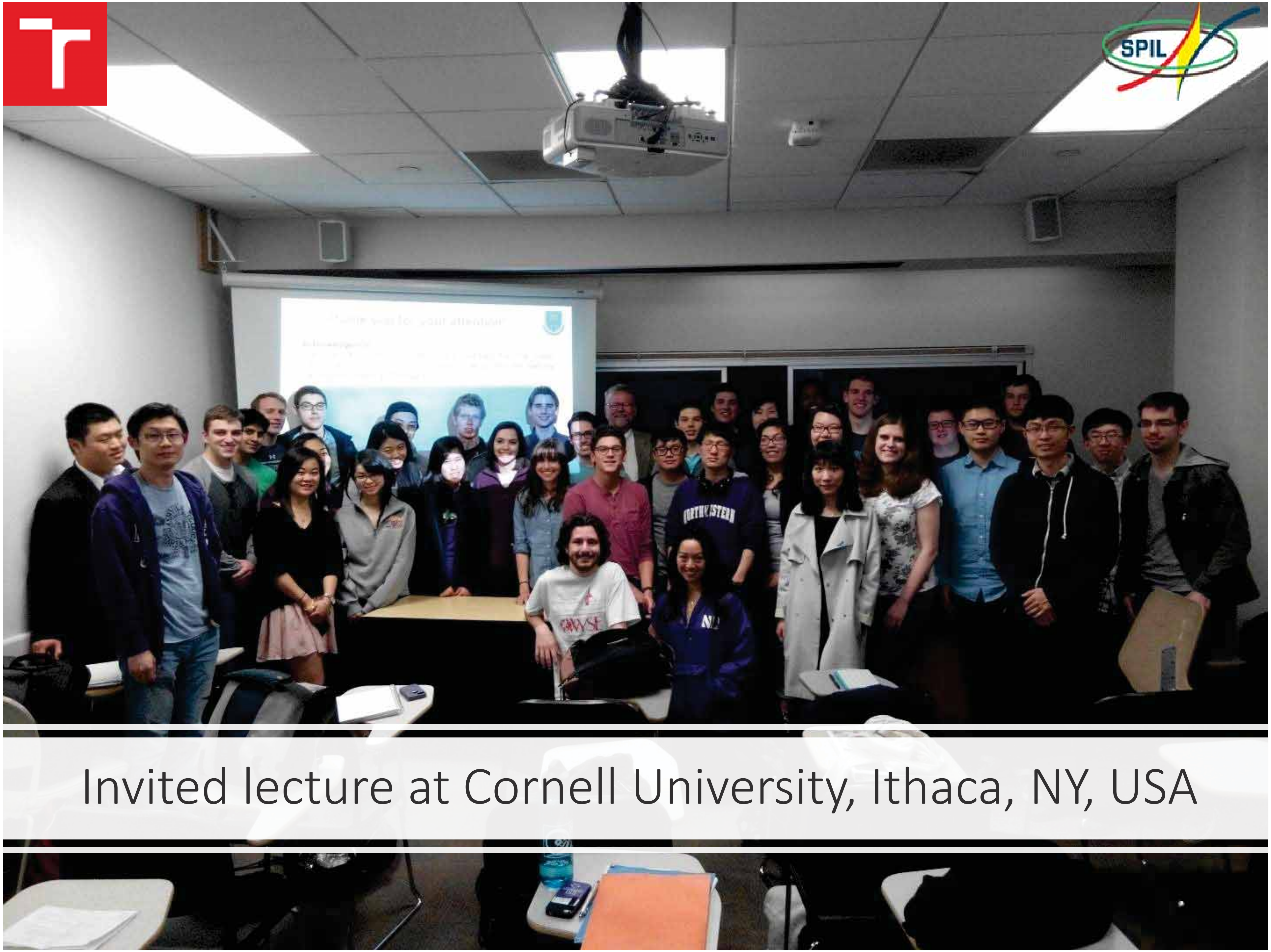
Invited Lectures (2018)

- University of Miskolc, **Hungary**
- Economics University in Bratislava, **Slovakia**
- Faculty of Business Economics in Košice, **Slovakia**
- National Chengchi University, Taipei, **Taiwan China**
- South China University of Technology, Guangzhou, **China**
- Politechnika Krakowska, Cracow, **Poland**

Stockholm, Sweden



Johor Bahru, Malaysia



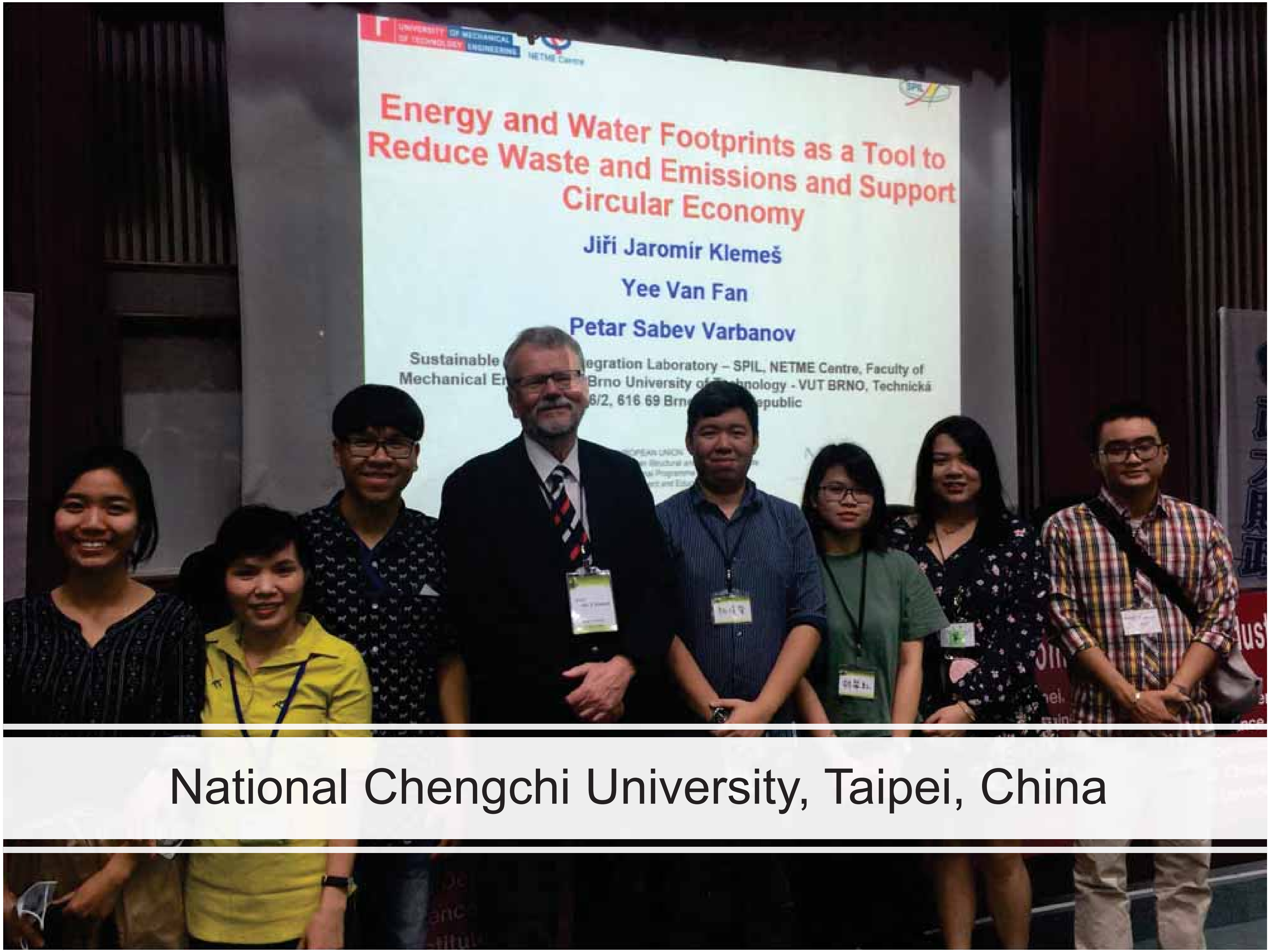
Invited lecture at Cornell University, Ithaca, NY, USA

CAPE WP Business Meeting EFChE, Graz, Austria, June 2018

University of Pannonia, July 2018

Izmir, Turkey, July 2018

National Chengchi University, Taipei, China



National Chengchi University, Taipei, China

Košice, Slovakia

SINOPEC, Shanghai

Collaboration Agreement PPKE

Collaboration Agreement, Fudan University

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Google Scholar

Jiří Jaromír KLEMEŠ

FOLLOW

Sustainable Process Integration Laboratory (SPIL), NETME Centre, FME, Brno University of Technology
Verified email at fme.vutbr.cz - Homepage

Process Integration   energy savings   pollution reduction   environmental footprints   waste minimisation

TITLE	CITED BY	YEAR
A review of footprint analysis tools for monitoring impacts on sustainability L Čuček, JJ Klemeš, Z Kravanja Journal of Cleaner Production 34, 9-20	554	2012
Targeting and design methodology for reduction of fuel, power and CO2 on total sites J Klemeš, VR Dhole, K Raissi, SJ Perry, L Puigjaner Applied Thermal Engineering 17 (8-10), 993-1003	379	1997
Sustainability in the process industry J Klemes, F Friedler, I Bulatov, P Varbanov McGraw-Hill, New York, USA	338	2011
Integrating waste and renewable energy to reduce the carbon footprint of locally integrated energy sectors S Perry, J Klemeš, I Bulatov Energy 33 (10), 1489-1497	337	2008
The Environmental Performance Strategy Map: an integrated LCA approach to support the strategic decision-making process L De Benedetto, J Klemeš Journal of Cleaner Production 17 (10), 900-906	318	2009
Cleaner energy for sustainable future VG Dovì, F Friedler, D Huisingh, JJ Klemeš Journal of Cleaner Production 17 (10), 889-895	257	2009

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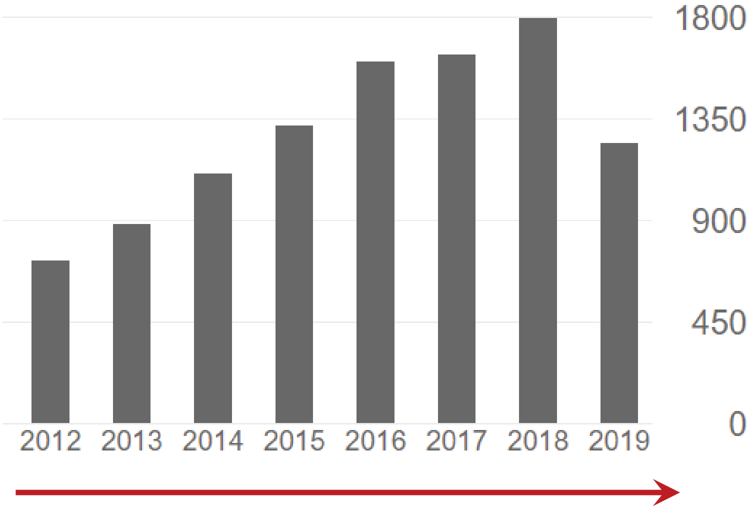
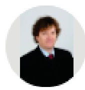


Co-authors   VIEW ALL

Petar Varbanov
Senior Researcher, NETME Cen…



Zdravko Kravanja
Professor of Chemical Engineeri…

Scopus
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Klemeš, Jiří Jaromír

Vysoké učení technické v Brně, Fakulta strojního inženýrství, Brno, Czech Republic
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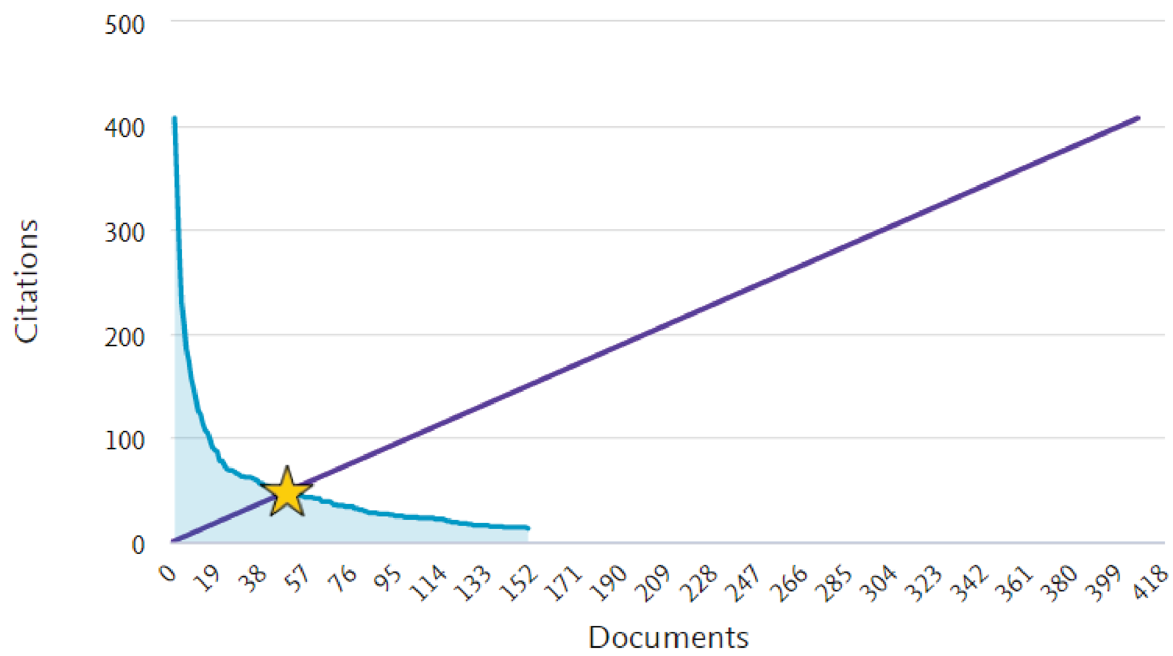

Scopus
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Vysoké učení technické v Brně, Fakulta strojního inženýrství, Brno, Czech Republic

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2011	290

Citations by year

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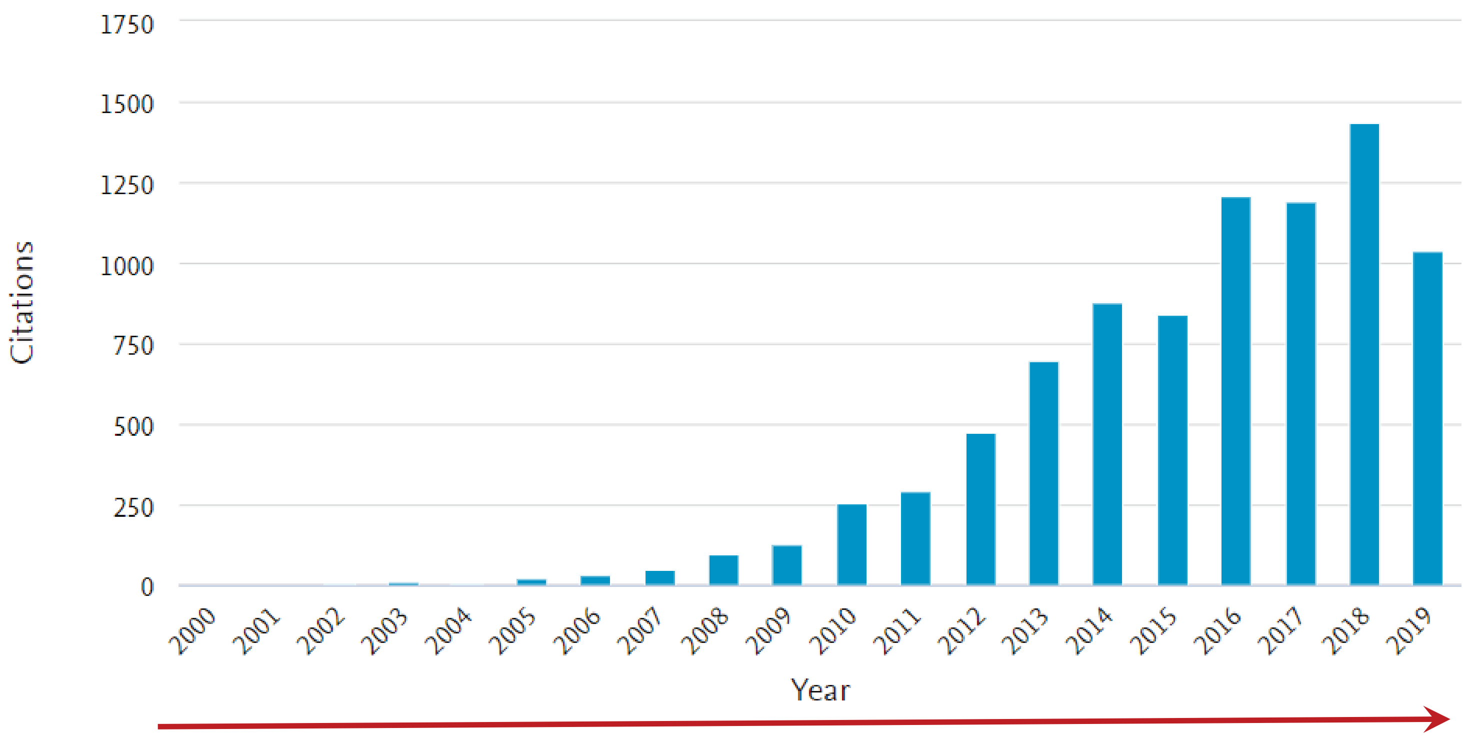

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	814	1050	911	1046	723	7285	169.42
1. **A Review of Footprint analysis tools for monitoring impacts on sustainability** By: Cucek, Lidija; Klemes, Jiri Jaromir; Kravanja, Zdravko JOURNAL OF CLEANER PRODUCTION Volume: 34 Special Issue: SI Pages: 9-20 Published: OCT 2012	52	57	62	56	40	346	43.25
2. **Targeting and design methodology for reduction of fuel, power and CO2 on total sites** By: Klemes, J; Dhole, VR; Raissi, K; et al. APPLIED THERMAL ENGINEERING Volume: 17 Issue: 8-10 Pages: 993-1003 Published: AUG-OCT 1997	28	23	15	13	9	305	13.26
3. **Integrating waste and renewable energy to reduce the carbon footprint of locally integrated energy sectors** By: Perry, Simon; Klemes, Jiri; Bulatov, Igor Conference: 10th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction Location: Ischia Isl, ITALY Date: JUN 24-27, 2007 ENERGY Volume: 33 Issue: 10 Special Issue: SI Pages: 1489-1497 Published: OCT 2008	32	12	16	13	12	229	19.08
4. **The Environmental Performance Strategy Map: an integrated LCA approach, to support the strategic decision-making process** By: De Benedetto, Luca; Klemes, Jiri JOURNAL OF CLEANER PRODUCTION Volume: 17 Issue: 10 Pages: 900-906 Published: JUL 2009	19	33	15	20	13	182	16.55
5. **Cleaner energy for sustainable future** By: Dovi, Vincenzo Giorgio; Friedler, Ferenc; Huisingh, Donald; et al. JOURNAL OF CLEANER PRODUCTION Volume: 17 Issue: 10 Pages: 889-895 Published: JUL 2009	19	19	20	14	12	172	15.64

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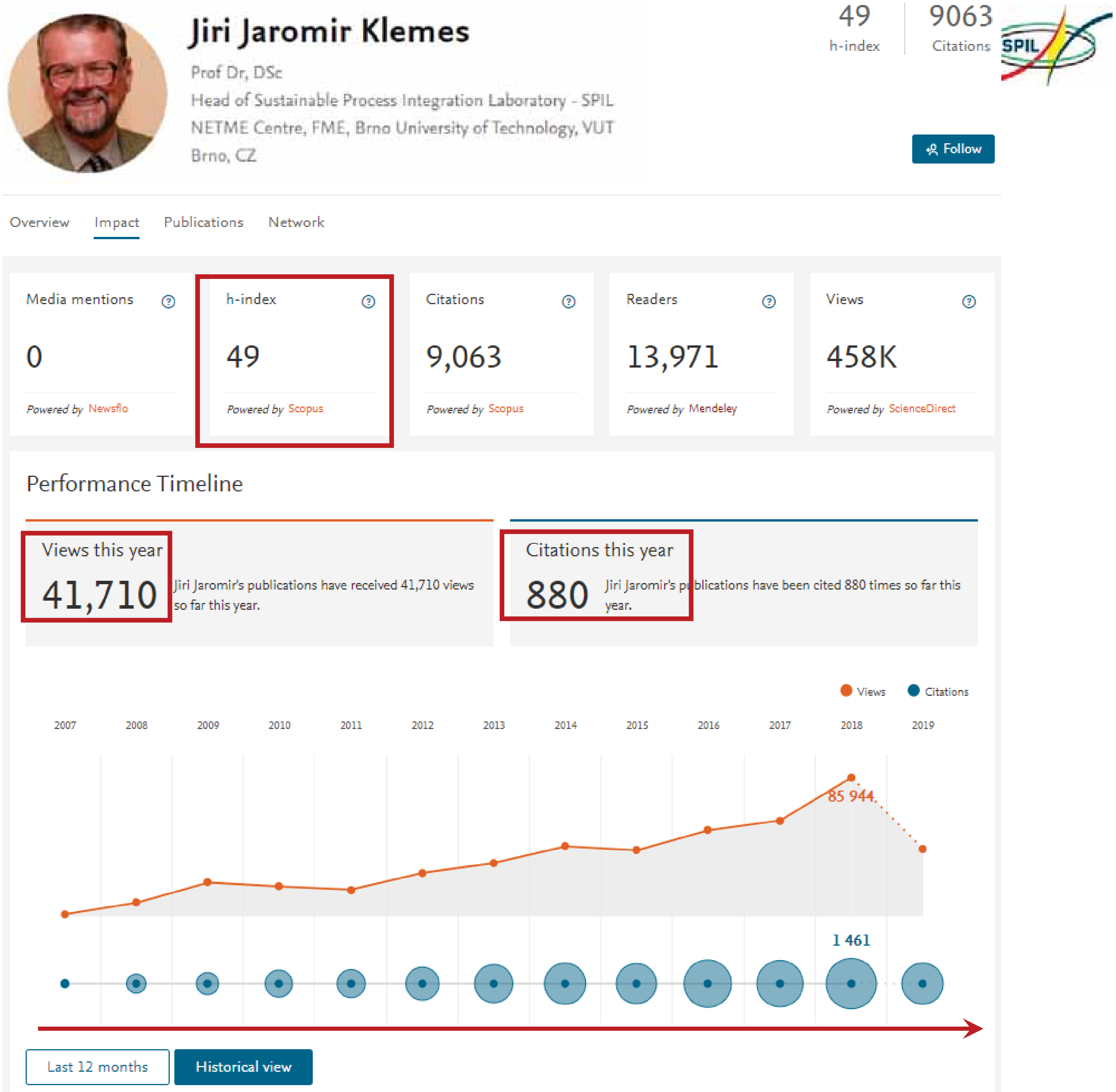
Jiri Jaromir Klemes
Prof Dr, DSc
Head of Sustainable Process Integration Laboratory - SPIL
NETME Centre, FME, Brno University of Technology, VUT
Brno, CZ
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Jiří Jaromír Klemeš

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Highly cited | Top peer reviewer

Professor - NETME Centre, Brno University of Technology

98th Percentile

PUBLICATIONS	TOTAL TIMES CITED	VERIFIED REVIEWS	VERIFIED EDITOR RECORDS
453	7,503	1,472	5,132

Awards

- Highly Cited Researcher in the field of Cross-Field - 2018
- Top Handling Editors - September 2018
- Top Reviewers for Engineering - September 2018

Currently serves on **20** editorial boards
Totally serves on **25** editorial boards

Editorial board memberships

CURRENT MEMBERSHIPS

- Chemical Engineering Transactions
- CHISA - International Congress of Chemical a...
- Conference on Process Integration for Energy ...
- Conference on Process Integration, Modelling ...
- Energies WOS
- Heliyon WOS
- International Conference on Low Carbon Asia ...
- Journal of Cleaner Production WOS
- Resources, Conservation and Recycling WOS
- Theoretical Foundations of Chemical E... WOS
- CHISA - International Congress of Chemical a...
- Clean Technologies & Environmental Policies
- Conference on Process Integration, Modeling, ...
- Conference on Sustainable Development of En...
- Energy WOS
- ICHEAP12: 12TH INTERNATIONAL CONFERE...
- International Congress of Chemical and Proce...
- Renewable and Sustainable Energy Rev... WOS
- South East European Conference on Sustaina...
- Thermal Science and Engineering Progress

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Editor-in-Chief / President

PAST MEMBERSHIPS

- Applied Energy WOS
- CAPE Forum Computer Aided Process Engine...
- Heat Transfer Engineering WOS
- Applied Thermal Engineering WOS
- Computer Aided Process Engineering (CAPE) ...

Has reviewed for **103** journals

- (314) Conference on Process Integration for E...
- (145) Energy WOS
- (95) Applied Thermal Engineering WOS
- (37) Industrial & Engineering Chemistry ... WOS
- (33) Computers & Chemical Engineering WOS
- (27) International Journal of Hydrogen ... WOS
- (19) Energy Policy WOS
- (17) Conference on Process Integration, Mode...
- (15) Renewable and Sustainable Energy... WOS
- (10) AICHE Journal WOS
- (233) Journal of Cleaner Production WOS
- (135) Chemical Engineering Transactions
- (46) Clean Technologies and Environme... WOS
- (36) Applied Energy WOS
- (30) Conference on Sustainable Development ...
- (23) Sustainability WOS
- (19) Resources, Conservation and Recy... WOS
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- (12) South East European Conference on Sust...
- (10) Journal of Environmental Manage... WOS

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Plus 1 more review awaiting verification.

Publons' ECR Reviewer Choice Award

http://wshe.es/eDiGSmrg

Hao Li, University of Texas in Austin

Hao Li has completed an significant number of peer reviews for a researcher who has not yet completed his PhD - and quantity has been no substitute for quality with Hao receiving awards from both Publons and Elsevier.

Yee Fan, Brno University of Technology

Environmental Engineer Yee Fan has contributed a significant amount in the peer review and editorial space. She has edited for two high impact factor journals, completed almost 400 reviews, and been recognised as an 'Outstanding Reviewer' - all before completing her PhD

Jon Tennant, Imperial College London

Rogue Palaeontologist Jon Tennant is well known among peer review and open access circles worldwide. He's led multiple innovative projects in these realms (and won awards for his efforts), and has a strong, straight-up, and well respected social media presence

Veronika Cheplygina, Eindhoven Universit...

As well as completeing over 70 reviews for machine learning and medical analysis papers, Veronika Cheplygina has published innovative ideas and guidance around peer review.

During Veronika's PhD in machine learning

Xinyan Huang, Hong Kong Polytechnic Uni...

Mechanical Engineer Huang has been recognised for his outstanding review efforts with awards not only from Publons but also from Springer and Elsevier journals, scooping up 11 awards in total (on top of his 180 reviews).

Theodore D Cosco, University of Oxford

Epidemiologist (PhD, University of Cambridge) and psychologist (CPsychol, British Pyschological Society) Theodore D. Cosco contibutes to peer review by mentoring more junior researchers, developing podcasts on the topic, and winning Publons awards for his numerous

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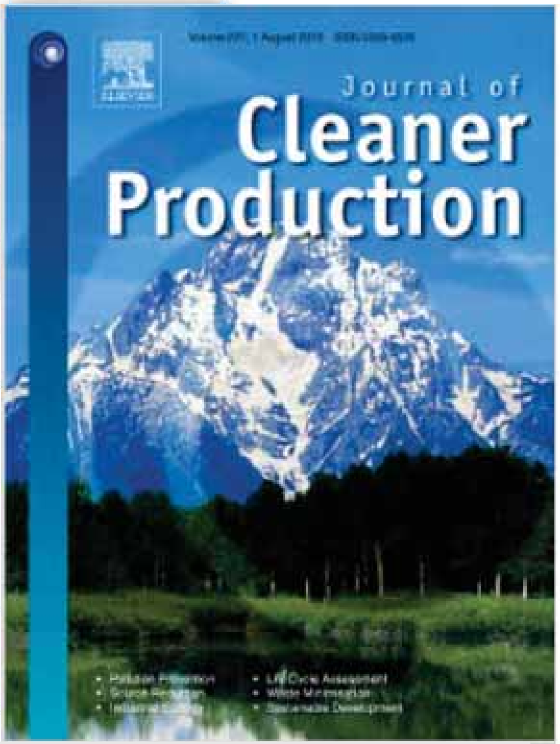
Journal of Cleaner Production



Journal of Cleaner Production

Co-Editors-in-Chief: Jiří Jaromír Klemeš, Cecília Maria Villas Bôas de Almeida, Yutao Wang

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Additional Publications

- Klemeš, J.J. (ed), Assessing and Measuring Environmental Impact and Sustainability, 2015, Elsevier / Butterworth-Heinemann, Oxford, UK, ISBN: 978-0-12-799968-5, 559 ps.
- Klemeš, J.J. (ed), 2013, Handbook of Process Integration (PI): Minimisation of Energy and Water Use, Waste and Emissions, Woodhead/Elsevier, Cambridge, UK, 1184 ps. ISBN – 987-0-85709-0.
- Klemeš, J.J., Varbanov, P.V., Walmsley, T.G., Jia, X.X., 2018. New directions in the implementation of Pinch Methodology (PM). Renewable and Sustainable Energy Reviews, 98, 439-468.
- Varbanov PS, Walmsley TG, Fan YV, Klemeš JJ, Perry S, 2018, Spatial targeting evaluation of energy and environmental performance of waste-to-energy processing. Frontiers of Chemical Science and Engineering, 12 (4), 731-744.
- Fan YV, Klemeš JJ, Walmsley TG, Perry S., 2019. Minimising Energy Consumption and Environmental Burden of Freight Transport using a Novel Graphical Decision-Making Tool. Renewable and Sustainable Energy Reviews, 2019.
- Fan Y.V. , Klemeš J.J. , Tan R.R. , Varbanov P., 2019. Graphical Break-Even Based Decision-Making Tool to Minimise GHG Footprint of Biomass Utilisation: Biochar by Pyrolysis. Chemical Engineering Transactions, 76, 2019.

Additional Publications

- Fan YV, Perry S, Klemeš J J, Lee CT., 2018. A review on air emissions assessment: Transportation. Journal of Cleaner Production, 194, 673-684.
- Fan YV, Klemeš JJ, Lee CT, Perry S, 2018. Anaerobic digestion of municipal solid waste: energy and carbon emission footprint. J of Environmental Management, 223, 888-897.
- Fan YV., Klemeš JJ., Perry S., Lee CT., 2019. Anaerobic digestion of lignocellulosic waste: Environmental impact and economic assessment. J of Environmental Management, 231, 352-363.
- Fan YV, Klemeš JJ, Lee CT, Perry S, 2019, GHG Emissions of Incineration and Anaerobic Digestion: Electricity Mix, Chemical Engineering Transactions, 72, 145-150.
- Fan YV, Varbanov PS, Klemeš JJ, Nemet A., 2017. Process efficiency optimisation and integration for cleaner production. Journal of Cleaner Production. 174, 177-183.
- Fan YV, Lee CT, Klemeš JJ, Leow CW, 2017. Evaluation of Effective Microorganisms on Small Scale Food Waste Composting, J of Environmental Management. 216, 41-48.
- Fan YV, Lee CT, Klemeš JJ, Bong CPC, Ho WS, 2016. Economic assessment system towards sustainable composting quality in the developing countries. Clean Technologies and Environmental Policy, 18 (8), 2479-2491.

Outline

1. Sustainability
2. Issues: Environmental Impact, Economic Development, Societal Development
    1. Resource demands and extraction
    2. Emissions (gaseous), Effluents (liquid), Solid Waste
3. Solutions proposed worldwide
4. Mapping inputs to outputs: the Big Picture
5. General strategy to follow
6. Process Integration: leading the way for 4 decades

Sustainability

What is sustainability?

Dictionary definition

sustainability

/səsteɪnəˈbɪlɪti/

noun

the ability to be maintained at a certain rate or level.
"the sustainability of economic growth"

- avoidance of the depletion of natural resources in order to maintain an ecological balance.
  "the pursuit of global environmental sustainability"

In the context of human society

Sustainability

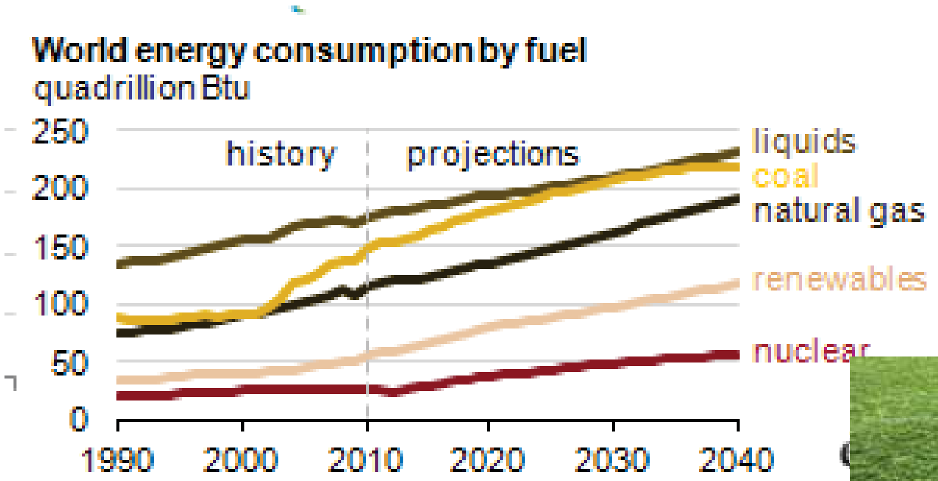
REVIEWED BY MITCHELL GRANT AND WILL KENTON | Updated May 23, 2019

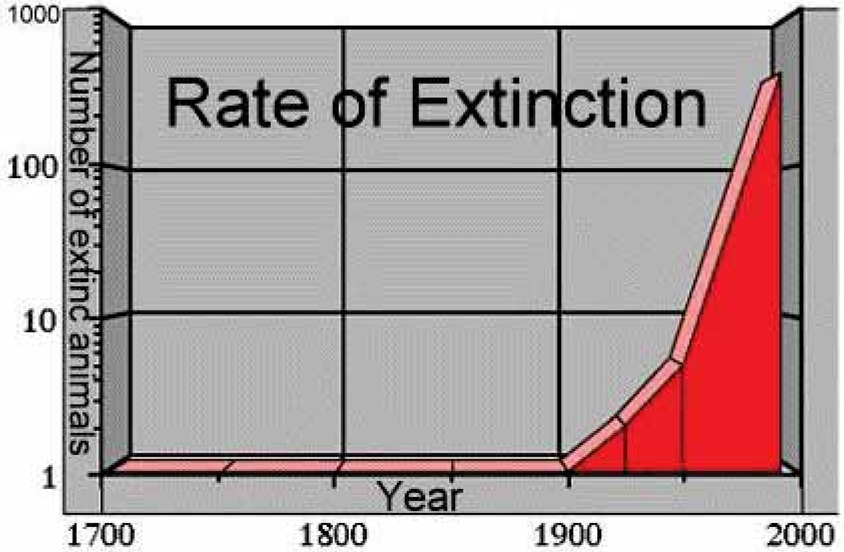
What Is Sustainability?

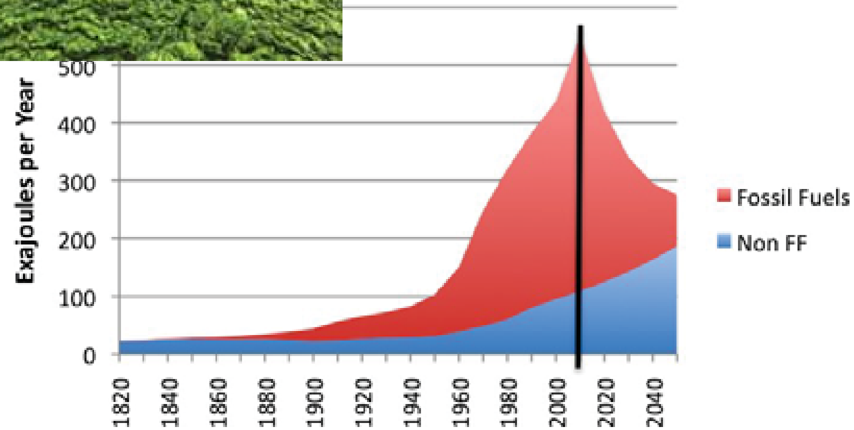
Sustainability focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs. The concept of sustainability is composed of three pillars: economic, environmental, and social—also known informally as profits, planet, and people.

https://www.investopedia.com/terms/s/sustainability.asp

Why sustainability?

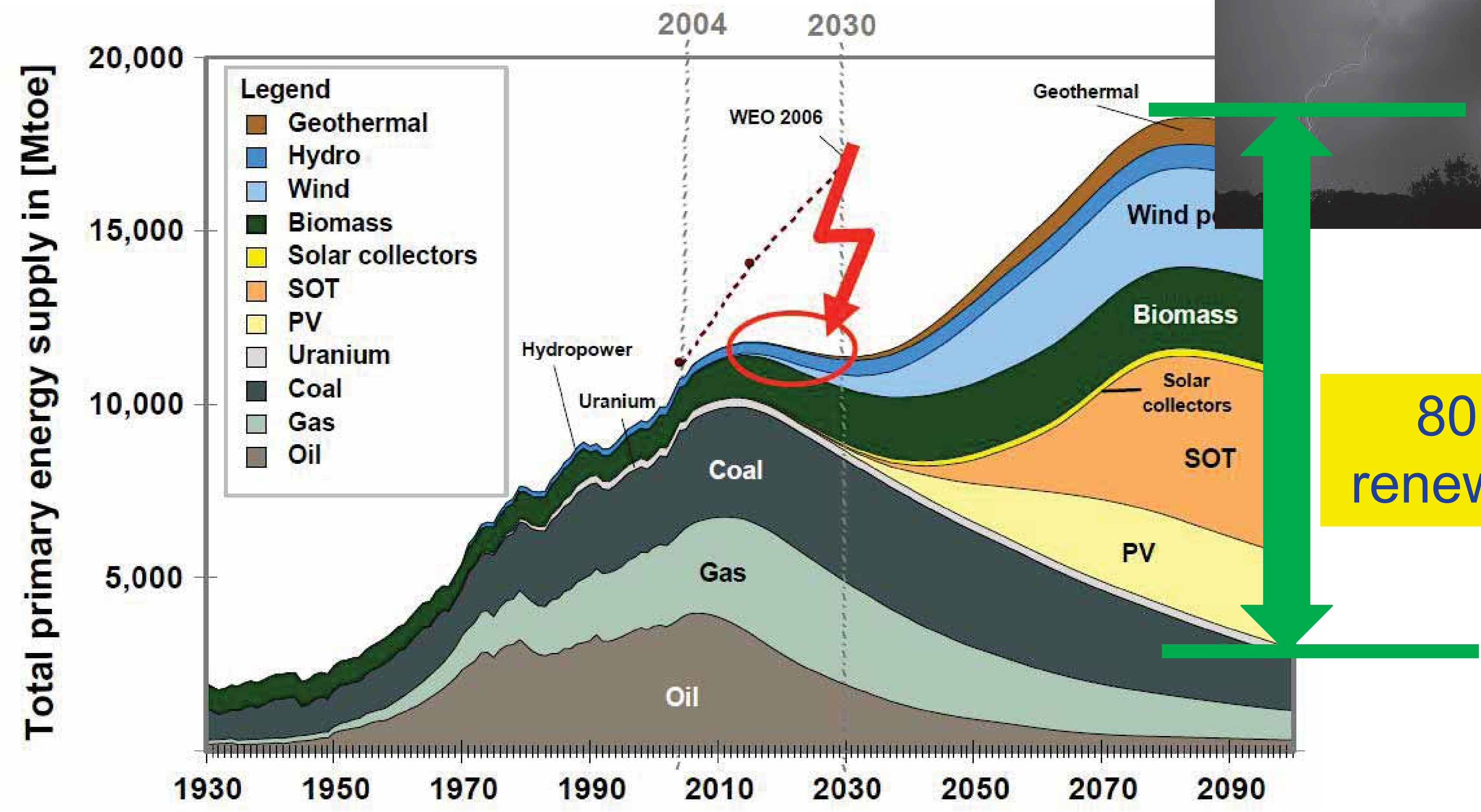






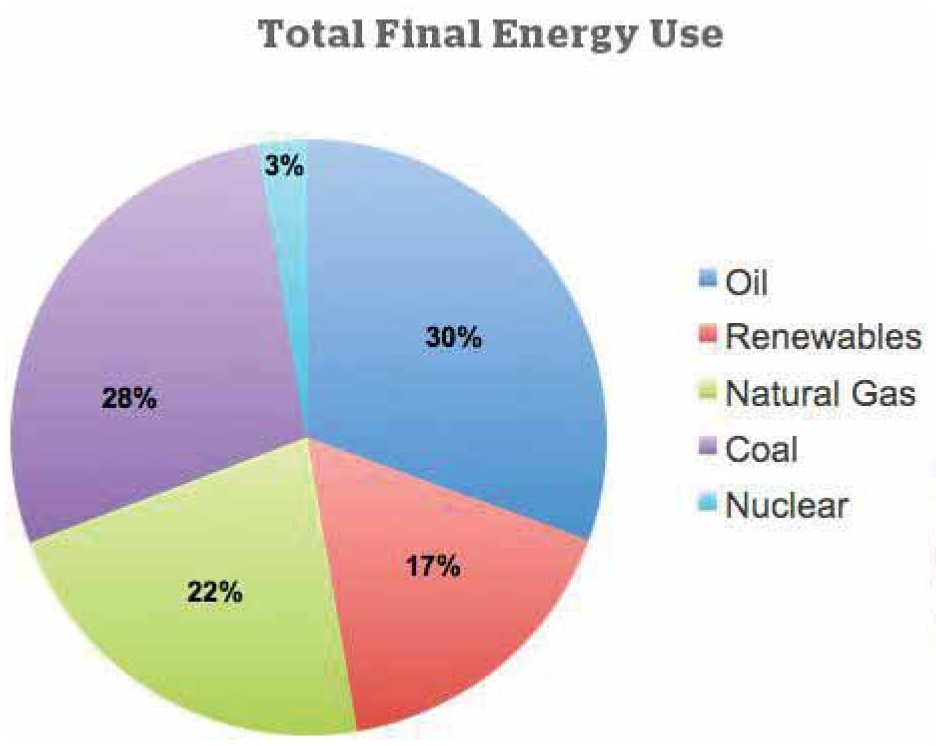
Predictions for the future

Primary energy supply



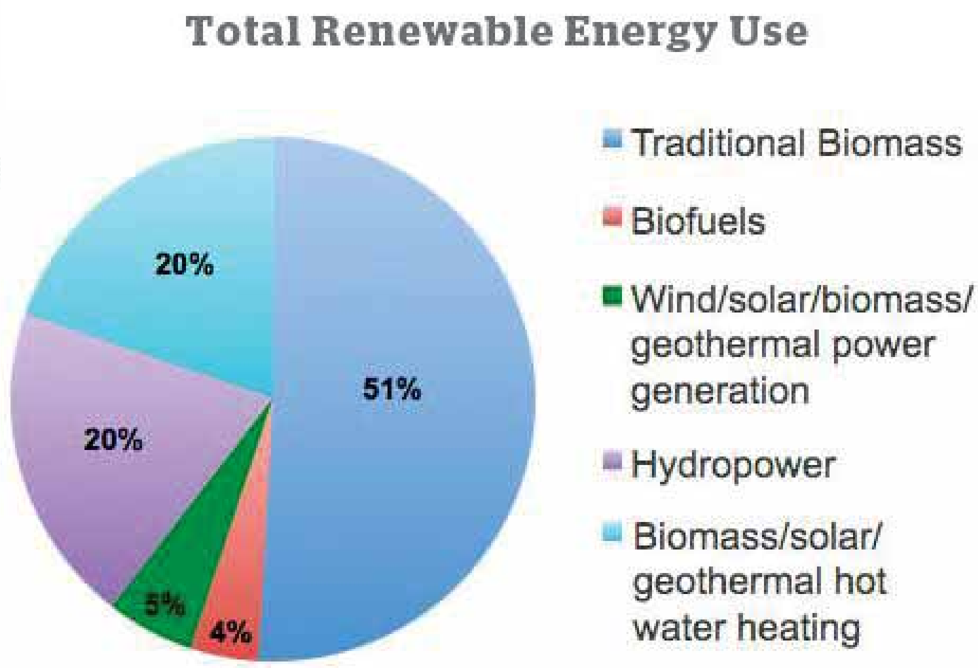
80 % renewable

Total final energy use (2010)



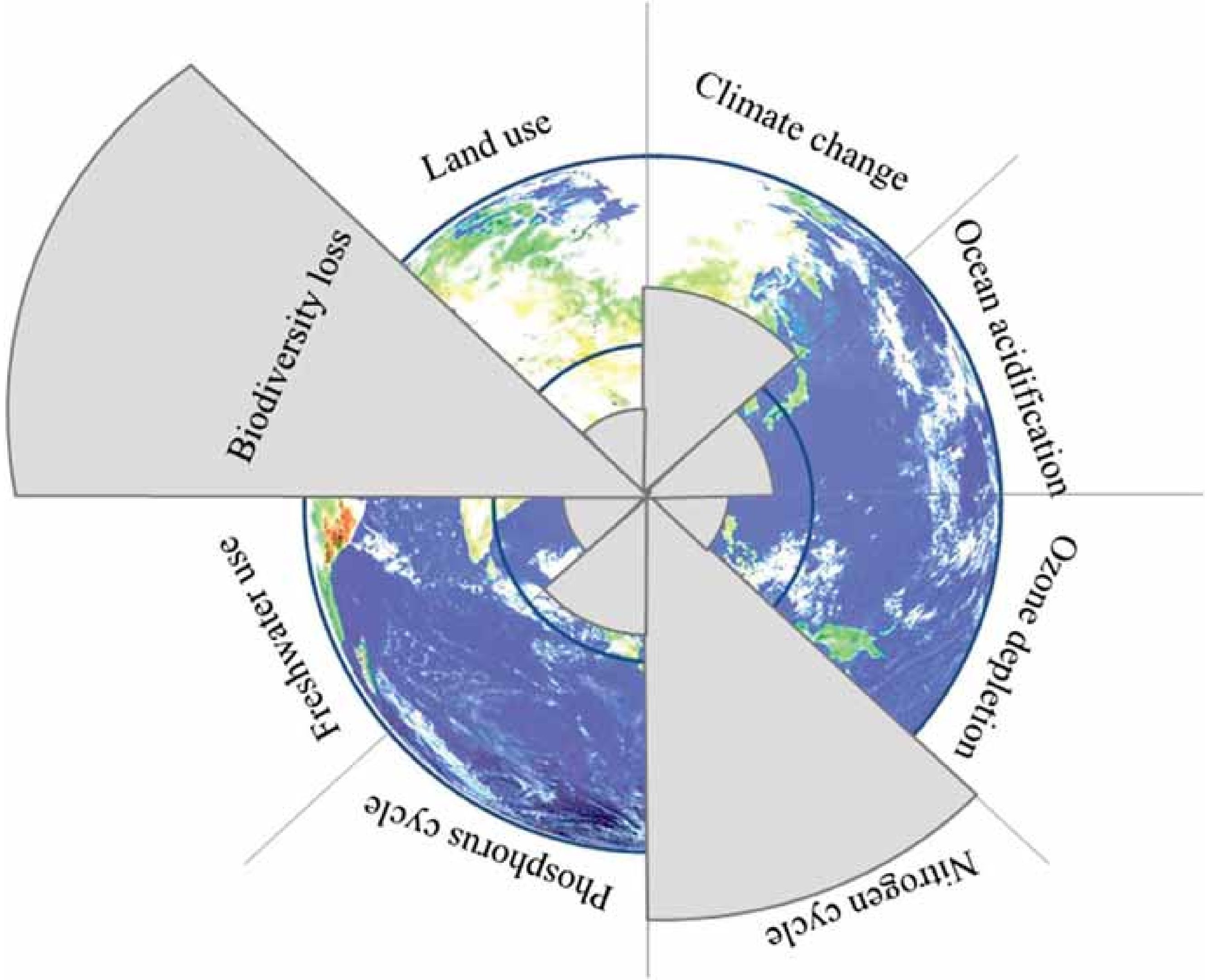
World energy consumption by fuel type in 2010

Out of 17 %



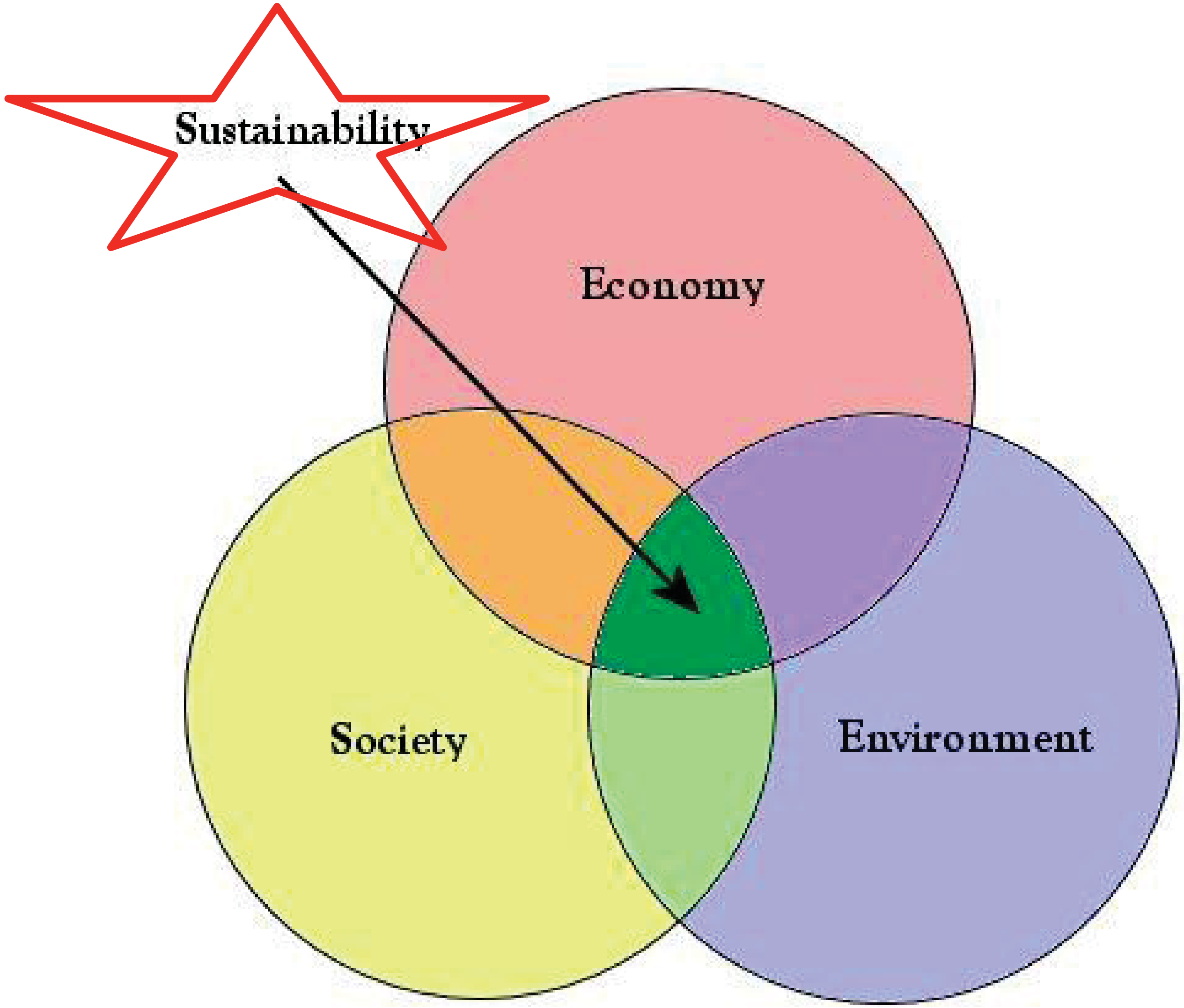
Renewable energy consumption by fuel type in 2010

Planetary boundaries



Čuček L., Klemeš J. J., Kravanja Z., 2014, Overview of Environmental Footprints, In: J. J. Klemeš (editor), Assessing and Measuring Environmental Impacts in Engineering: Chapter 5, Elsevier

Sustainability Components



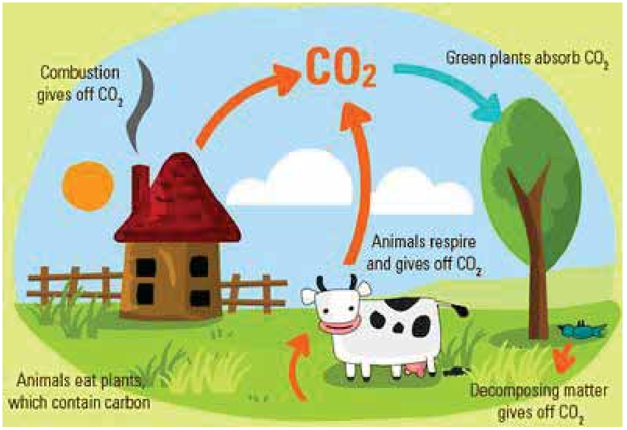
How to measure Economy?

Simple

In one word: money

How to measure Environment?

Not simple

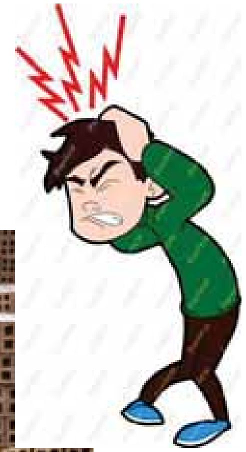


In several words: number of Earths (ecological footprint)
CO_2 emissions (carbon footprint)
CO2-eq emissions (global warming potential)
biodiversity (biodiversity footprint)

....

How to measure Society?

Very difficult (therefore mostly not considered)



How to put social sustainability in a number?

Mostly qualitative

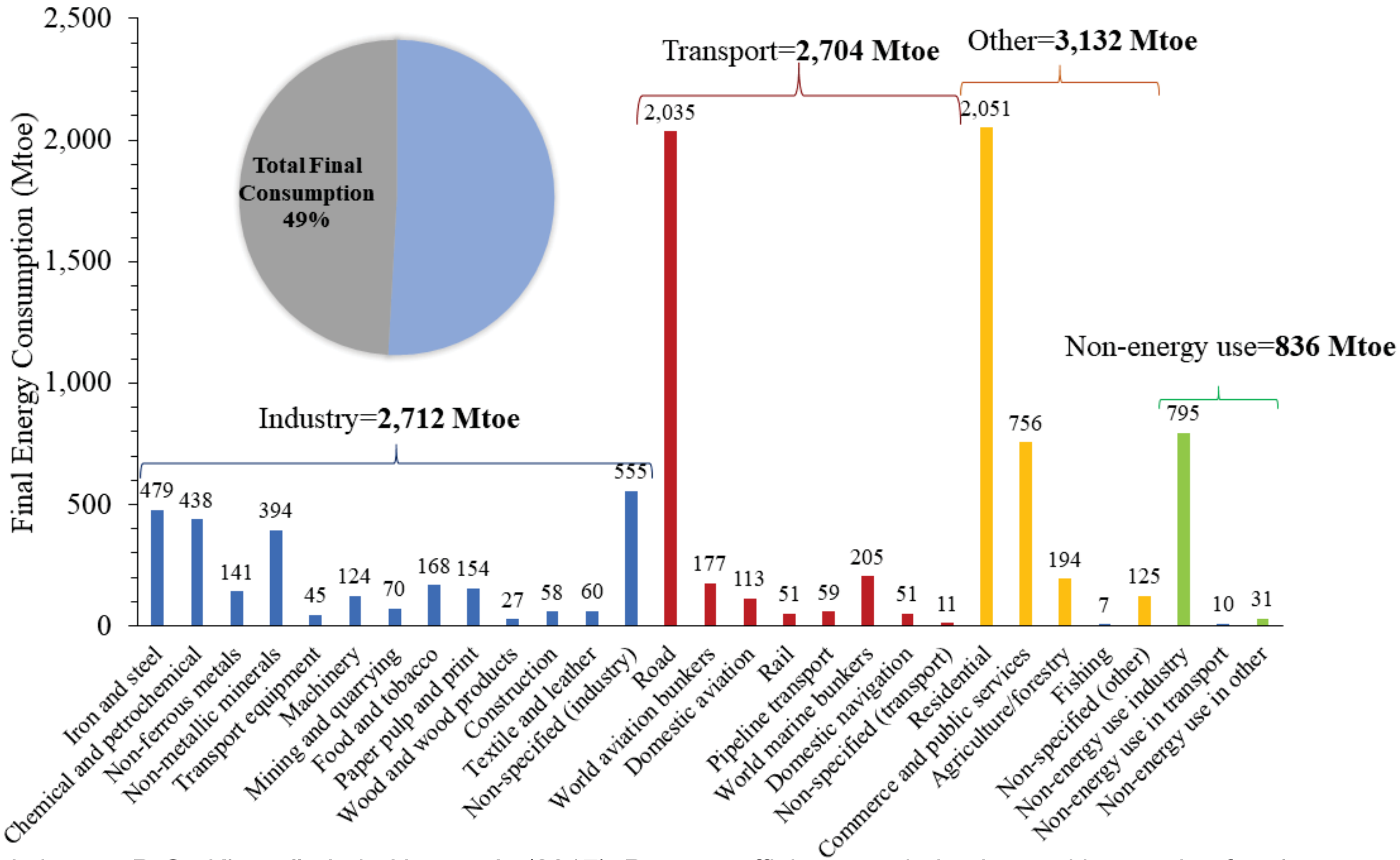
Issues:
Environmental Impact, Economic Development, Societal Development

Two main categories of issues:

1. Energy flow related: energy supply, GHG, climate
2. Material flow related: resource extraction and depletion; urban and eco-system pollution

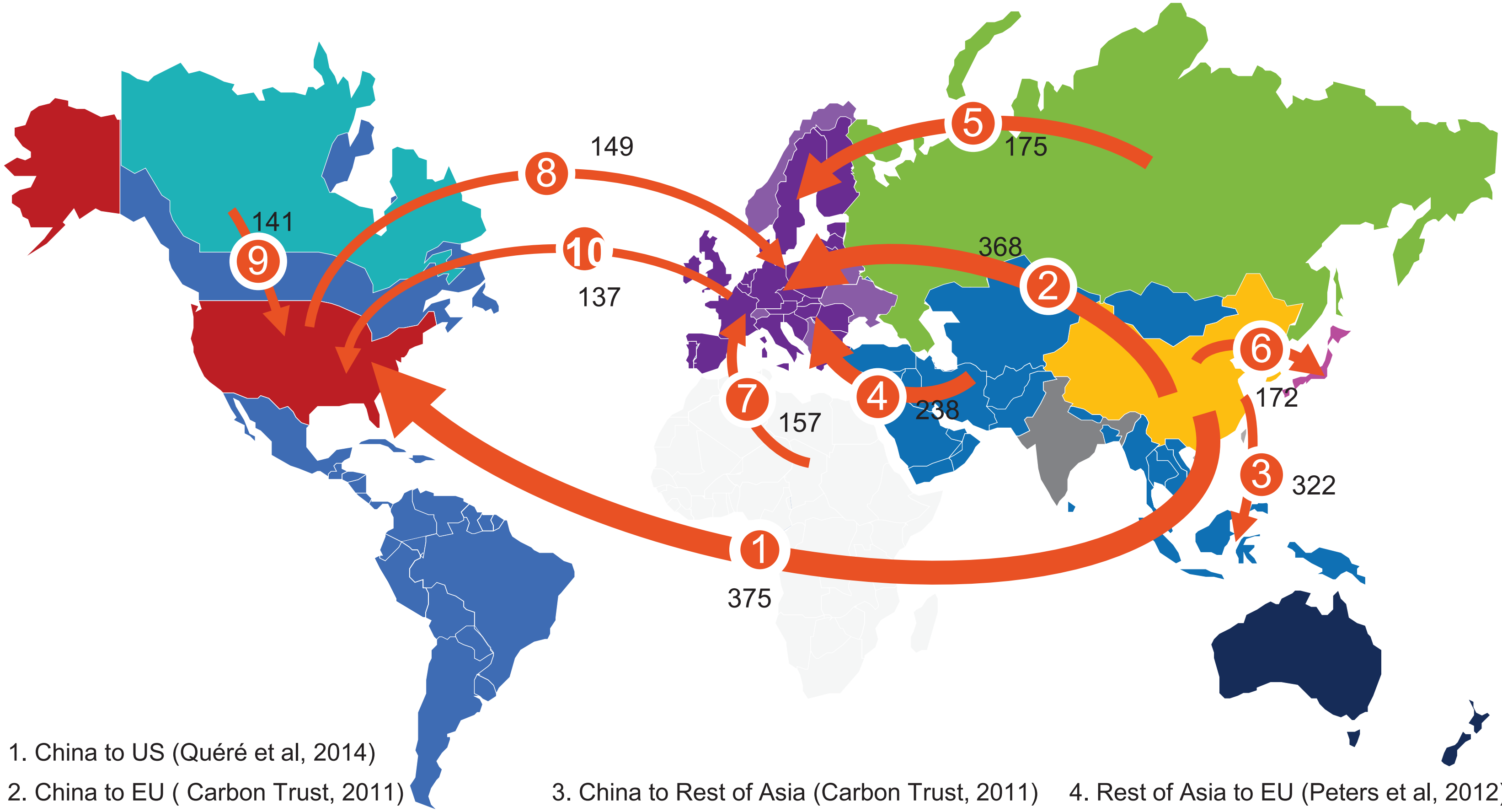
Energy flow related issues

Global Energy Consumption by Sector (Year 2015)



Fan, Y. V, Varbanov, P. S., Klemeš, J. J., Nemet, A. (2017). Process efficiency optimisation and integration for cleaner production. Journal of Cleaner Production, 174, 177-183.

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)
9. Canada to EU (Petar et al, 2012)
8. US to EU (Peters et al, 2012)
10. EU to US (Petar et al, 2012)

Liu, X., Klemeš, J. J., Varbanov, P. S., Čuček, L., Qian, Y. (2017). Virtual carbon and water flows embodied in international trade: a review on consumption-based analysis. Journal of Cleaner Production, 146, 20-28.

Large Scale Energy Generation

Fossil fuels

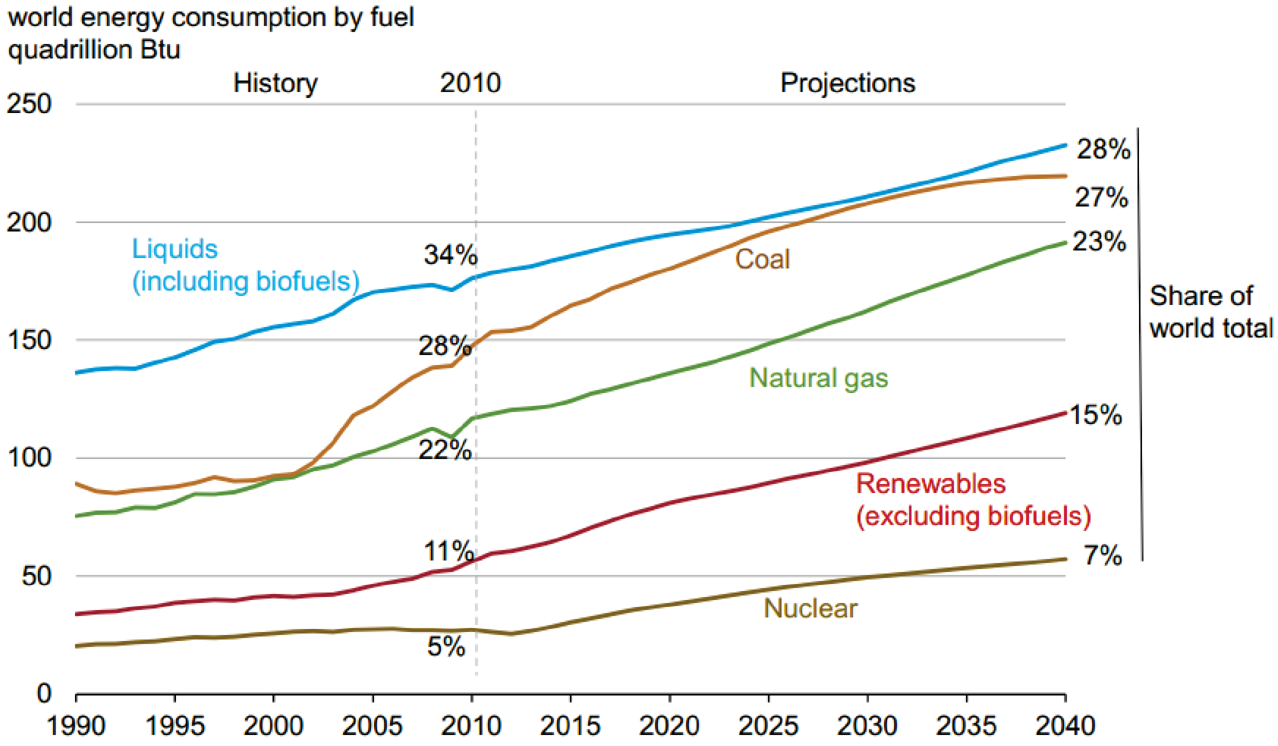
- Coal
  - Anthracite (hardest, more Carbon, higher energy content)
  - Bituminous
  - Lignite (low in Carbon high in Hydrogen and Oxygen content)
- Crude Oil
- Natural Gas

Renewables

- Solar – PV and Thermal
- Hydro power
- Wind
- Waves (Tidal)
- Biomass
- etc.

Energy demand trends

World Energy Consumption by Energy Source, 1970-2040

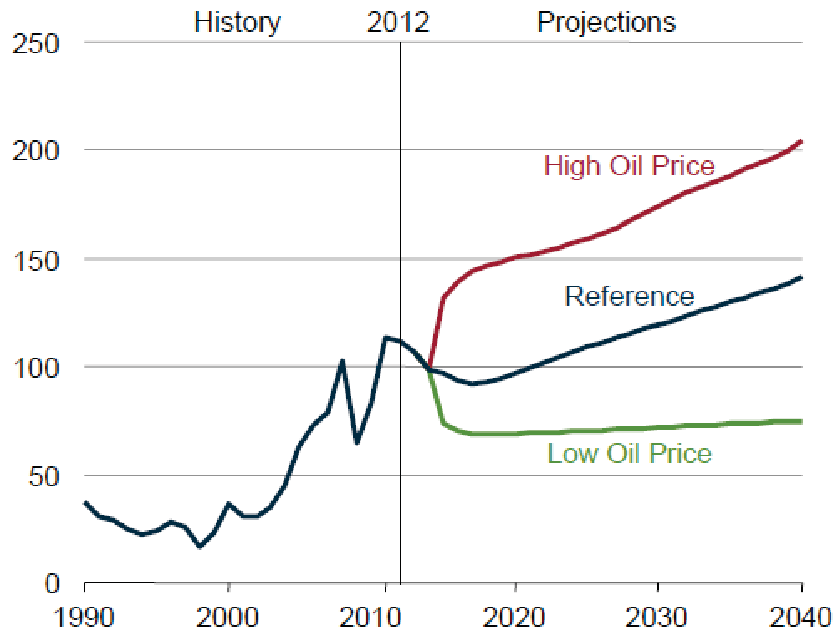


Source: EIA, International Energy Outlook 2013

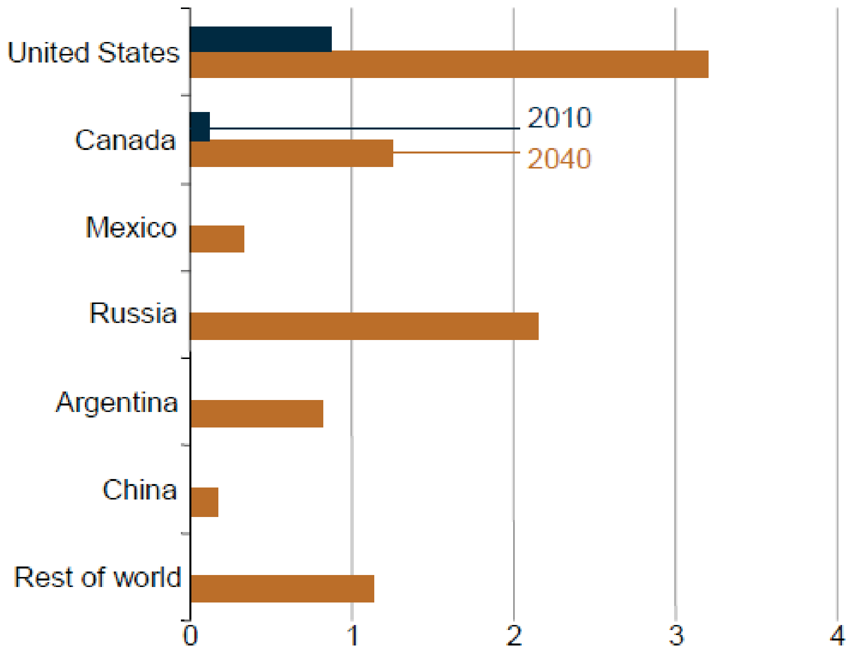
International Energy Outlook 2013,
www.eia.gov/pressroom/presentations/sieminski_07252013.pdf

World crude oil production trends

North Sea Brent crude oil spot prices in three cases, 1990-2040 (2012 dollars per barrel)



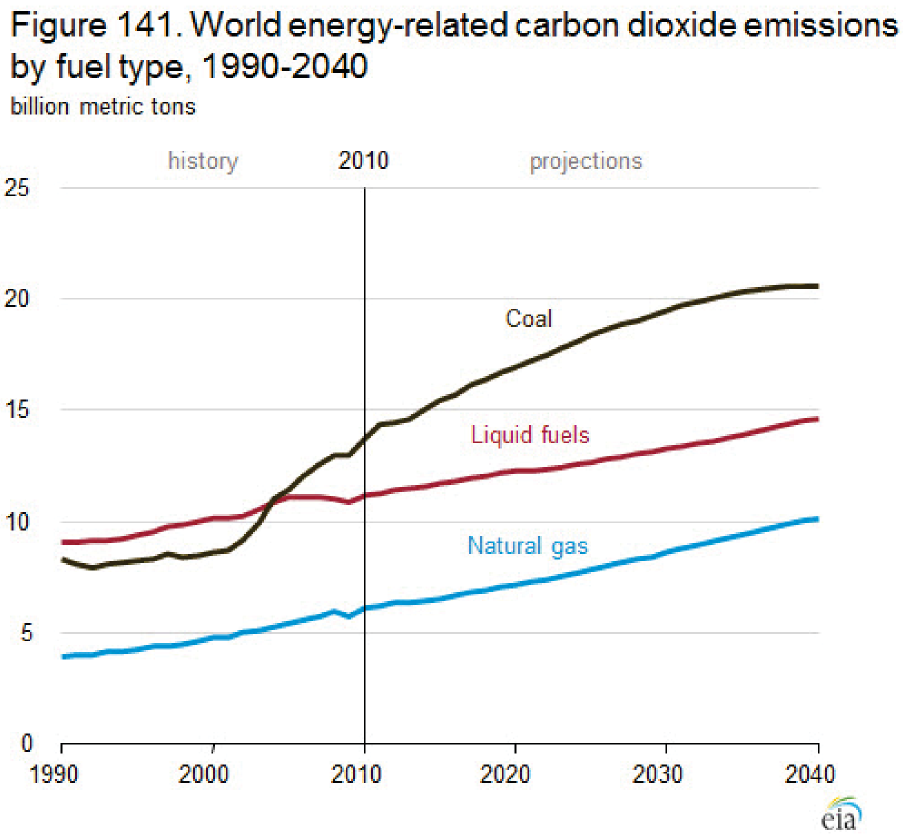
World tight oil production in the Reference case, 2010 and 2040 (million barrels per day)



International Energy Outlook 2014,
www.eia.gov/forecasts/ieo/pdf/0484(2014).pdf

Environmental Impact

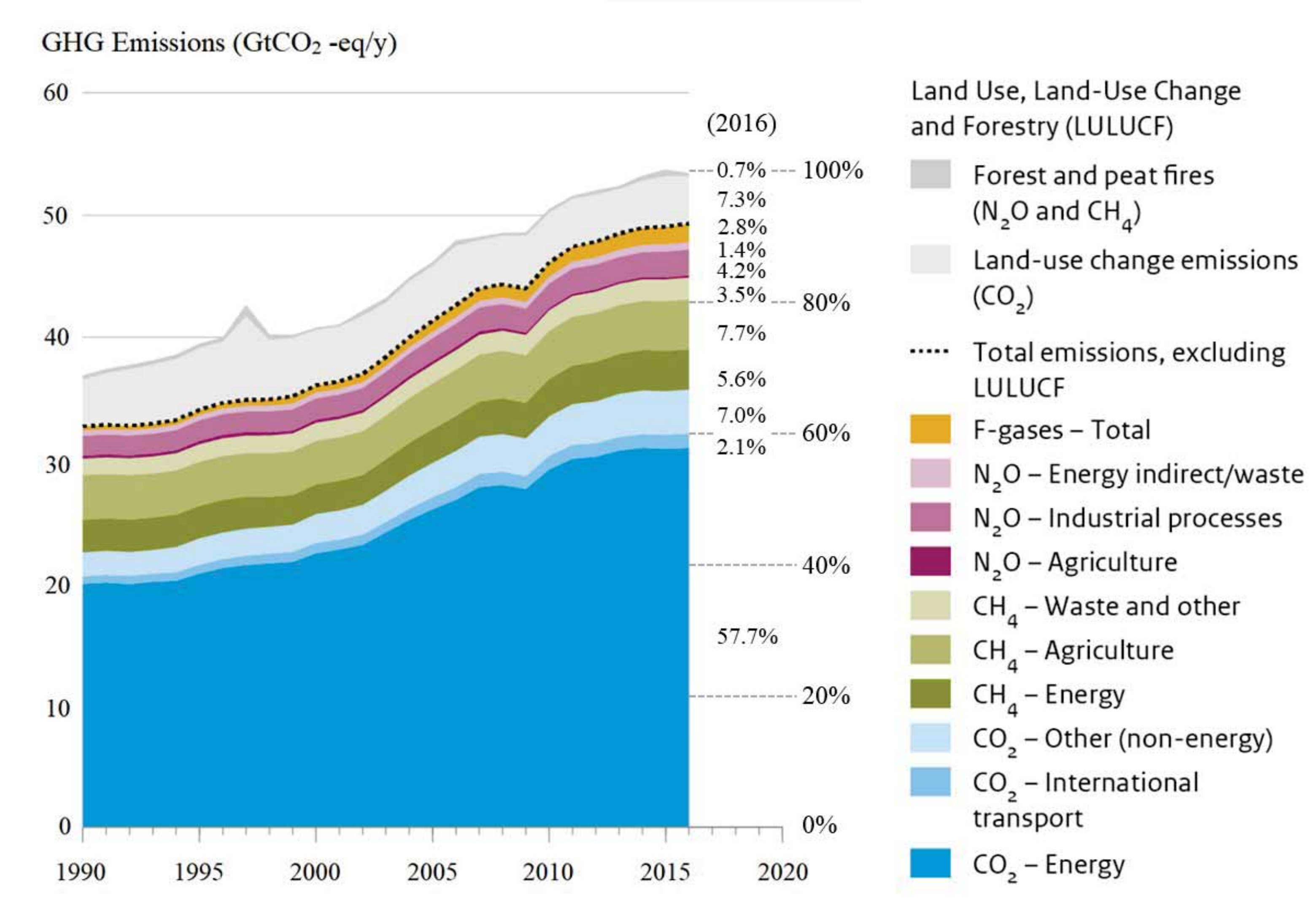
World CO_2 Emissions by Fossil Fuel, 1990 - 2040



- In the foreseeable future we still have to use considerable amount of fossil fuels
- This means release of large quantity of CO_2
- Vicious circle of CO_2 emissions is speeding up the climate change

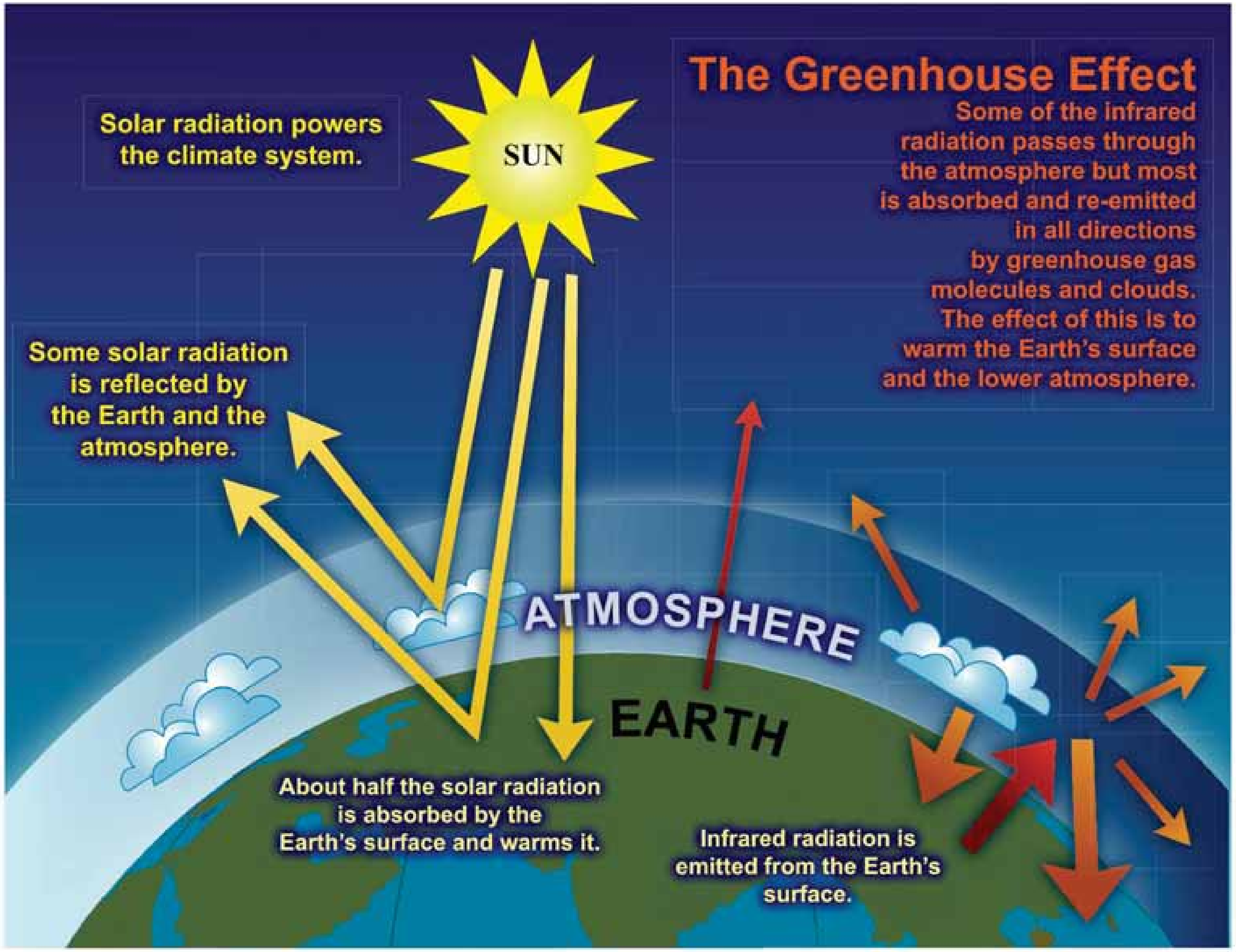
International Energy Outlook 2013
www.eia.gov/forecasts/ieo/emissions.cfm

Global GHG Emissions



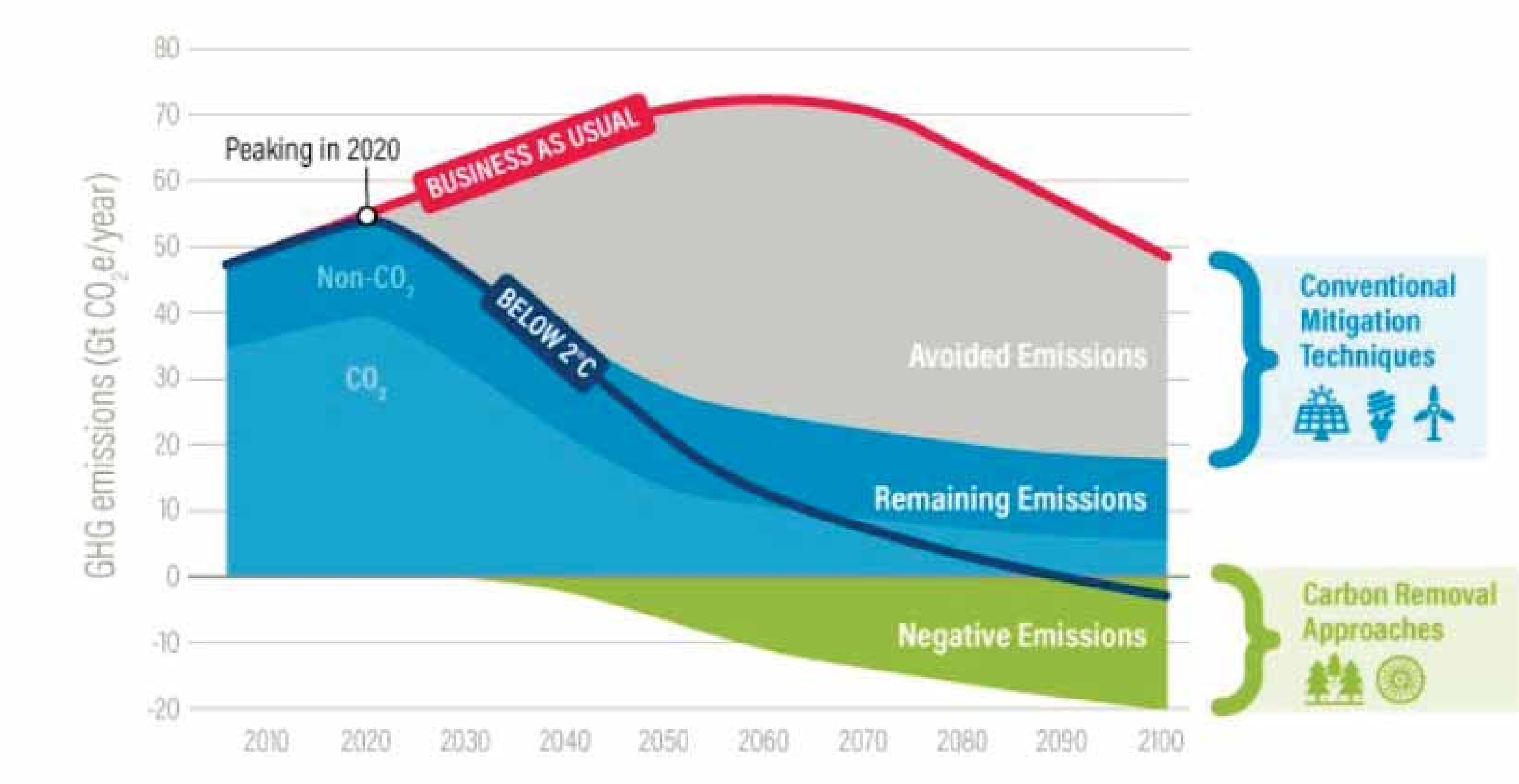
(Developed from “Olivier, J.G.J., Schure, K.M., Peters, J.A.H.W., 2017. Trends in global CO_2 and total greenhouse gas emissions. Summary of the 2017 Report. PBL Netherlands Environmental Assessment Agency. The Hague, Netherlands.”)

Climate



Source: IPCC Working Group I http://www.ipcc.ch/

Staying Below 2 °C of Global Warming



Source: Adapted from UNEP 2016.
For more information, visit wri.org/carbonremoval.

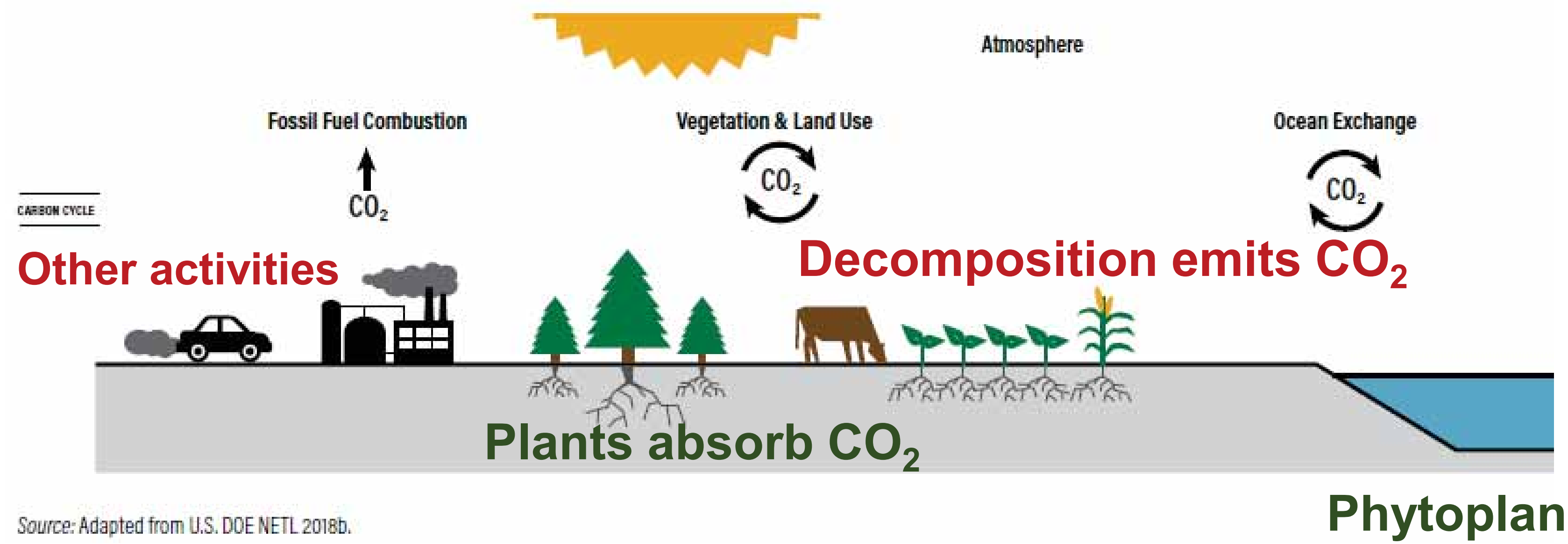
WORLD RESOURCES INSTITUTE

The need to pursue both aggressive emissions reductions and significant deployment of GHG removal/ sequestration

<www.wri.org/our-work/project/carbon-removal> accessed 13 September 2018

The Carbon Emissions Cycle

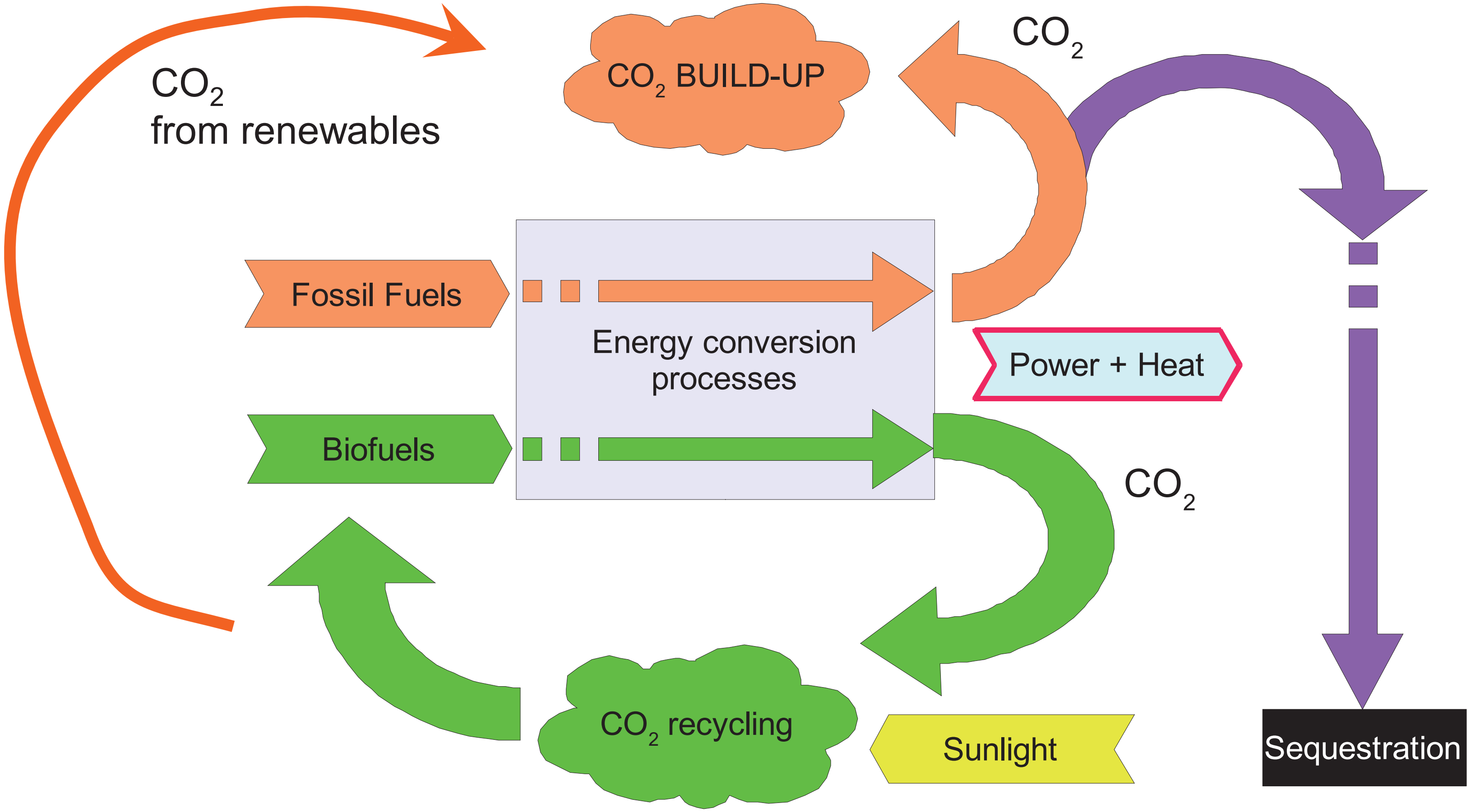
Fossil fuel combustion and deforestation or other land use changes emits CO_2



Phytoplankton absorb CO_2

Mulligan J, Ellison G, Levin K and McCormick C, 2018. Technological carbon removal in the United States. Working Paper. Washington, DC: World Resources Institute. <www.wri.org/publication/tech-carbon-removal-usa>.

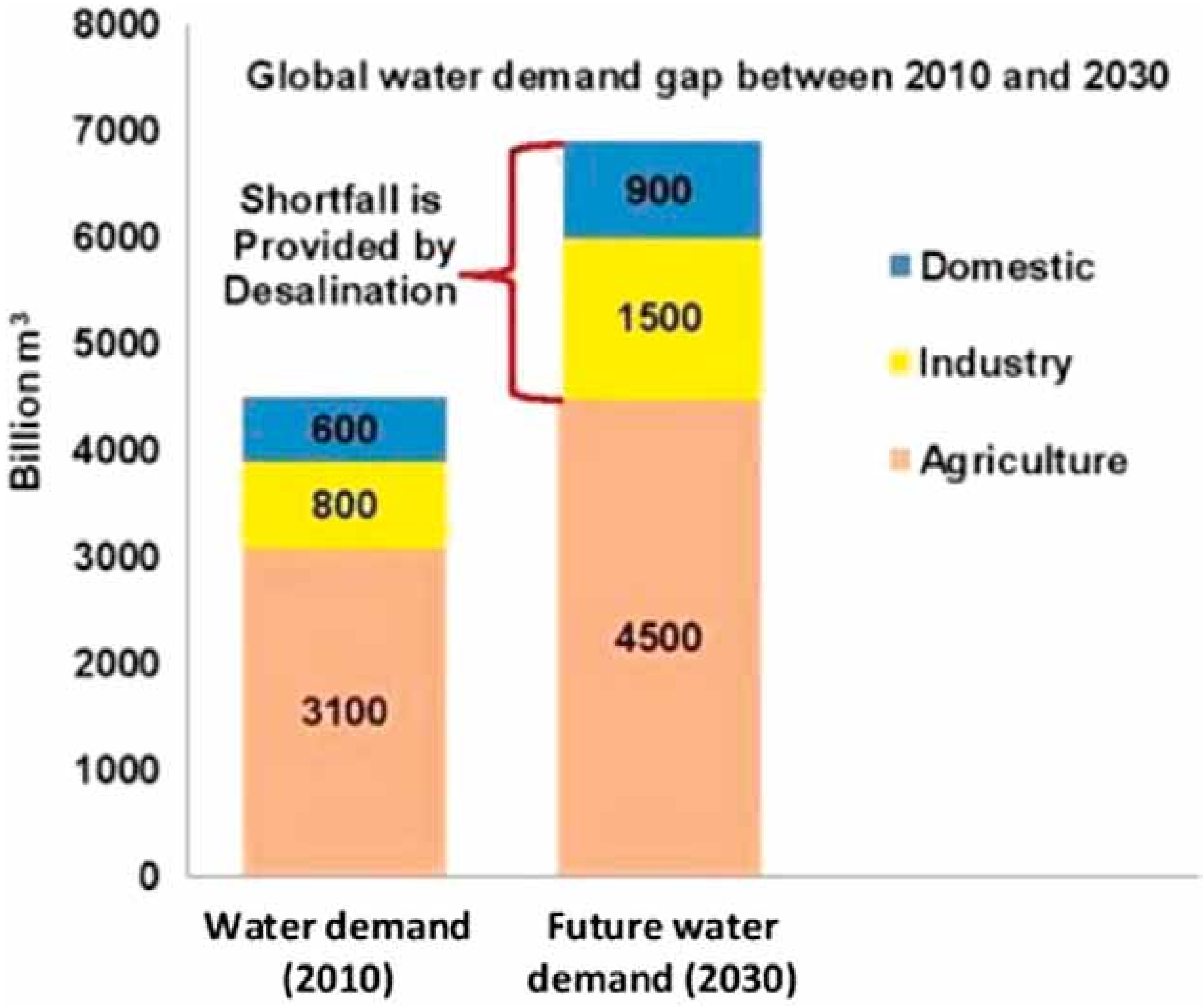
The general picture



1. Maximise the efficiency of conversion and use
2. Maximise the supply from renewables
3. CCU / CCS

Material flow related issues

Global Water Demand



Chandrashekara, M., Yadav, A. (2017). Water desalination system using solar heat: a review. Renewable and Sustainable Energy Reviews, 67, 1308-1330.12

Air pollution has been a big threat to

Climate Health

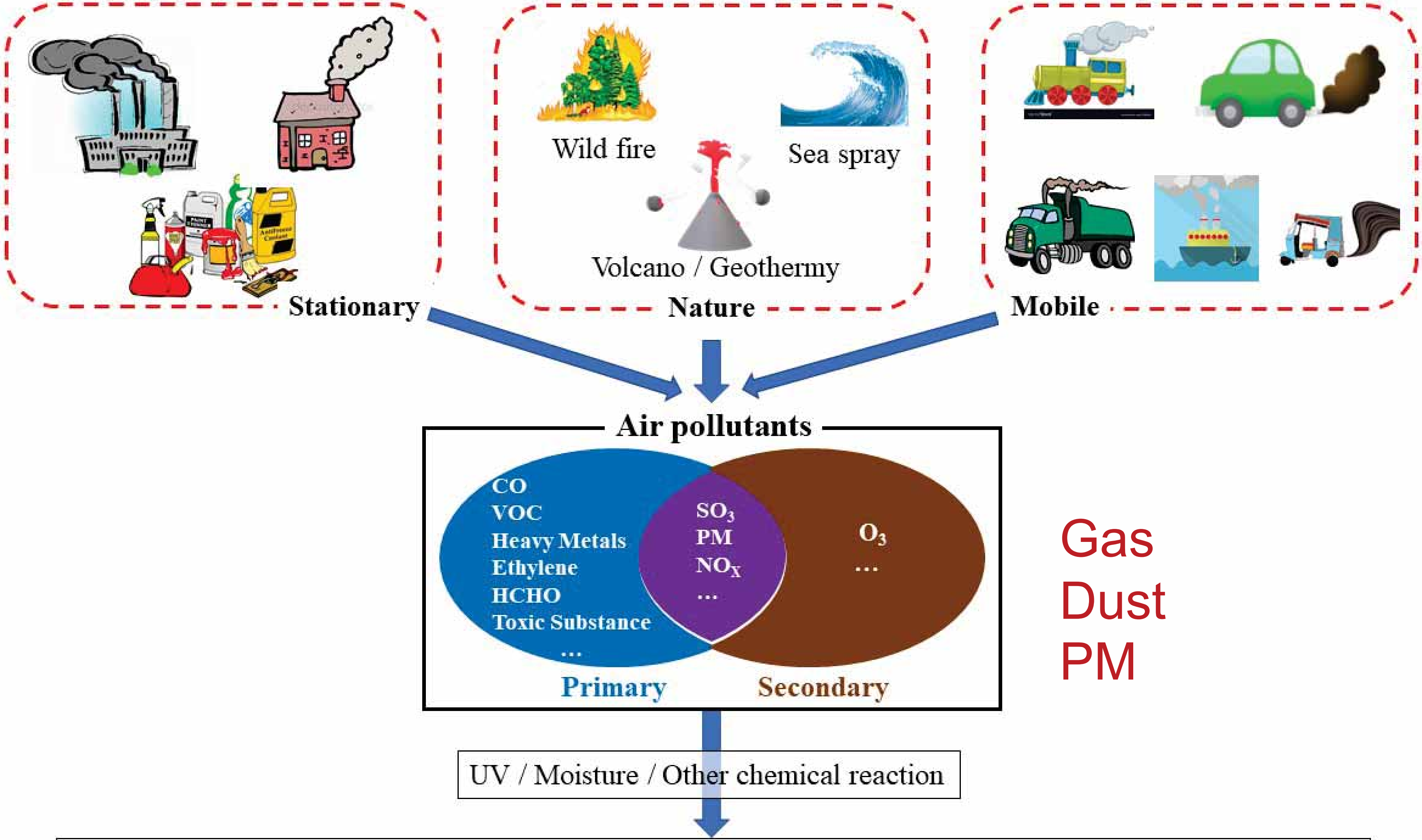
Plants Living

Human Well-being

Economic

Ecosystem Services

Sources and Types of Air-Pollutants



Gas
Dust
PM

Haze: PM, Dust, Smoke, Complex mixture of air pollutants Heavy Metals, SO_2, NO_2, Toxic Substance, etc.

Smog (Western Smog):

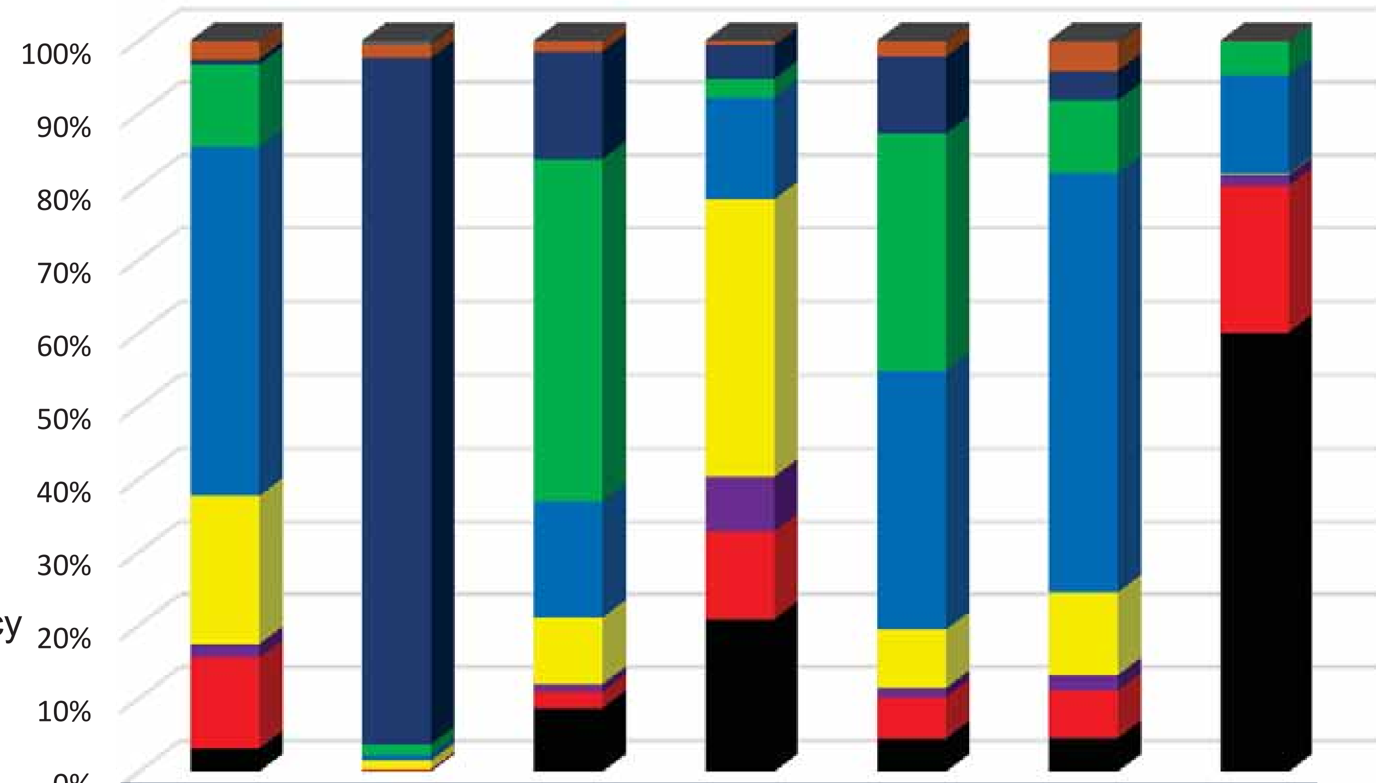
- Sulphurous Smog – London Type: SO_2, Stagnant Air
- Photochemical Smog – Los Angeles Type: NO_2, O_3, UV

Sources & Types of Air-Pollutants

Contributors of Main air-pollutants in EU

(NMVOC: non-methane volatile organic compounds)

(European Environment Agency 2017)

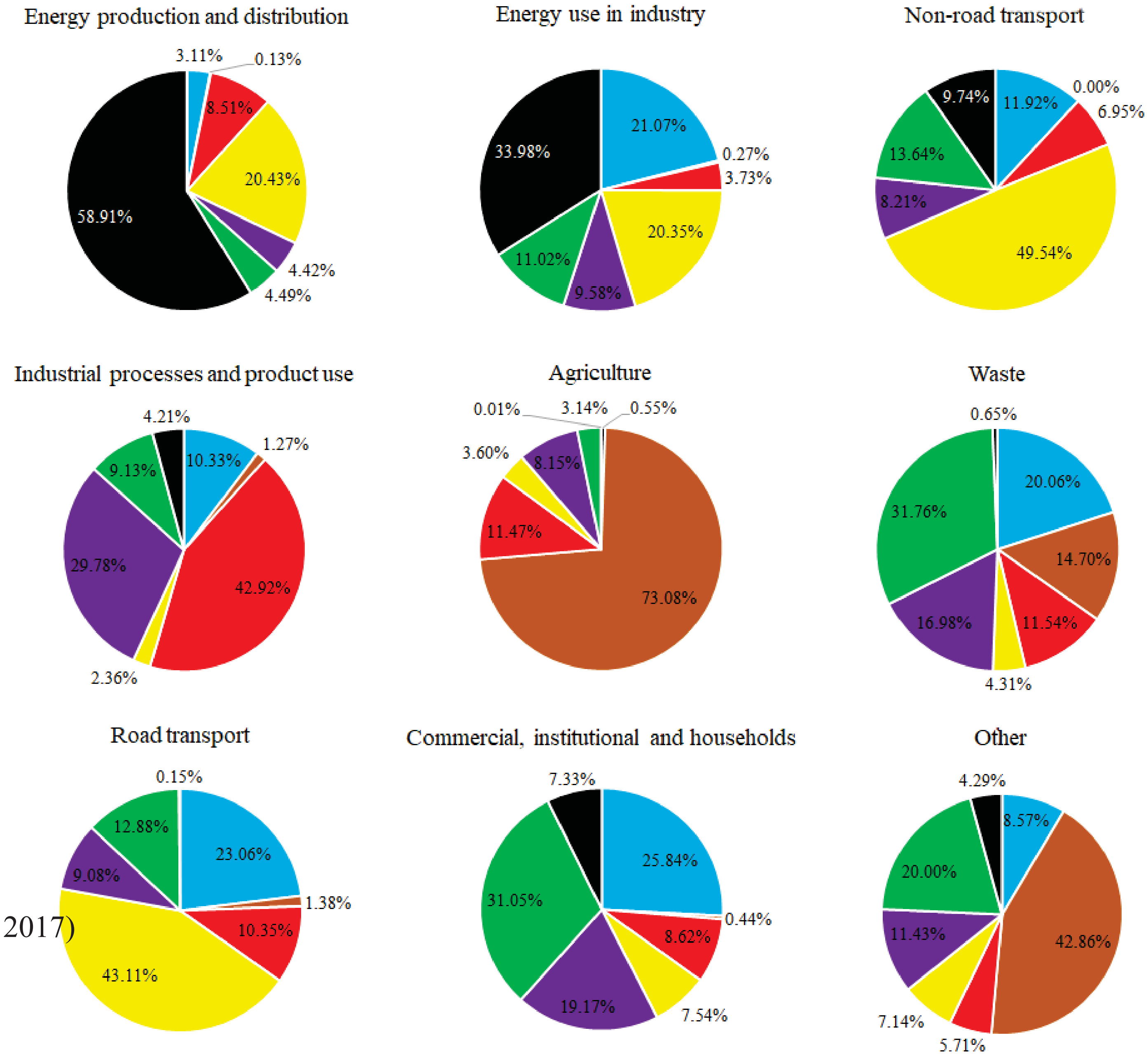


	CO	NH3	NMVOC	NOx	PM10	PM2.5	SOx
Other	0.12	0.6	0.08	0.1	0.16	0.28	0.06
Waste	2.47	1.81	1.42	0.53	2.09	3.91	0.08
Agriculture	0.71	93.88	14.74	4.62	10.47	4.03	0.01
Industrial processes and product use	11.26	1.39	46.79	2.57	32.47	9.95	4.59
Commercial, institutional and households	47.74	0.82	15.93	13.93	35.41	57.36	13.54
Road transport	20.29	1.21	9.11	37.93	7.99	11.33	0.13
Non-road transport	1.8	0	1.05	7.48	1.24	2.06	1.47
Energy use in industry	12.43	0.16	2.2	12	5.65	6.5	20.04
Energy production and distribution	3.17	0.13	8.68	20.83	4.51	4.58	60.08

Sources and Types of Air-Pollutants

Emissions of different sector groups in EU.

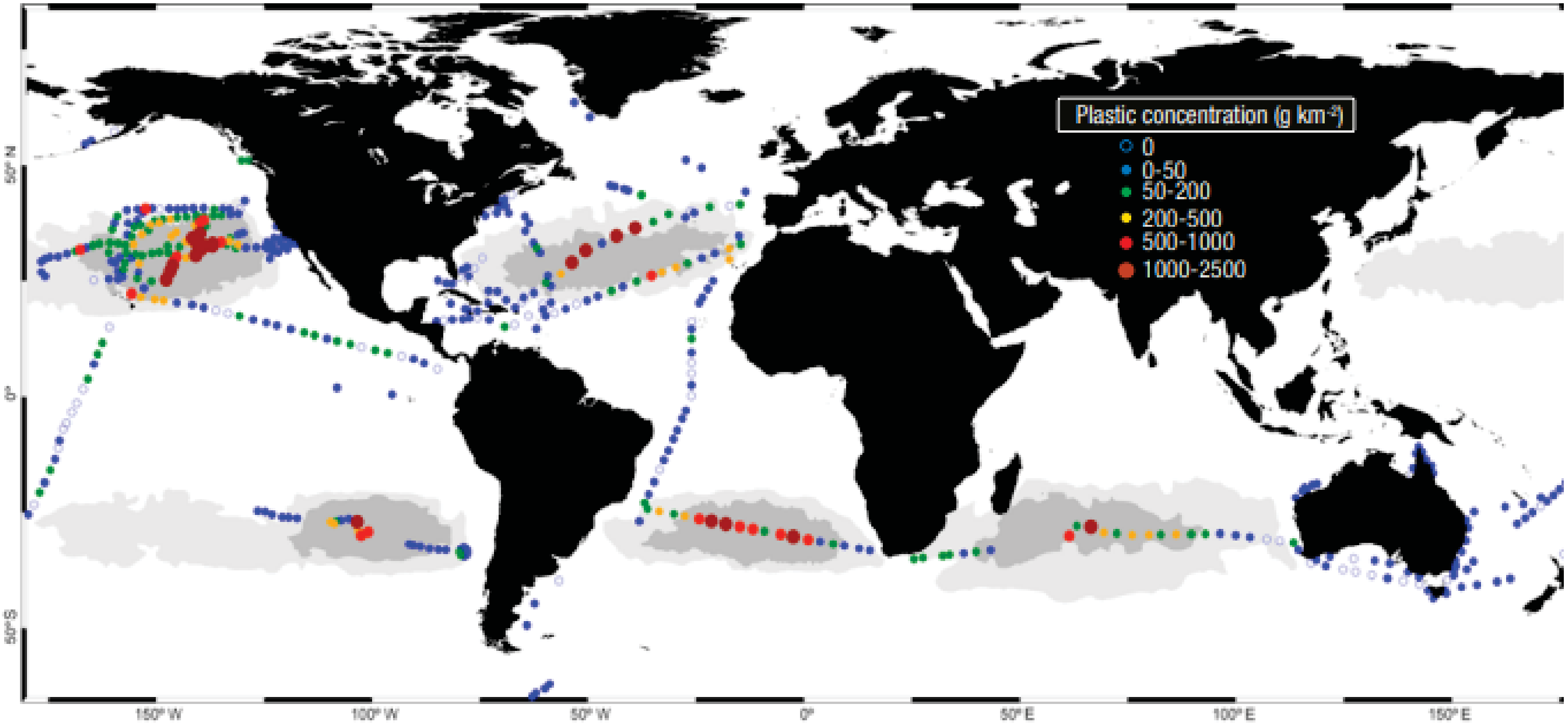
- CO
- NH3
- NMVOC
- NOx
- PM10
- PM2.5
- SOx



(European Environment Agency, 2017)

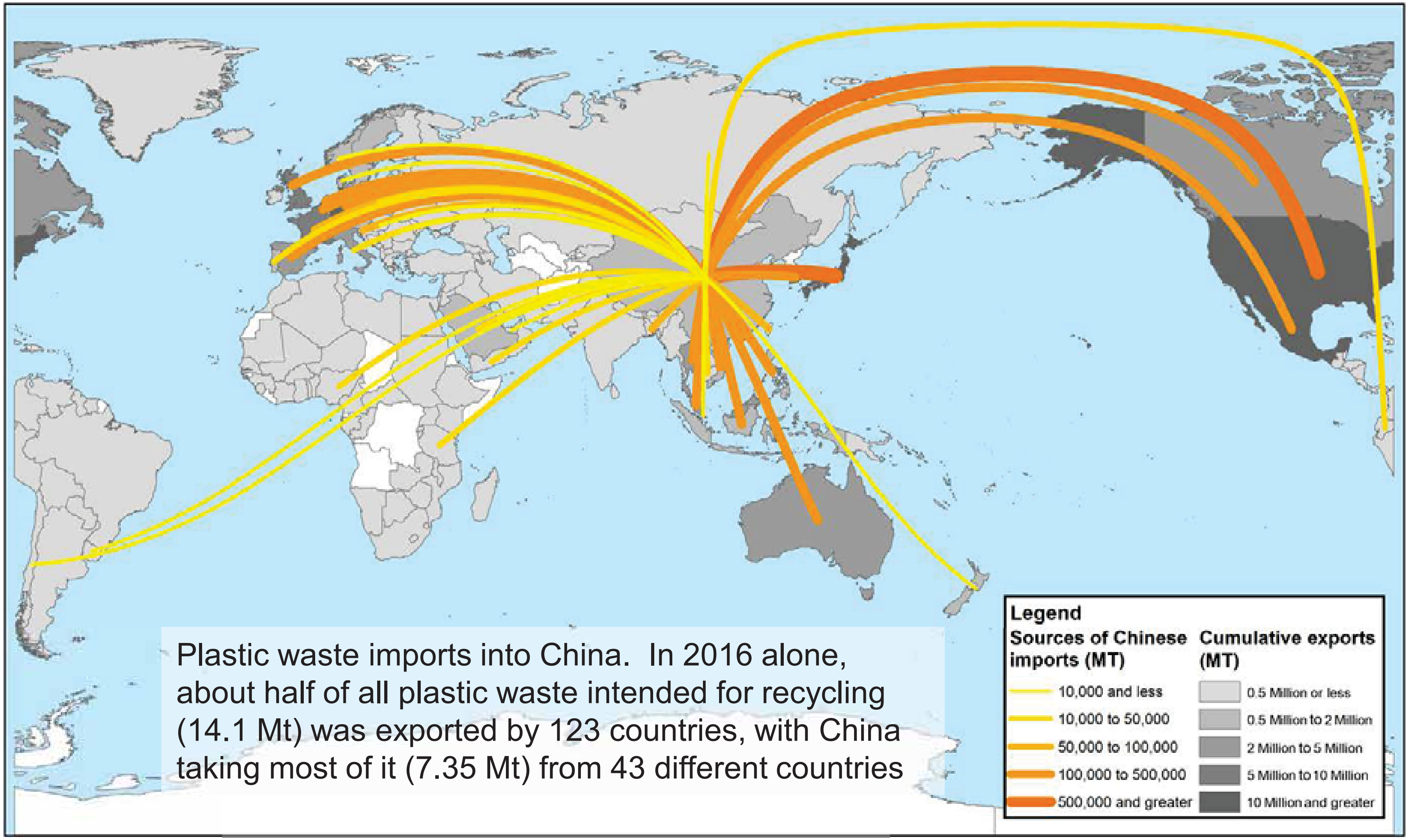
Plastic Pollution

Concentration of Plastic Debris in Surface Waters of the Global Ocean



<wedocs.unep.org/bitstream/handle/20.500.11822/9672/-Global_Waste_Management_Outlook-2015Global_Waste_Management_Outlook.pdf.pdf?sequence=3&amp%3BisAllowed=> accessed 6 March 2019

Waste Exports and Imports



Brooks, A. L., Wang, S., Jambeck, J. R. (2018). The Chinese import ban and its impact on global plastic waste trade. *Science Advances*, *4*(6), eaat0131.

The New Dumping Ground- Southeast Asia

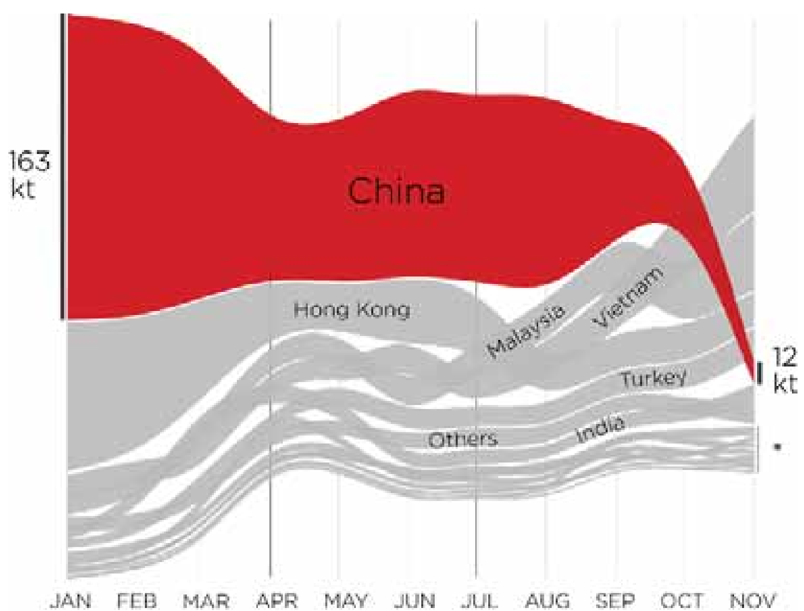
To Philippines

Plastic problem in South Korea is a literal trash fire <cnn.it/2ExkhY8> accessed 6 March 2019

The Waste Issues

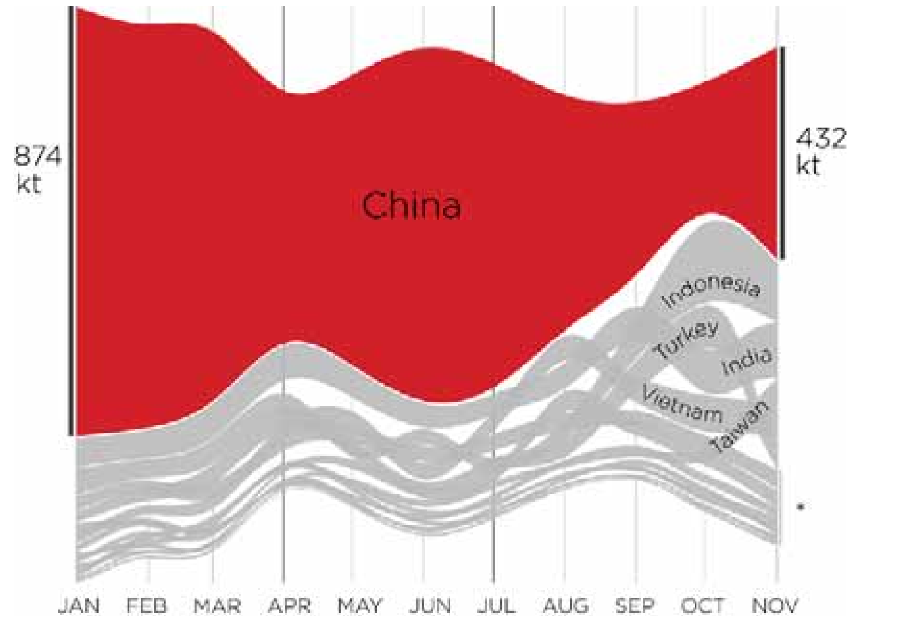
- Europe has been long time proud on being an environmental leader — a champion of “the circular economy”
- Green success has relied on exporting its trash elsewhere (e.g. Ireland)
- China ban on “Foreign garbage”, boost the flow of waste to other Asian countries

Plastic Waste (2017)



*In descending order, these countries are Switzerland, Thailand, Taiwan, United States, Pakistan, Indonesia, Bosnia and Herzegovina, Ukraine and Serbia.

Paper Scrap (2017)



*In descending order, these countries are Switzerland, Thailand, South Korea, Norway, Ukraine, others, Malaysia, Serbia, Singapore and Pakistan.

<www.politico.eu/article/europe-recycling-china-trash-ban-forces-europe-to-confront-its-waste-problem/> accessed 6.03.2019

Plastic – Marine leakage

<journals.openedition.org/factsreports/5319#tocto2n3> accessed 25.06.2019

Plastic Recycling

- Plastic waste residing in landfills = harmful to the environment + missed economic opportunities.
- Contamination
- Pre-sorting = costly, time intensive, energy intensive, often leads to low-quality polymers
- Mechanical recycling (washing, shredding, melting, and remoulding of the polymer, blended with virgin plastic of the same type to produce a material with suitable properties) = widely adopted
- Cannot be applied to all polymeric materials (different chemical structures)
- Limitations = each plastic type responds differently depend on chemical makeup, mechanical behaviour, and thermal properties.
- Others = pyrolysis (thermolysis), the use of catalysts (chemical recycling).
- Chemical recycling = costly.
- Incineration is convenient but no recovery and reuse, less energy saving as recycling.

Garcia, J. M., Robertson, M. L., 2017. The future of plastics recycling. Science, 358(6365), 870-872.

About Plastic and Recycling

- **Not all plastic is recyclable up to 15 times**

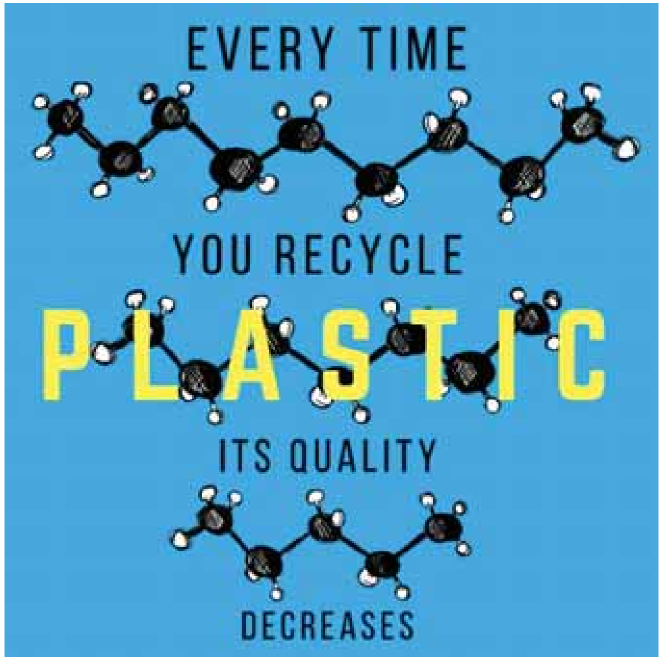
Just because it has the recycling sign doesn't mean it actually gets recycled

- **Not all plastic is created equal**
- **Coffee cups can't actually be recycled**

There are two materials (thin PP film)

- **Dirty plastic cannot be recycled**
- **Recycling plastic downgrades its quality**

Recycle 2-3 times; each time recycled, additional virgin material is added to help "upgrade" the quality



National Geographic 2018. 7 Things you didn't know about plastic (and recycling) <blog.nationalgeographic.org/2018/04/04/7-things-you-didnt-know-about-plastic-and-recycling/> 16.02.2019

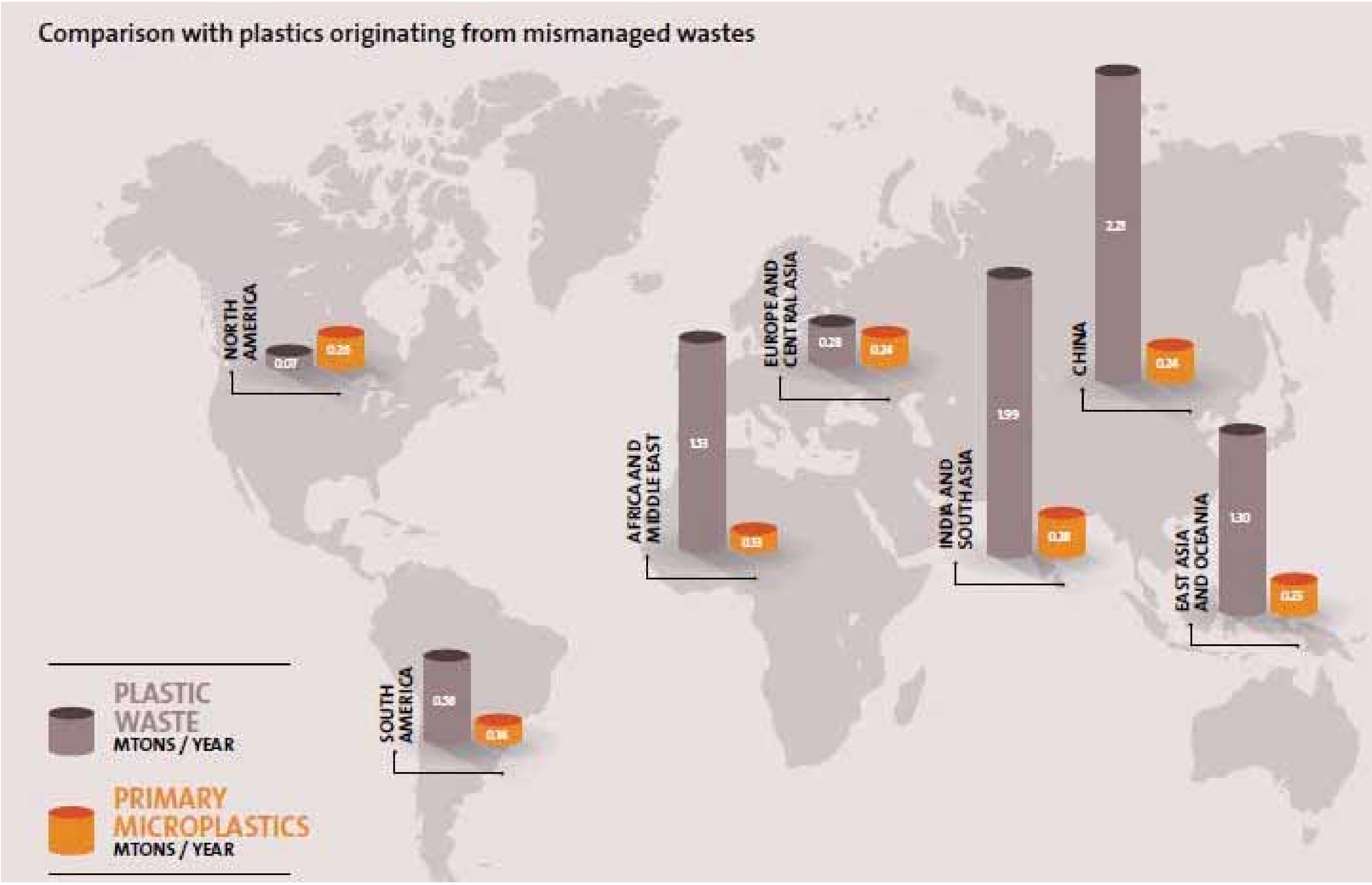
r-PET

- PET (Polyethylene terephthalate) = highly recyclable plastic
- Washed and re-melted into plasma
- Hardly to collect clean and high quality plastic (few re-enter the cycle as food grade)
- Decreases amount of plastic waste
- Decreases resource extraction
- Decreases energy consumption (use 75 % less energy compare to virgin product)
- Consumes water
- Microfibers/microplastics - water pollution

Reuse and recycle is the solution after waste prevention

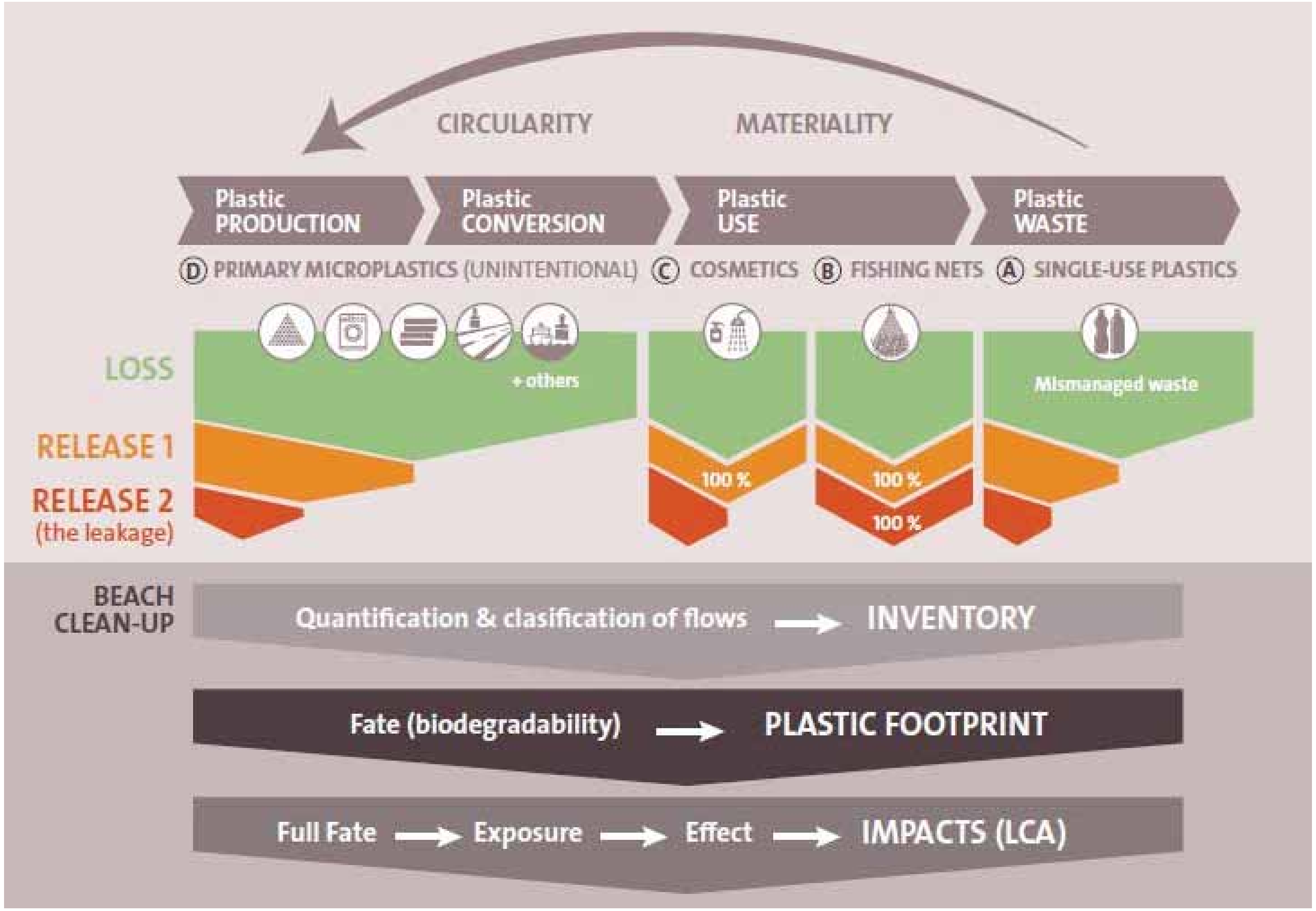
<earthhero.com/whats-the-deal-with-rpet/> accessed 6.03.2019

Global Releases of Primary Microplastics and Plastic Waste into the World Ocean



Boucher J., Billard G., 2019. The challenges of measuring plastic pollution, Field Actions Science Reports, Special Issue 19, 68-75.

Plastic Footprint Framework



Boucher J., Billard G., 2019. The challenges of measuring plastic pollution, Field Actions Science Reports, Special Issue 19, 68-75.

Replace Plastic?

- Not completely banned
- **Minimise** the plastic usage, reuse, recycling
- Make sure the replacement (e.g. by paper) is **sustainable** (in term of cost, durability and environmental impacts, LCA and comparison)




Plastic bag?
Paper bag? Recycle bag?

Studies of bags' environmental impacts over their life cycle have reached widely varying conclusions

Contradiction

- Paper bags have a **higher GHG footprint** than plastic. **More energy (emissions)** is required to produce and transport paper bags.
- **Any replacement** for plastic shopping bags, each have their **own environmental impacts**.
- This includes material use, water and energy consumption, marine impacts, GHG emissions and litter.
- **Additional research, assessment and scoping is required** before a final determination can be made on the feasibility of any option.

Plastic bag?
Paper bag? Recycle bag?

Bag type	Number of reuses required for life cycle equivalence with a HDPE bag	Consumption			Litter marine impacts	GHG
		Energy	Water	Material		
HDPE	-	♦♦	♦	♦♦♦	♦♦♦♦♦	♦♦
Paper	3	♦♦♦♦♦	♦♦♦	♦♦♦♦♦	♦	♦♦♦♦♦
LDPE	4	♦♦♦	♦	♦♦♦♦	♦♦♦♦♦	♦♦
Non-woven polypropylene	11	♦	♦	♦	♦♦	♦
Cotton	131	♦♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦	♦♦	♦♦♦♦♦

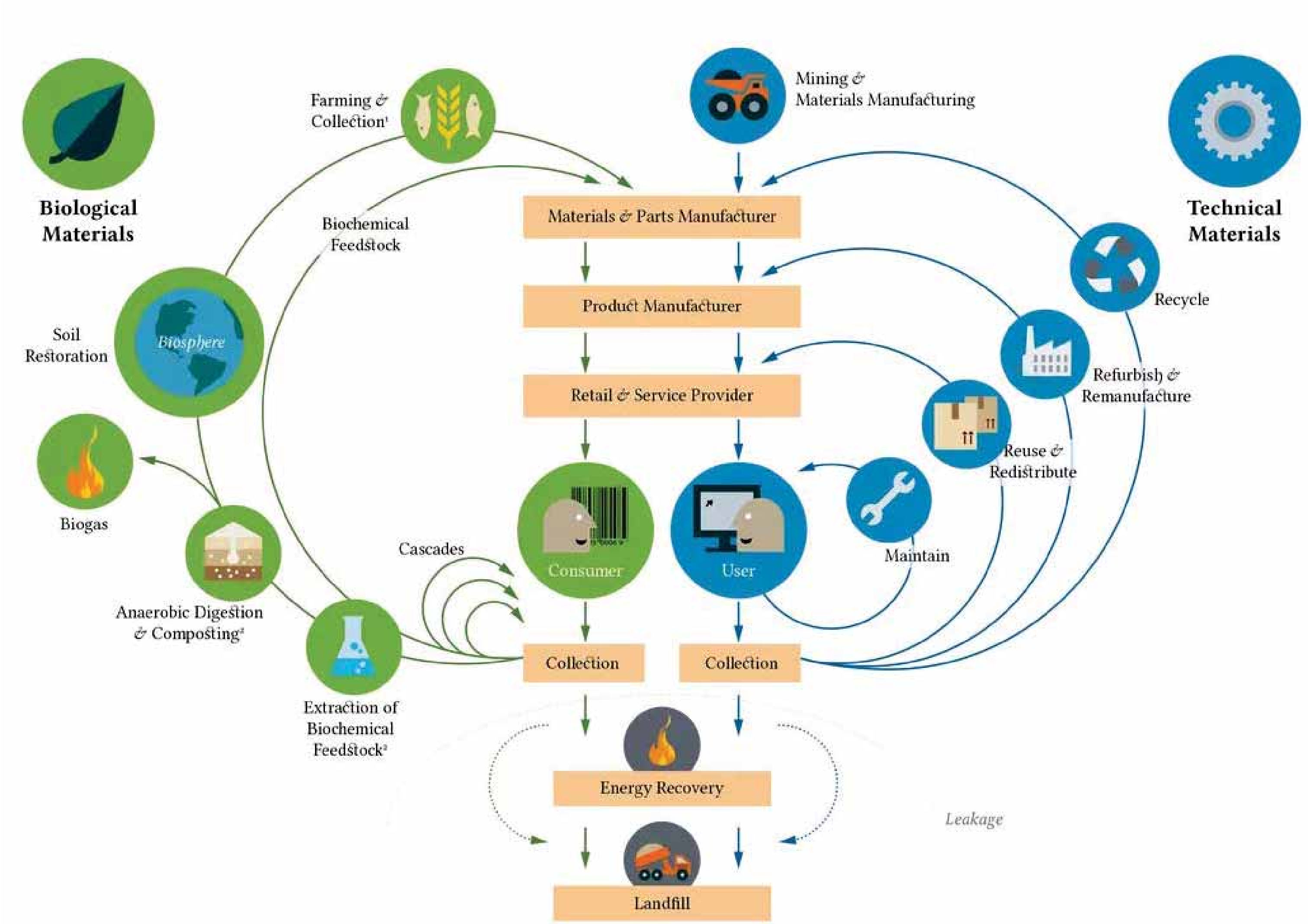
The durability and impacts of different bag type (NSW EPA, 2016)
NA = information not available. ♦ is the rating from 1 to 5
HDPE = High-density polyethylene
LDPE = Low-density polyethylene

Fan, Y.V., Lee, C. T., Lim, J. S., Klemeš, J. J., Le, P. T. K., 2019. Cross-disciplinary approaches towards smart, resilient and sustainable circular economy. Journal of Cleaner Production, 232, 1482-1491.

NSW EPA, 2016. Plastic shopping bags: Practical actions for plastic shopping bags <www.epa.nsw.gov.au/~/media/EPA/Corporate%20Site/resources/waste/160143-plastic-shopping-bags-options.ashx>

Solutions proposed worldwide

Overview of Circular Economy

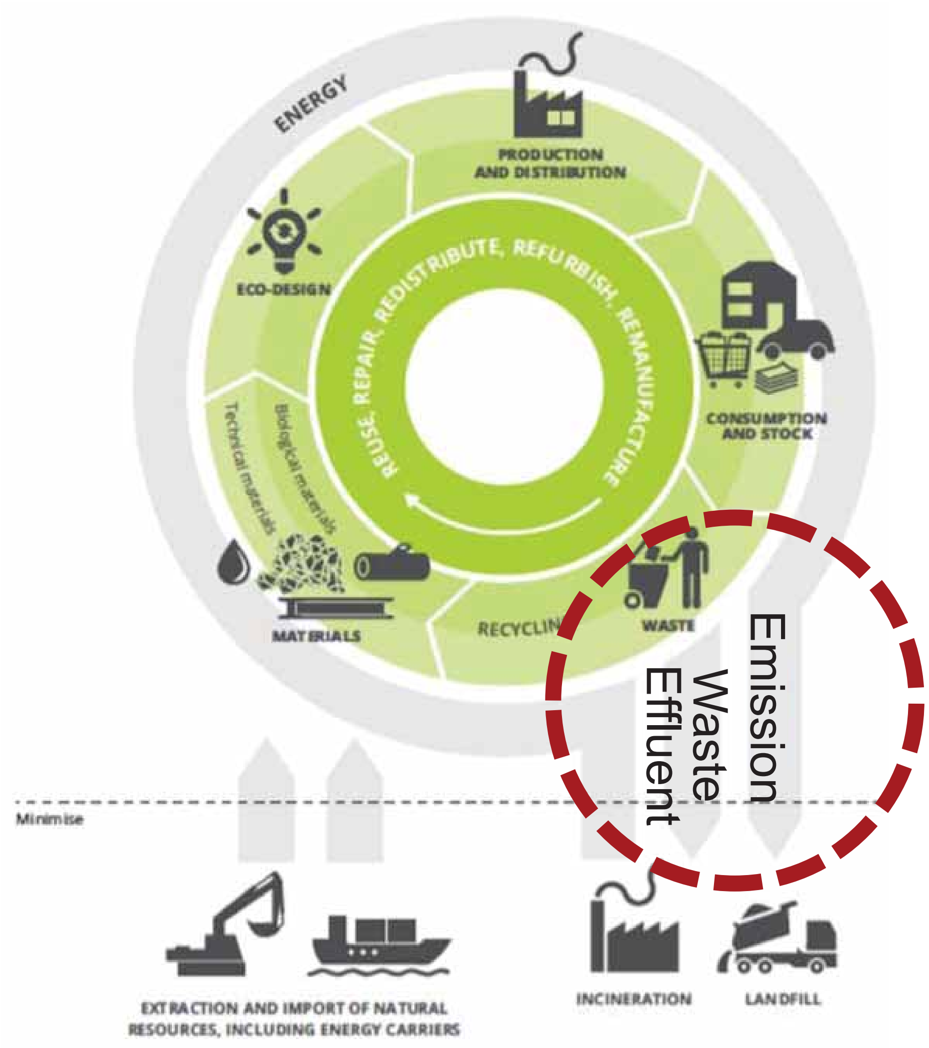


<aspenpartnerships.com/what-is-the-circular-economy/> accessed 20/3/2018

Market Drivers

- Win-win situation, create value
- Risk management (raw material shortage, disruption in the supply chain, accumulation of contaminants)
- Environmental efficiency
- Innovation and brand image

The Circular System



Have to minimise/ close the loop to achieve circularity

- Waste/Effluent Recovery and Treatment
- Emission mitigation, sequestration/captured

Source of picture: <www.europarl.europa.eu/RegData/etudes/STUD/2017/581913/EPRS_STU%282017%29581913_EN.pdf>

Challenges in CE

- **Thermodynamic limits**
  - Cyclical systems consume resources and create wastes and emissions
- **System boundary limits**
  - Spatial: problems are shifted along the product life cycle
  - Temporal: short term non-renewables use can 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

Korhonen, J., Honkasalo, A., Seppälä, J. (2018). Circular economy: the concept and its limitations. Ecological economics, 143, 37-46.

Challenges in CE

- **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 utilization

  - The concept is culturally and socially constructed

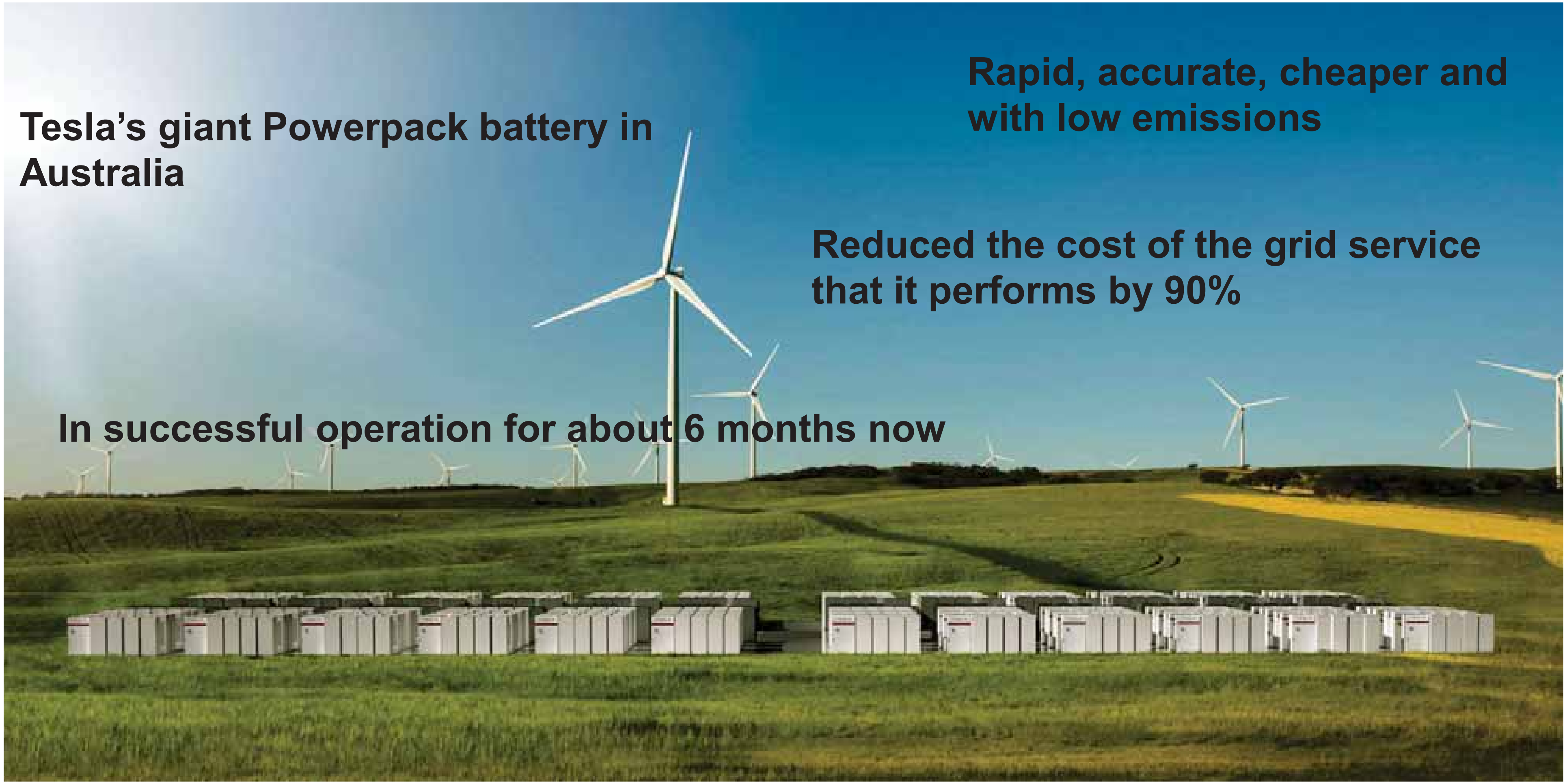
  - The concept of waste is always constructed in a certain cultural, social and temporal context and this context is dynamic and changing

Korhonen, J., Honkasalo, A., Seppälä, J. (2018). Circular economy: the concept and its limitations. Ecological economics, 143, 37-46.

Renewable Energy and Efficiency

Energy Storage

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



<electrek.co/2018/05/11/tesla-giant-battery-australia-reduced-grid-service-cost/> accessed 19 May 2018.

Energy storage

- Reduce the reliance on gas.
- Significant steps to take the place of fossil fuel generation on the power grid

<www.utilitydive.com/news/storage-will-replace-3-california-gas-plants-as-pge-nabs-approval-for-worl/541870/>

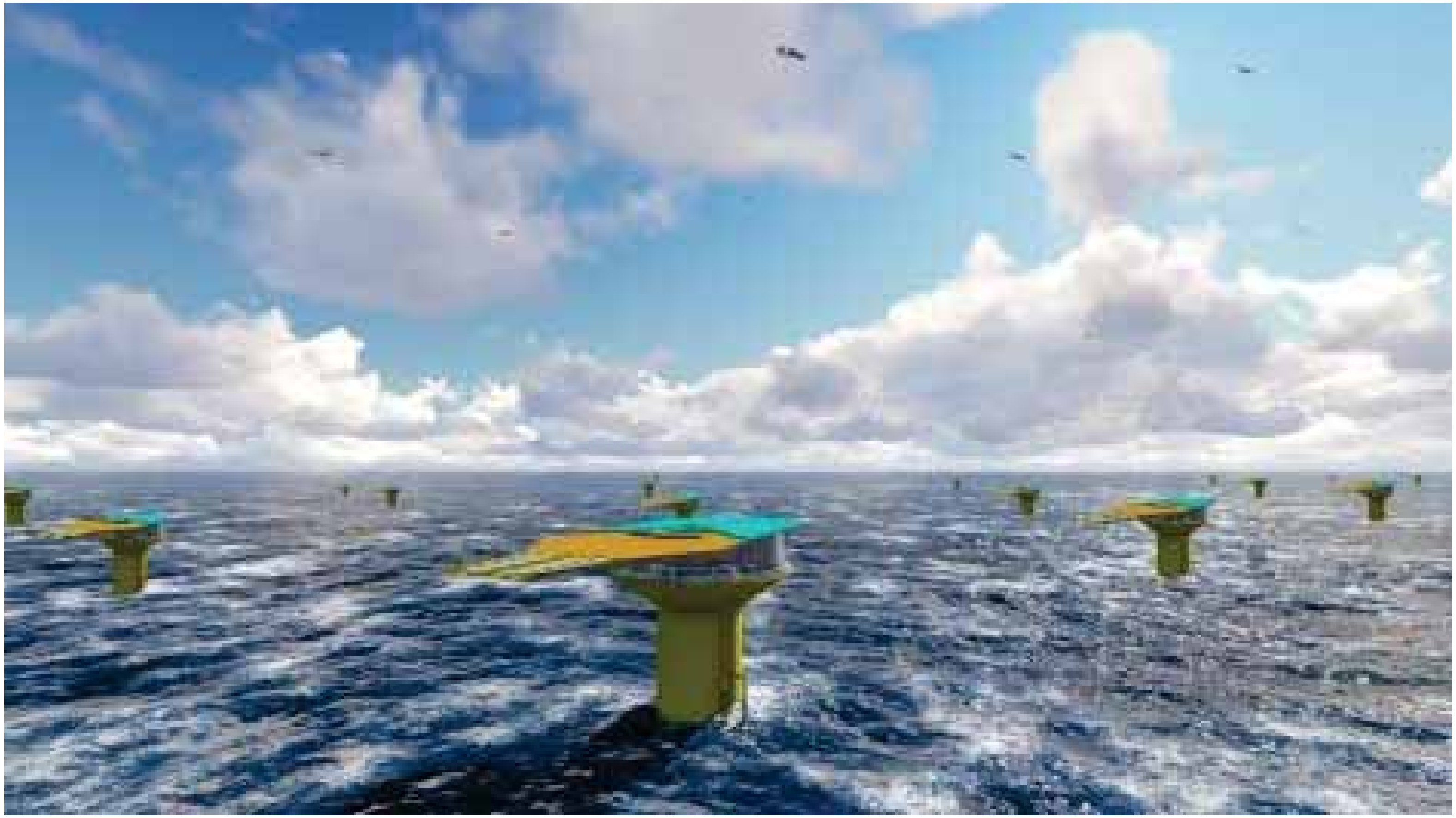
Current Progress

- 4 energy storage projects for Pacific Gas & Electric (PG & E) approved
- World's largest batteries (Lithium ion)
- A total of 567.5 MW/ 2,270 MWh of storage
- Including 300 MW/1,200 MWh (Vistra Energy), 182.5 MW/730 MWh (Tesla)
- **Storage at this scale is likely now cheaper than the total cost to run the gas plants**

<www.utilitydive.com/news/storage-will-replace-3-california-gas-plants-as-pge-nabs-approval-for-worl/541870/> accessed 31.11.2018

Airborne Wind Technology

- Test 2 MW in Ireland



<www.eon.com/en/media/news/press-releases/2017/4/11/eon-develops-a-demonstration-site-for-airborne-wind-technology-in-ireland.html> accessed 12 April 2018

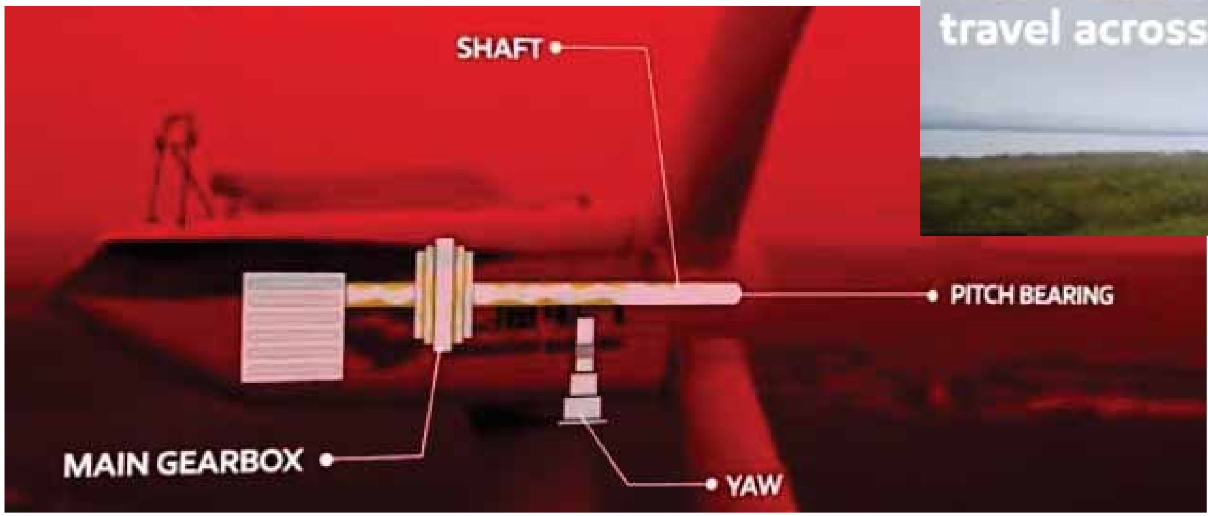
World Largest Concentrated Solar Power Plant Powered by the Saharan Sun

Project to generate **580 MW** of electricity. Noor 1 has a generating capacity of 160 MW

Parabolic Mirrors

Truck for Maintenance- Wind Power

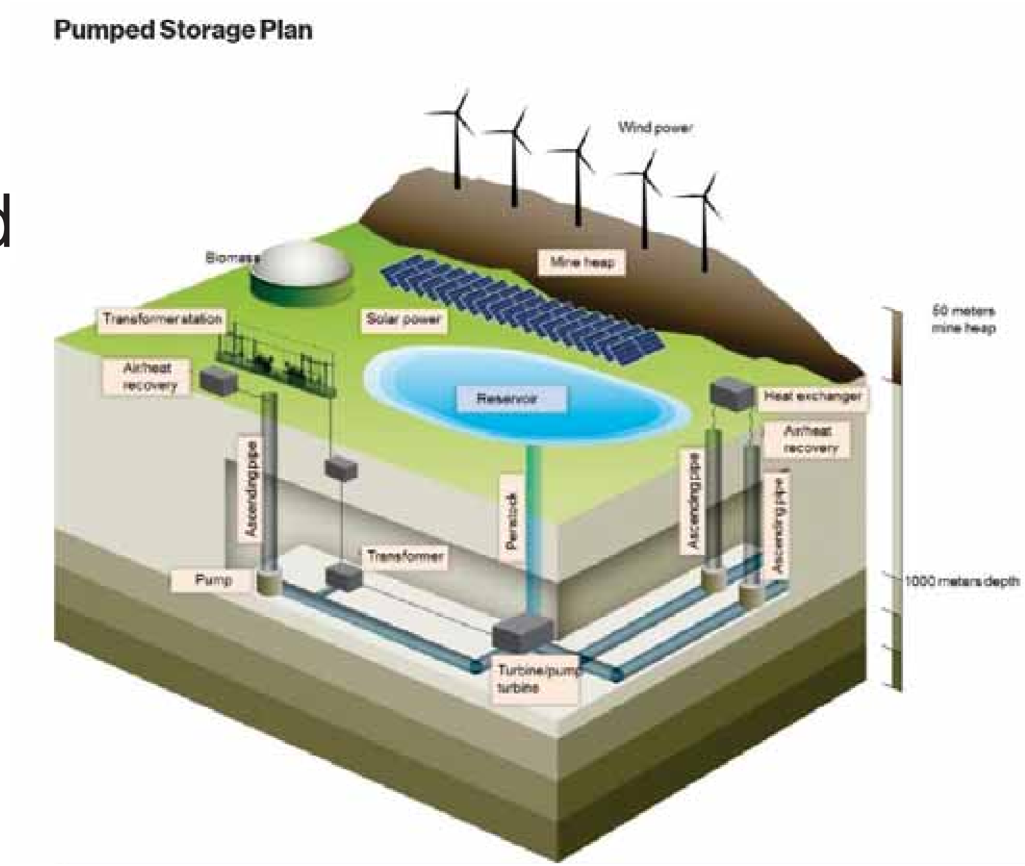
- Lubricants and greases are used in nearly all the moving parts of a turbine
- One truck services and average of three turbines in a day



ExxonMobil. A very special truck <energyfactor.exxonmobil.com/science-technology/a-very-special-truck> accessed 8.7.2018

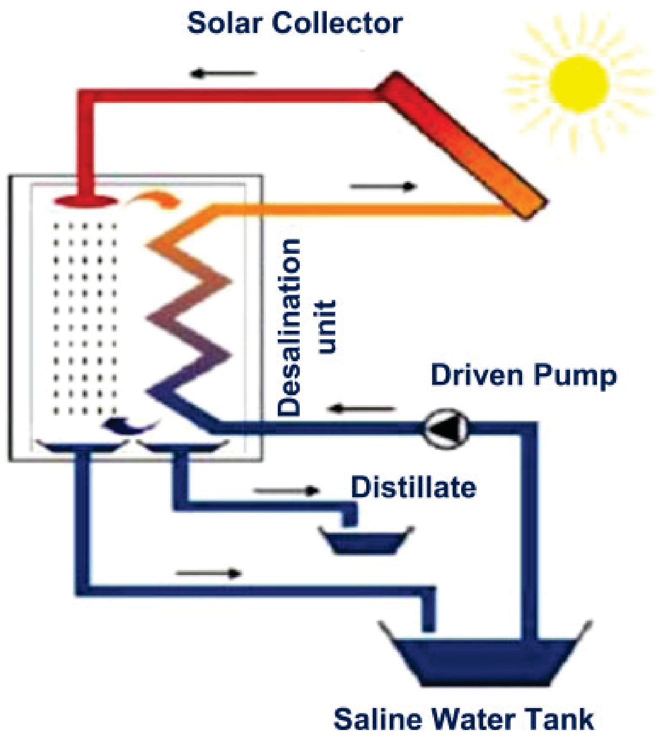
New Technology – Expansion of RE

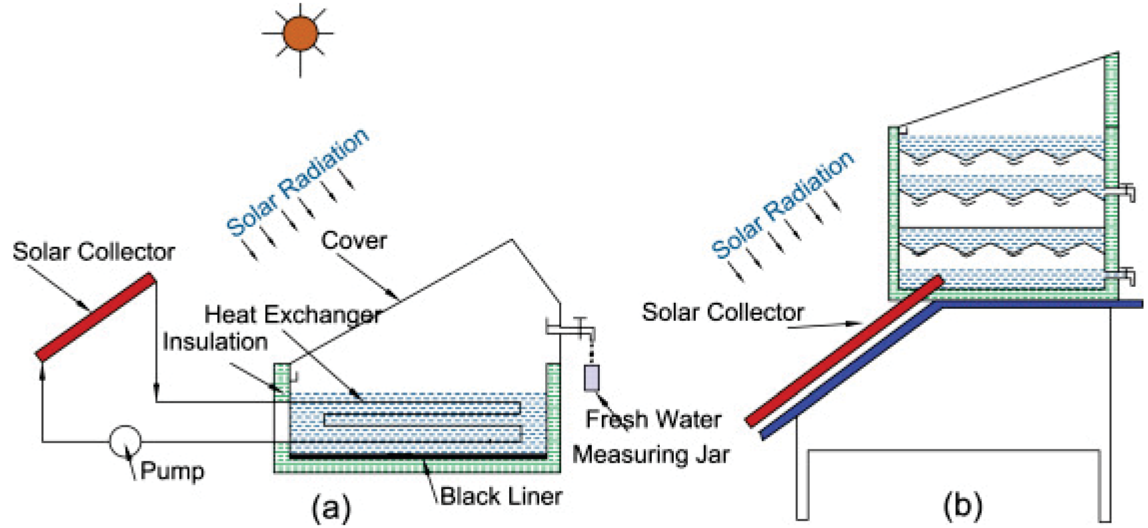
- Coal mine → a giant battery (200 MW pumped hydro storage station)
- Stores excess solar and wind energy



<www.miningweekly.com/topic/university-of-duisburg-essen> accessed 6.7.1018>

Water Desalination System Using Solar Heat





Humidification and dehumidification desalination unit coupled with solar collector

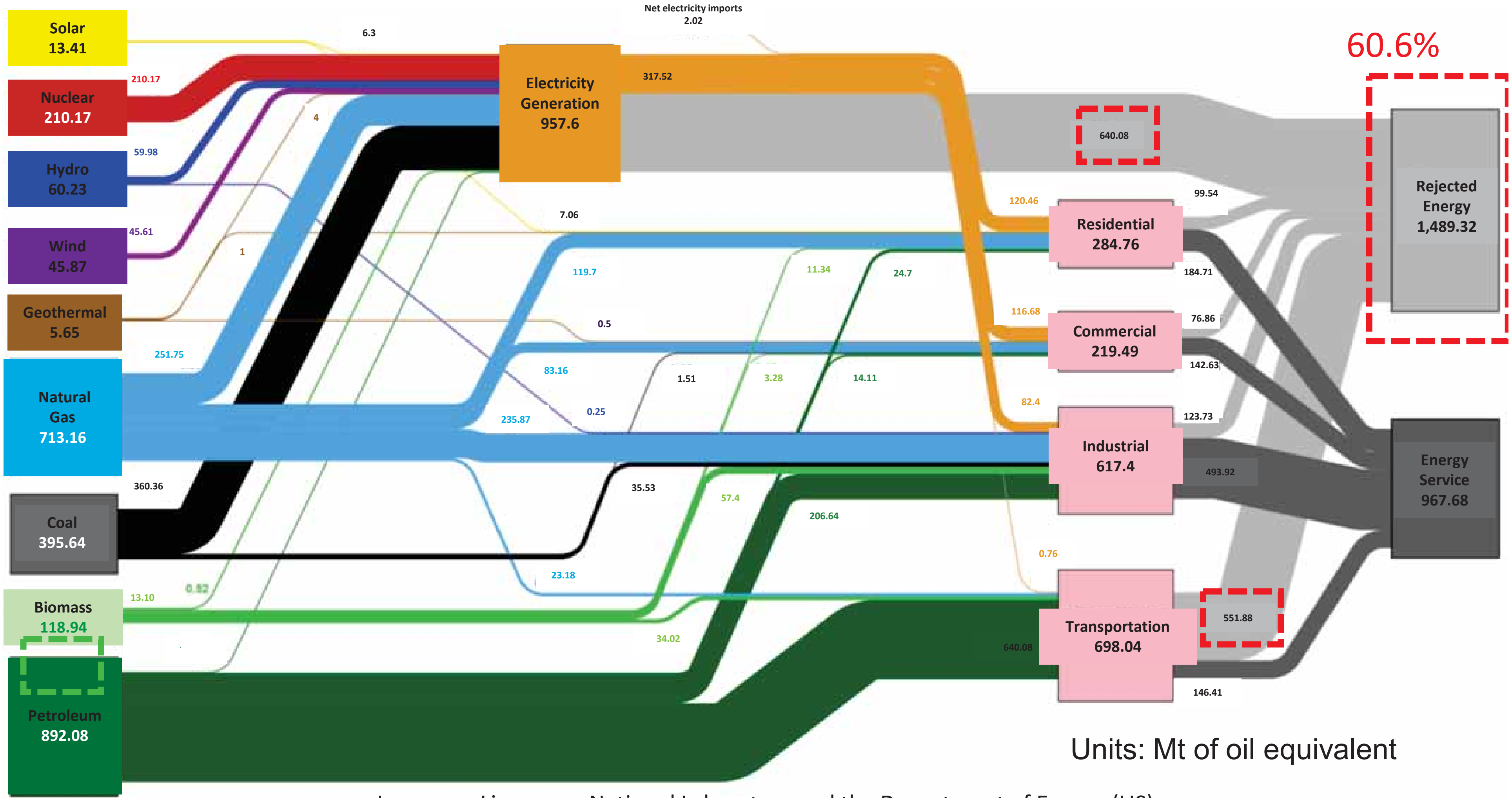
Chandrashekara, M., Yadav, A. (2017). Water desalination system using solar heat: a review. Renewable and Sustainable Energy Reviews, 67, 1308-1330.12

Mapping inputs to outputs: the Big Picture

General strategy to follow

The US Energy

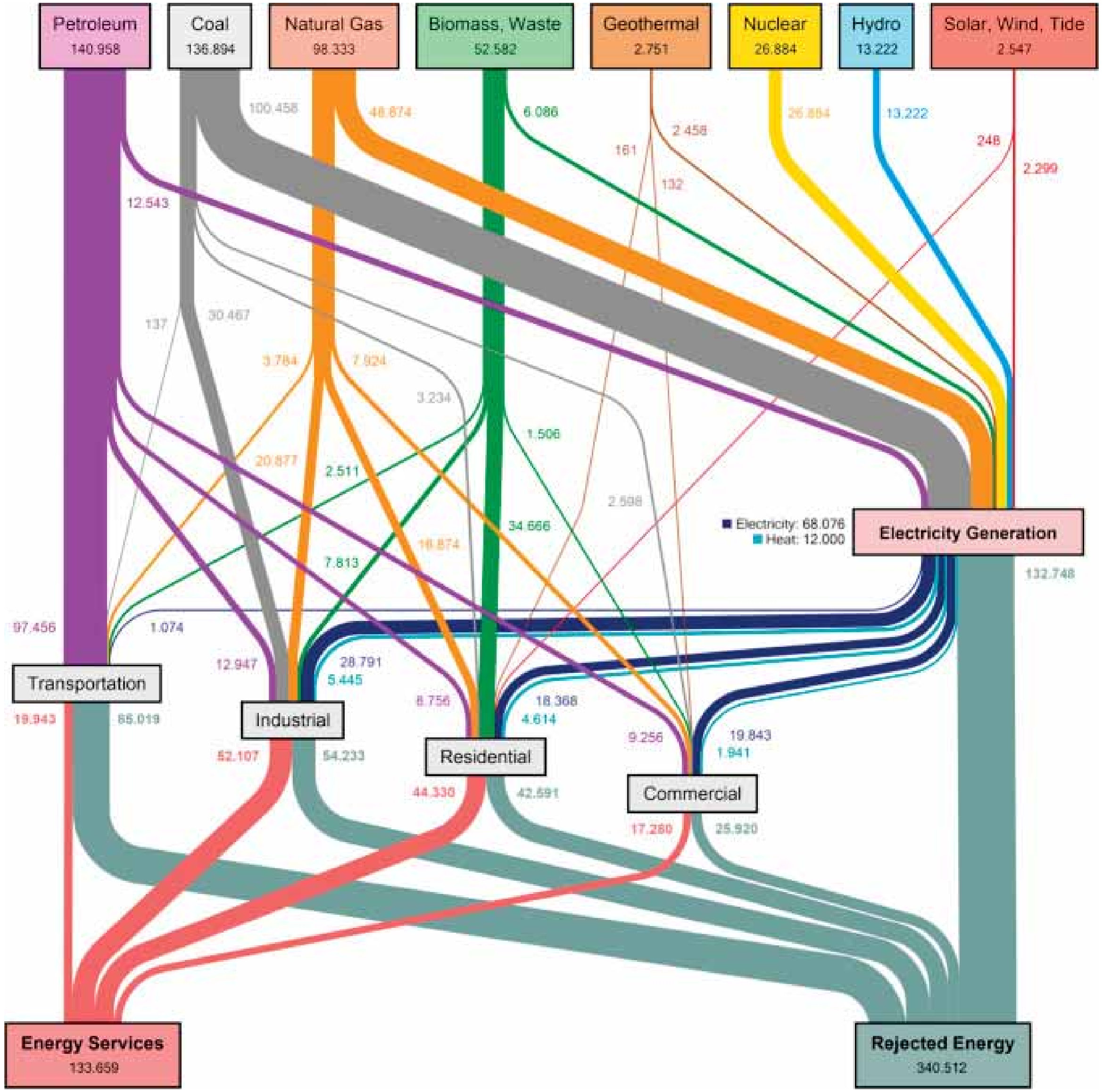
Estimated Energy Consumption in 2,457 Mtoe



Units: Mt of oil equivalent

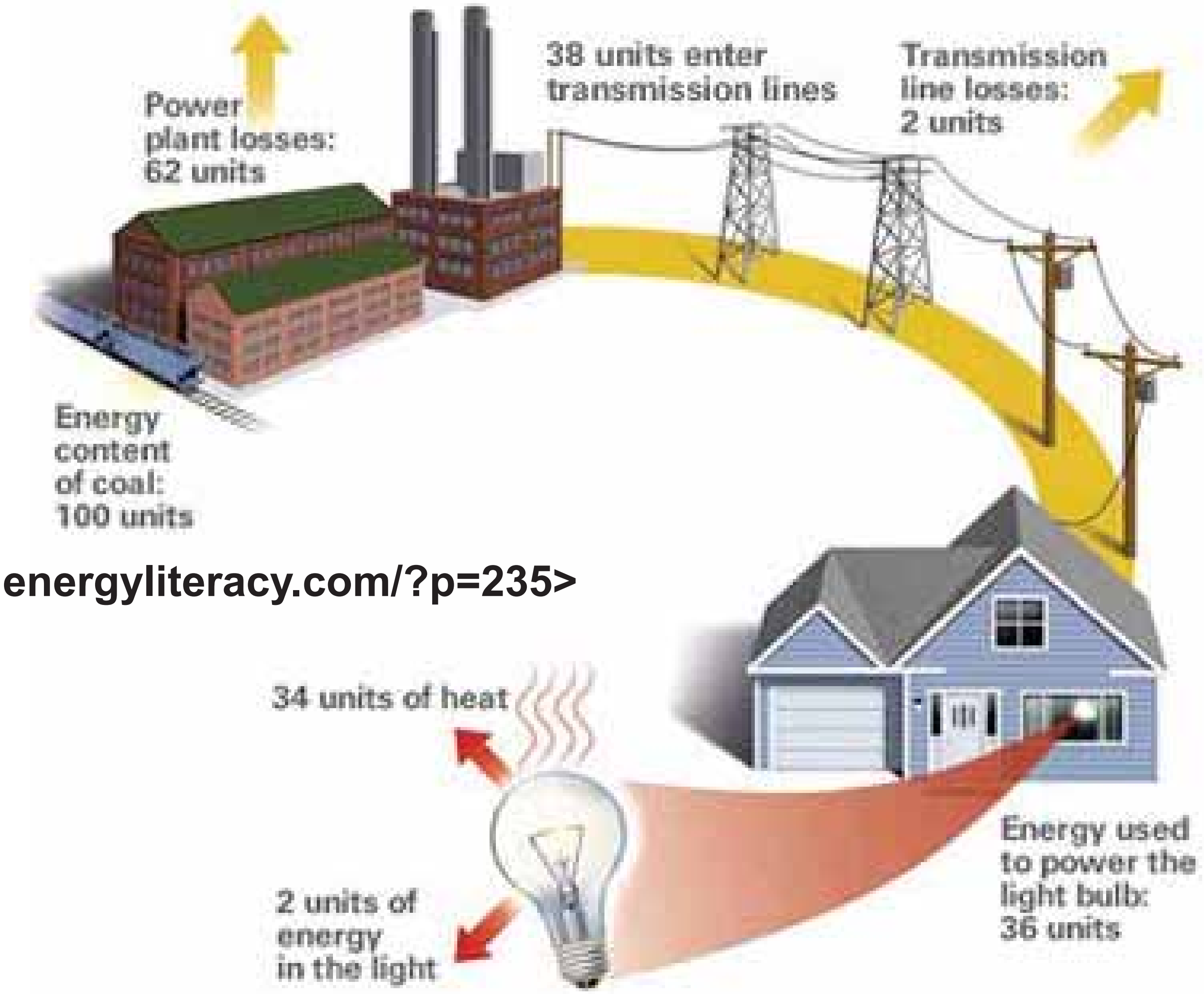
Lawrence Livermore National Laboratory and the Department of Energy (US)
<www.visualcapitalist.com/u-s-energy-consumption-one-giant-diagram/>accessed 16 May 2017

Global Energy Use



Forman, C., Muritala, I. K., Pardemann, R., Meyer, B. (2016). Estimating the global waste heat potential. Renewable and Sustainable Energy Reviews, 57, 1568-1579.

Losses for Electricity Conversion and Transmission



<www.energyliteracy.com/?p=235>

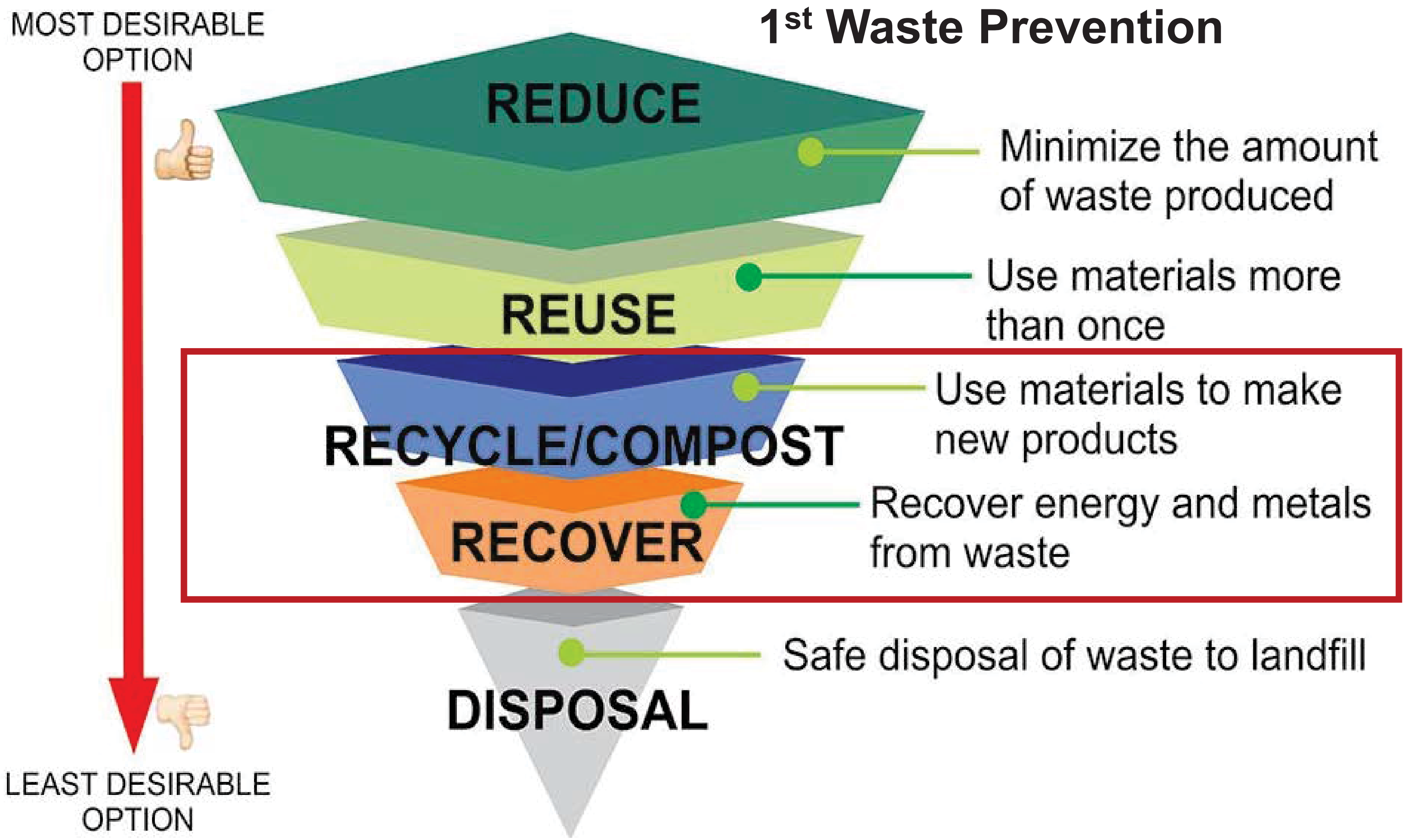
Strategy

1. Any sensible strategy starts with demand reduction!
2. The reuse and recycling form a second tier
3. Any energy recovery takes priority after that
4. Remaining waste has to be absorbed, deposited, diluted

RESULT:

The Waste Hierarchy

Waste Management Hierarchy



Burdening (Processing) vs Unburdening effect (Avoided)

<www.usgbcwm.org/no-time-to-waste-waste-diversion-in-construction/>accessed 23 September 2018

Process Integration:

Leading the way for 4 decades

The First Steps – HEN synthesis

Pinch Analysis

Hohmann, E. C., 1971. Optimum networks for heat exchange. PhD thesis, University of Southern California, LA, USA.
Linnhoff B., Flower J.R., 1978, Synthesis of heat exchanger networks: I. Systematic generation of energy optimal networks. AIChE Journal, 24(4), 633–642.
Umeda, T., Harada, T., Shiroko, K.A., 1979. Thermodynamic approach to the synthesis of heat integration systems in chemical processes. Computers & Chemical Engineering, 3(1-4), 273–282.

Heuristic methods

Ponton, J W, Donaldson, R A B, 1974. A fast method for the synthesis of optimal heat exchanger networks, Chem.Eng.Sci., 29, 2375-2377 (1974)

Mathematical programing

Papoulias, S.A., Grossmann, I.E.,1983. A structural optimization approach in process synthesis-II. Heat recovery networks, Comp.Chem.Eng., 7 (6), 707-721.
Yee, T.F., Grossmann, I.E.,1990, Optimization models for heat integration—II. Heat exchanger network synthesis. Comput.Chem.Eng. 14, 1165–1184

The Roots of Pinch Analysis

- Hohmann, E. C. (1971). Optimum networks for heat exchange. PhD thesis, University of Southern California, Los Angeles, USA.
- Linnhoff, B. (1972) Thermodynamic analysis of the cement burning process (Thermodynamische Analyse des Zementbrennprozesses). Diploma work, Abteilung IIIa, ETH Zurich (1972) (in German).
- Hohmann, E. C., Lockhart, F. J. (1976). Optimum heat exchanger network synthesis. AIChE 82nd National Meeting, Atlantic City, NJ, USA, Paper No 22a.

What is Process (Heat) Integration?

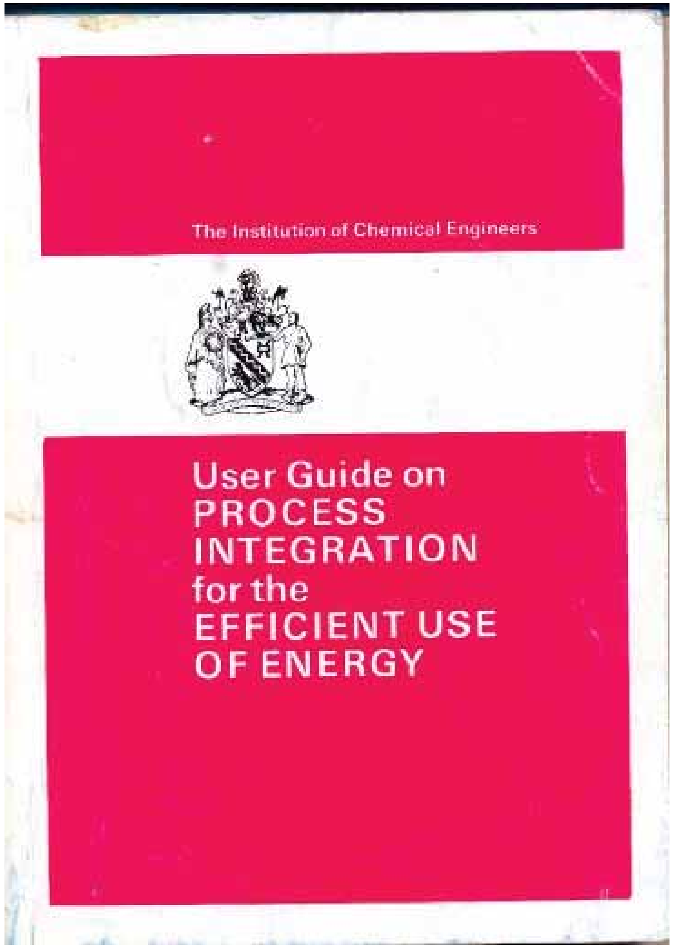
- A family of methodologies for combining several processes to reduce consumption of resources and/or harmful emissions to the environment
- It started as Heat Integration stimulated by the energy crisis in the 1970's
- **Definition of Process Integration by IEA:**

  Systematic and General Methods for Designing Integrated Production Systems ranging from Individual Processes to Total Sites, with special emphasis on the Efficient Use of Energy and reducing Environmental Effects.

Main Features

- A clear pattern:
  - Targets, problem decomposition, guidance for design
- The widest application is for energy savings
- Other areas:
  - Water networks, GHG emission minimisation,
  - Inventory planning
  - Regional development and supply chains
  - Electrical power management
  - …
- Potential applications to regional water-energy nexus

The "Red Book"



A User Guide on Process Integration for the Efficient Use of Energy

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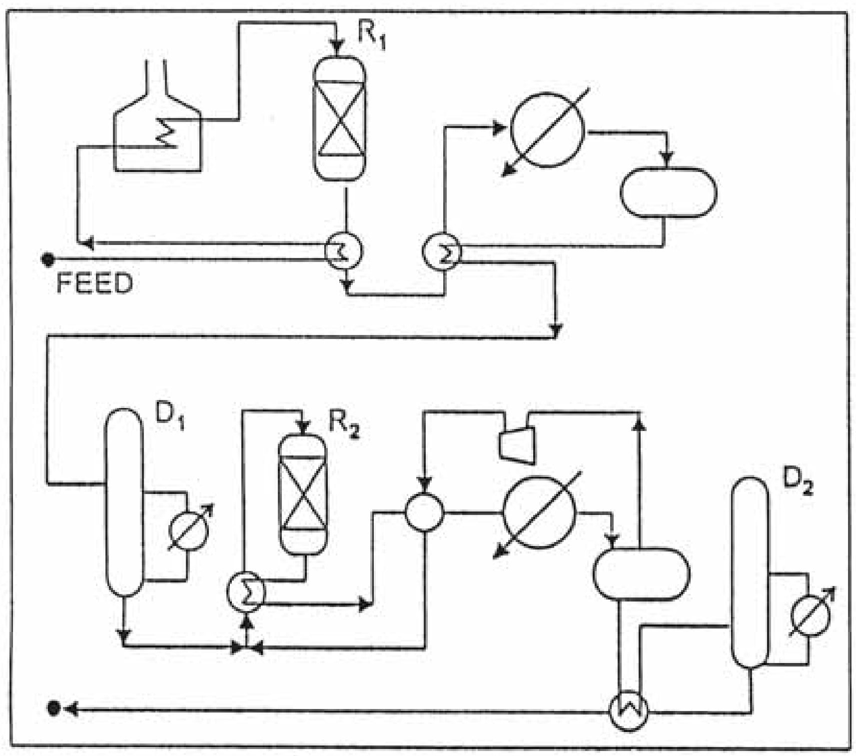
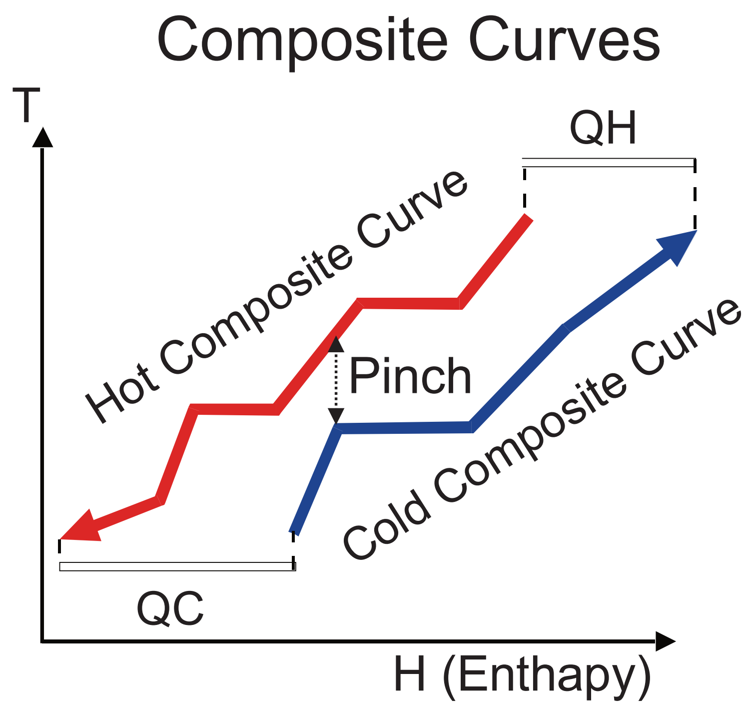
The authors were members of a Working Party set up by the Institution of Chemical Engineers to prepare this Guide under the Chairmanship of B.E.A. Thomas.

SPIL, VUT Brno, 2 May 2018

Prof Bodo Linnhoff, Pioneer of Pinch Analysis

Pinch based approach





Complicated Flowsheet ⇨ Simple Diagram

Mathematical Programming OR Pinch

Mathematical Programming

- Describes a problem as a set of equations
- An objective function (Mixed Integer Nonlinear Problem) + Multiobjective optimisation

Minimize (or maximize) $F(\mathbf{x}, \mathbf{y})$	Objective function, performance criterion
where $\mathbf{x} \in \mathbf{R}^n$ (continuous variables)	Continuous domain
$\mathbf{y} \in \mathbf{Z}^n$ (integer variables)	Discrete domain
subject to $h(\mathbf{x}, \mathbf{y}) = 0$	Equality constraints
$g(\mathbf{x}, \mathbf{y}) \leq 0$	Inequality constraints

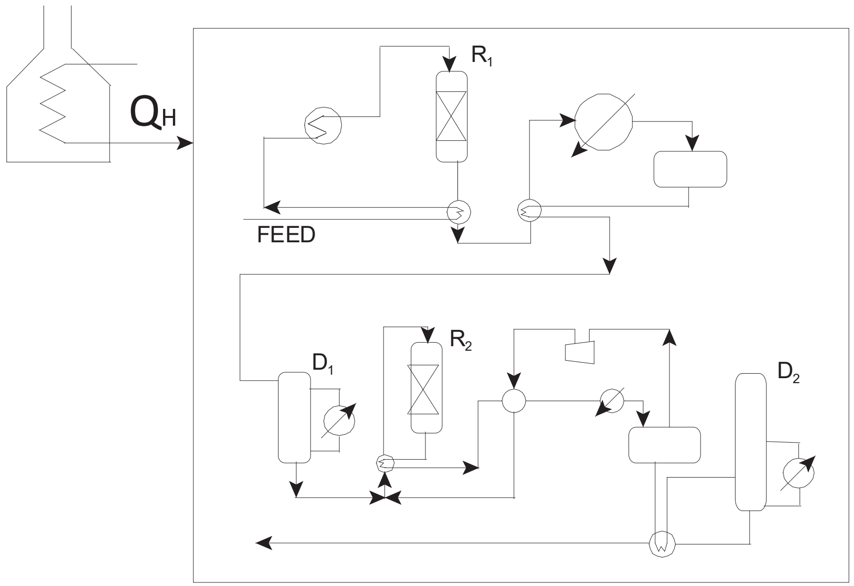
Powerful Tool

- There are a number of environments for developing and solving mathematical models: GAMS, LINDO, IBM-ILOG Studio, etc.
- A variety of solvers for solving successfully LP, NLP, MILP, MINLP problems
- Solution times are constantly being reduced as a result of novel algorithms as well as hardware development

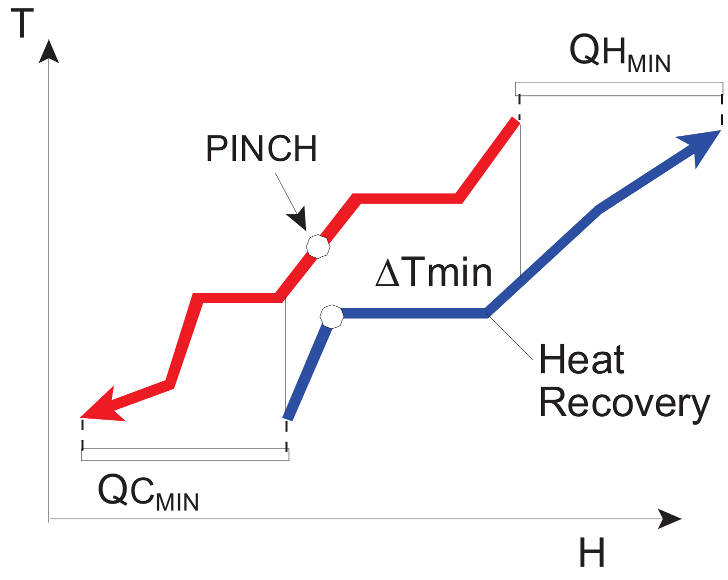
BUT

Pinch AND Mathematical Programming

Heat Integration Principle

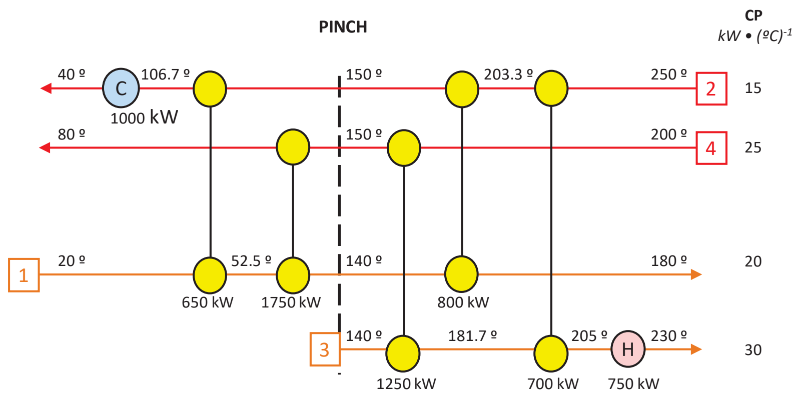


Existing Energy Consumption

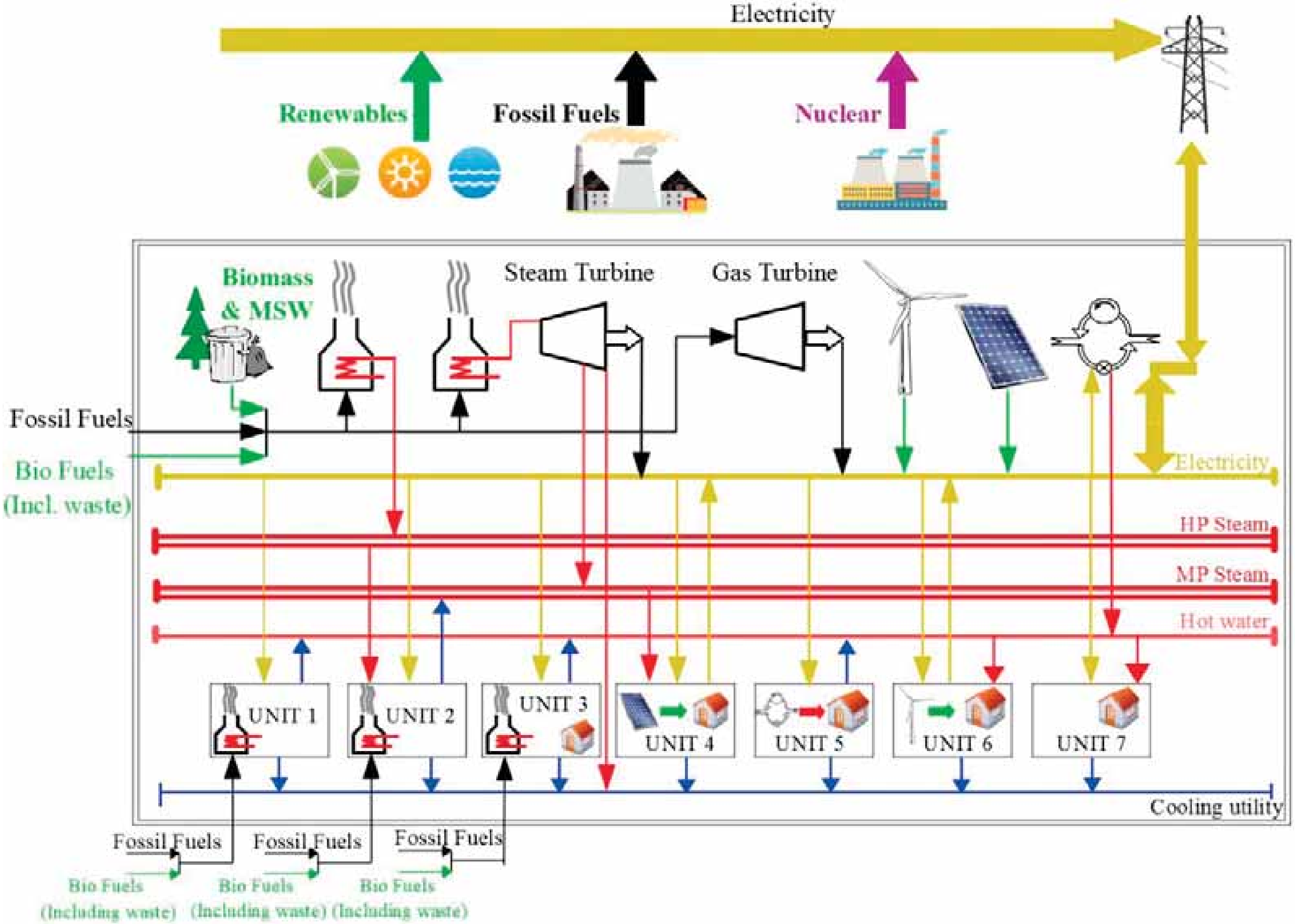


Minimum Energy **Target**

Complicated Flowsheet ⇨ Simple Diagram ⇨ Optimal HEN



Advanced Redesign-
Total Site Concept



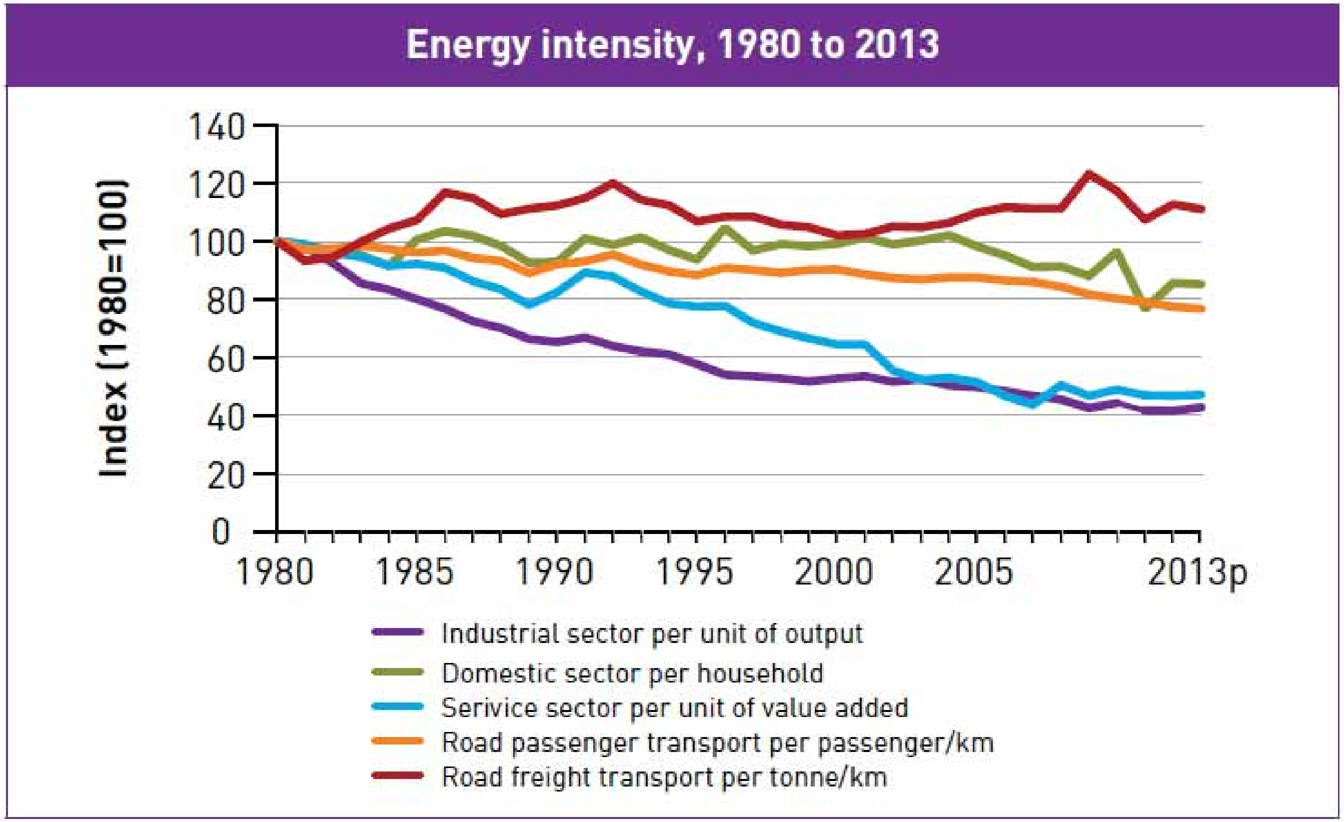
Klemeš J.J., Varbanov P.S., Walmsley, W.G., Jia X., 2018. New directions in the Implementation of Pinch Methodology, Renewable and Sustainable Energy Reviews, 98, 439-468.

Benefits of Process Integration

- Heat Integration roots
  - Identify heat recovery targets and aid in synthesizing maximum heat recovery systems
  - Minimise utility demands and CO_2 emissions of a process
- Minimisation of resource consumption
  - Total Sites Optimisation
  - Supply Chains
  - Optimal time scheduling and tracking

Energy Efficiency / Savings in the UK

The fall in energy intensity over the last 30 years
The industrial sector and mainly due to structural changes



www.gov.uk/government/uploads/system/uploads/attachment_data/file/350941/UK_Energy_in_Brief_2014_revised.pdf

Summary

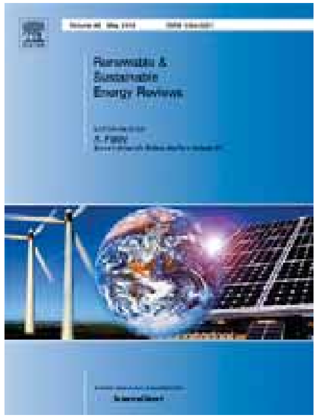
- Sustainable Development: a major goal
- How to quantify the sustainability?
- Issues of sustainability – related to mass flows and energy flows
- Mass-flow issues are best served by the Circular Economy paradigm
- Energy-flow issues are better modelled using a cascade model
- Seeing the big picture naturally leads to the “Waste Hierarchy”
- An example of excellence in resource conservation: Process Integration

PRES'19

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

20–23 October 2019
Crete, Greece

IF=10.556



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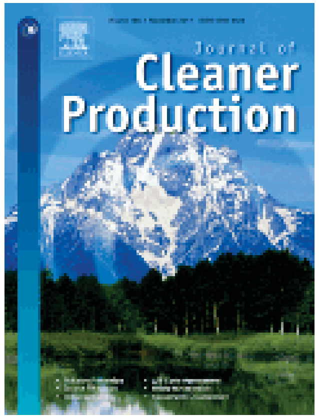

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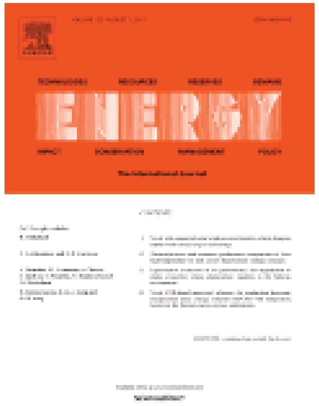

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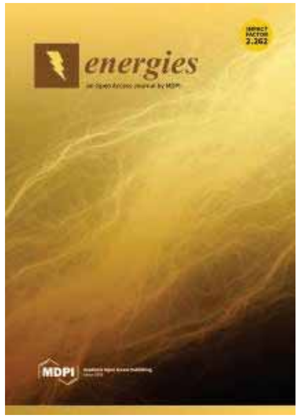
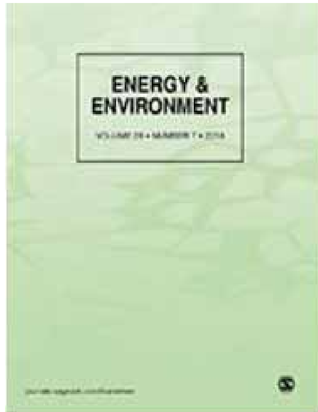


(open access)

IF=1.092



<conferencepres.com> | <pres2019.cperi.certh.gr>

Special Session Invitation:
SDEWES 2020 Gold Coast, Australia

6 - 9 April 2020

<www.goldcoast2020.sdewes.org/>

1st Asia Pacific SDEWES (Sustainable Development on Energy and Water Systems)

Engineering a Sustainable Circular Economy:

Materials, Energy and Infrastructure Integration for Smart Cities and Industry

Timothy Gordon Walmsley*, Jiří Jaromír Klemeš, Kim Pickering, Petar Sabev Varbanov

Corresponding email: **spil@fme.vutbr.cz**

Abstract submission (session invitation code): **gc2020esce**

Special Session Invitation: SEE 2020 Bosnia and Herzegovina

28 June - 2 July 2020

<www.sarajevo2020.sdewes.org/>

Integration of Smart cities and Smart Industry for Circular Economy: Energy, Water and Waste to Secondary raw material for Sustainable Future

Contact us for invitation email and more information:
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abstract submission (session invitation code):

sdsee20scsi

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