Sustainable Process Integration: Simultaneous Minimisation of Resources Intake and Emissions

Moderators:

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EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
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MINISTRY OF EDUCATION,
YOUTH AND SPORTS

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Dubrovnik, Croatia, 4-8 October 2017

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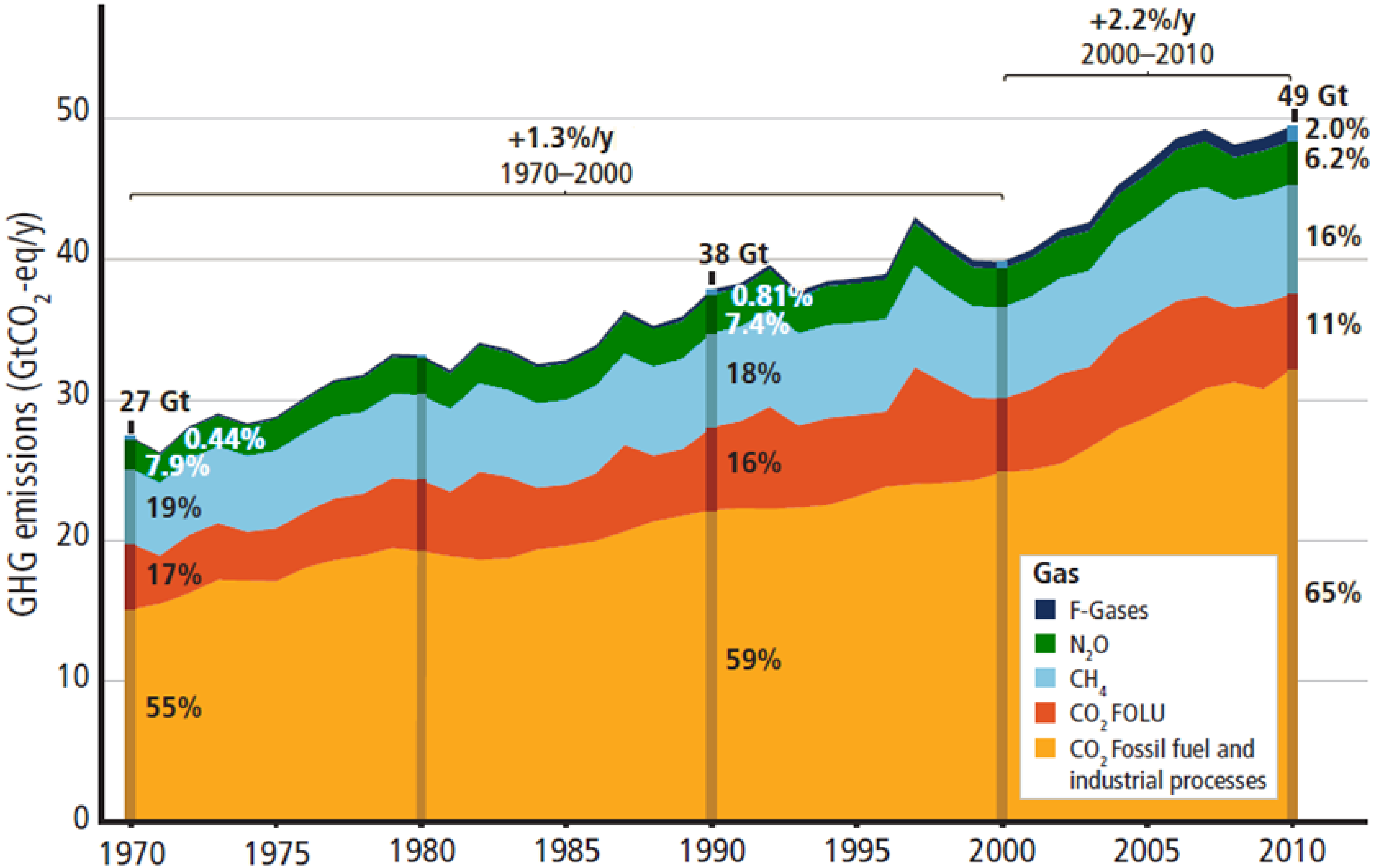
Introduction

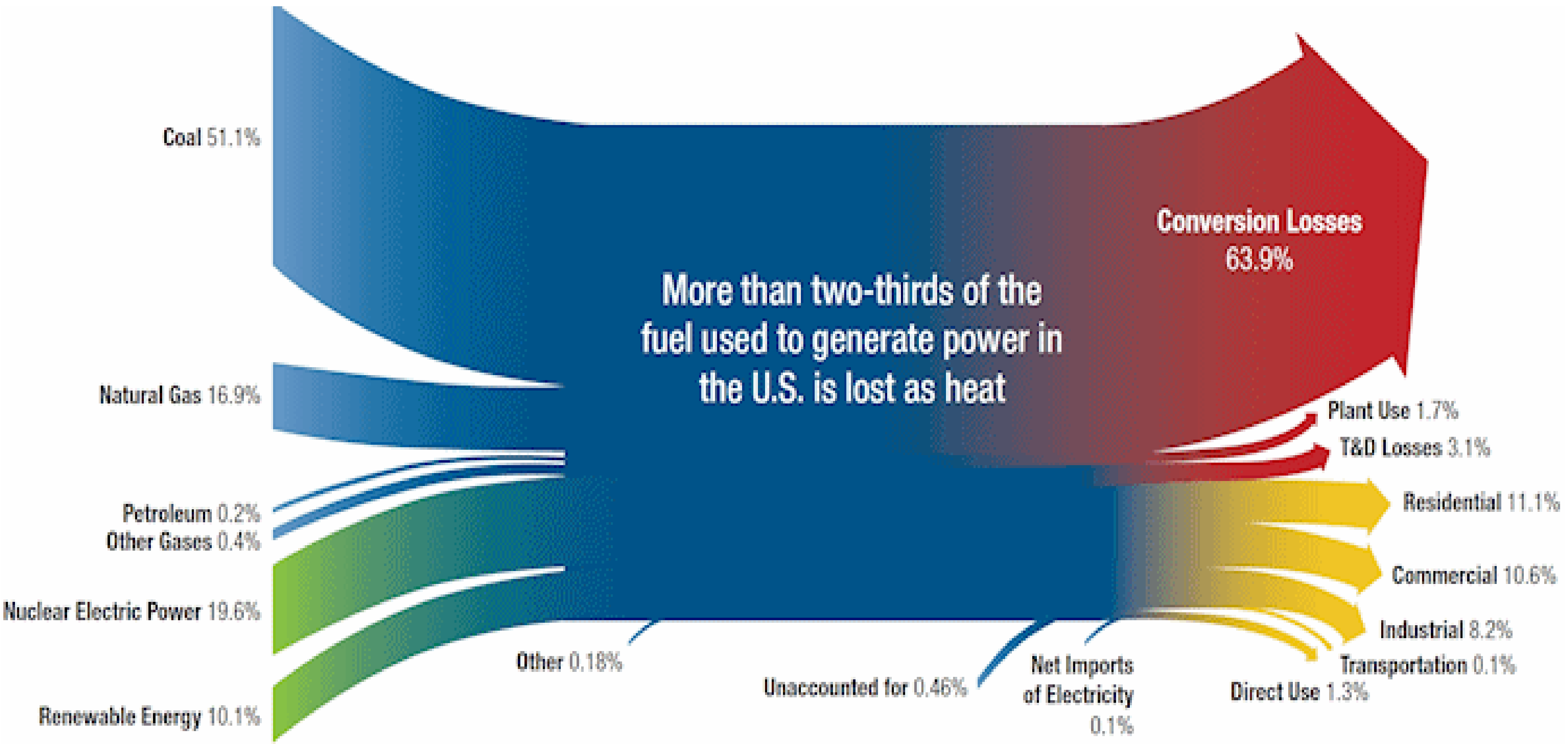
- Alarming levels of GHGs (CO_2, CH_4, NO_x) emissions
- R&D development: Focused on minimising GHGs, N, energy and water footprint
- Area: energy saving, improving efficiency of fossil fuel installations etc.
- Sustainability: Economic vs Environmental vs Social
- Provide appropriate system models & supporting efficiently decision making on sustainability issues

Total Annual GHG Emissions



(FOLU - Forestry and other Land Use, F-Gases = Fluorinated Gases). Developed from (IPCC 2014)

US Balance: Economy Wide Losses



<www.gulfcoastcleanenergy.org/CLEANENERGY/CombinedHeatandPower/tabid/1698/Default.aspx>

The Topics

- **Several topics can be researched with maximal impact**

1. The human dimension of sustainability (social sustainability): Haze footprint, quantifying the threats to human health

2. Selection of environmental impact indicators. Multiple footprint-connection, choice of the keys one, system behaviour

3. Key energy ratio: guiding decision making

4. Energy water nexus and considering the food dimension

5. Solution side: Sustainable process integration

The Speakers

Prof Vincenzo Dovi'
Universita' di Genova, Genova, Italy

Prof Neven Duić
University of Zagreb, Zagreb, Croatia

Prof Zdravko Kravanja
University of Maribor, Maribor, Slovenia

Dr Aoife Foley
Queen's University Belfast, Belfast, United Kingdom

Prof Michael Walmsley
University of Waikato, Hamilton New Zealand

Ms Yee Van Fan
Brno University of Technology, Brno, Czech Republic

The Role of Environmental Modelling in Process Optimisation

UNIVERSITÀ DEGLI STUDI DI GENOVA

Prof Vincenzo Dovi

- Identification of environmental models possesses 3 unique features that make their validation particularly burdensome and error-prone

- Give rise to 3 main problems.

- Examining different scenarios and possibly identifying a new metric capable of combining goals, uncertainties and precautionary criteria capable of obtaining a wide consensus might help improving the overall system optimisation process.

Integration of Power, Heating, Water and Transport Systems, using Excess in one as Resource in the Other

Prof Neven Duić

- Transition to decarbonised energy systems is becoming more attractive.
- Further penetration of renewables: integrating power and heating/cooling systems. In countries with low heat demand = water supply system.
- Electrification of personal car transport
- Electric cars due to low daily use may be excellent for demand response and even for storage potential, through vehicle to grid technology.
- Allow reaching 80% renewable in energy system, remaining 20% needs technology breakthrough.
- Integration is discussed at different time levels, day ahead, hour ahead, 15 min ahead, secondary and primary reserve level, as well as capacity markets and balancing.

Optimal Synthesis of Sustainable Systems by Considering Sustainability Measurement

Prof Zdravko Kravanja

- Roles of Sustainable Systems Engineering in the sustainable developments
- Chemical and Energy supply chains
- Sustainability measurement e.g. Sustainability Profit, Sustainability Net Present Values, two step superstructure approach, total footprint, total LCA indexes
- The principles and illustration in case study

Zdravko Kravanja*, Lidija Čuček, Žan Zore

Minimisation of Resource Intake and Emissions in the Era of the Instantaneous Gratification

Queen's University Belfast

Dr Aoife Foley

- The ever increasing demand for the basic necessities of life and the drive for ‘modern’ technology and lifestyles is leading to a fast spiral of ‘disposable’ living.
- Is this the root cause of continued global warming, economic migration and geopolitical and economic uncertainties?
- How can the needs of the individual, society and the planet be proactively balanced such that the aspirations of all are met sustainably considering social equity, economics and the environment?

Key Energy Ratios

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Prof Michael Walmsley

- Reducing GHGs through using less fossil fuels for energy production
- Providing technical solutions and share findings in a way the community can understand
- Introduction of Energy Ratios
- Illustrate the trade offs involved in choosing between energy system or technologies
- Thermodynamics or the science of energy governs the constraints. Thermodynamic principals.

Towards Sustainable Sea Transportation

BRNO UNIVERSITY OF TECHNOLOGY

Ms. Yee Van Fan

- Transportation is one of the largest contributors to GHG emission and other pollutants.
- Smog related and shipping activities assessment is relatively less established in optimisation study

❖ Emission Measurement ✓
❖ Assessment approach for decision

- Sum up five issues to be considered in assessment

21st Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction

25 - 29 August 2018, Prague, Czech Rep

www.PRESconference.com

Acknowledgement

To the EC project Sustainable Process Integration Laboratory – SPIL funded as project No. CZ.02.1.01/0.0/0.0/15_003/0000456, by Czech Republic Operational Programme Research and Development, Education, Priority 1: Strengthening capacity for quality research and by the collaboration agreement with The University of Manchester, UK, Universiti Teknologi Malaysia, Malaysia, University of Maribor, Slovenia, Hebei University of Technology, China, Pázmány Péter Catholic University, Hungary, Fudan University, China based on the SPIL project.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- EU project Sustainable Process Integration Laboratory – SPIL funded as project No. CZ.02.1.01/0.0/0.0/15_003/0000456, by Czech Republic Operational Programme Research and Development, Education in collaboration with.

Bike Sharing:
Comprehensive Sustainability Improvement

Petar Sabev Varbanov, Jiří Jaromír Klemeš

Sustainable Process Integration Laboratory (SPIL)

NETME CENTRE, Brno University of Technology

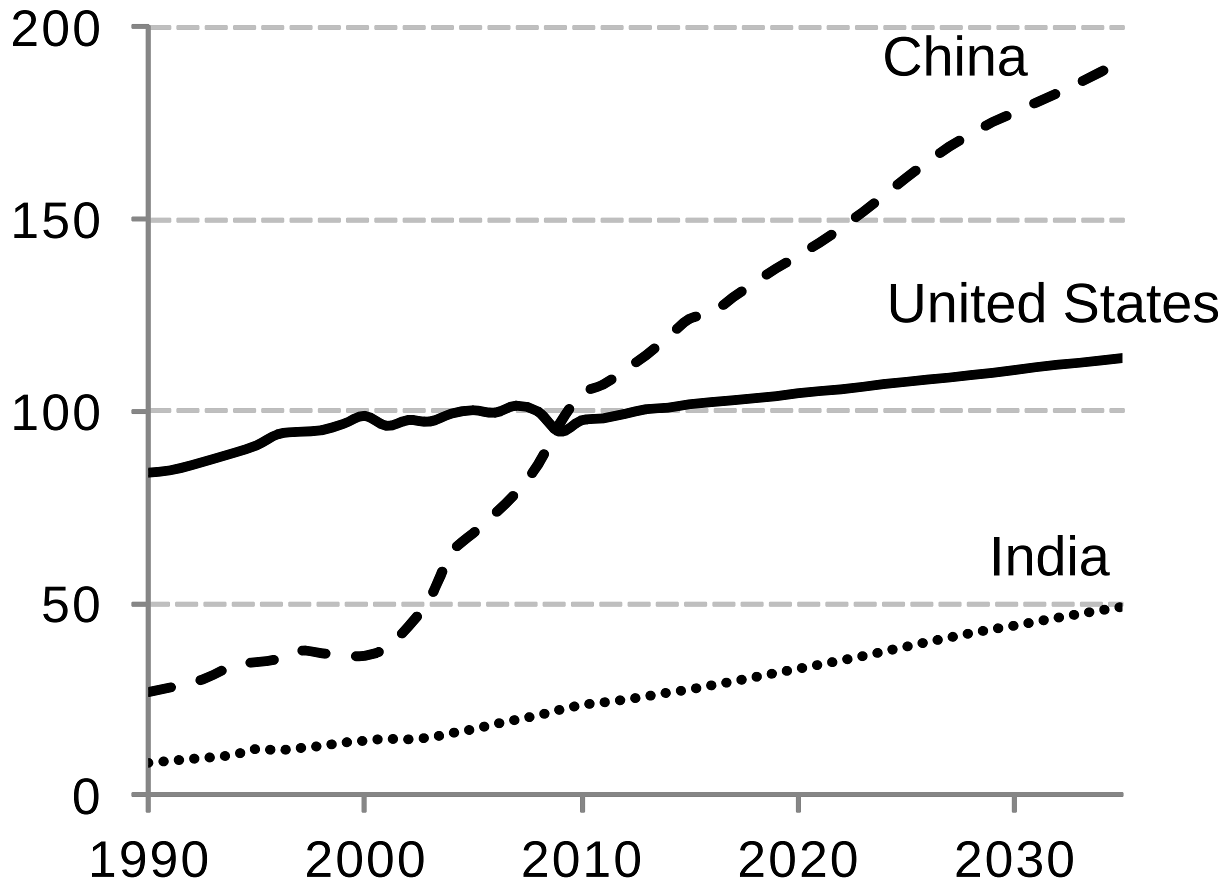
Brno, Czech Republic

SPIL Project

- Supported by Operational Programme Research, development and education
- Motivated by the alarming values of GHG
- Objective: achieve unique and practically applicable findings that may help increase the efficiency of the processing industry and power engineering
- Minimise the greenhouse, nitrogen, ecological and water footprints.

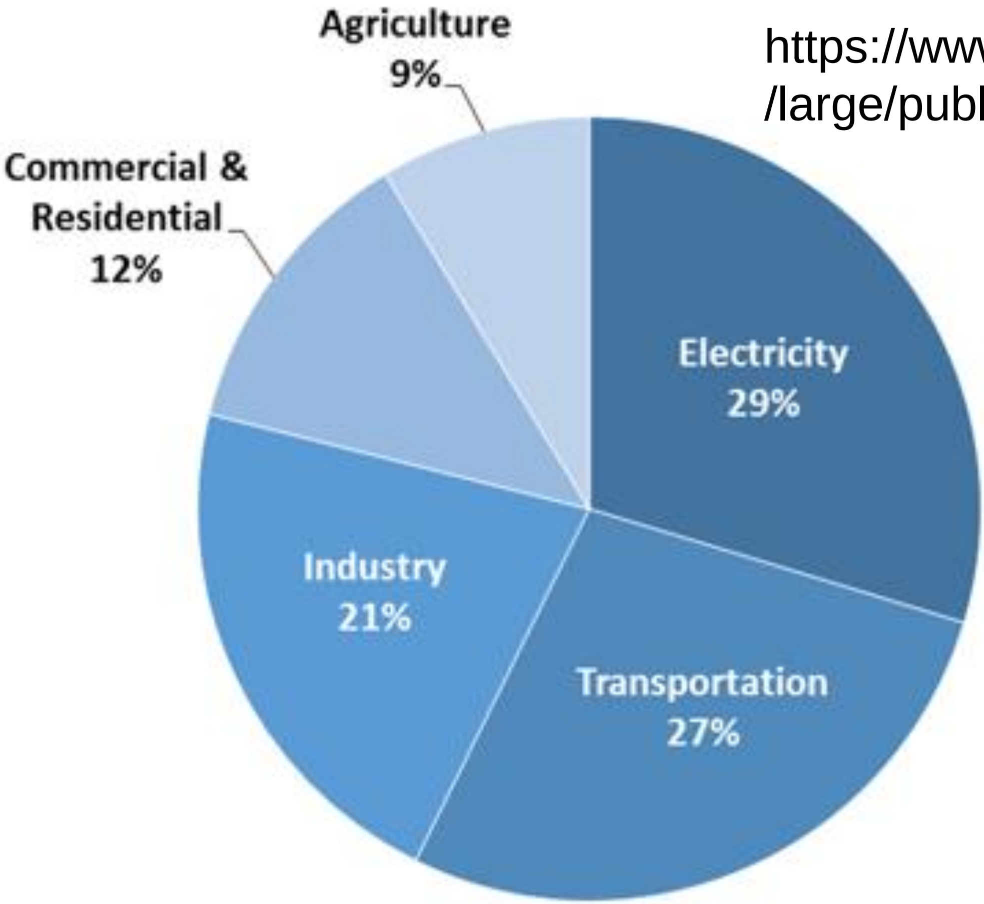
<netme.cz/cs/spil/>

High and Growing Energy Demands



www.eia.gov/totalenergy/data/annual/pdf/aer.pdf (accessed 19.02.14).

US GHG Emissions in 2015



https://www.epa.gov/sites/production/files/styles/large/public/2017-04/totala.png

U.S. Environmental Protection Agency (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015.

Hangzhou, National Tea Museum

Shanghai, Atour Hotel

Well Used in China

World-Wide

<www.bikesharingmap.com>

Barcelona

Belgium

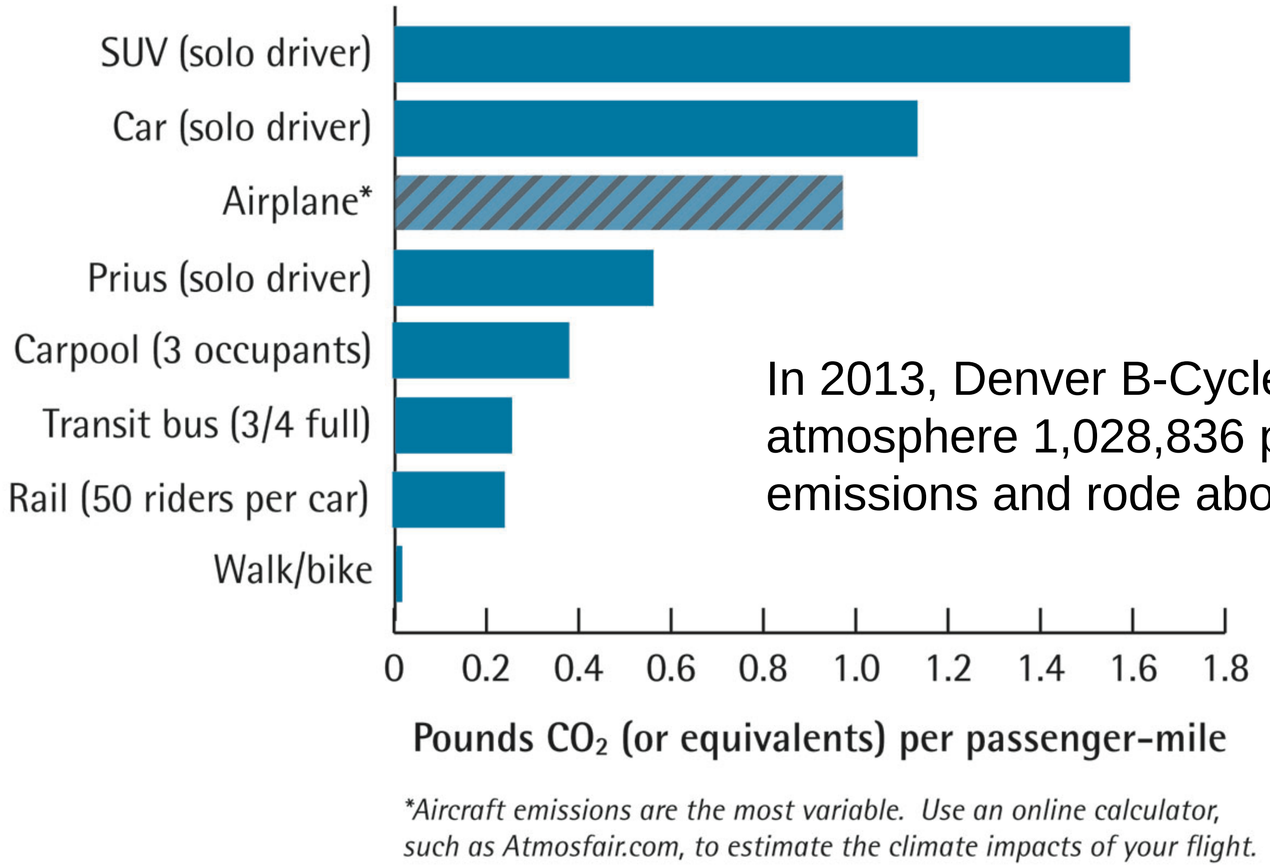
A line of bikes at a Villo! station.
<en.wikipedia.org/wiki/List_of_bicycle-sharing_systems#/media/File:VilloStationAlmostFull.jpg>

Social Impact

- Increased Connectivity: up by 40-45 %
- More exercise: rise 35-40 %
- Equitable Transportation to Lower Income Areas

<www.academia.edu/7934412/The_Impact_of_Bikesharing_White_Paper_on_the_Social_Environmental_and_Economic_Effects_of_Bikesharing>

Environmental Impact



In 2013, Denver B-Cycle users spared the atmosphere 1,028,836 pounds of CO2 emissions and rode about 560,424 miles.

Sightline INSTITUTE

<www.academia.edu/7934412/The_Impact_of_Bikesharing_White_Paper_on_the_Social_Environmental_and_Economic_Effects_of_Bikesharing>

Overall Potential Benefits

- Reduced emissions
  - GHG
  - Toxic releases from fuel combustion
  - Particulates
- Improved health, increased transport availability
- Choice and convenience, reduced travel times and costs, and improved travel experience

Spread in China: What and Why

- Elsewhere: have existed for almost fifty years
  (Ricci M., 2015. Bike sharing: A review of evidence on impacts and processes of implementation and operation. Research in Transportation Business & Management, 15, 28–38, DOI: 10.1016/j.rtbm.2015.03.003)
- Not pervasive until now

- **CHINA:**
- Take from anywhere in the local community
- Leave anywhere
- **=> FLEXIBLE**

Simple: DOCKLESS

- Solar panels
- Smart locks
- Real-time position tracking

Spread in China: How

- **SIMPLE TO USE**
- Mobile applications for each company
- Very low cost and easy to pay (by mobile!)
- Very good infrastructure and maintenance – no broken bikes or flat tyres
- Low-cost down to USD 45 per bike (www.techinasia.com/talk/bike-sharing-china-future)

- **=> PERVASIVE**

What is the Future?
Shared Electirc Cars?

6 Electric Car-Sharing Programs Better Than a Billion Teslas on the Road

Bryan Lufkin
3/31/16 6:45pm • Filed to: TESLA

22.8K 64 10

Acknowledgement

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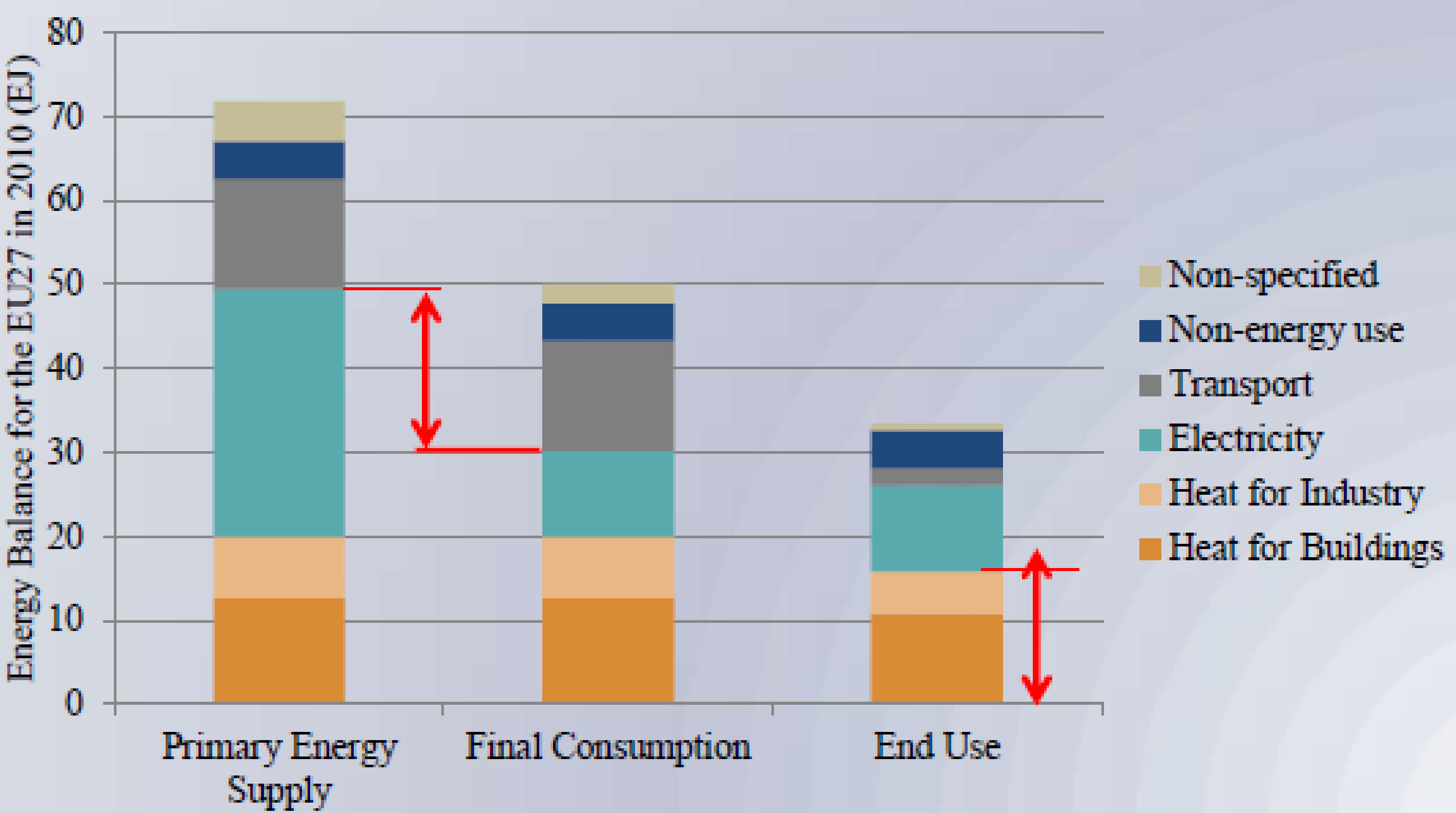
Integration of power, heating, water and transport systems, using excess in one as resource in the other

Prof.dr.sc. Neven Duić

Power Engineering and Energy Management Chair
Department of Energy, Power Engineering and Environment
Faculty of Mechanical Engineering and Naval Architecture
University of Zagreb, Croatia

SDEWES 2017, Dubrovnik, 6.10.2017

Surplus heat today in Europe

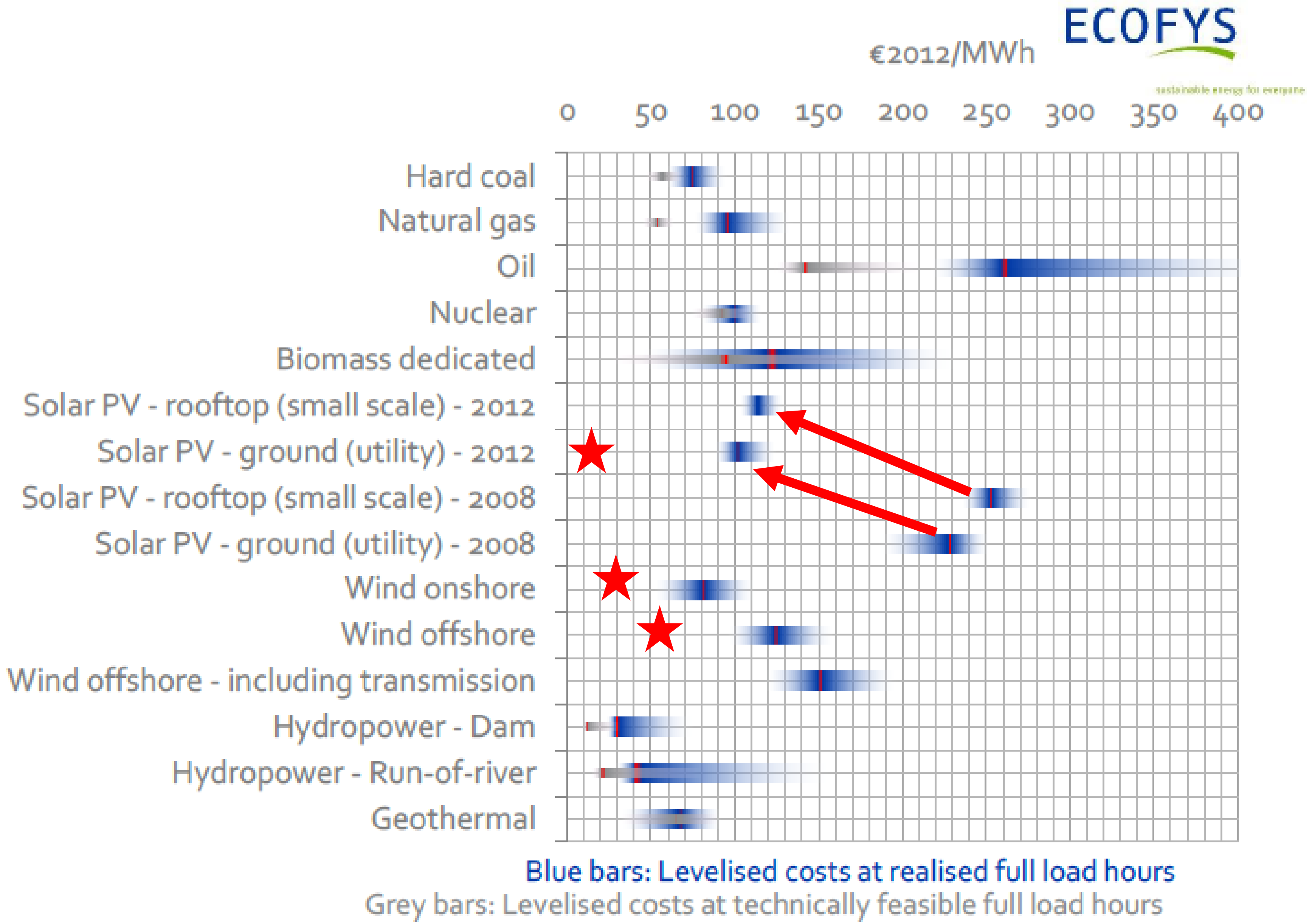


S. Vincente, Cape Verde

Currently – 20% wind

Water (desalination) – power integration

- Power up to 88% of RES
- Water up to 76% of RES:

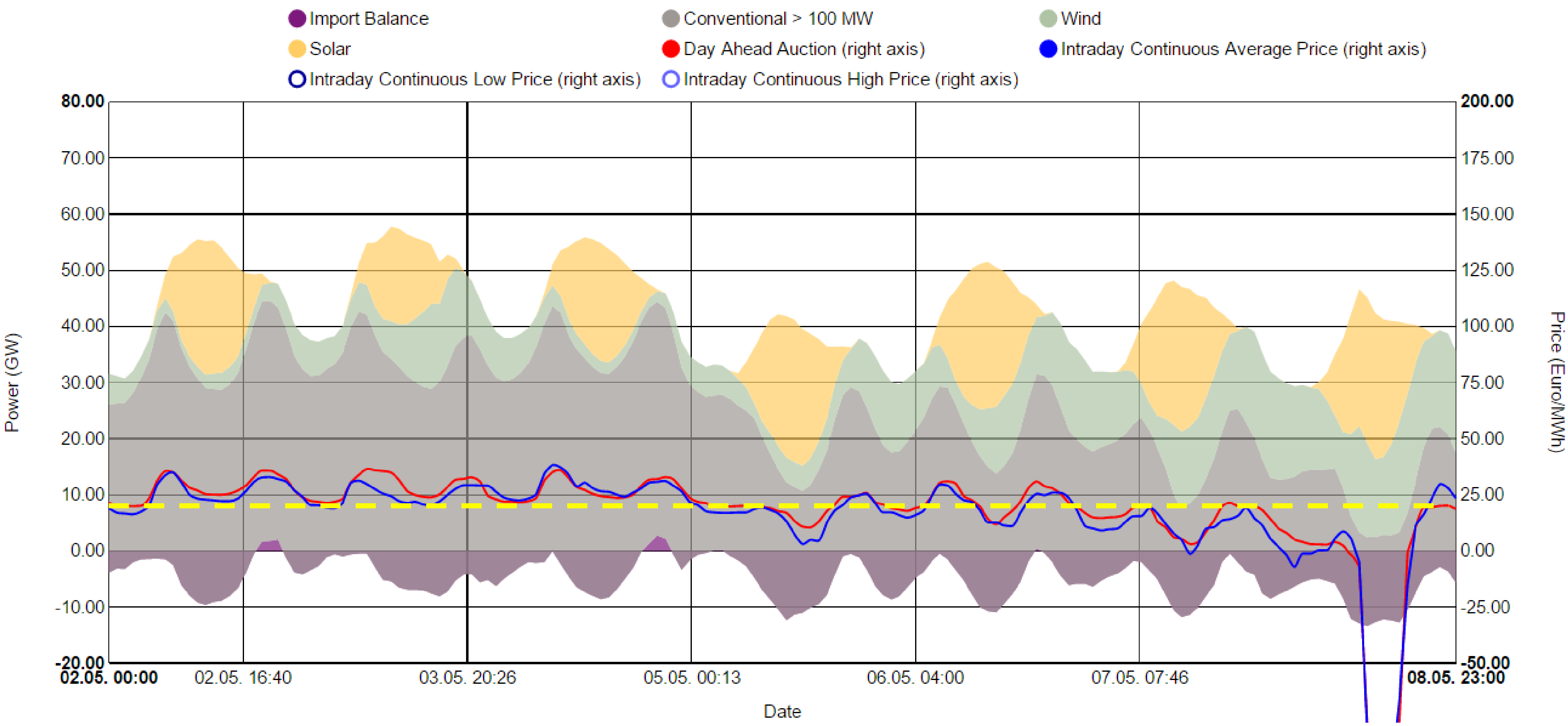


LCOE – various technologies

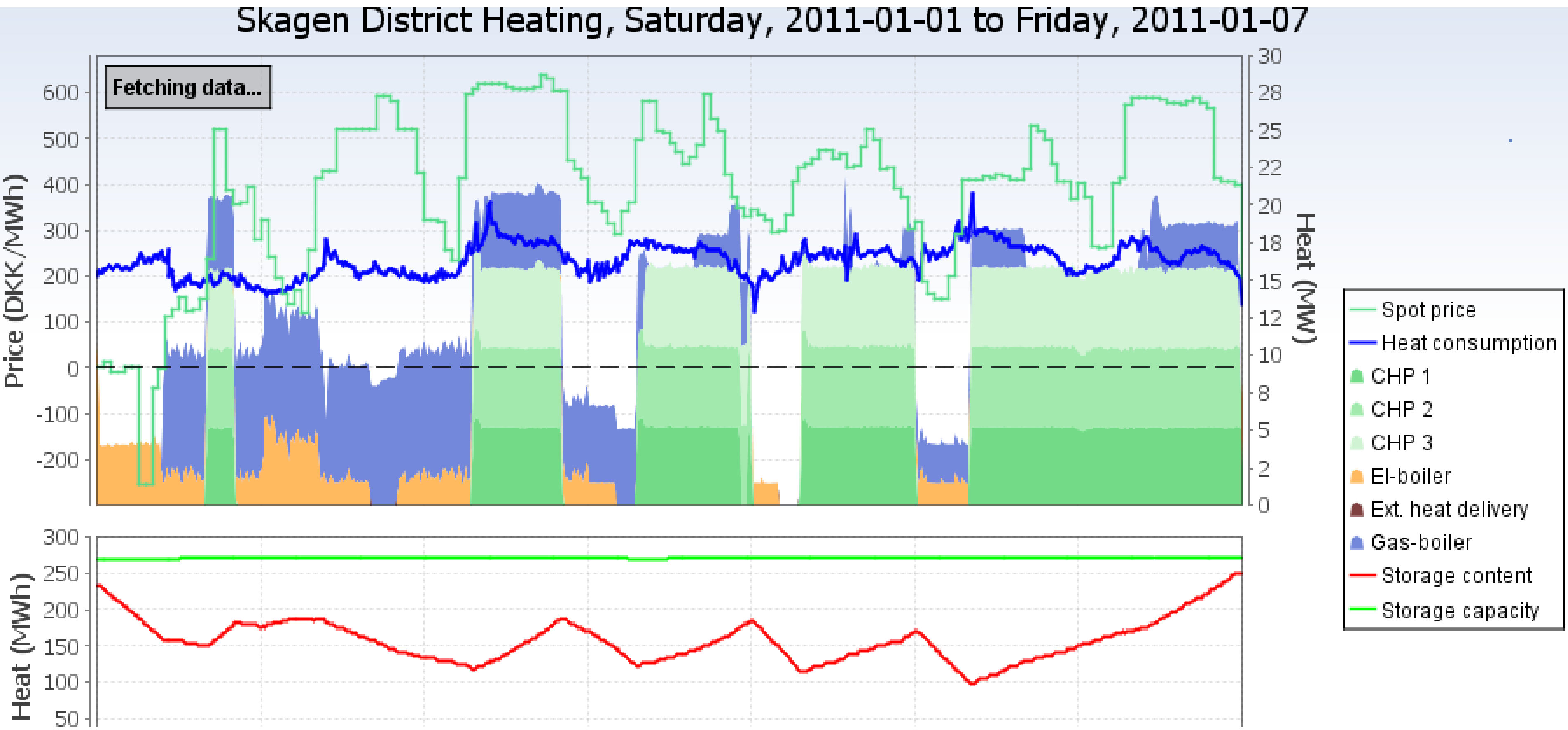
Demand response

- 20th century energy systems: supply follows demand
- 21st century energy systems: demand follows supply -> smart energy systems

Electricity production in Germany in week 18 2016

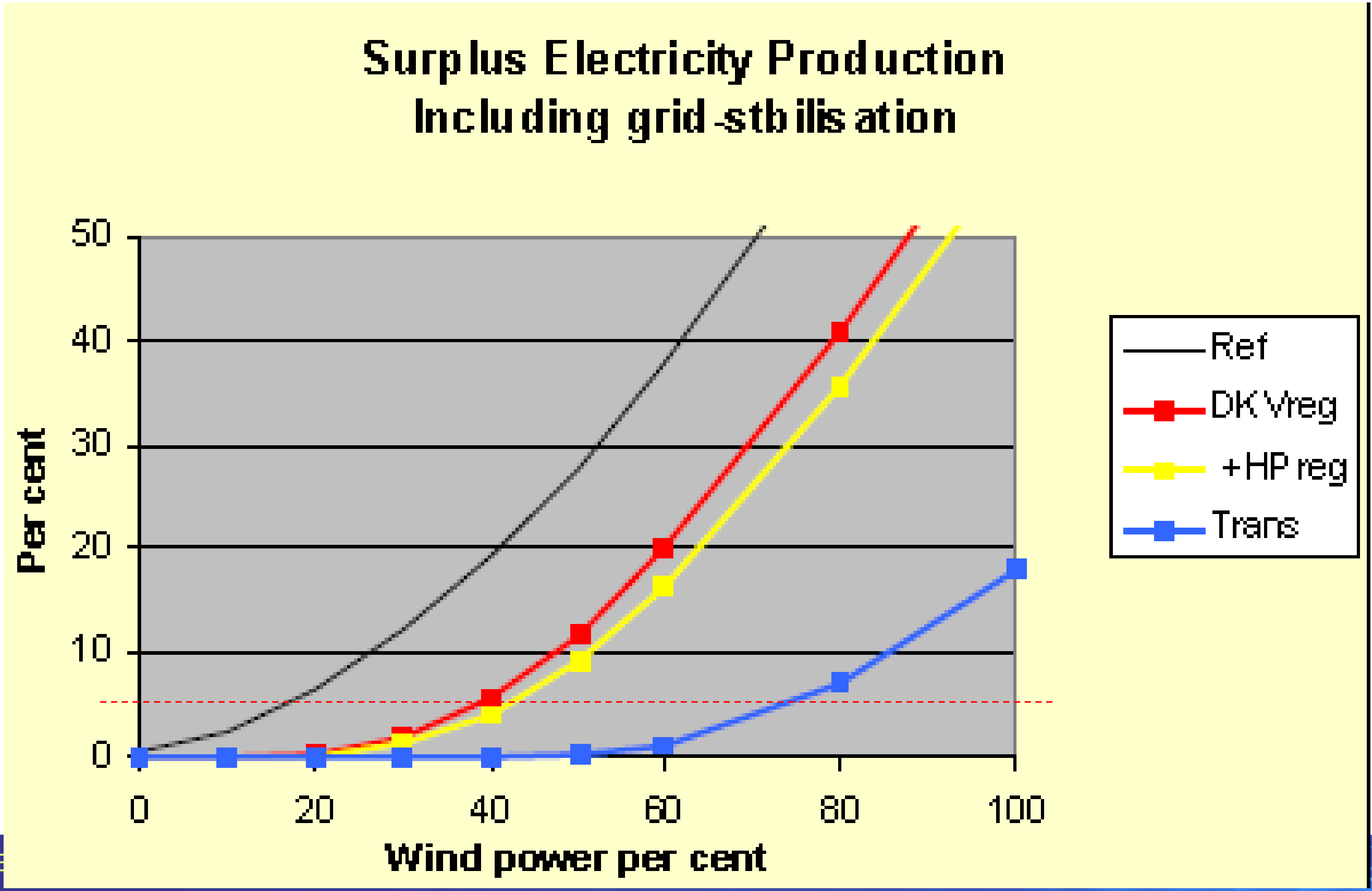


Power to heat



Demand management

- Electromobility
  - Only personal cars and short distance utility vehicles, 774000 PHEV and BEV sold in 2016 (http://www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/)
  - If RESe 80% reduction of primary energy
  - Fast charging 70 kW – huge problem if left uncontrolled, ex AT, 4 mln cars arrives home, plugs in – 280 GW (14 GW installed cap)
  - Smart charging – market based, smoothing the demand


Surplus Electricity Production
Including grid-stbilisation
Per cent
50
40
30
20
10
0
0
20
40
60
80
100
Wind power per cent
Ref
DK Vreg
+HP reg
Trans

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Faculty of Chemistry and Chemical Engineering

Optimal Synthesis of Sustainable Systems by Considering Sustainability Measurements

Zdravko Kravanja, Lidija Čuček and Žan Zore

Faculty of Chemistry and Chemical Engineering, University of Maribor, Slovenia

Panel session at SDEWES 2017, Dubrovnik, Croatia, October the 6th, 2017

Sustainable Development: Blue Map – New Scenario for CO_2 Emissions

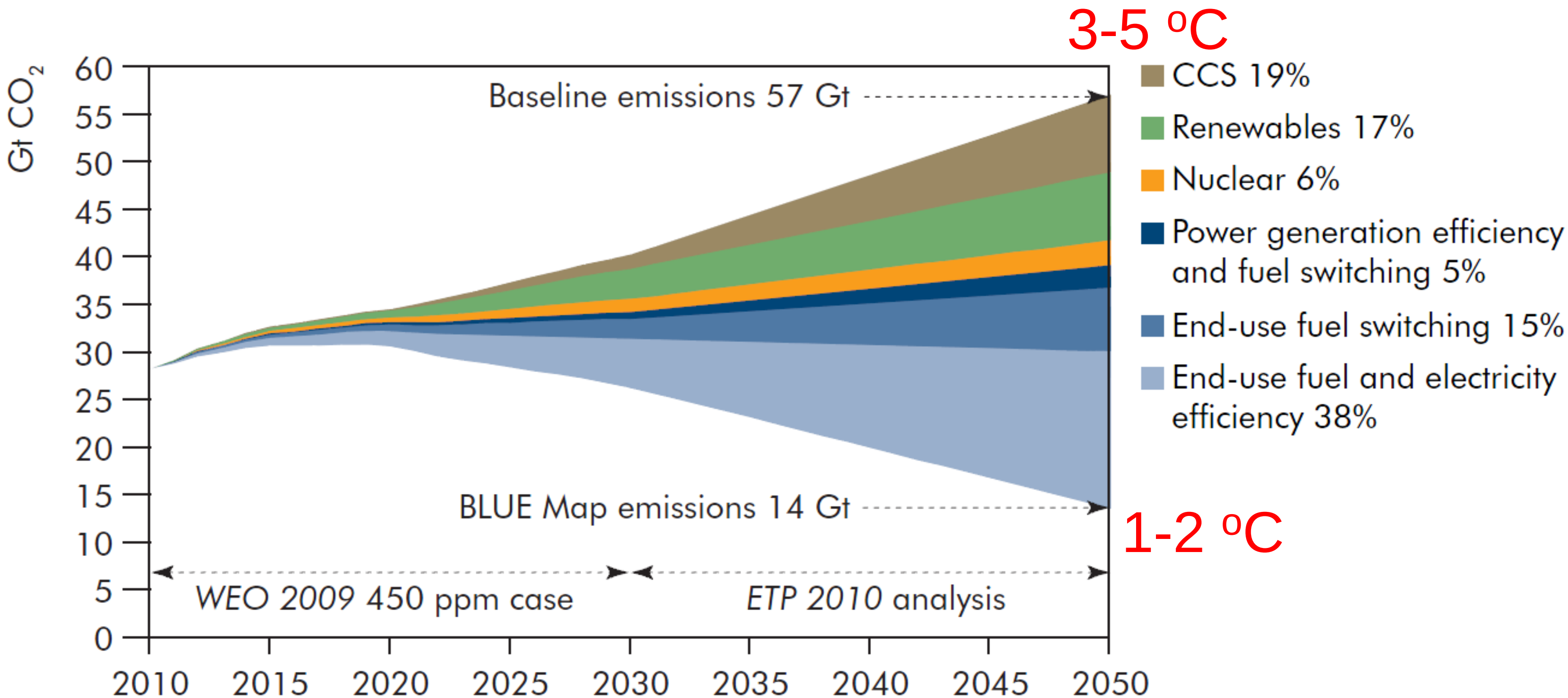

Fig. 19: Blue Map scenario and key technologies for reducing CO2 emissions
OECD/IEA. Energy Technology Perspectives 2010, Scenarios & Strategies to 2050, http://www.iea.org/techno/etp/etp10/English.pdf

Sustainable Systems Engineering can contribute significantly!

Emissions trends in countries from 1990 - 2015

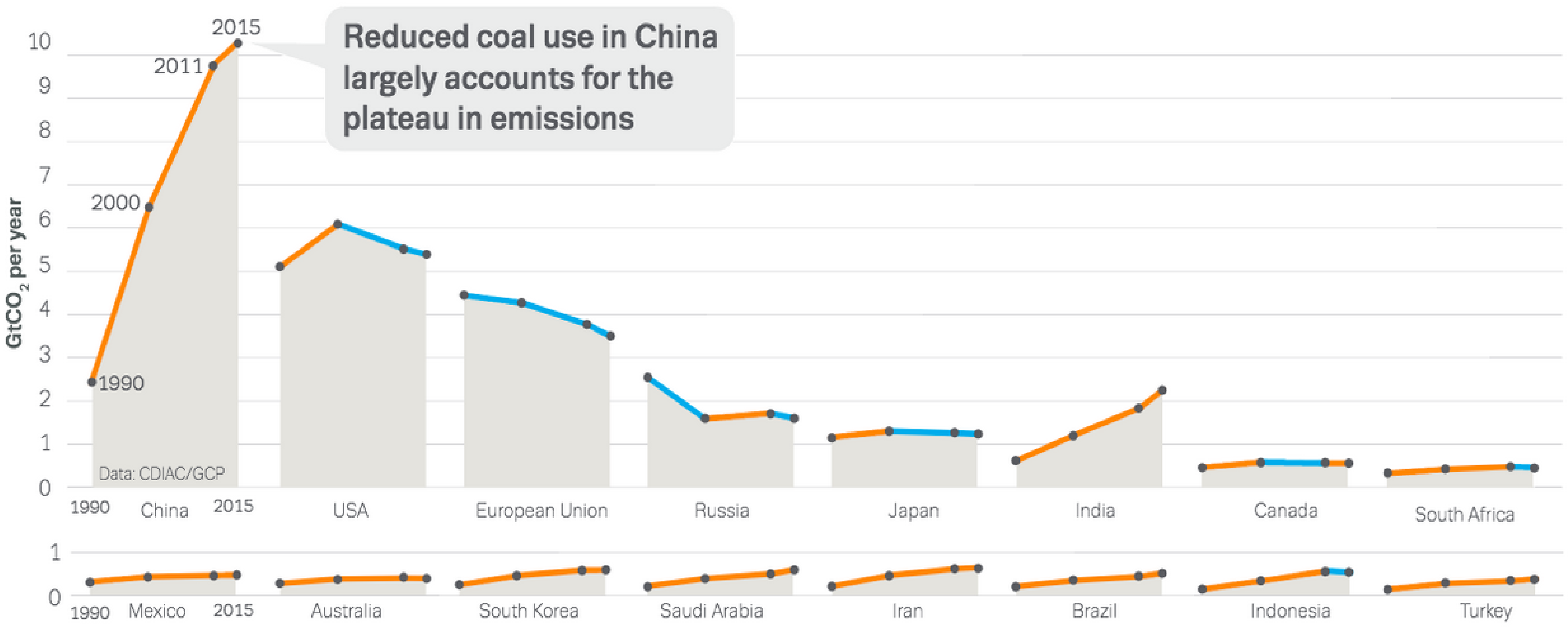

Fig. 2:Emissions trends in countries (R. Pidcock (2016) https://www.carbonbrief.org/what-global-co2-emissions-2016-mean-climate-change after Le Quéré, C. et al. 2016)

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Projection of CO_2 Emissions

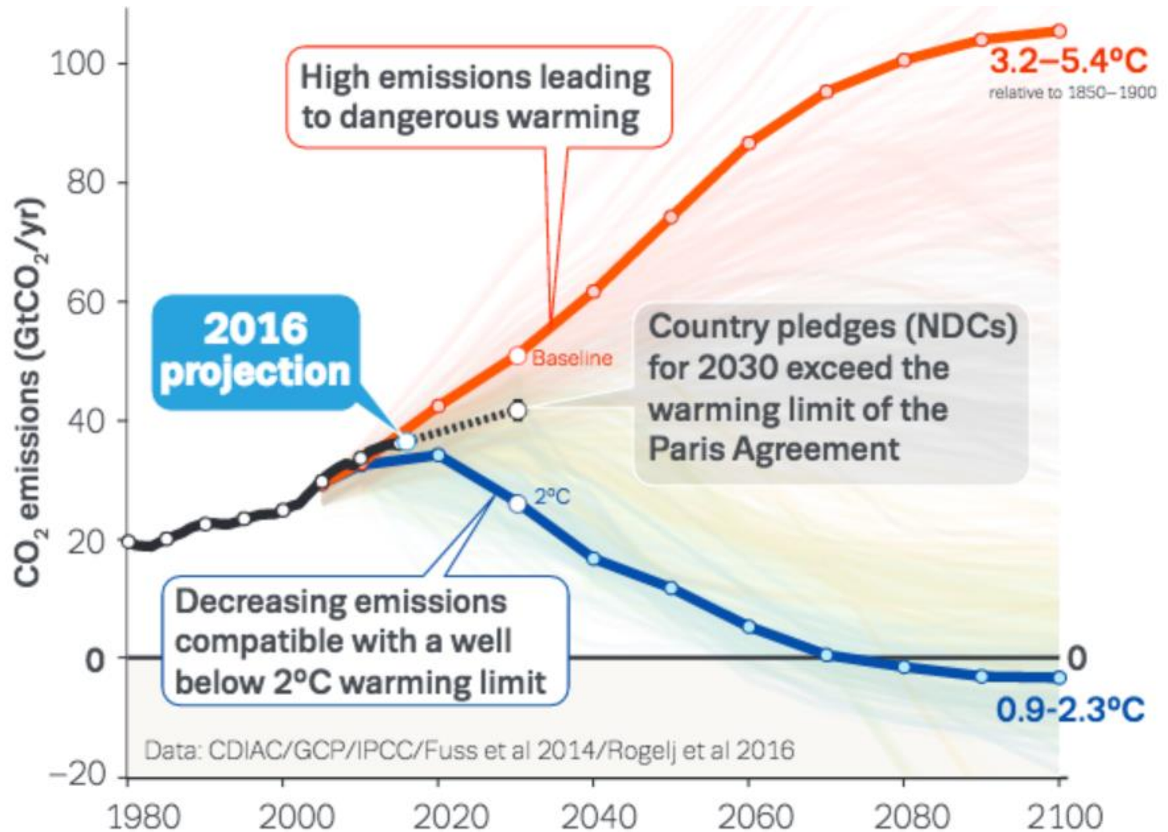

Fig. 3:Projection of global CO_2 emissions (R. Pidcock (2016) https://www.carbonbrief.org/what-global-co2-emissions-2016-mean-climate-change after Le Quéré, C. et al. (2016) based on Rogelj et al, (2016))

More efficient and faster reduction of CO2 emissions needed!

Simultaneous approach to Sustainable System Synthesis (SSS)

Basic governing principle of SSS is to select and adjust constitutive elements from the view of maximizing the system‘s overall sustainability

How?

By exploring to the maximal extent:

- Inherent interations and
- External interactions by widening system‘s borders

Simultaneous overall systems approach!

Cross-sectorial mass and energy intergration!

Circular economy!

System-wide supply network synthesis

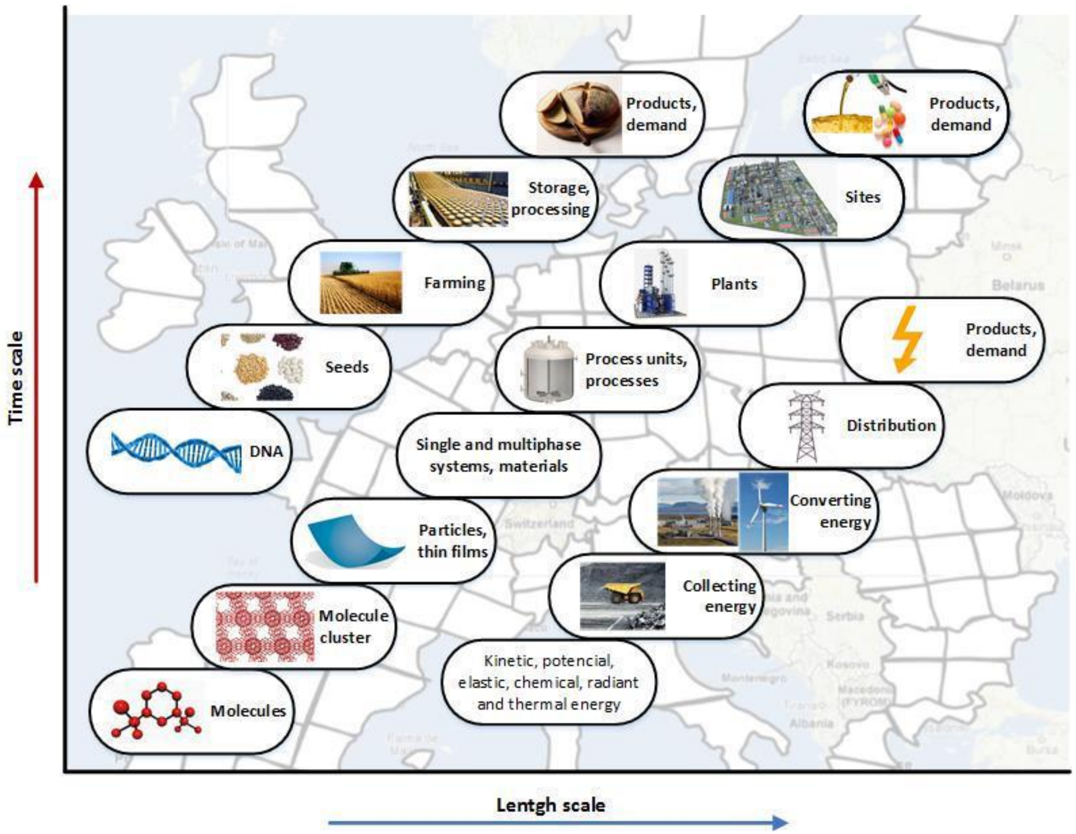

Fig. 4: System-wide supply network at the continental scale (Zore et al., 2018)

New alternatives and interactions give rise to WIN-WIN SOLUTIONS

Sustainability indicators and metrics

- Economic, environmental and social
- From qualitative to quantitative
- Widely vary in scope and scale
- At least 140 indicators (Singh et al., 2012)
- More than 500 efforts to develop quantitative indicators (Parris and Kates, 2003)
- Single indicators, Set of indicators, Composite indexes (weighting, normalisation, monetary-based)
- Different comprehension (different perspectives)

Environmental indicators

- Resource usage indicators, solid waste, material and energy intensity, product durability, etc. (Azapagic and Perdan 2000)
- Mid-point indicators of potential environmental impacts:
  - ✓ global warming potentials, acidification potentials, ozone depletion potentials, eutrophical potentials…
- End-point categories of impacts:
  - ✓ human health impacts in terms of disability adjusted life years, climate change, changes in biodiversity…
- Environmental footprints:
  - ✓ carbon, water, ecological, energy, nitrogen…
- Aggregated measures:
  - ✓ eco-indicator 99, Environmental Priority Strategy, eco-scarcity method, pollution index…
- Eco-cost (Vogtländer et al., 2010), eco-benefit and eco-profit (Čuček et al., 2012)

Social indicators

- Qualitative, quantitative and semi-quantitative
- Unemployment, wealth gap, number of people living below the poverty line, occupational health and safety, child labor, working hours, issues concerning discrimination, violation of human rights, corruption…
- Work environment footprint (DeBenedetto and Klemeš, 2009)
- Social indicators could be divided into ethics and welfare indicators (Azapagic and Perdan 2000)
  - Ethics indicators:
    - ✓ child labor, fair prices, corruption, intergeneration equity…
  - Welfare indicators:
    - ✓ income distribution, work satisfaction…

Sustainability indicators

- Only few integrate economic, environmental and social aspects
- Examples of composite indexes considering all three aspects:
  - ✓ Sustainability Performance Index (Krotscheck and Narodoslawsky 1996)
  - ✓ Human Development Index (UNDP 2000)
  - ✓ Genuine Progress Indicator (Cobb et al. 1995)
  - ✓ Eco-efficiency (Keffer et al. 1999)
  - ✓ Composite sustainable development index (Krajnc and Glavič 2005),
  - ✓ Composite sustainability performance index (Singh et al. 2007),
  - ✓ Dow Jones Sustainability Index (S&P Dow Jones Indices 2016)
  - ✓ Sustainability profit (Zore et al, 2017), and sustainability net present value (Zore et al, 2018),…
- ✓ Major advantages: multidimensionality, use of normalization and aggregation which are scientifically based (Singh et al. 2012).

Concepts

- Damage assessment
  - Conventional approach
  - Measure of direct harmful effects (footprints..)
- Prevention-based approach
  - Concept of eco-cost (www.ecocostsvalue.com/, Vogtländer et al., 2010)
- Prevention Cost-Benefit approach
  - Besides damage it consists of unburdens or benefits
  - Sustainability profit / sustainability net present value
    (Žan, Čuček, Kravanja, CACE 2017)

Selection of sustainable alternatives

1. Incomplete measurements for sustainability is one of the major limitations of LCA methodology

   Consequences: poor or wrong solutions and decisions!

2. More advanced concept and measurements are needed

   a) Indirect unburdening effects on the environment have to be considered too, besides the direct burdening one

   b) Social dimension has to be considered too, besides economic and environmental one

   c) Could these dimensions be expressed by terms of equal units, to obtain appropriate trade-off solutions

   d) Circularity indicators should also be considered in order to reduce the consumption of resources

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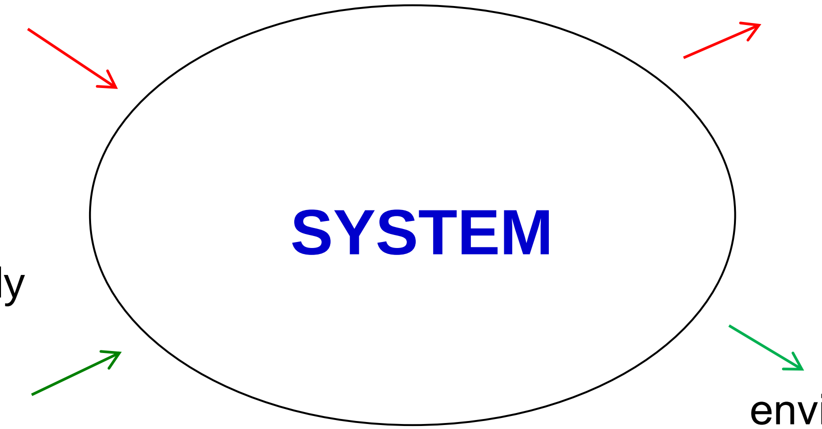
LCA-based System Synthesis: Direct and Indirect Effects

Raw materials, which **burden** the environment if they are processed

DIRECT impacts (BURDEN)

Products, which **burden** the environment related to processing, disposal, and transportation

DIRECT impacts (BURDEN)



Raw materials, which mainly **unburden** or benefit the environment , e.g. utilization of waste rather than deposit

INDIRECT impacts (UNBURDEN)

Products, which also **unburden** or benefit the environment due to products‘ substitution

INDIRECT impacts (UNBURDEN)

TOTAL effects = INDIRECT (unburdenning) + DIRECT (burdening) effects

Eco-profit(€/yr) = Eco-benefit (unburdenning) - Eco-cost (burdenning)

LCA-based Synthesis Approach

Sustainability profit (€/yr) = Economic profit + Eco-profit + Social profit

$$\max SP = P^{\text{Economic}}(y,x) + P^{\text{Eco}}(y,x) + P^{\text{Social}}(y,x)$$

$$\text{s.t} \quad h_{ls}(x,y) = 0$$

$$g_{ls}(x,y) \leq 0$$

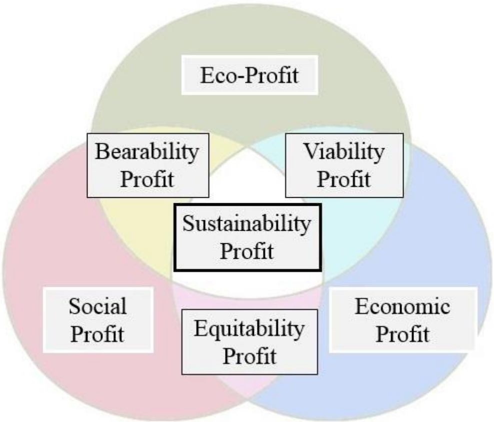
$$B_{ls}y + C_{ls}x \leq b_{ls}$$

$$x \in X = \{x \in R^n : x^{LO} \leq x \leq x^{UP}\}$$

$$y \in Y = \{0,1\}^m$$

$$\forall\, l \in Levels_S$$

$$\forall\, S \in Supply\ chains$$



Conclusions

Significant resource and emission reduction can be achieved by applying:

- Composite sustainability objectives such as Sustainability profit where optimal trade-offs between economic efficiency, preventing burdening of environment, and creating new job positions can be obtained
- Integrated simultaneous approach across system-wide supply networks
- Cross-sectorial mass and energy integration
- Other principles of circular economy

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FNSNF – Fonds National Suisse de la Recherche Scintifique: SCOPES

Thank you

Minimisation of Resource Intake and Emissions in the era of the Instantaneous Gratification

Dr Aoife Foley

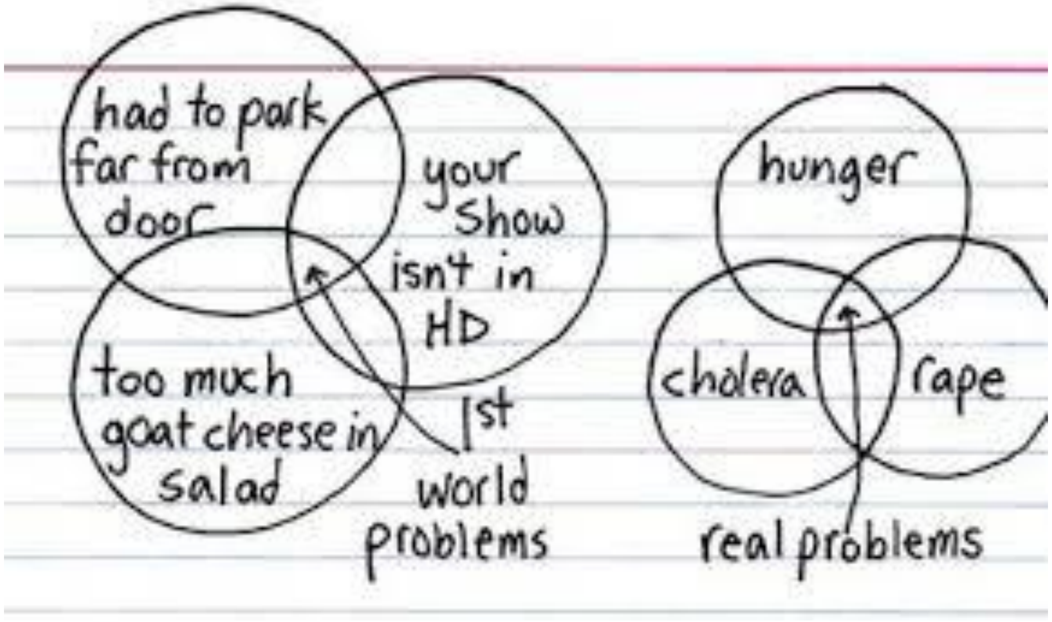
Queen's University Belfast

Push & Pull

- The ever increasing demand for the basic necessities of life (i.e. fresh air, food, sanitation, energy and water) and the drive for ‘modern’ technology and lifestyles (e.g. Wi-Fi, fast cars, beauty products, paper cups, Botox, fake tans etc.) by young and old alike in developed and developing countries is leading to a fast spiral of ‘disposable’ living.

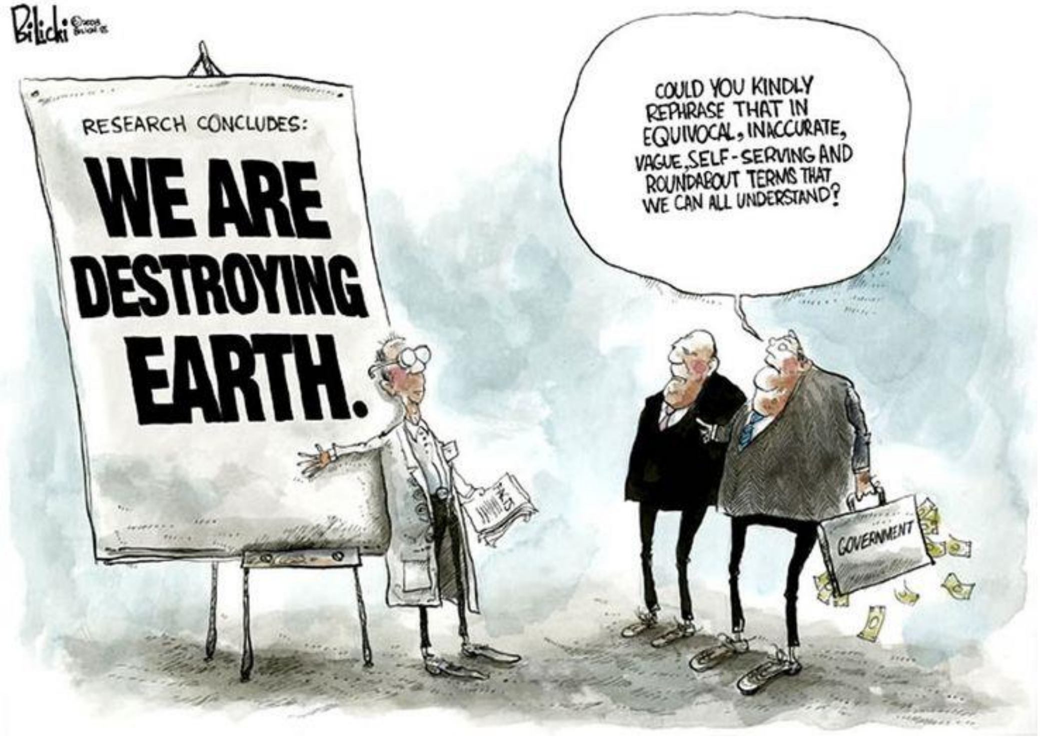
Gratification

- Is this disposable instantaneous gratification attitude in some strata of society really the root cause of continued global warming, extreme weather events, economic migration and geopolitical and economic uncertainties?



Balance

- How can the needs of the individual, society and the planet be proactively balanced such that the aspirations of all are met sustainably considering social equity, economics and the environment?



Commitment

- In an era of instantaneous millisecond knee jerk reactions and responses on social and mainstream media, is the genuine commitment of the individual to the whole missing?

Roadmaps

- Despite the best attempts of politicians and regulators and the warnings of the world foremost thinkers, scientists and engineers on the importance of sustainable development the spiral of the 'self' seems to continue unabated.

Integrated Systems

- Renewable energy technology, greenhouse gas emissions reduction targets and energy efficiency targets in a multi-systems-interaction and -integration approach have a vital role to play, but what is missing in terms of human commitment?

Thank you!

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Key Energy Ratios

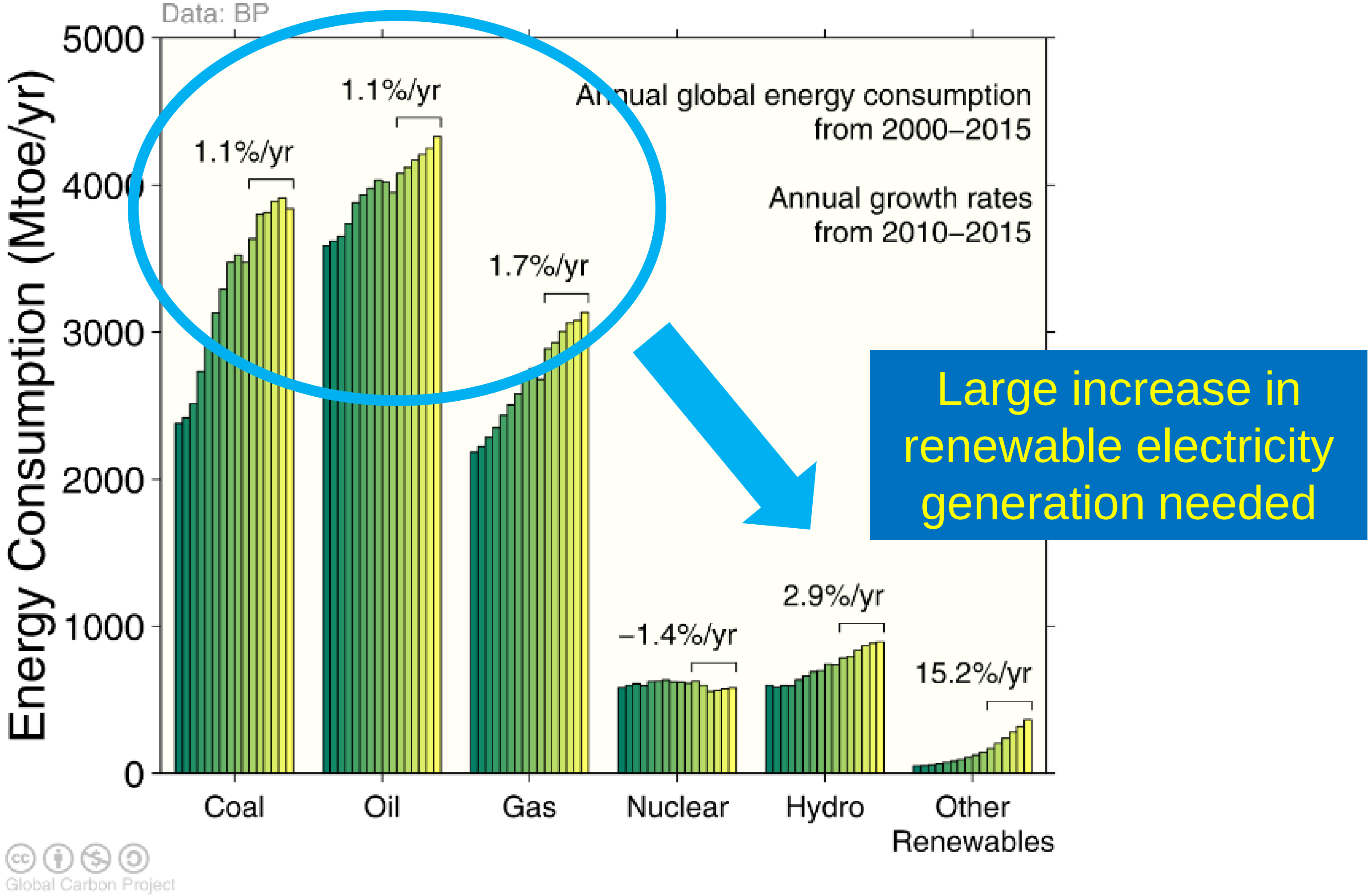
Michael R. W. Walmsley

Energy Research Centre,
School of Engineering,
University of Waikato,
Hamilton, New Zealand

SDEWES 2016

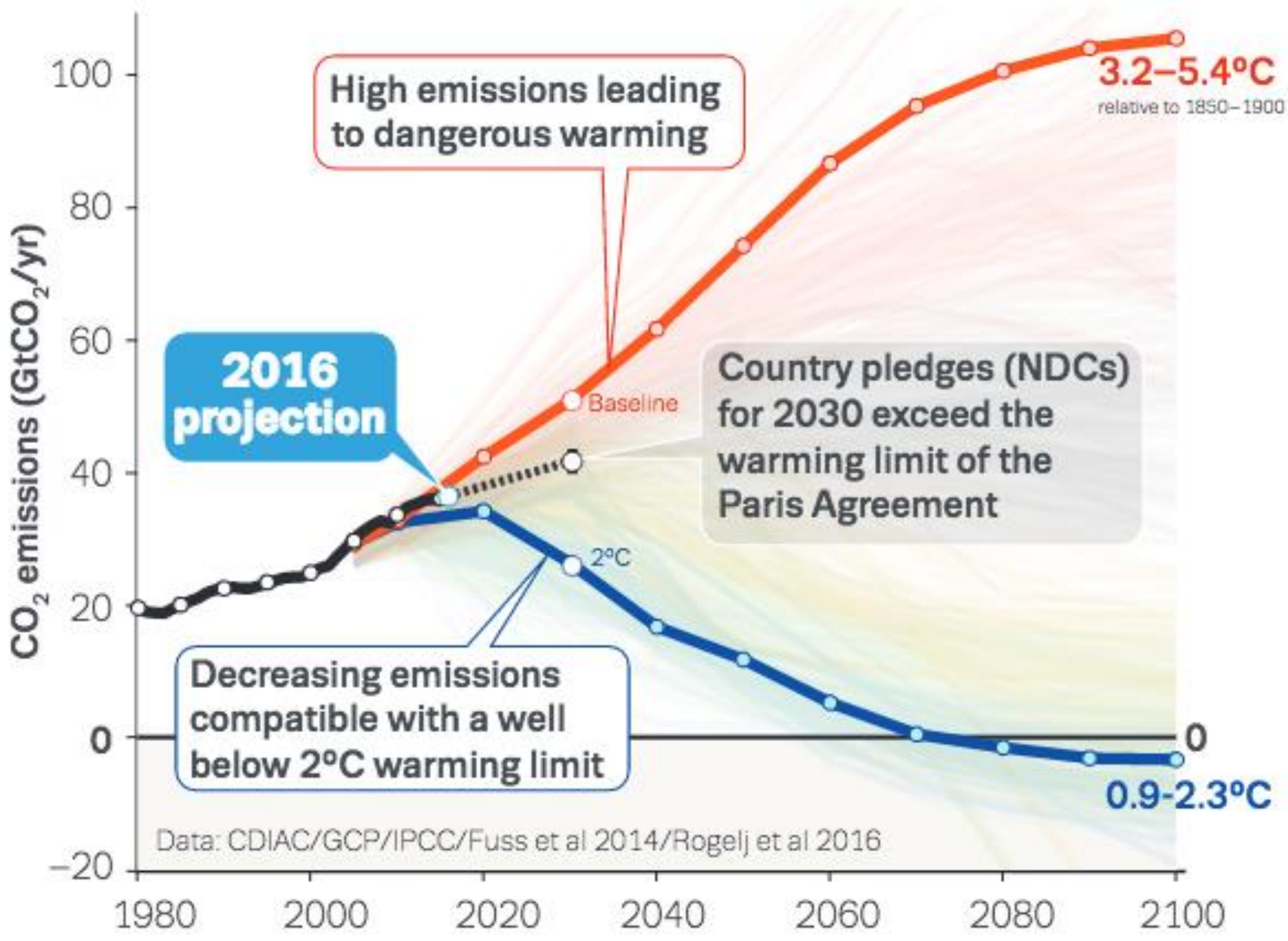
Global Energy Challenge

Reduce fossil fuels from 81%



Source: BP 2016; Jackson et al 2015; Global Carbon Budget 2016

Global CO_2 emissions reduction challenge



Political Reality

Recent NZ election, Sept 2017

Labour

Won 36% of the vote plus Greens 6% = 42%

Current NZ Government since 2008

We will **develop a plan** to reduce emissions while **growing the economy** and jobs.

We will **not place unnecessary costs on business.**

There is no point in shutting down businesses in NZ, only for them to go offshore to less environmentally friendly places.

Won 46% of the vote

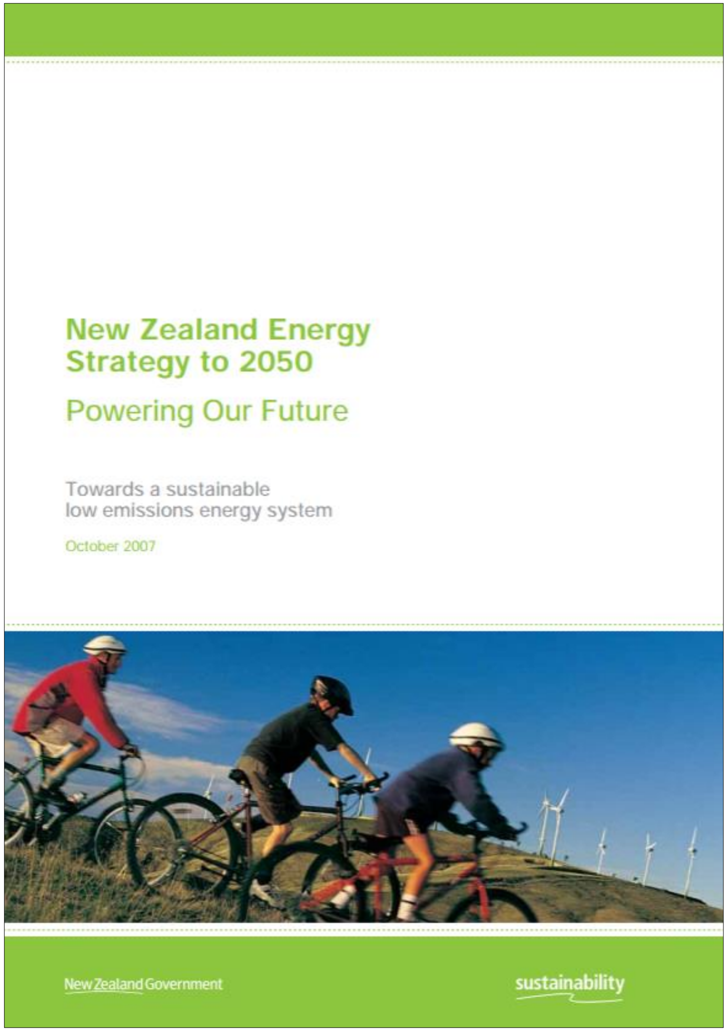
'Fake News'


INFOWARS
RADIO SHOW
NEWS
VIDEOS
STORE
TOP STORIES
BREAKING NEWS
REPORT: NO GLOBAL WARMING FOR 215 MONTHS
So-called "pause" in global warming has baffled climate scientists
Michael Bastasch | Daily Caller - SEPTEMBER 8, 2014
Comments


THE CLIMATE CHANGE HOAX
THE BIGGER THE LIE
THE MORE WILL BELIEVE IT
(WHICH IS WHY THEY WANT TO SILENCE THE OPPOSITION)
DAVIDICKE.COM


THE DONALD TRUMP INTERVIEW
"I'M NOT A BIG BELIEVER IN GLOBAL WARMING"
CNN
9:17 AM ET

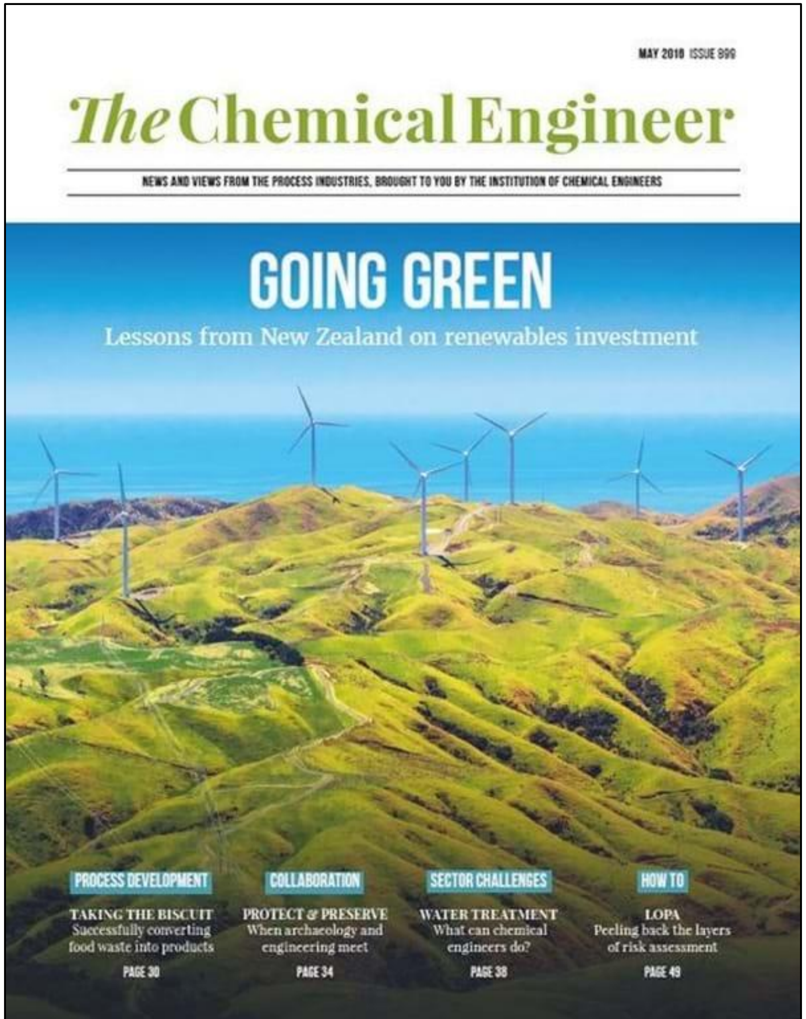
New Zealand Energy Strategy Document



Written by a person from the Ministry of Environment.

Qualifications:
Major in communications !!!

Making our voice heard



General article for non-specialists

Won global best paper award in 2016

Concept of ‘Energy Return on Investment’ (EROI) explained and illustrated

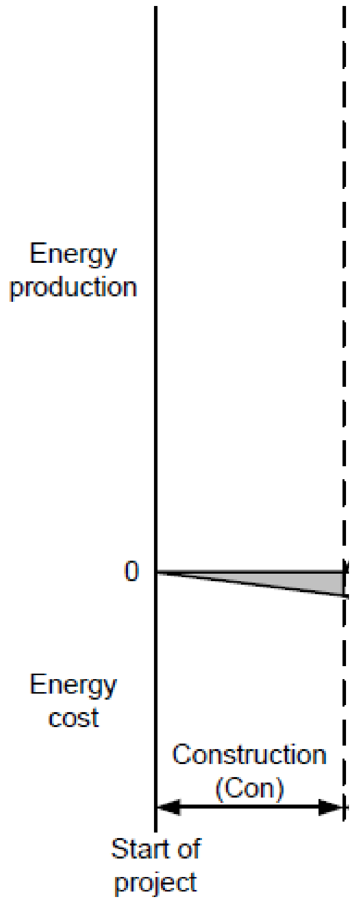
Three Energy Ratios

- **Energy Return on Investment** - EROI (Hall, 1984)
  - Various definitions, systems boundaries
  - How much return on investment?

- **Energy Payback Time** – EPT (Palz & Zibetta, 1991)
  - How fast is the repayment of energy?

- **Primary Energy Factor** – PEF (Fritsche and Greß, 2015)
  - How much resource is consumed?

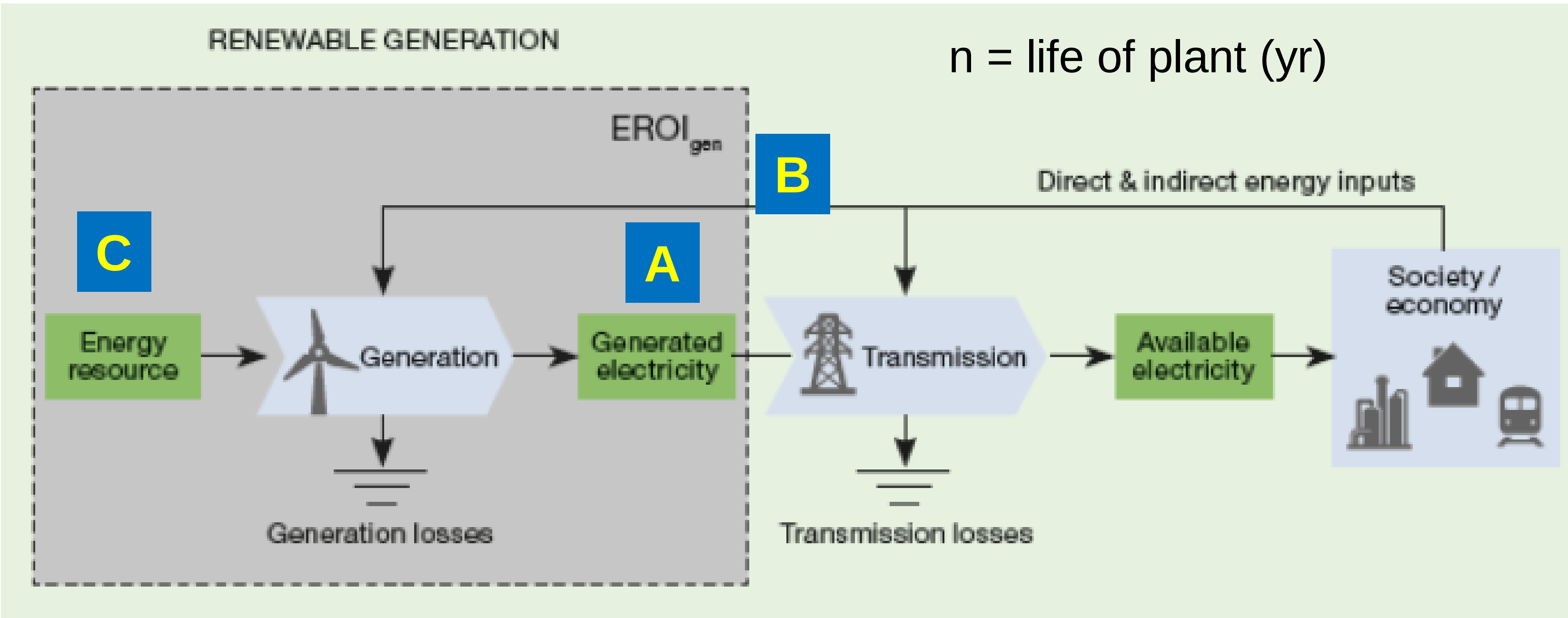
Energy Return on Investment (EROI)



$$\mathrm{EROI} = \frac{A}{B}$$

Walmsley, M.R.W., Walmsley, T.G., Atkins, M.J., Kamp, P.J.J., Neale, J.R., 2014. Minimising carbon emissions and energy expended for electricity generation in New Zealand through to 2050. Applied Energy 135, 656–665.

Energy Ratios - Renewables

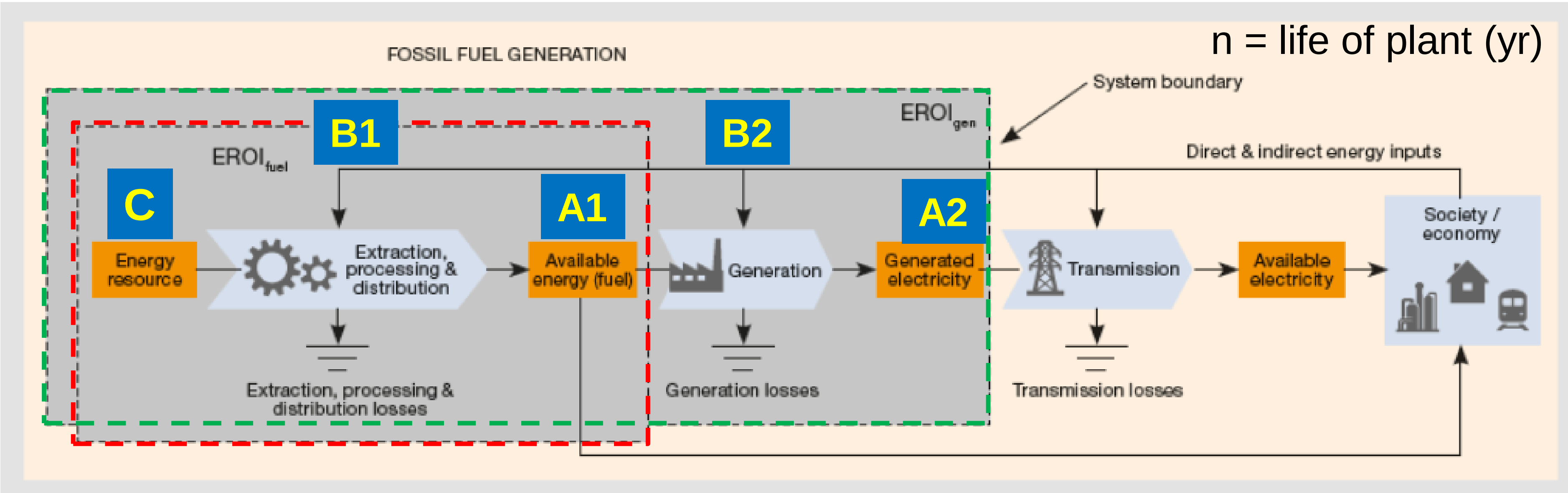


Energy Return on Investment **EROI = A / B**

Energy Payback Time **EPT = B / (A/n)**

Resource Utilisation Factor **RUF = A / (B + C)**

Energy Ratios – Non Renewables



Energy Return on Investment $EROI_{fuel} = A1 / B1$

$EROI_{gen} = A2 / (B1 + B2)$

Energy Payback Time $EPT_{gen} = (B1 + B2) / (A2/n)$

Resource Utilisation Factor $RUF_{gen} = A2 / (B1 + B2 + C)$

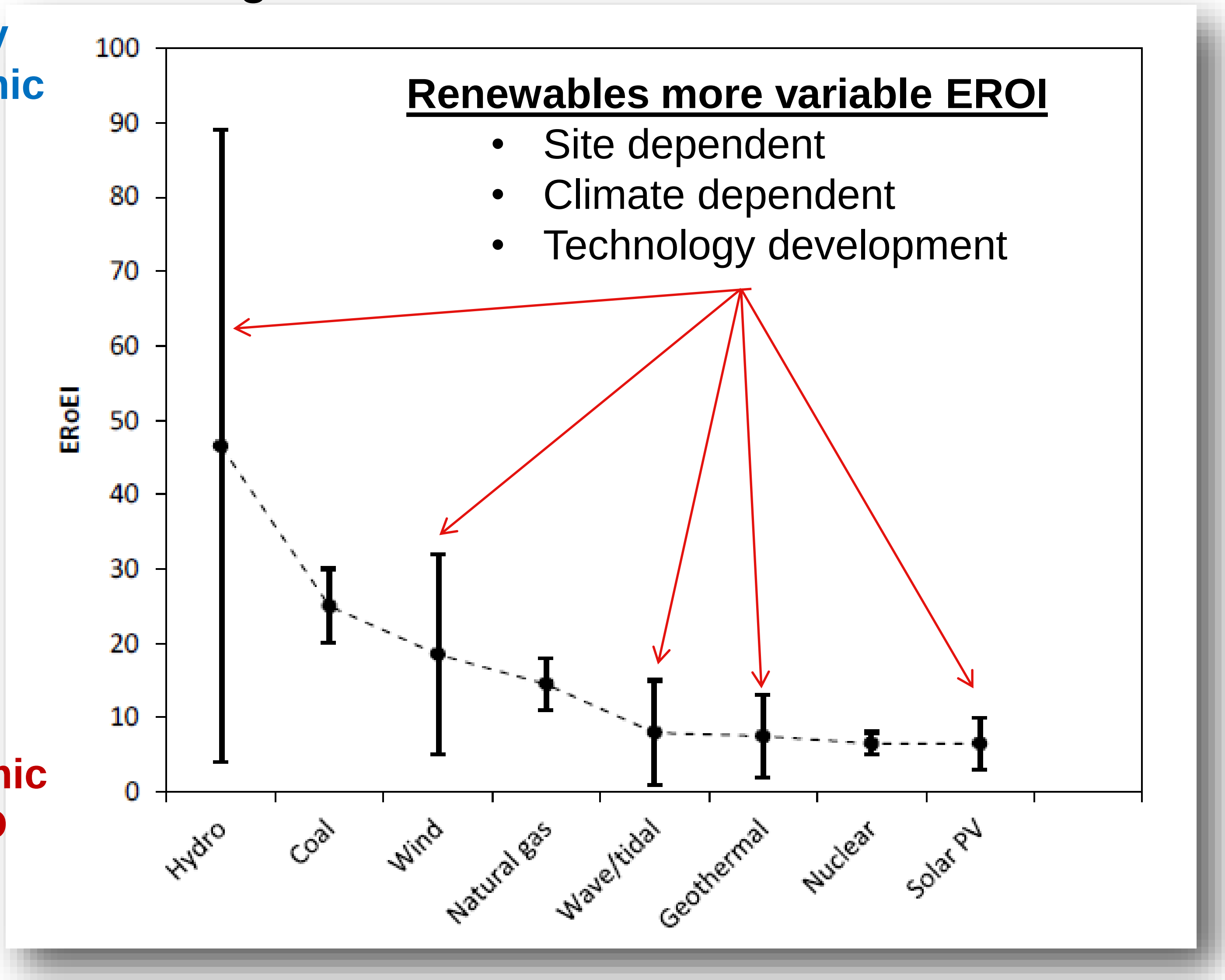
ERoEI Energy Resource Comparison

High EROI more favourable economics

Highly Economic EASY

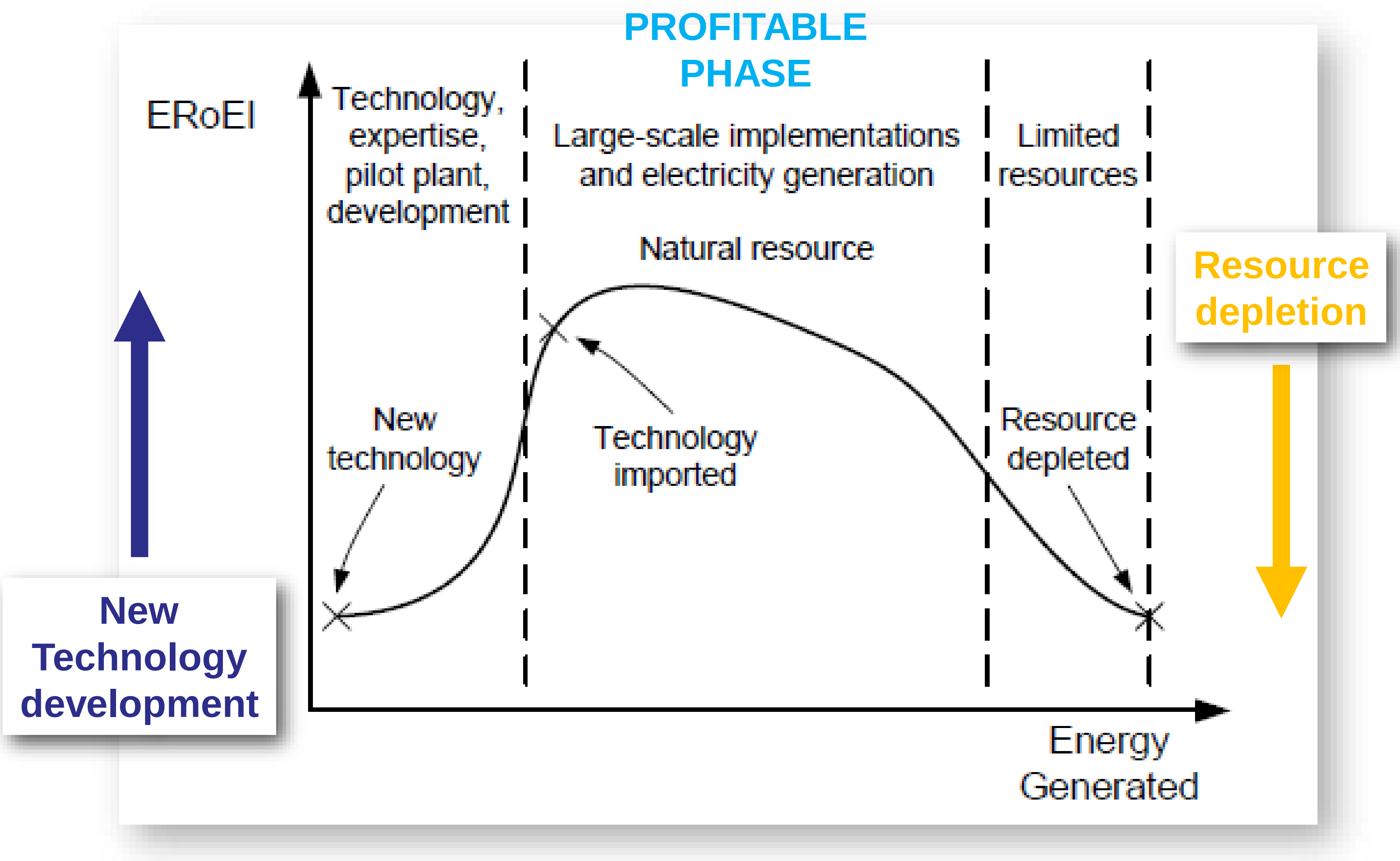
A / B

Less Economic HARD



[Gupta & Hall 2010]

EROI Resource Life Cycle



Big challenge for renewables

Time value of energy

Lots of energy has to be invested at the start of project

Where EROI is low e.g. Solar EROI <10, energy pay back can be many years

GHG emissions peak arises from new installations

How does the EROI relate to Emissions?

Relating EROI to GHG Emissions for electricity generation

Emissions factor electrical

Emissions factor thermal

Emissions factor fuel

$$F_{GHG} = \left[\left(EF_{el} \left(\beta_{om(el)} \right) + \frac{EF_{th}}{\omega} \left(1 - \beta_{om(el)} \right) \right) \frac{1}{EROI_{ext}} + EF_f \frac{1}{\eta_0} \right] n \dot{E}_{net}$$

GHG emissions from energy for equipment, construction, M&O

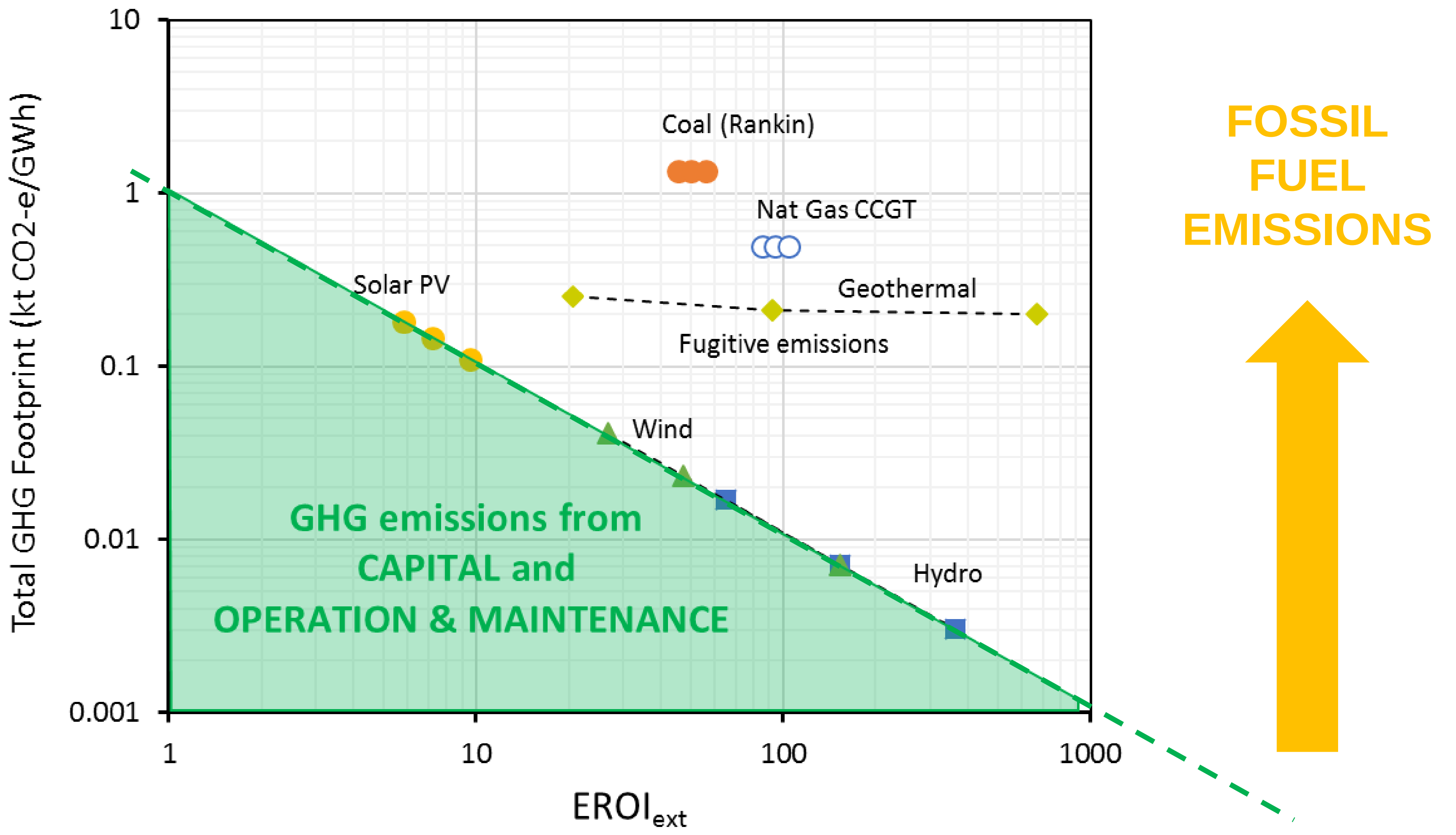
GHG for fuel

Total GHG emissions footprint

Net energy out

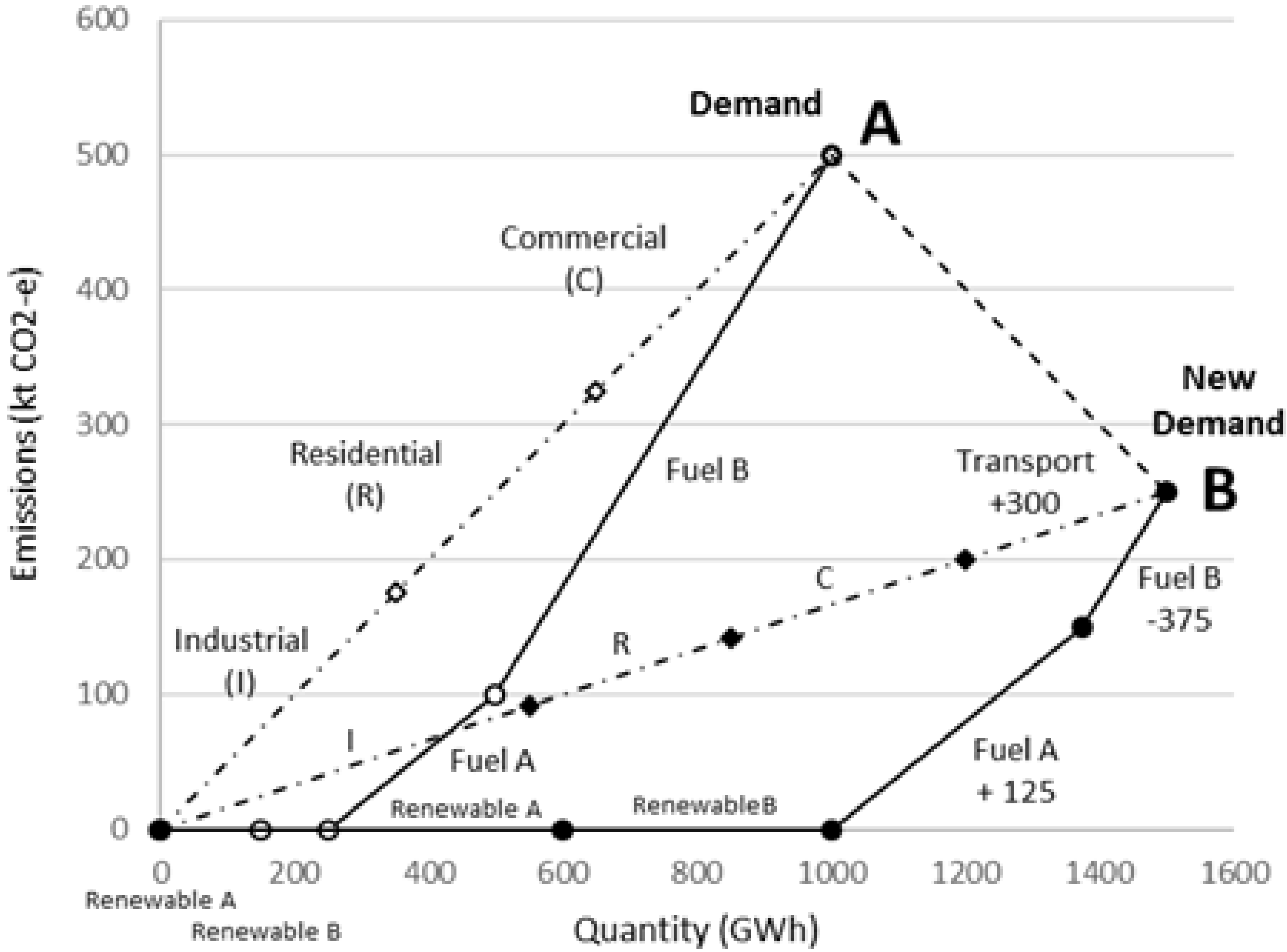
SDEWES paper Sunday 10:20am Room A

Relationship between EROI & GHG Footprint

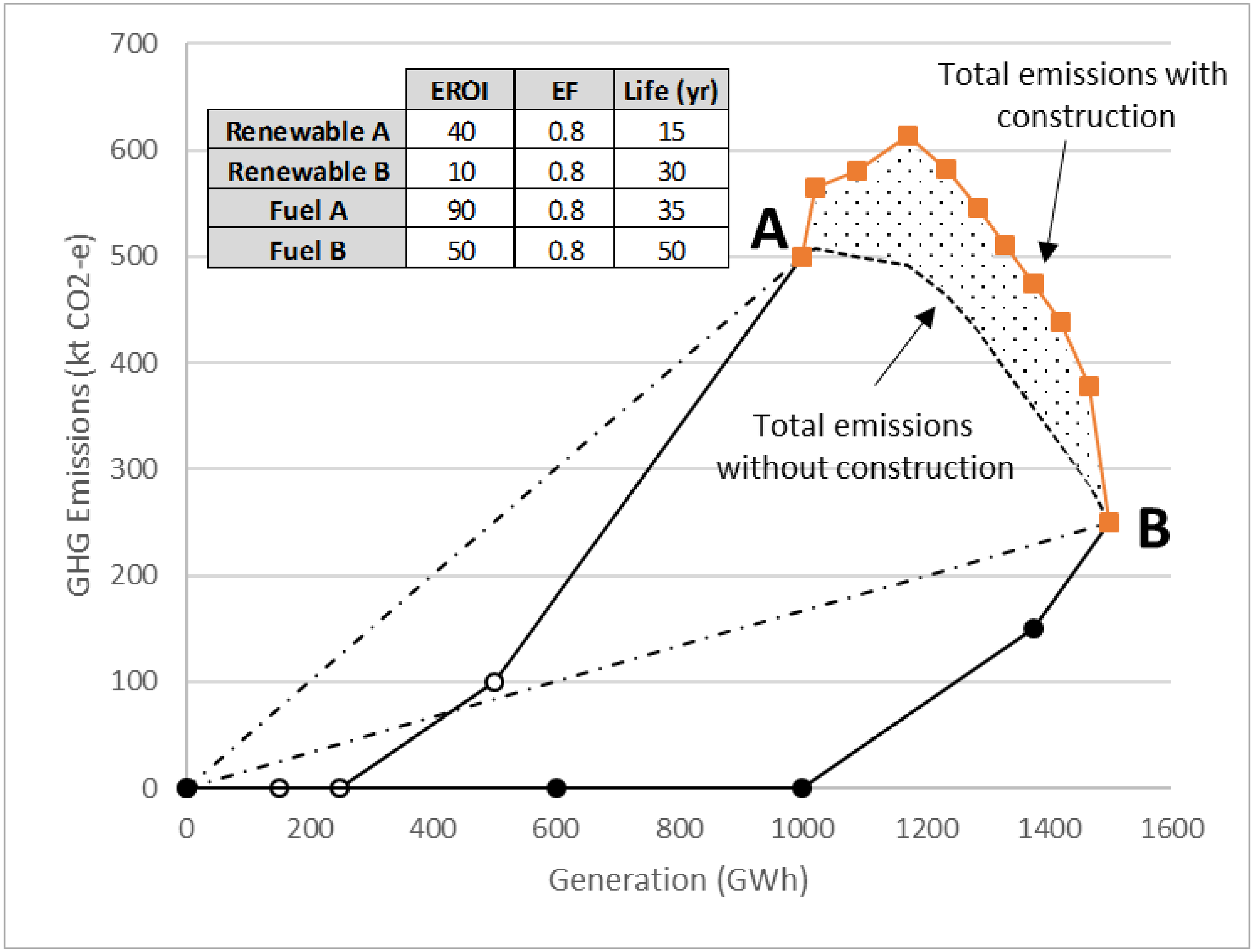


So what???

GHG emissions scenario analysis



GHG emissions peak



	EROI	EF	Life (yr)
Renewable A	40	0.8	15
Renewable B	10	0.8	30
Fuel A	90	0.8	35
Fuel B	50	0.8	50


Thank You!
Questions?

Towards Sustainable Sea Transportation

Yee Van Fan

[a]Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT Brno, Technická 2896/2, 616 69 Brno, Czech Republic.

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
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MINISTRY OF EDUCATION,
YOUTH AND SPORTS

12th Conference on Sustainable Development of Energy, Water and Environment System (SDEWES2017),
Dubrovnik, Croatia, 4-8 October 2017

Transportation

- One of the largest GHG contributors

- 26 % of the total GHG emissions, US (EPA, 2017)

EPA (United States Environmental Protection Agency), 2017. Sources of greenhouse gas emission. <www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions> accessed 8 April 2017.

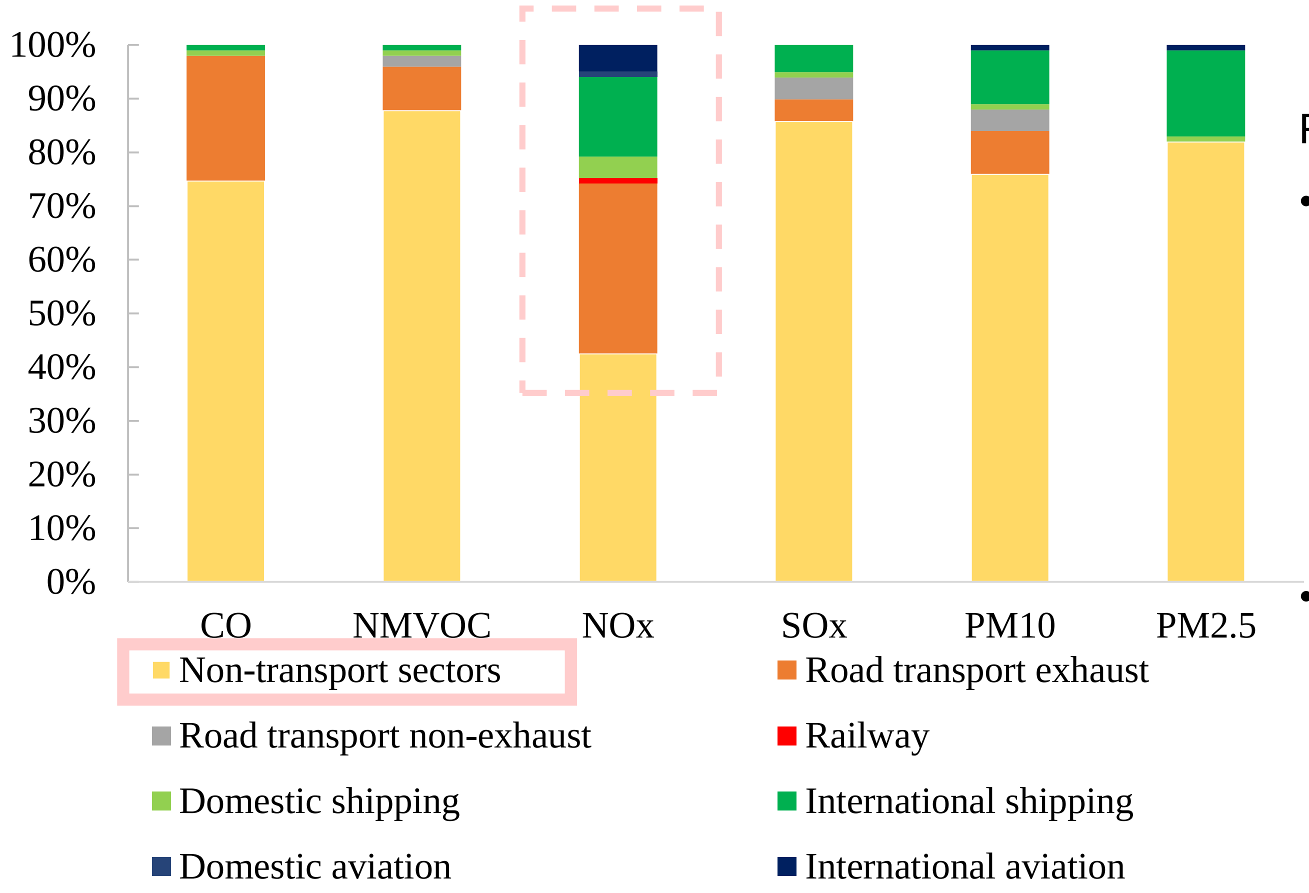
- 23.2 % of EU-28 (Eurostat, 2016)

Eurostat, 2016. Greenhouse gas emission statics. <ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics> accessed 8 April 2017.

- Responsible for other negative externalities (Eurostat, 2017).

Eurostat, 2017. International trade in goods. ISSN 2443-8219. < ec.europa.eu/eurostat/statistics-explained/index.php/International_trade_in_goods> accessed 13 June 2017.

Transport vs Non-Transport



Remarks:

- The concern on the **pollutants** in **optimisation study** (e.g. waste to energy planning, freight transports mode choice) is relatively **less established**.
- LCA Distribution study: **GWP** relatively **common than POCP**

Dataset from EEA (European Environment Agency), 2016. Emissions of air pollutants from transport. <www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-pollutants-4 > accessed 20 June 2017.

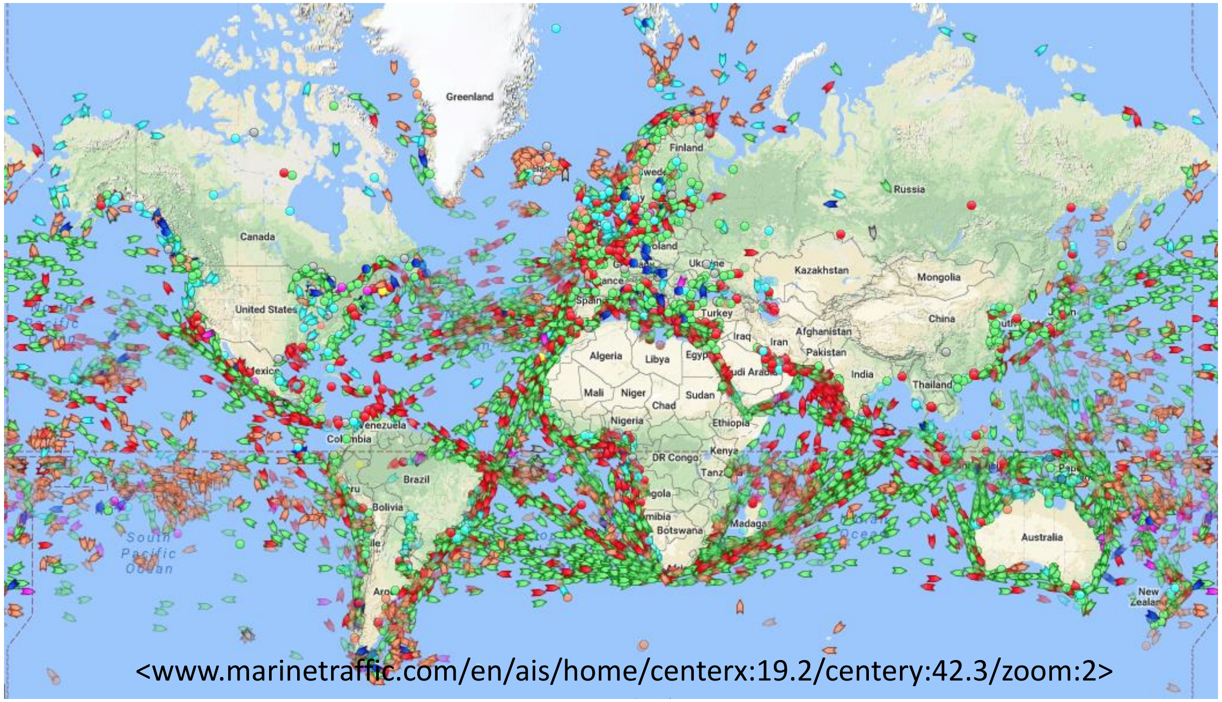
Transportation: Ship

- Mainly focusing on land transportation, the road vehicles.
- More than 80 % of world trade is carried by shipping industry (UNCTAD, 2015)

UNCTAD (United Nations Conference on Trade and Development), 2015. Review of maritime transport, United Nations Publication, eISBN 978-92-1-057410-5.

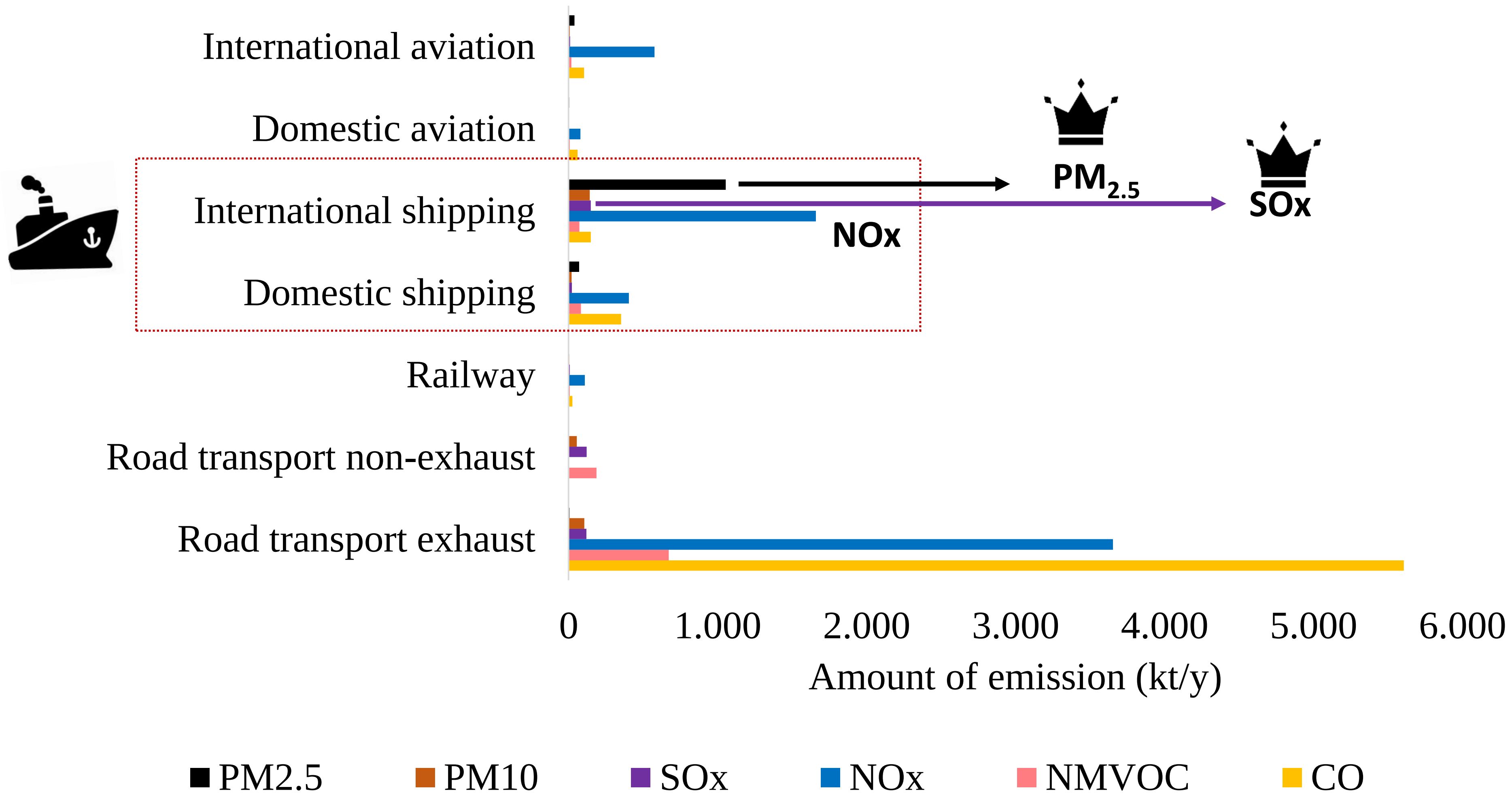
- Likely continuing to increase due to the increase of global scale trade.

Real-time ship traffic



Green=Cargo, Red= Tankers

Transportation: Ship



Dataset from EEA (European Environment Agency), 2016. Emissions of air pollutants from transport. <www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-pollutants-4 > accessed 20 June 2017.

Emission Factor-Example*

- **CO_2/t-km:** Truck= **348** g/tkm, Ship= **4**g/tkm

	Emission factor (g/ tkm)	
Pollutants	Road Transport (Truck)	Sea Transport (Ship)
SO_x	**0.00175**	**0.091**
NO_x,	0.127	0.033
$PM_{2.5}$	**0.00136**	**0.00187**
CO	0.272	0.0402

- VOCs, lead, PM_{10}, PM>10 etc

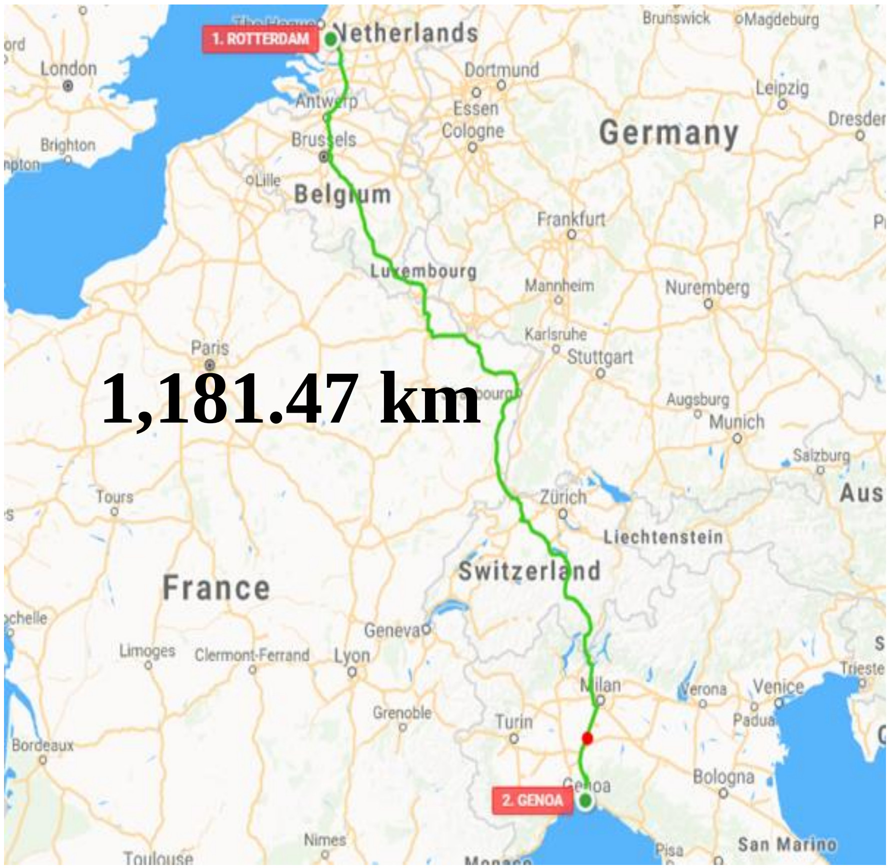
Ecoinvent Database

<www.nature.com/>

</twitter.com/KNectMaritime>

Distance

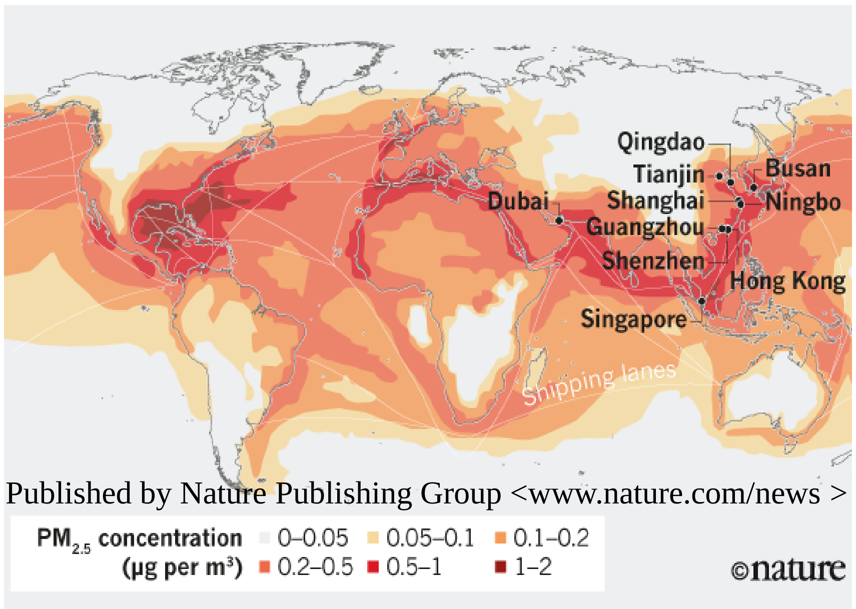
Example: Rotterdam to Genoa

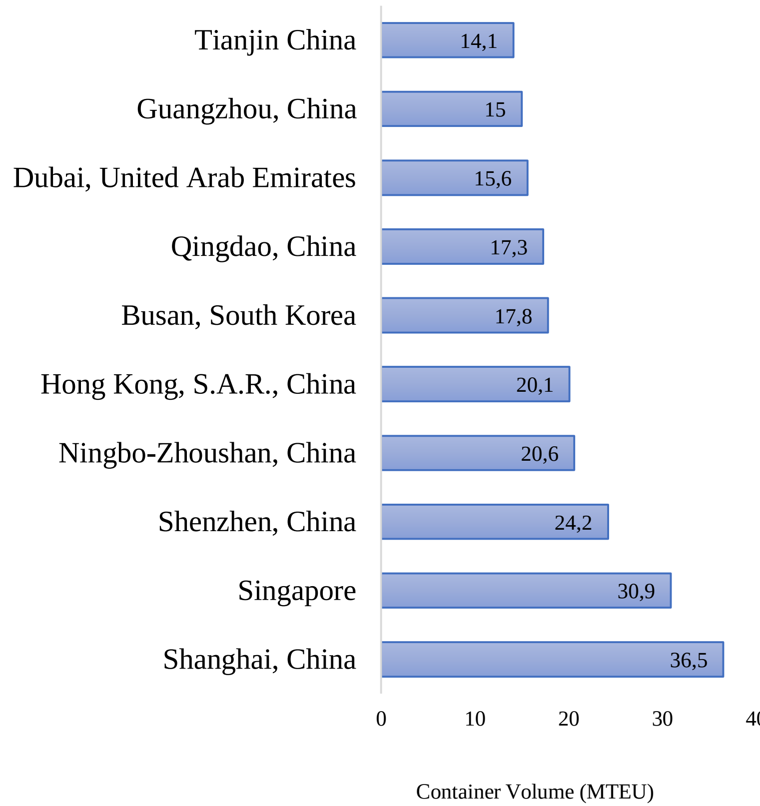


Presented by <www.searates.com/reference/portdistance/>, Google maps

Concentration at Place

Dirty Ten





Asia Weekly, 2016. Shipping's dirty secrets by Marc Lajole. <www.projects. asiaweekly.com/shippings-dirty-secrets/> accessed 12 April 2017.

Wan, Z., Zhu, M., Chen, S., Sperling, D., 2016. Pollution: three steps to a green shipping industry, Nature. <www.nature.com/news/pollution-three-steps-to-a-green-shipping-industry-1.19369> accessed 8 April 2017.

Freight

- Method and measurement of emission ✓
- Assessment **approach/ framework/ methodology** for decision making needs more development. (Environmental issues vs time vs cost vs flexibility/frequency vs reliability/safety)

Remarks

- 5 issues should be considered towards **a better assessment** for sustainable sea transportation:

General

1. Optimisation study/decision making: Environmental sustainable solution= ↓ GHGs or only CO_2 emission.

Freight Transport- Ship

2. Inland or international shipping- not commonly include in LCA (distribution stage).

You cannot manage what you cannot measure by Deming (2000)

Remarks

3. The emissions factors of CO_2 is much lower but it might not for the other harmful pollutants (e.g. SO_x). A longer distance may be needed by ship but it has a larger capacity

4. The high concentration at one place (big port cities) could significantly affect the local air quality and human health.

5. The impact of other activities such as ship scrapping, container loading, unloading, distribution also contribute to the pollution. The ship engines are not always turn off at the berth.

Air emission impact in optimisation study- consider both GHG and the air pollutants in an overall system

- Especially: Transportation mode, Biomass energy etc.
- Methodology- Criteria, boundary, interaction/ relationship between GHG and air pollutant
- Minimise the potential of footprint shifting
- Support more appropriate decision-making.

Acknowledgement

To the EC project Sustainable Process Integration Laboratory – SPIL funded as project No. CZ.02.1.01/0.0/0.0/15_003/0000456, by Czech Republic Operational Programme Research and Development, Education, Priority 1: Strengthening capacity for quality research and by the collaboration agreement with the The University of Manchester, **UK**, Universiti Teknologi Malaysia, **Malaysia**, University of Maribor, **Slovenia**, Hebei University of Technology, **China** and Pázmány Péter Catholic University, **Hungary**, Fudan University, **China** based on the SPIL project.