Which Research and Innovation for the Anthropocene Era?

An Ecological Transition Initiative Example

Prof. David Bol & ECS group

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UCLouvain ISIT Institute for Sustainable IT

EN MIEUX www.enmieux.be

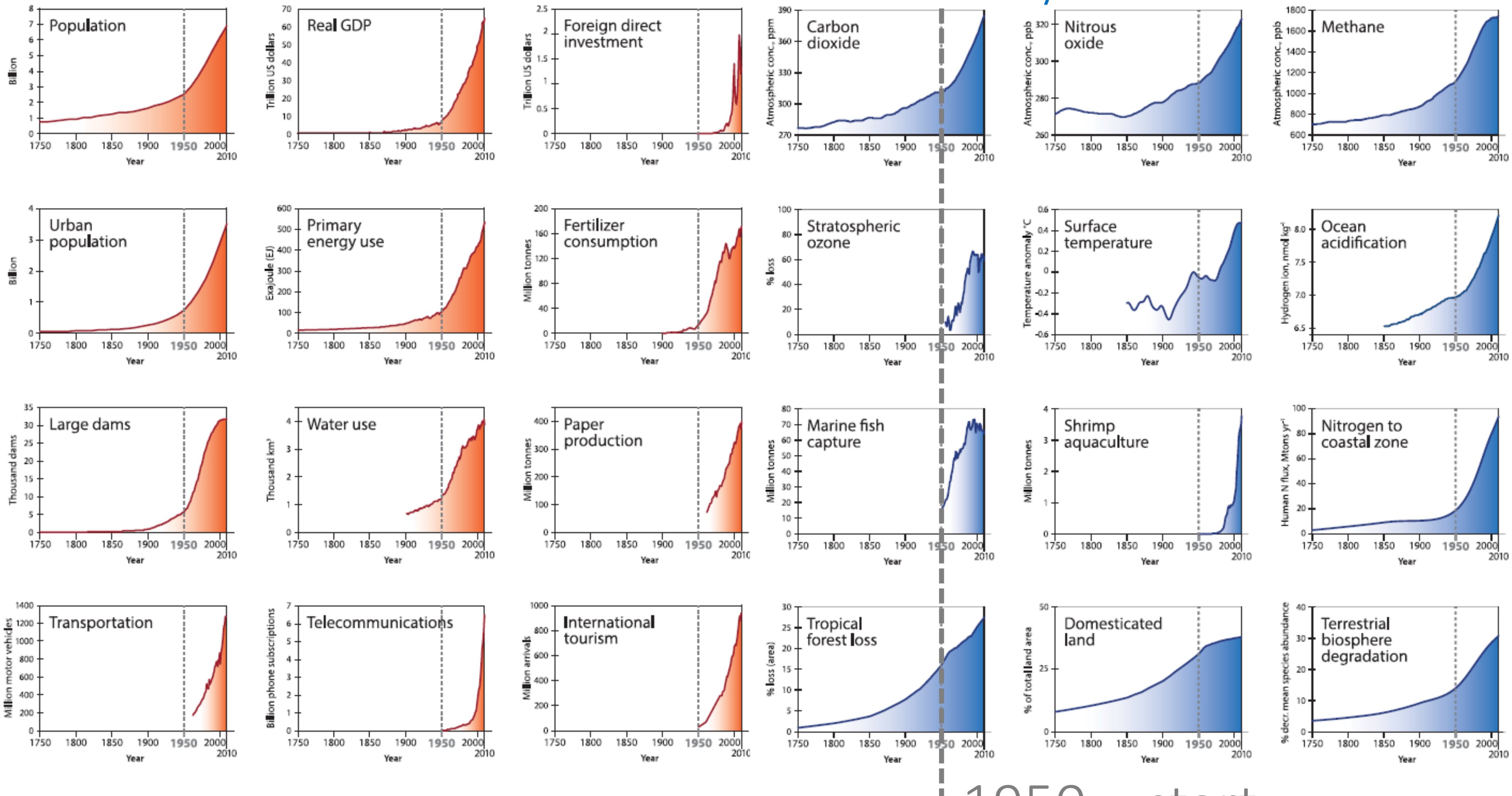
FEDER UNION EUROPEENNE Wallonie

LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

The Great Environmental Acceleration

Socio-economic indicators

Earth-system indicators



1950 = start of the Anthropocene

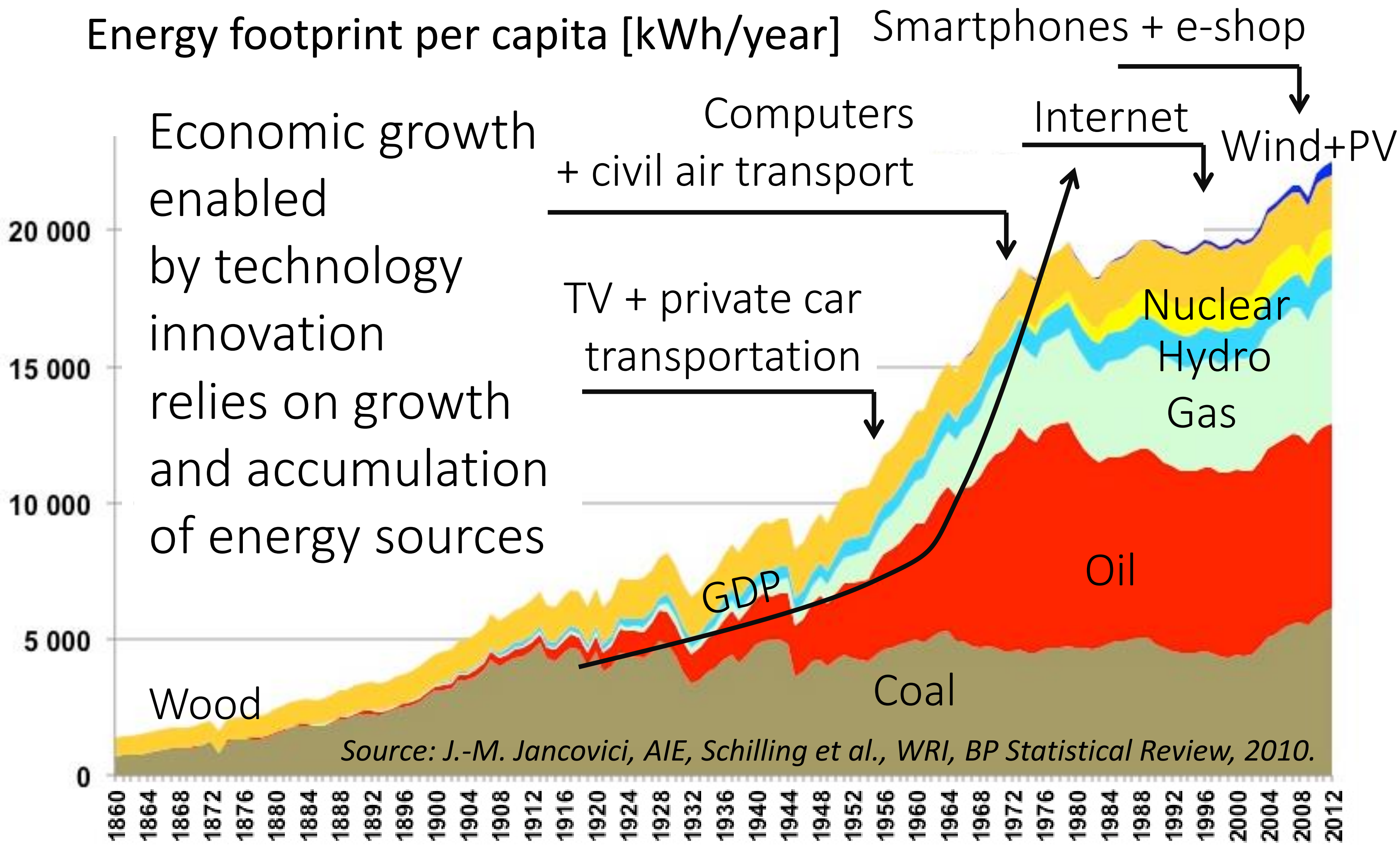
[W. Steffen et al, « The trajectory of the Anthropocene: The Great Acceleration », in Anthropocene Review, 2015]

Technological progress in the XXth century

Prof. Robert J. Gordon

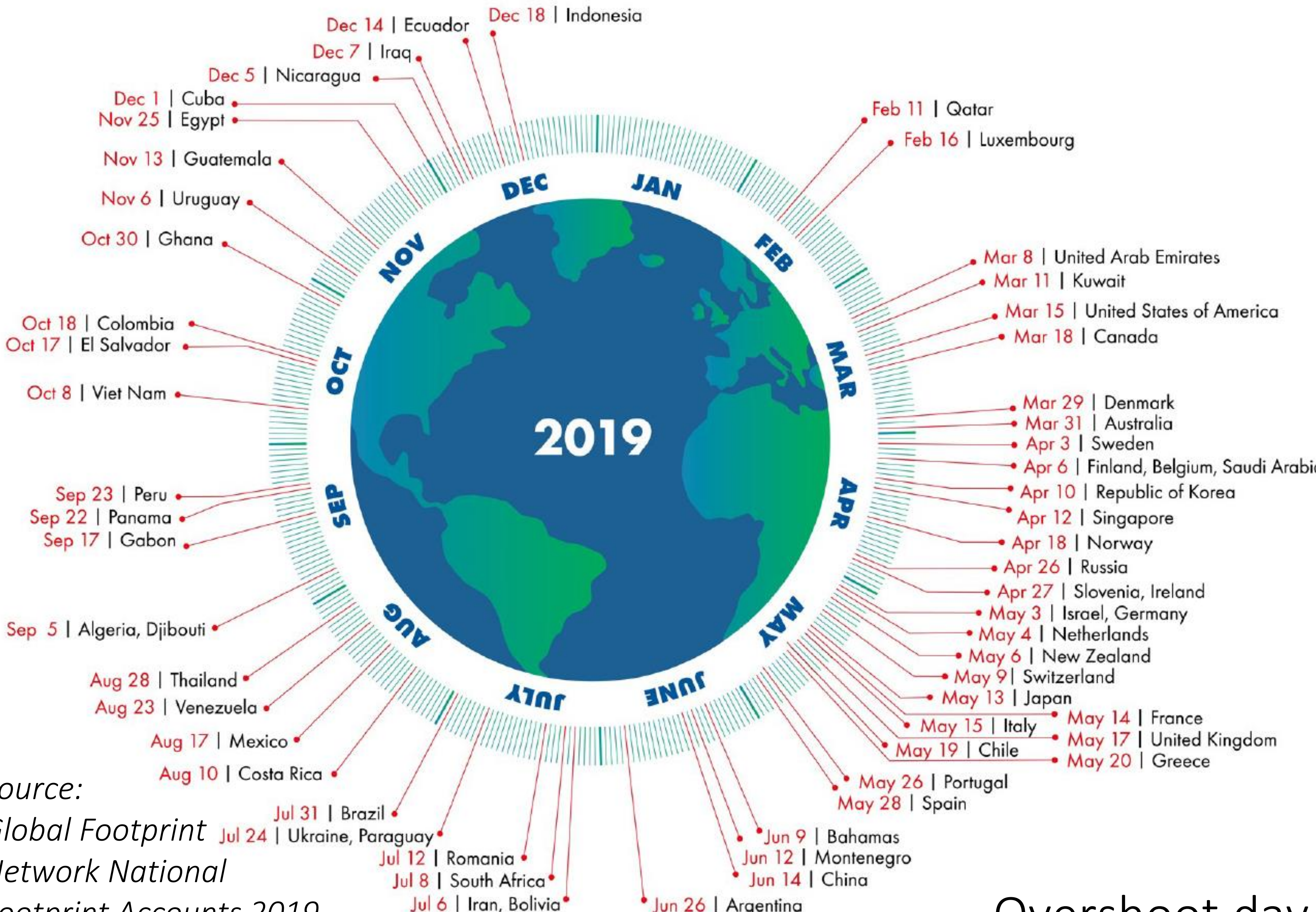
- The "Great Inventions of the 20th century":
  - water system,
  - combustion engine, electricity,
  - chemistry/drugs,
  - information and communication technologies,
- Great benefits for humanity:
  - Economic growth (+2%/year average),
  - Improvement of living standards,
  - Increase of the life expectancy,
  - Access to knowledge, information and mobility.

The Great Technical Acceleration



Source: J.-M. Jancovici, AIE, Schilling et al., WRI, BP Statistical Review, 2010.

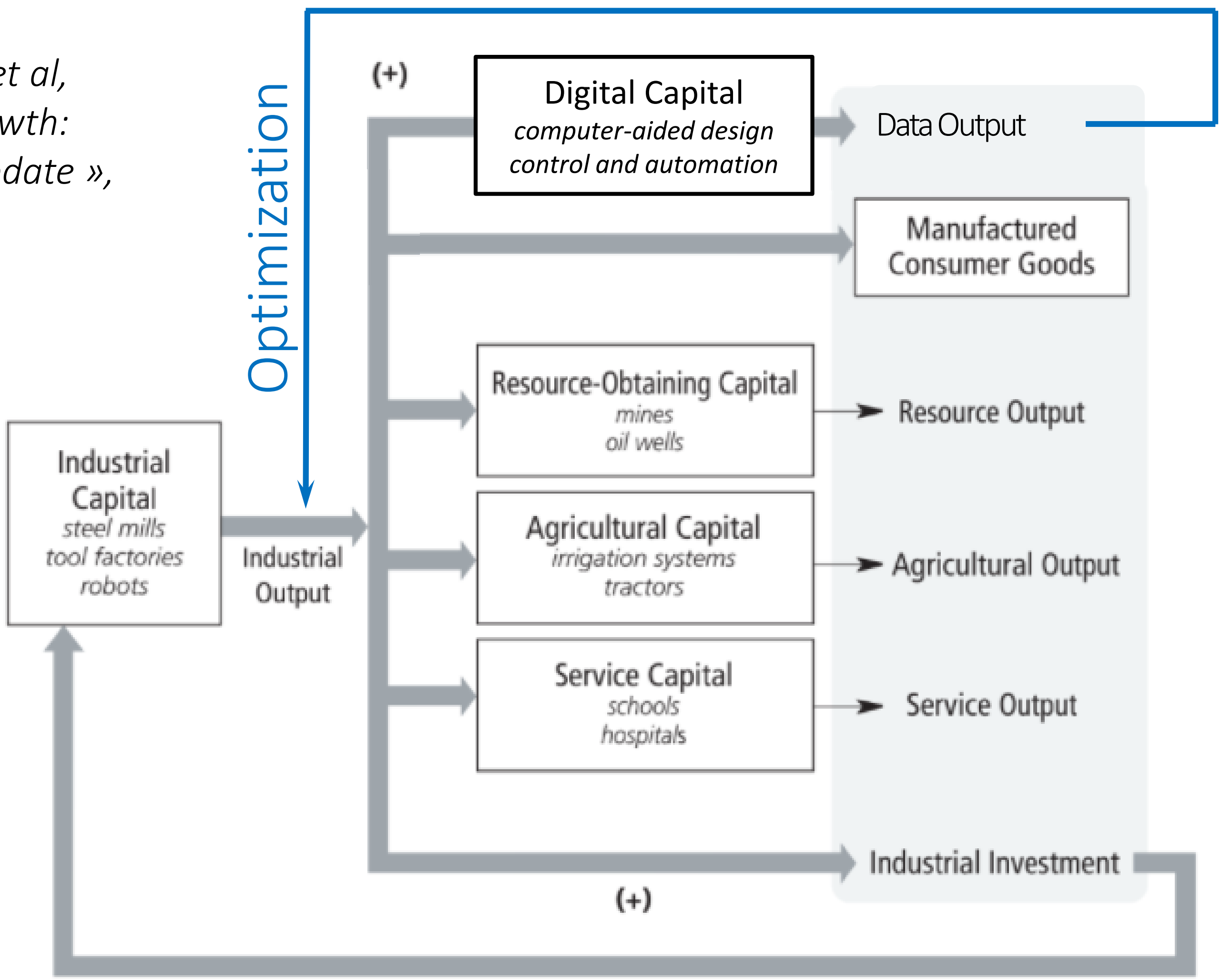
Overshoot day



Source: Global Footprint Network National Footprint Accounts 2019

ICT in the Great Technical Acceleration

Modified from [D. Meadows et al, « Limits to growth: the 30-year update », 2004]



Computing capability allows the optimization of industrial production

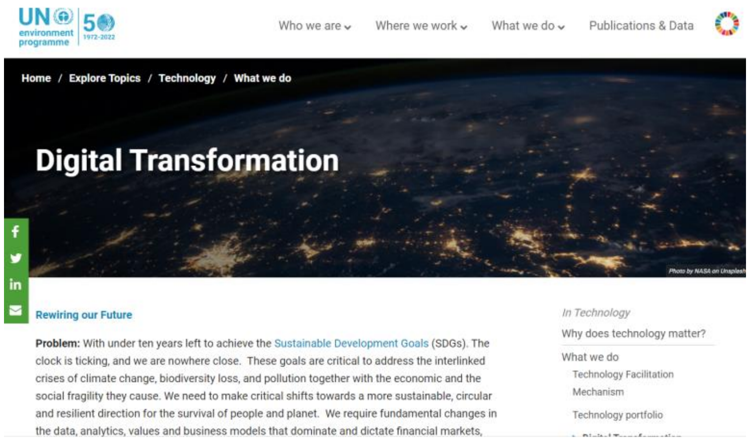
La grande accélération sociale

- Rétrécissement des distances grâce à la tech. (transport + communication)
- Accélération du changement social et du rythme de vie

- Triomphe du libéralisme:
  - Disparition des espaces publics
  - Affaiblissement du pouvoir public
  - Isolement consumériste
- Disparition de la mixité sociale
- Dernier idéal restant: consommer et produire → repli sur soi, populisme, terrorisme

Hartmut Rosa

Raphael Gluckсmann



Digital transition to the rescue ?

Outline

- Context: the Great Acceleration of the XXth century
- Digital transition to the rescue against climate change ?
  - Origin of the digital transition
  - Direct environmental impacts of ICT
  - Indirect environmental impacts of digital services
  - What about the efficiency improvement ?
- Socio-ecological transition
  - Concept and pillars
  - Application in ICT research
- Our socio-ecological transition initiative example

Economic carbon footprint analysis

Prof. Yoichi Kaya

$$GHG\ emissions\ (CO_2e)$$

$$= Pop \times \frac{GDP\ (\$)}{Pop} \times \frac{Energy\ (J)}{GDP\ (\$)} \times \frac{GHG\ (CO_2e)}{Energy\ (J)}$$

Economic affluence

Energy intensity of economy

Carbon intensity of energy

Politico-technical response:

The Third Industrial Revolution

Jeremy Rifkin

Transition numérique

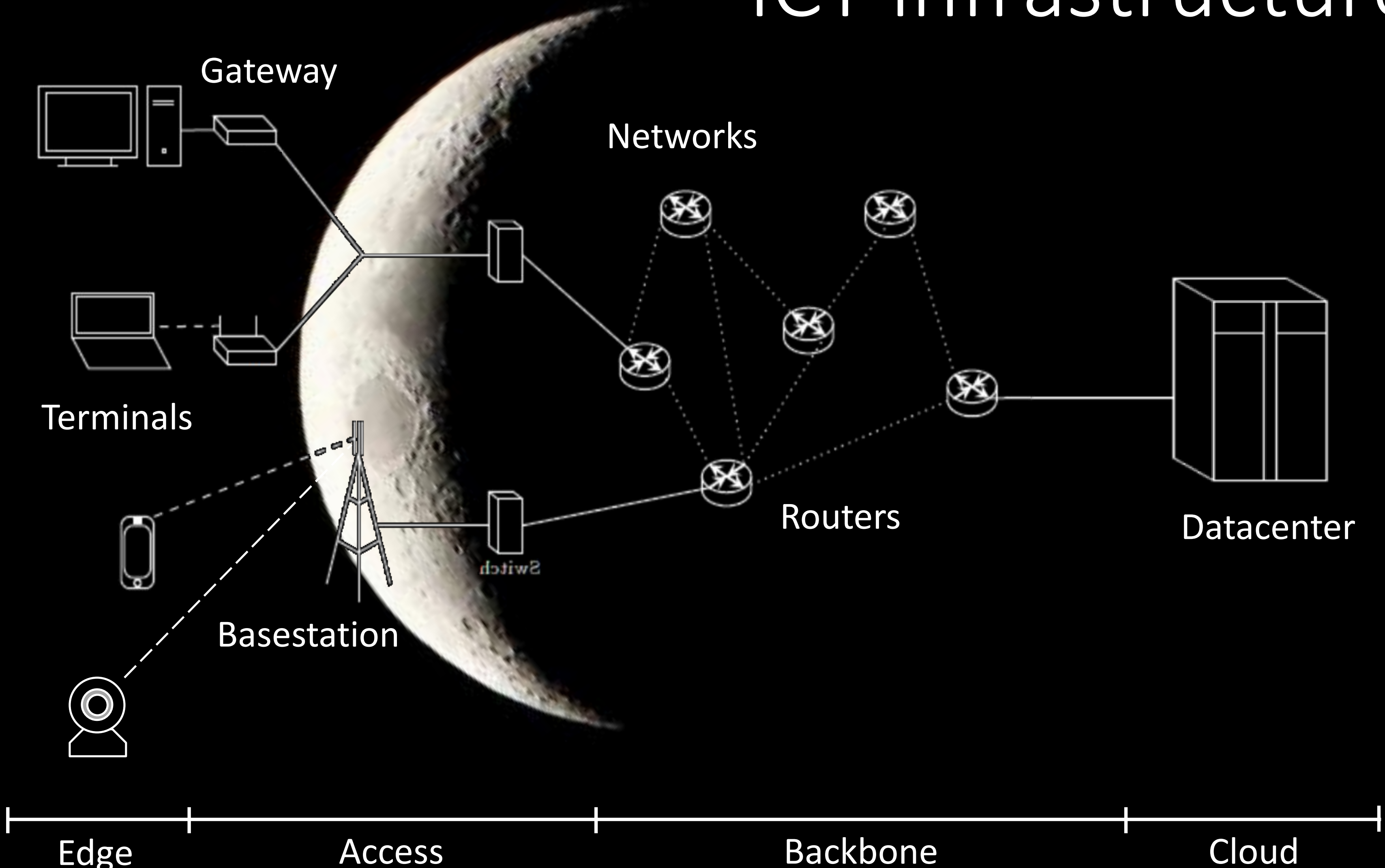
Erik Brynjolfsson

- Le monde digital (« Second machine age ») promet des innovations car:
  - La duplication des données est immédiate et gratuite
  - Les capacités numériques augmentent exponentiellement
  - Les innovations sont empilables (« combinatorial »)
- Mais la croissance de productivité des machines mène à des pertes d'emplois humains (→ inégalités)
- Clé: ne pas se dresser face aux machines mais faire équipe avec les machines (éducation !)

Digital transition to the rescue against climate change ?

- Origin of the digital transition
- Direct environmental impacts of ICT
- Indirect environmental impacts of digital services
- What about the efficiency improvement ?

Digital services run on the physical ICT infrastructure



Global ecological footprint of ICTs

Source	Reference year	Annual operational electrical energy [final TWh]		Total annual GHG emissions [MT $CO2_e$]
Ericsson [1]	2010	1500	Substitution by smartphones	N/A
Ericsson [1]	2015	1390		1160
GreenIT.fr [2]‡	2019	1300		1400
Huawei [3]	2018	*1900*	Correction of errors	N/A
Huawei [4] ‡	2020	1600		N/A
Relative to total world footprint		6-7%		2-4%

‡ *Source published without peer review.*

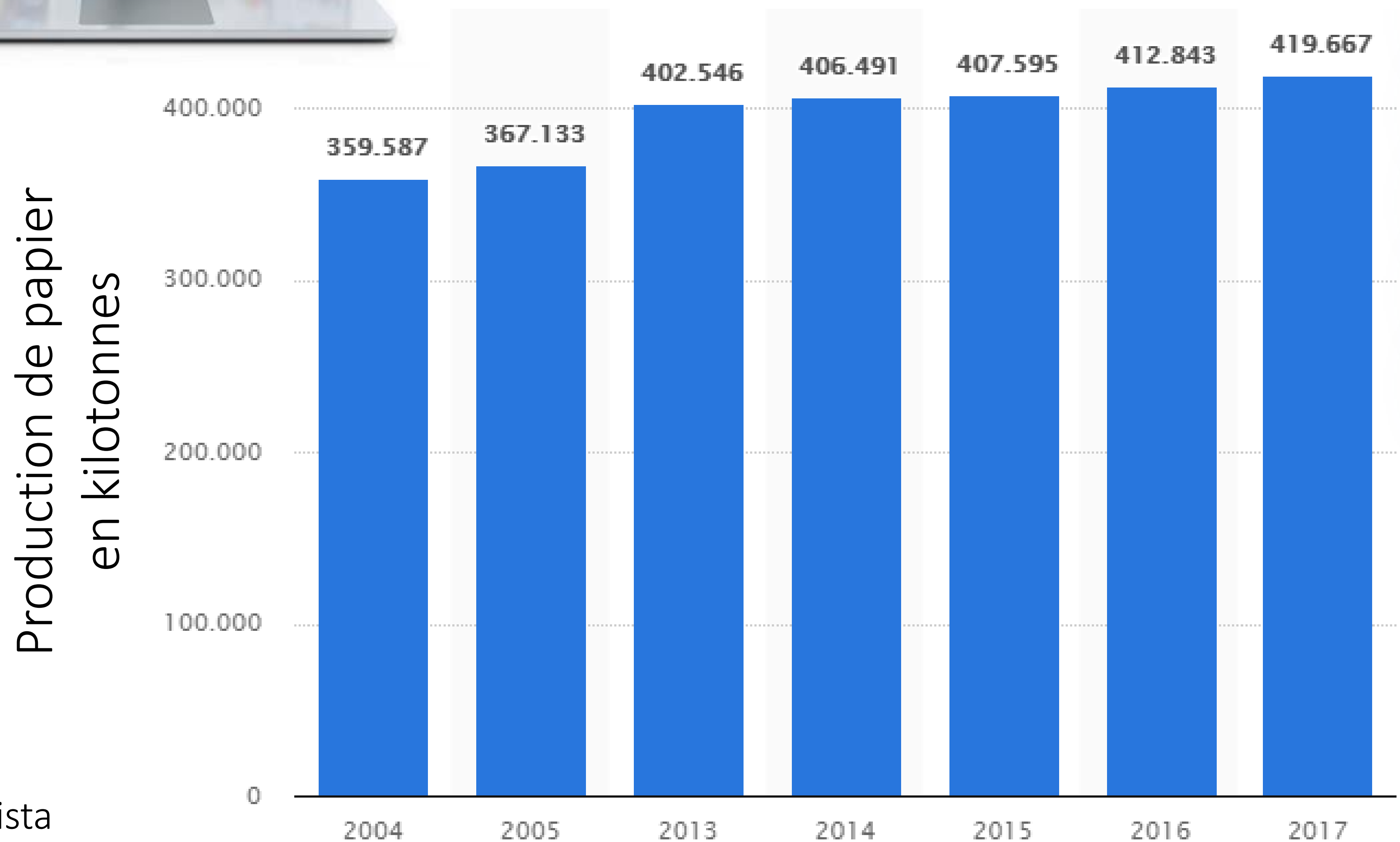
- Caution: it is not only about energy and carbon (waste, resources)
- General consensus over the order of magnitude
- The trend over time is less clear (non monotonic & non uniform)

[1] J. Malmodin and D. Lunden, "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015", in MDPI Sustainability, 2018. [2] F. Bordage, "The environmental footprint of the digital world", greenIT.fr, retrieved Nov. 2019. [3] A. Andrae, "Projecting the chiaroscuro of the electricity use of communication and computing from 2018 to 2030", researchgate.org, retrieved 2019. [4] A. Andrae, "New perspectives on internet electricity use in 2030", in Engineering and Applied Science Letters, 2020.

Digital transition to the rescue against climate change ?

- Origin of the digital transition
- Direct environmental impacts of ICT
- Indirect environmental impacts of digital services
- What about the efficiency improvement ?

Dématérialisation des médias papier ?



Source: Statista

Télétravail & visioconf.

- Réduction des déplacements professionnels mais impact direct du nouveau matériel IT

Ecran 24’’ (production): 250 kg CO2eq	Voiture	Train	Vélo électrique	Avion
Distance équivalente	1400 km	5200 km	16000 km	1250 km

- Impact indirect « catalyseur »: chauffage du domicile
- Impact indirect systémique: augmentation de la taille des habitations (bureaux)

Cadre d'analyse des impacts du numérique

Prof. Lorenz Hilty

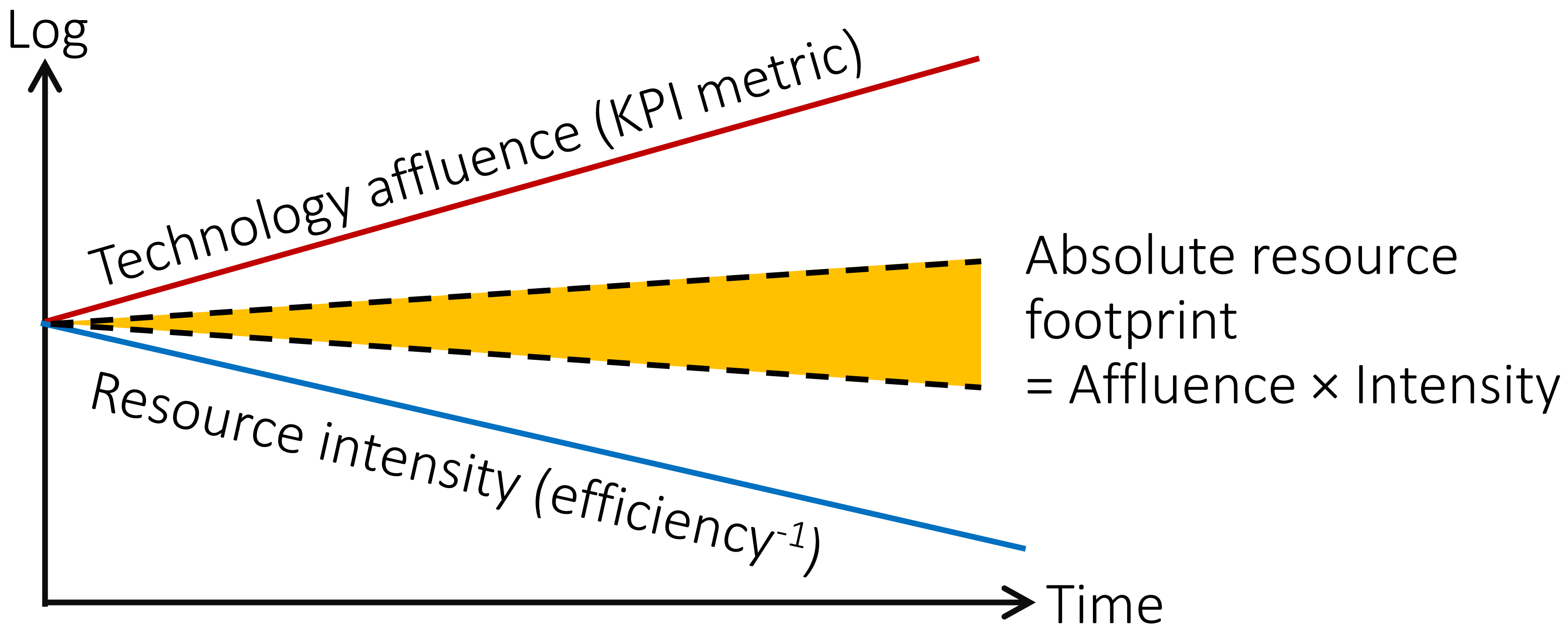
	Le numérique comme partie du problème	Le numérique comme partie de la solution	
Technologie	Cycle de vie des TICs: Production / Utilisation / Fin de vie	(Pas applicable)	1. Impacts directs (*life-cycle*)
Application	Induction Dépendance / Verrous (Lock-in)	Substitution Optimisation	2. Impacts indirects catalyseurs (*enabling*)
Changement structurel	Effet rebond à long-terme Risques émergents	Nouveaux modes de production et de consommation	3. Impacts indirects systémiques

Digital transition to the rescue against climate change ?

- Origin of the digital transition
- Direct environmental impacts of ICT
- Indirect environmental impacts of digital services
- What about the efficiency improvement ?

Empirical efficiency-improvement laws

Law	KPI metric	Physical resource	Efficiency CAGR
Moore	Transistors	Silicon wafer	+41%
Cooper	Datarate	RF spectrum	+32%
Koomey	Computations	Electrical energy	+59%



Moore's Law and ICT Innovation in the Anthropocene

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***Abstract*—In information and communication technologies (ICTs), innovation is intrinsically linked to empirical laws of exponential efficiency improvement such as Moore's law. By following these laws, the industry achieved an amazing relative decoupling between the improvement of key performance indicators (KPIs), such as the number of transistors, from physical resource usage such as silicon wafers. Concurrently, digital ICTs came from almost zero greenhouse gas emission (GHG) in the middle of the twentieth century to direct annual carbon footprint of approximately 1400 MT CO2e today. Given the fact that we have to strongly reduce global GHG emissions to limit global warming below 2°C, it is not clear if the simple follow-up of these trends can decrease the direct GHG emissions of the ICT sector on a trajectory compatible with Paris agreement.**

In this paper, we analyze the recent evolution of energy and carbon footprints from three ICT activity sub-sectors: semiconductor manufacturing, wireless Internet access and datacenter usage. By adopting a Kaya-like decomposition in technology affluence and efficiency factors, we find out that the KPI increase failed to reach an absolute decoupling with respect to total energy consumption because the technology affluence increases more than the efficiency. The same conclusion holds for GHG emissions except for datacenters, where recent investment in renewable energy sources lead to an absolute GHG reduction over the last years, despite a moderate energy increase.

We formulate hypotheses for this absence of absolute decou-

TABLE I
KEY STUDIES OF THE GLOBAL ICT FOOTPRINT.

Source	Reference year	Annual electricity consumption‡ [final TWh]	Annual GHG emissions [$MTCO_2e$]
Ericsson [2]	2010	1500	N/A
Ericsson [2]	2015	1390	1400
GreenIT.fr [3] †	2019	1300	1400
Huawei [4] †	2020	1600	N/A
GeSI [5] †	2020	N/A	1270
GeSI [6] †	2030	N/A	1250
Relative to world footprint (2018) [7]		*6-7%*	*3.5-4%*

† Source published without peer-review. ‡ Considering only operational electricity i.e. consumed by the use of ICT infrastructure and terminals.

In order to limit global average temperature increase close to 1.5°C according to the COP21 Paris agreement on climate change, we need to steadily reduce global GHG emissions by 7.6% a year to reach net zero emissions by 2050 [8], [9]. ICTs are responsible of GHG emissions resulting from the different life-cycle stages of the infrastructure and the terminals. In the infrastructure made up of datacenters and the network, use-phase electricity consumption usually dominates the carbon

Summary of the study

1. Method: Kaya-like decomposition of the carbon footprint of
   - semiconductor manufacturing (Moore's law 2004-2019),
   - mobile Internet access (Cooper's law 2010-2015),
   - data center usage (Koomey's law 2010-2018)
2. Observation: the follow-up of efficiency-improvement laws lead to carbon-footprint increase (+10 to +20%/year)
3. Reason: rebound effect (Jevons paradox)
   Technological affluence measured in KPI increases more than the KPI efficiency
4. Exception for datacenters :
   - limited affluence increase → limited energy footprint increase
   - shift to low-carbon renewable electricity purchase allowed carbon footprint reduction

Why do engineers optimize KPIs ?

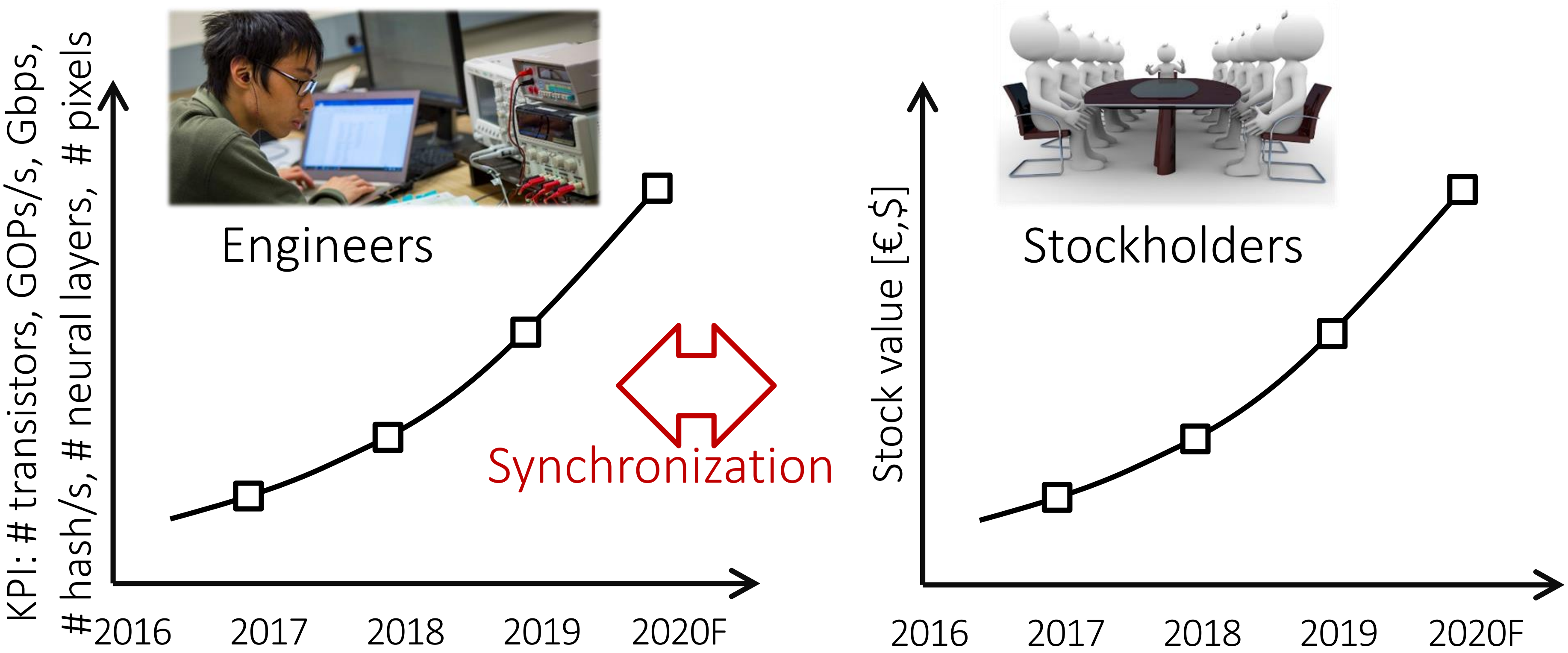
Thesis #1 :
The Race to Innovation
(Sociology of Technology)

Thesis #1: the Race to Innovation

- Fact: the "Great Inventions of the 20th century" *[Gordon, 2018]* improved survival and subsistence for a significant portion of humanity
- Result: humanity has a deep faith in the social benefits of technological progress *[Potts, 2018]*
- Fact: since 1980, huge capitalization available on the stock market lead to the *financial economy*
- Result: companies compete to attract capitals by promising growth of the stock value *[Krier, 2009][Mundt, 2014][Davis, 2018][Gomez, 2019]*

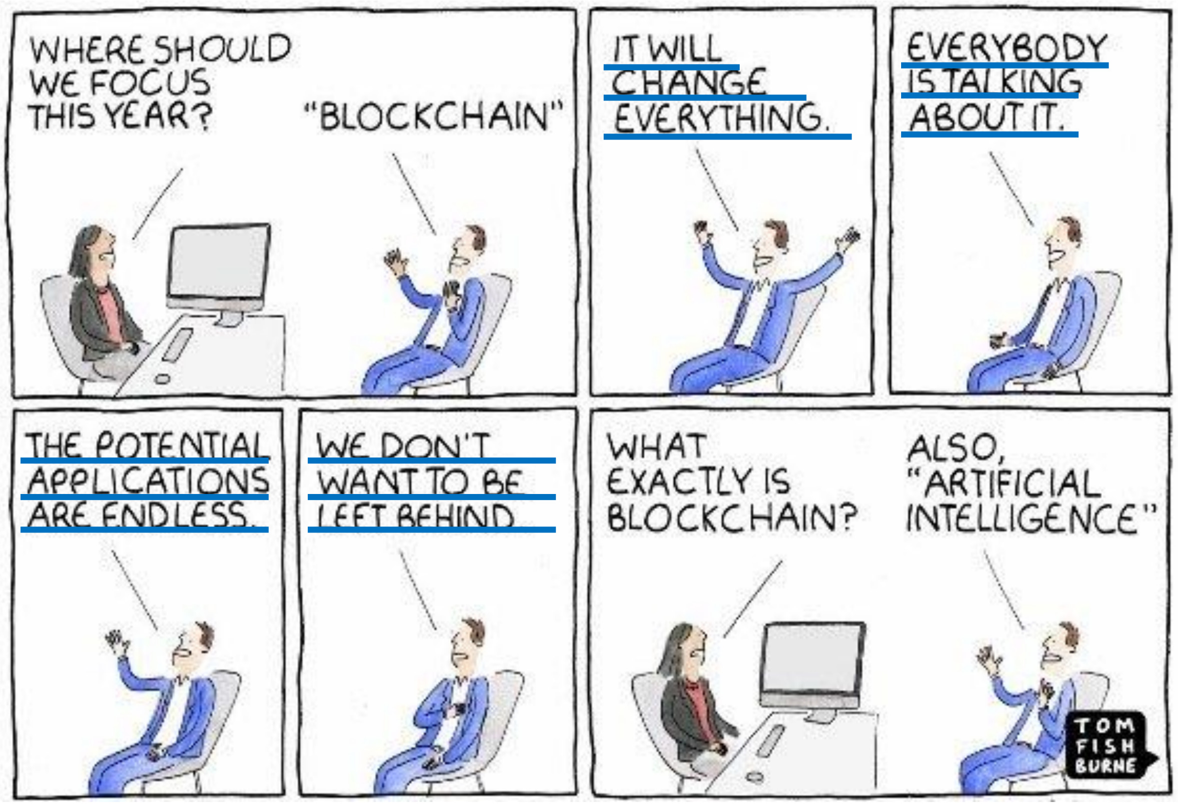
The Race to Innovation is one of the few means for companies to attract capitals [Dallyn, 2011][Gomez, 2019]

ICT innovation in a financial economy



- Pitfall A: KPI-driven innovation

ICT innovation in a financial economy



Speculative vocabulary

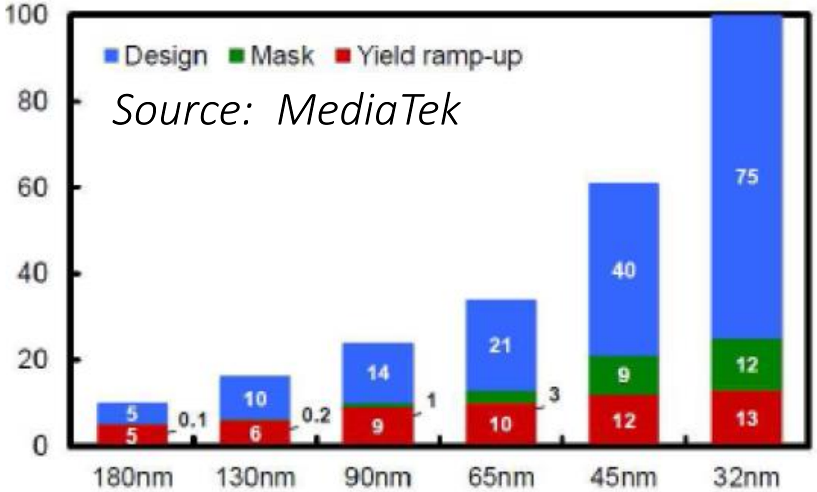
- Pitfall A: KPI-driven innovation
- Pitfall B: Buzzword-driven innovation

Why does technology affluence increase ?

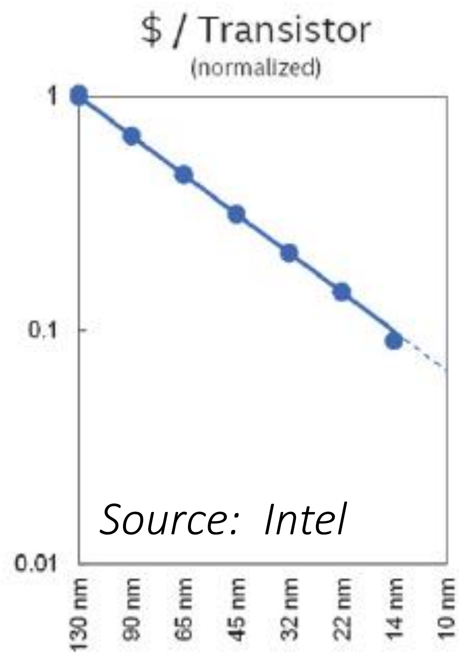
Thesis #2 :
Escalating Engineering Costs
(Economics of Technology)

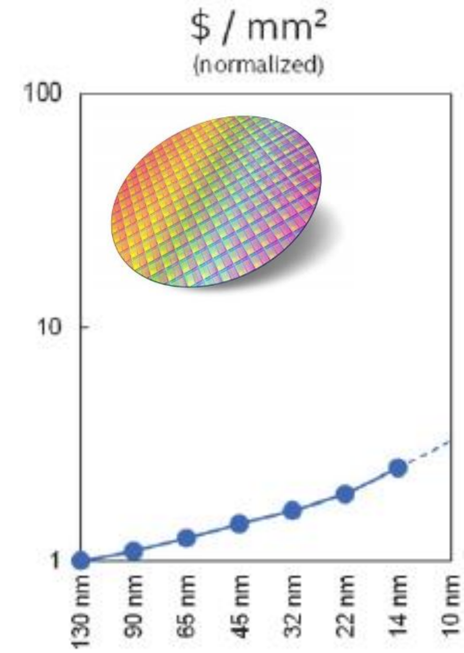
Thesis #2: Escalating costs

Chip design cost [M$]



[A. Chang, IEEE Design & Test of Computers, vol.26, pp. 14-19, 2009]



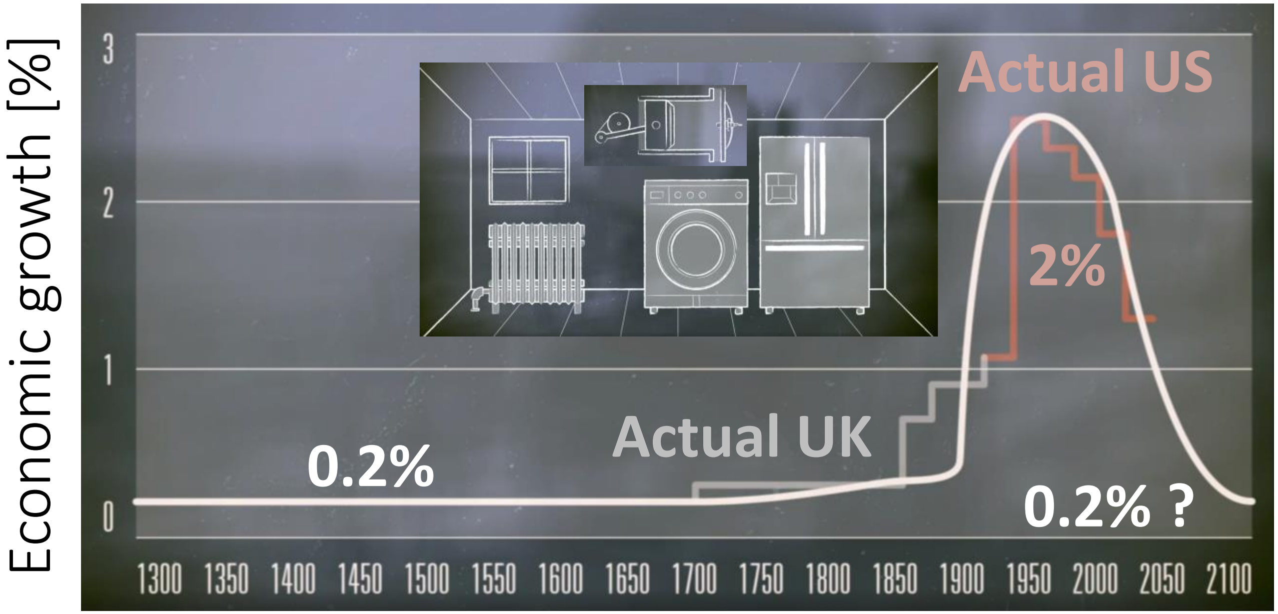


- All technological KPIs are bounded by a physical limit (e.g. atom size)
- Getting closer to the limit increases complexity and thus:
  - R&D efforts → non recurring engineering costs (NREs)
  - cost of production (equipment, labor) of the physical resource (e.g. wafer)
- Result: generating return on investment (RoI) is made by increasing the affluence of the physical resource

How do we increase technology affluence ?

Thesis #3 :
Limited Growth Perspectives
(Economics)

Economic Growth Perspectives



Prof. Robert J. Gordon

- Today, there are major socio-economic barriers to growth
- To continue the 2% historic GDP growth, future innovations should be as fundamental as the "Great Inventions from the 20th century"

→ KO: the 20th-century growth is a one-off episode in the history of humanity *[Gordon, 2018]*

Growth Strategies in ICT

- Strategy A: Addiction mechanisms

Growth Strategies in ICT

Yesterday

Incredible

Today

Outdated

- Strategy A: Addiction mechanisms
- Strategy B: Obsolescence generation

Growth Strategies in ICT

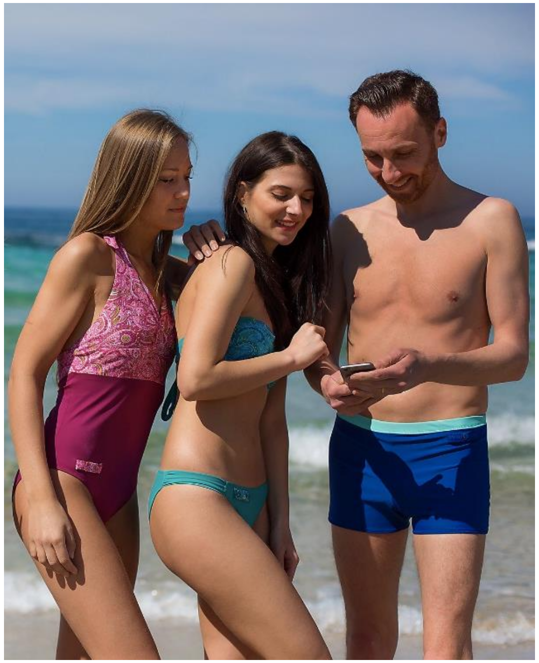
Internet of Shit (IoS) examples

Smart drink bottle

Connected razor

Alexa-enabled shower head

Connected swimwears



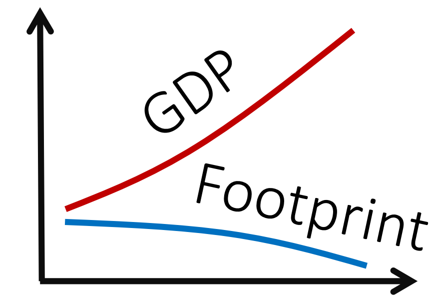
- Strategy A: Addiction mechanisms
- Strategy B: Obsolescence generation
- Strategy C: Creation of artificial needs

Can we decouple the affluence increase from the carbon footprint ?

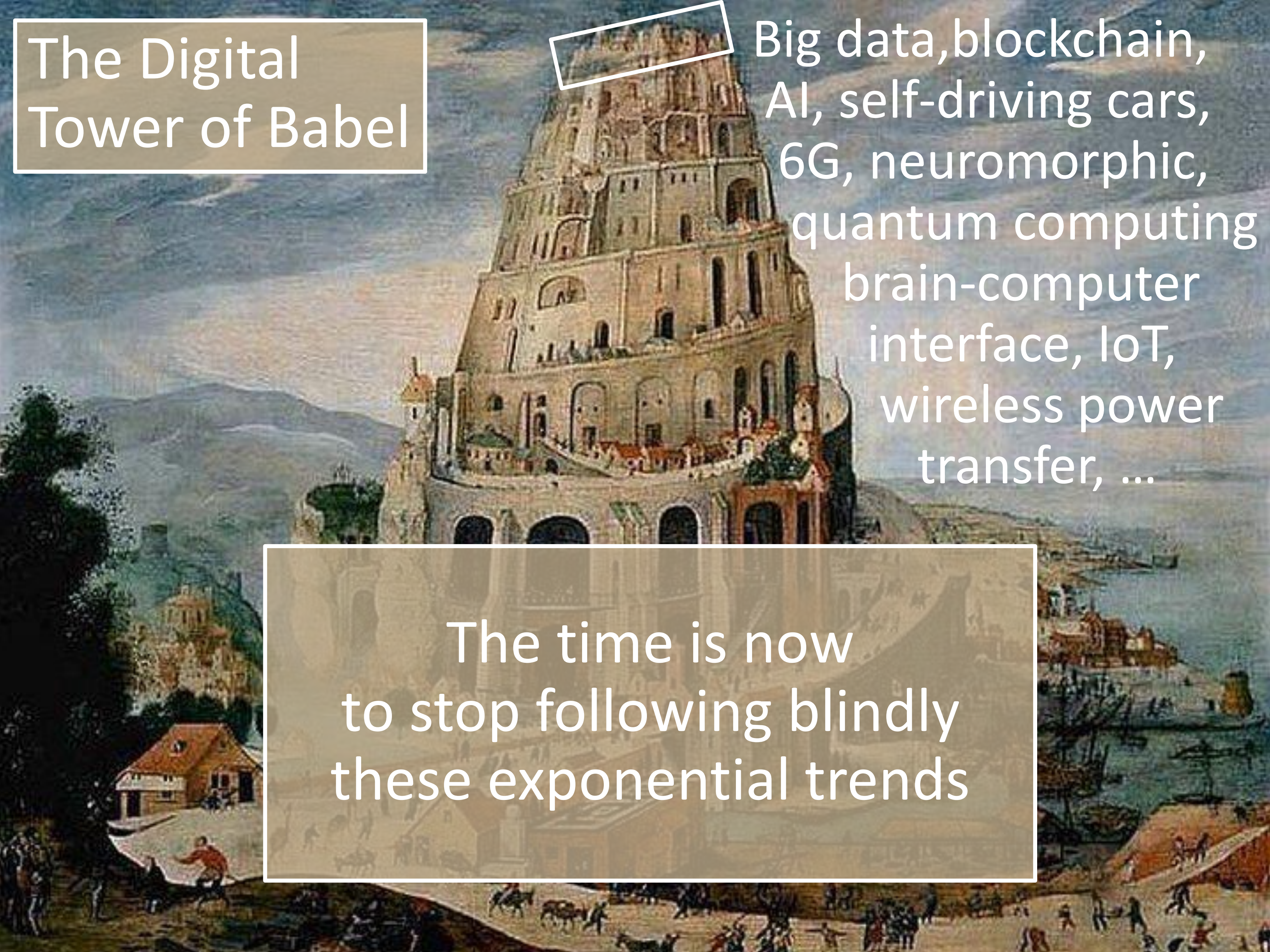
Thesis #4 :
The Impossibility
of « Green Growth »
(Ecological Economics)

The Impossibility of « Green Growth »

- Green growth
  = the absolute decoupling
  of GDP growth from ecological footprint



- Can only be studied at the global world scale because of rebound effects, problem/cost shifting *[Parrique, 2019]*
- Absolute decoupling has never been observed so far at large scale *[Jackson, 2009][Parrique, 2019][Hyckel and Kallis, 2020]*
- Some ICT companies claim carbon neutrality through renewable energy purchase and carbon offsetting
  → Theory: valid on a ideal energy / carbon market
  → Practice: pre-emption of renewable energy
  = accounting trick (cost shifting problem)

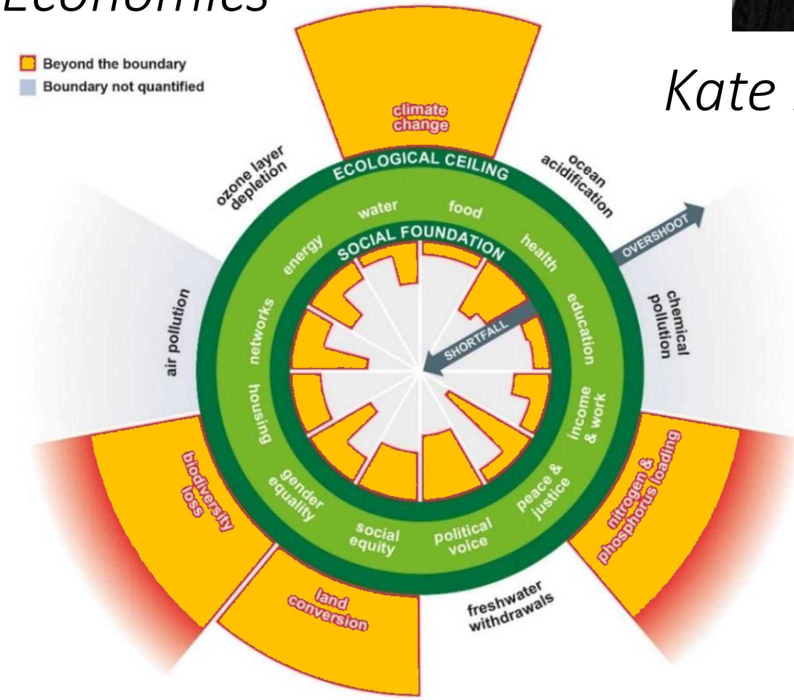

The Digital
Tower of Babel
Big data,blockchain,
AI, self-driving cars,
6G, neuromorphic,
quantum computing
brain-computer
interface, IoT,
wireless power
transfer, ...
The time is now
to stop following blindly
these exponential trends

The socio-ecological transition

- Concept and pillars
- Application in ICT research

Transition socio-écologique

Doughnt Economics



Kate Raworth

Vers un modèle socio-technico-économico-culturel
qui vise le bien-être humain collectif
tout en étant écologiquement soutenable (plafond)
et socialement équitable (plancher)
→ révision des valeurs éthiques fondamentales

Grassroot transition iniatives

Rob Hopkins

- Transition town movement
- Five pillars:

Resiliency

Environment preservation

Local organization

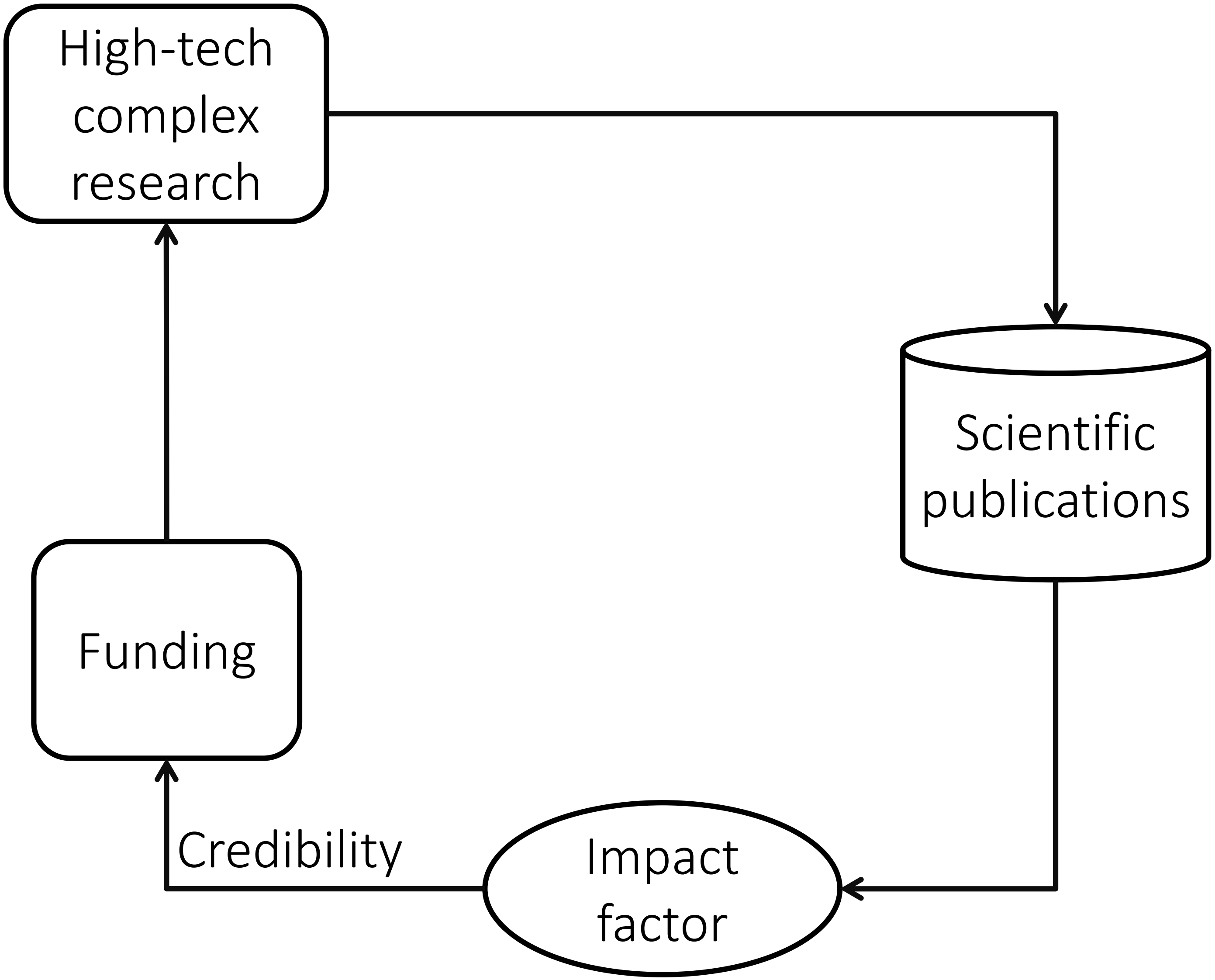
Social link

Sobriety

- *The social-ecological transition answers environmental change with social progress.*

  – Prof. E. Laurent, 2015

Research and publication model



20 IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 48, NO. 1, JANUARY 2013

SleepWalker: A 25-MHz 0.4-V Sub-mm^2 7-μW/MHz Microcontroller in 65-nm LP/GP CMOS for Low-Carbon Wireless Sensor Nodes

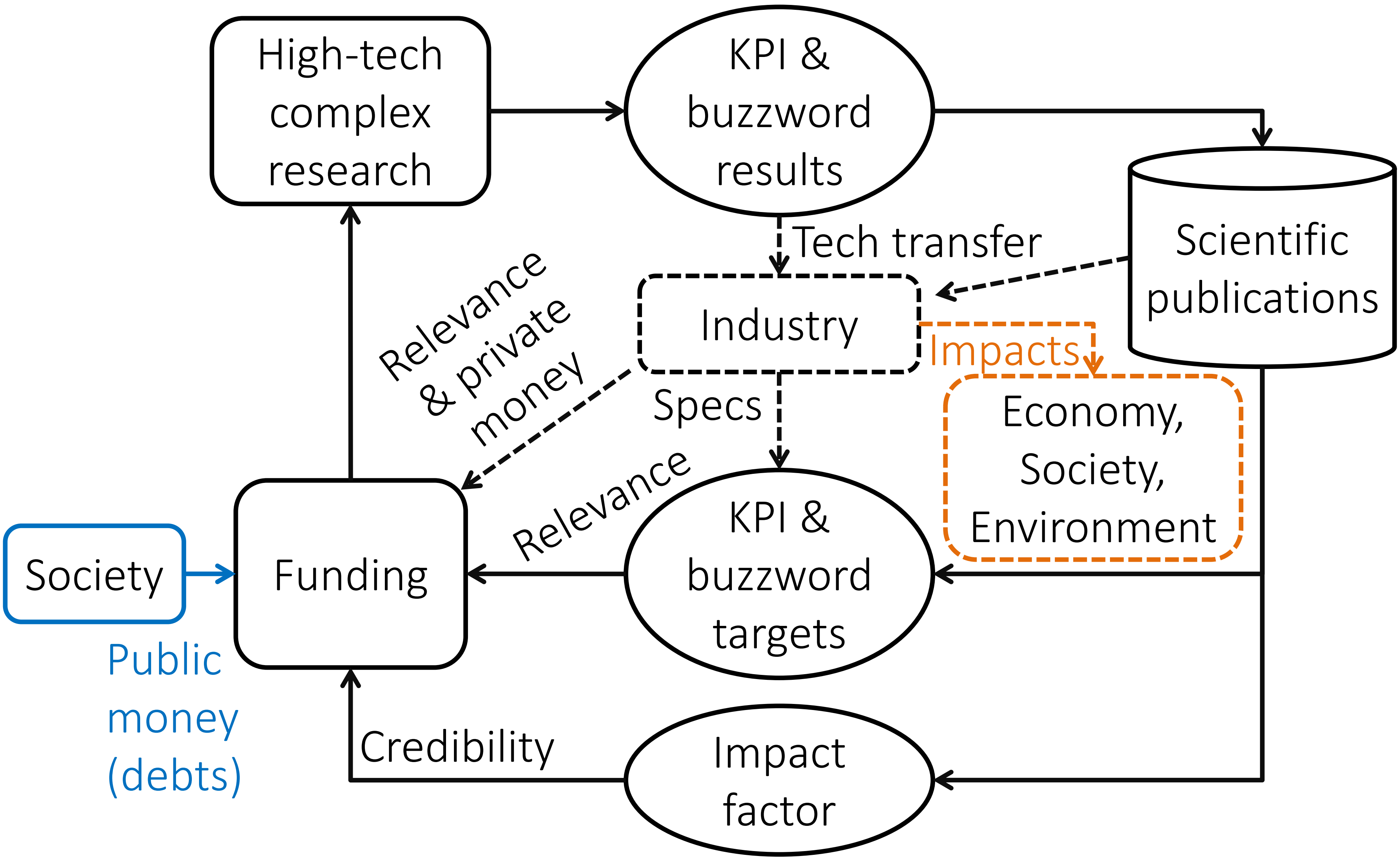
David Bol, *Member, IEEE*, Julien De Vos, *Student Member, IEEE*, Cédric Hocquet, François Botman, *Student Member, IEEE*, François Durvaux, Sarah Boyd, Denis Flandre, *Senior Member, IEEE*, and Jean-Didier Legat, *Member, IEEE*

***Abstract*—Integrated circuits for wireless sensor nodes (WSNs) targeting the Internet-of-Things (IoT) paradigm require ultralow-power consumption for energy-harvesting operation and low die area for low-cost nodes. As the IoT calls for the deploy-**

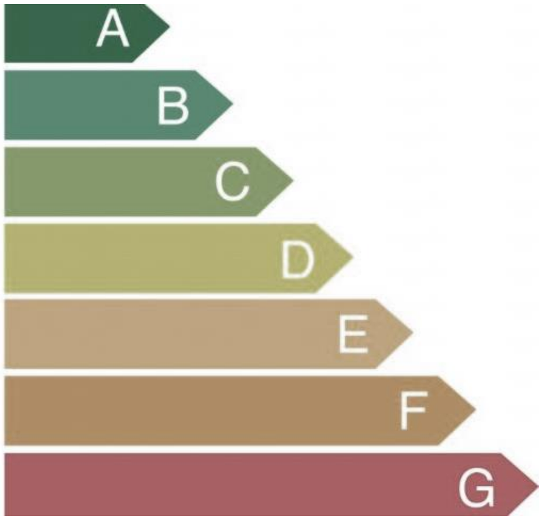
ject [1]. Such WSNs will feature sensing and computing capabilities with memories, energy management and wireless communication to allow interaction with the cloud. The IoT will en-

	Bol, JSSC, 2013	Myers, VLSIC, 2017	Prabhat, ISSCC, 2020	Lee, JSSC, 2020	Paul, JSSC, 2017	Ambiq, ApolloBlue3, 2019	Salvador, ESSCIRC, 2018	Abouzeid, ESSCIRC, 2015	Uytterhoeven, ESSCIRC, 2018	Lallement, JSSC, 2018	Lallement, SSCL, 2019	Höppner, ESSDERC, 2019	This work
CMOS technology	65nm LP/GP	65nm LP	65nm LP	55nm DDC	14nm FinFET	40nm ULP eFlash	90nm ULL eFlash	28nm FDSOI	28nm FDSOI	28nm FDSOI	22nm FDSOI	22nm FDSOI	28nm FDSOI
CPU	oMSP430	CM0+	CM33 SIMD	CM0	x86 IA	CM4F	CM3	CM4F	Zscale	CM0+	CM0+	CM4F	CM0DS
Memory	18kB SRAM	16kB SRAM	128kB ROM + 20kB RAM	8kB SRAM	16kB ROM + 80kB SRAM	384kB SRAM + 1MB Flash	32kB SRAM + 256kB Flash	16kB SRAM	64kB SRAM	8kB SRAM	12kB SRAM	84kB SRAM	64kB SRAM
Closed-loop PVT compensation	UFVR (AVS)	AFS	UFVR (AVS)	AVS+ABB with MEP tracking	×	N/A	UFVR (AVS)	×	×	×	Limited ABB	ABB	UFBR (ABB)
Embedded PM	✓	✓	✓	✓	×	✓	✓	×	×	×	×	×	✓
Max. frequency at MEP supply [MHz]	32	0.2	0.8	5	3.5	96	16	45	66	16	20	180	80
Active power at MEP [μW/MHz]	6.1 @25 MHz	7.6 @0.2 MHz	20 @4 MHz	6.4 @0.5 MHz	27* @3.5 MHz	32.8† @48 MHz	23 @5 MHz	8.9 @45 MHz	8.8 @22 MHz	2.7 @16 MHz	1.13 @20 MHz	6.9 @180 MHz	3.3 @40 MHz
Peak efficiency [DMIPS/mW]	~ 66* (10 DMIPS)	180 (0.24 DMIPS)	95 (7.6 DMIPS)	× (not enough RAM)	~ 74* (7 DMIPS)	58† (93 DMIPS)	82 (9 DMIPS)	215 (86 DMIPS)	126 (24 DMIPS)	× (not enough RAM)	841 (19 DMIPS)	278 (344 DMIPS)	385 (51 DMIPS)
Logic state retention in deep sleep mode	×	✓	×	N/A	✓	✓	✓	N/A	N/A	×	✓	✓	✓
Deep-sleep retention power [nW/kB]	95‡ (18kB RAM)	16 (4kB RAM)	2.5‡ (4kB RAM)	-	79 (80 kB RAM)	220† (8 kB RAM) 17† (384kB RAM)	4.3 (8kB RAM)	-	-	121 (8kB RAM)	308 (12kB RAM)	> 548° (84 kB RAM)	131 (64 kB RAM)
Wake-up time	30 μs	N/A	180 μs	-	> 1 ms	15 μs	N/A	-	-	N/A	N/A	N/A	< 20 μs

A familiar model in ICT research ?



Socio-ecological transition in ICT innovation



Efficiency
(energy or resource)

+

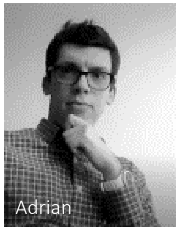
Sobriety
(stable affluence)

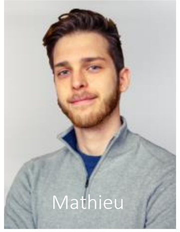
Daring to say 'No' !

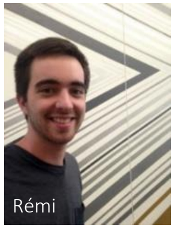
Refusing Limits in Technology Innovation

Keysight Chairman and CEO, Ron Nersesian, discusses the increasing pace of technology development and the challenges that nearly every innovator faces today: complexity, time, dynamic requirements, and productivity. Watch Ron break down the four challenges of design.

The socio-ecological transition initiative in our ECS research group







Our targets

Sobriety

Strict selection of a limited set of applicative projects we pursue

Environment preservation

Systematic footprint analysis of the projects
Direct: LCA of the circuits and systems
Indirect: application

Local organization

Prioritize local field actors + integrate the transition in local university courses

Social link

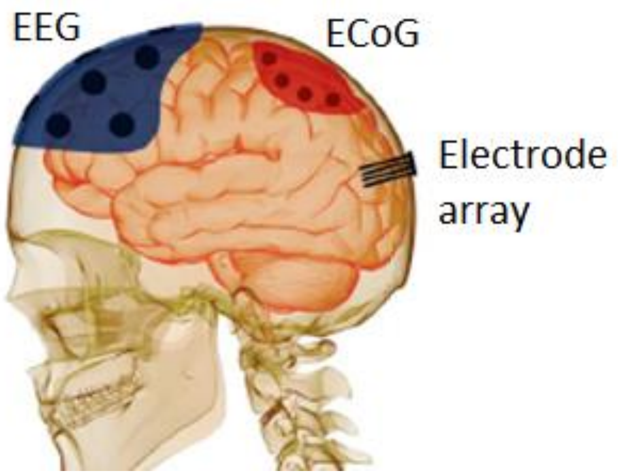
Collaborative PhD work: internal in the group and external with field actors + transition network

Resiliency

Open-source HW/SW ?
Low-tech ?

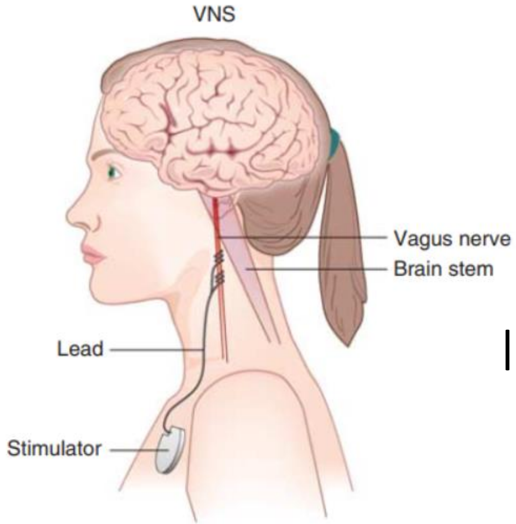
Example A: implanted electronics

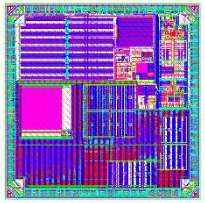
Before: chips for treating epilepsy with closed-loop deep brain stimulation (DBS)



- ✓ Social benefit
- ✓ Very low ecological footprint
- × High risk of detour (augmented human)

Now: chips for treating epilepsy with closed-loop vagus nerve stimulation (VNS)



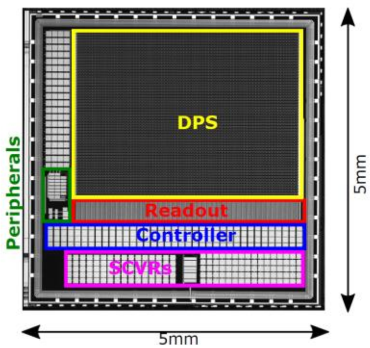


ICare 22nm MCU SoC (in fab)

- ✓ Social benefit
- ✓ Very ecological low footprint
- ✓ Limited risk of detour

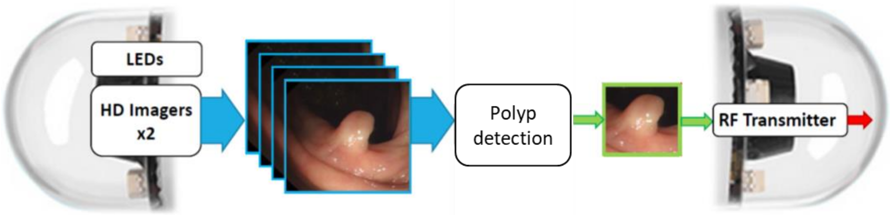
Example B: vision systems

Before: ultra-low-power chips <u>for motion detection and face recognition</u>



- ✓ Low ecological footprint
- × No social benefit (futile applications)
- × High risk of detour (surveillance capitalism)

Now: ultra-low-power chips <u>for polyp detection in pillcam colorectal cancer diagnosis</u>



- ✓ Low ecological footprint
- ✓ Clear social benefit
- ✓ Limited risk of detour

Example C: IoT sensors

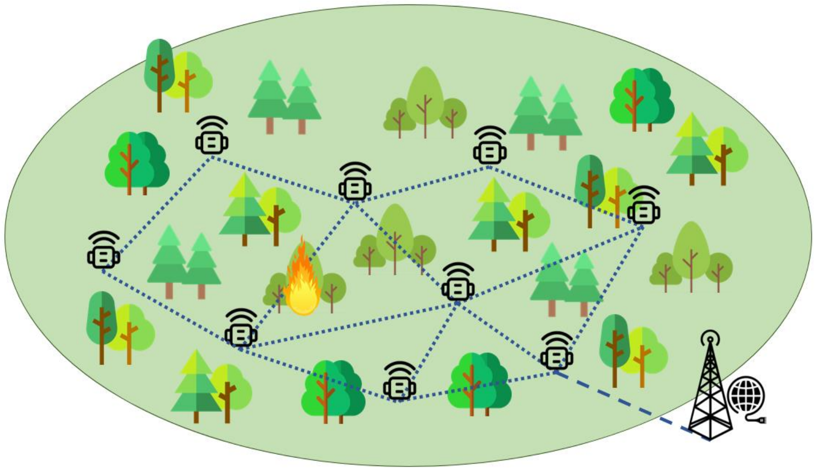
Before: ultra-low-power miniature batteryless solar-powered voice recognition

✓ Footprint reduction

× Questionable need

× High risk of rebound & detour

Now: low-carbon large-scale detection of abnormal events in natural ecosystems (wildfires, floods, illegal poaching, sawing)



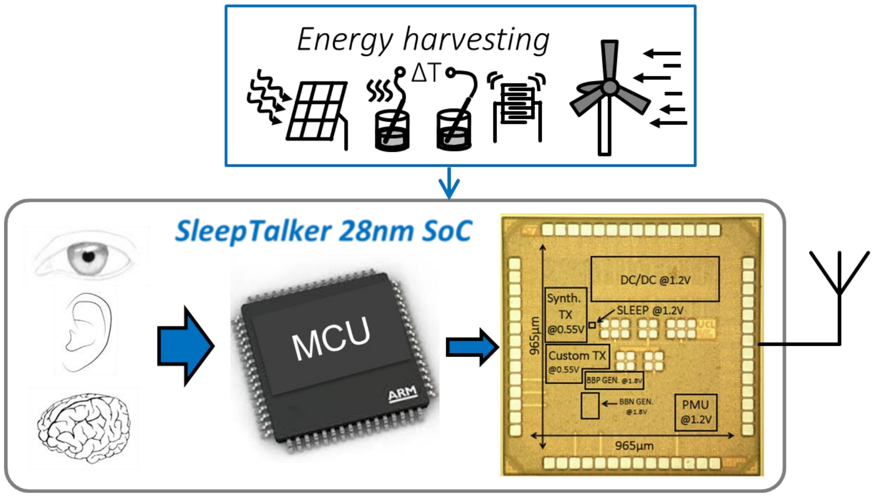
✓ Low ecological footprint

✓ Clear ecological benefit

✓ Limited risk of detour

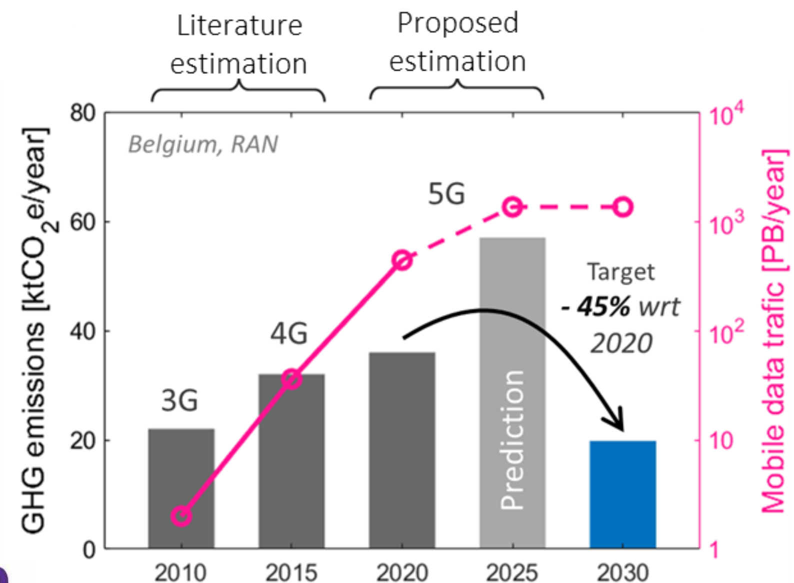
Example D: wireless communications

Before: <u>chips for batteryless IoT smart sensors</u>



- ✓ Low *relative* footprint
- × Risk of need creation (futile applications)
- × High risk of rebound effect → high <u>absolute</u> footprint of the IoT *[Pirson, JCP, 2021]*

Now: <u>reducing the global energy footprint of mobile Internet access</u>



- ✓ Ecological benefit: Reduction of <u>absolute</u> footprint (no rebound)
- ✓ "Need" is already there

Conclusions

- Hoping to effectively reduce the absolute ecological footprint of humanity to avoid the collapse, we first have to depart from the blind faith in the automatic benefits of technological progress
→ No innovation for the sake of innovation
- The 21st-century Anthropocene urgently calls for combining the quest for efficiency with sobriety by restricting R&I to meaningful applications with socio-ecological benefit (clearly demonstrated)
- Open (non technological) question:
how do we select meaningful applications ?

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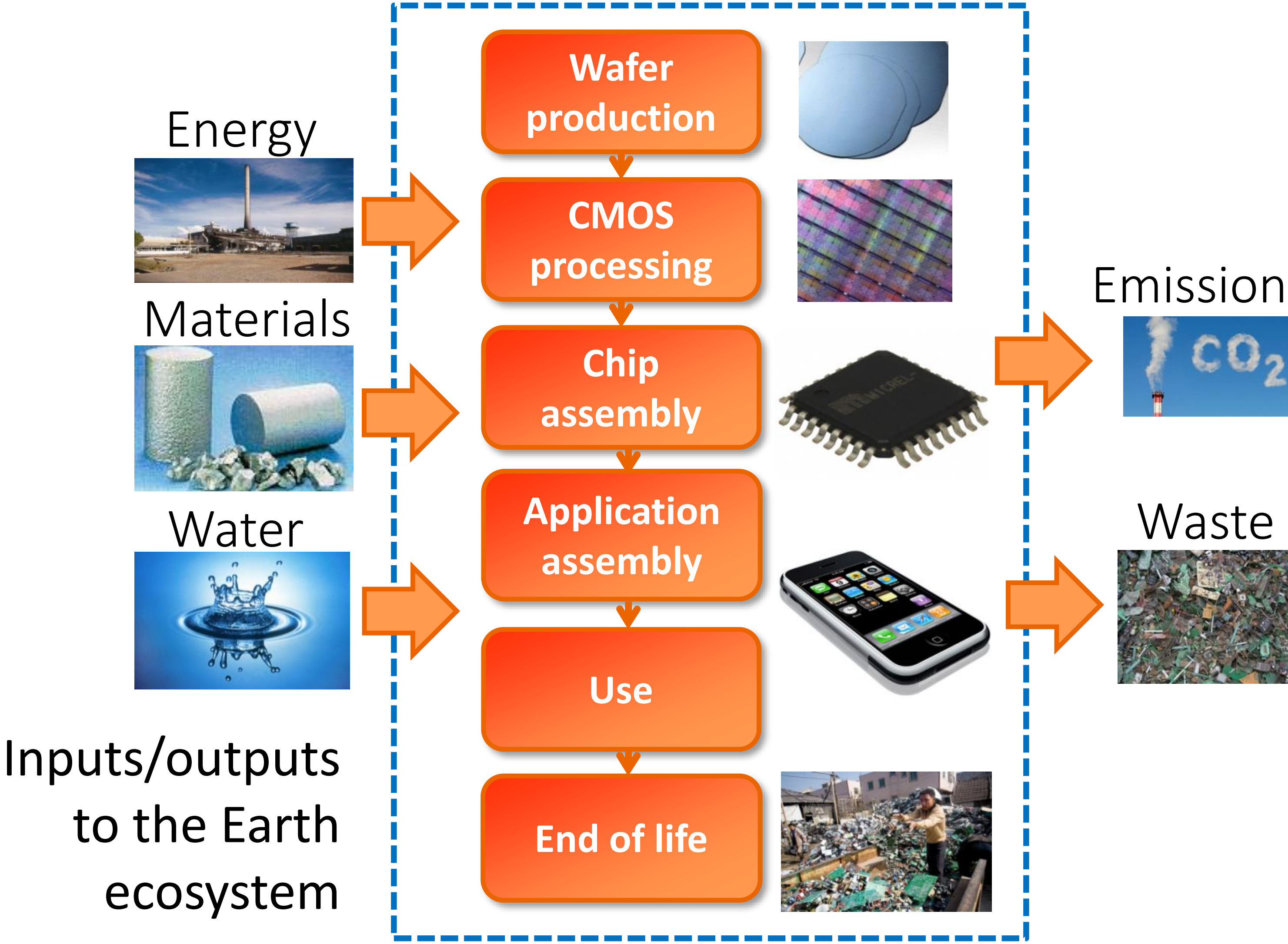
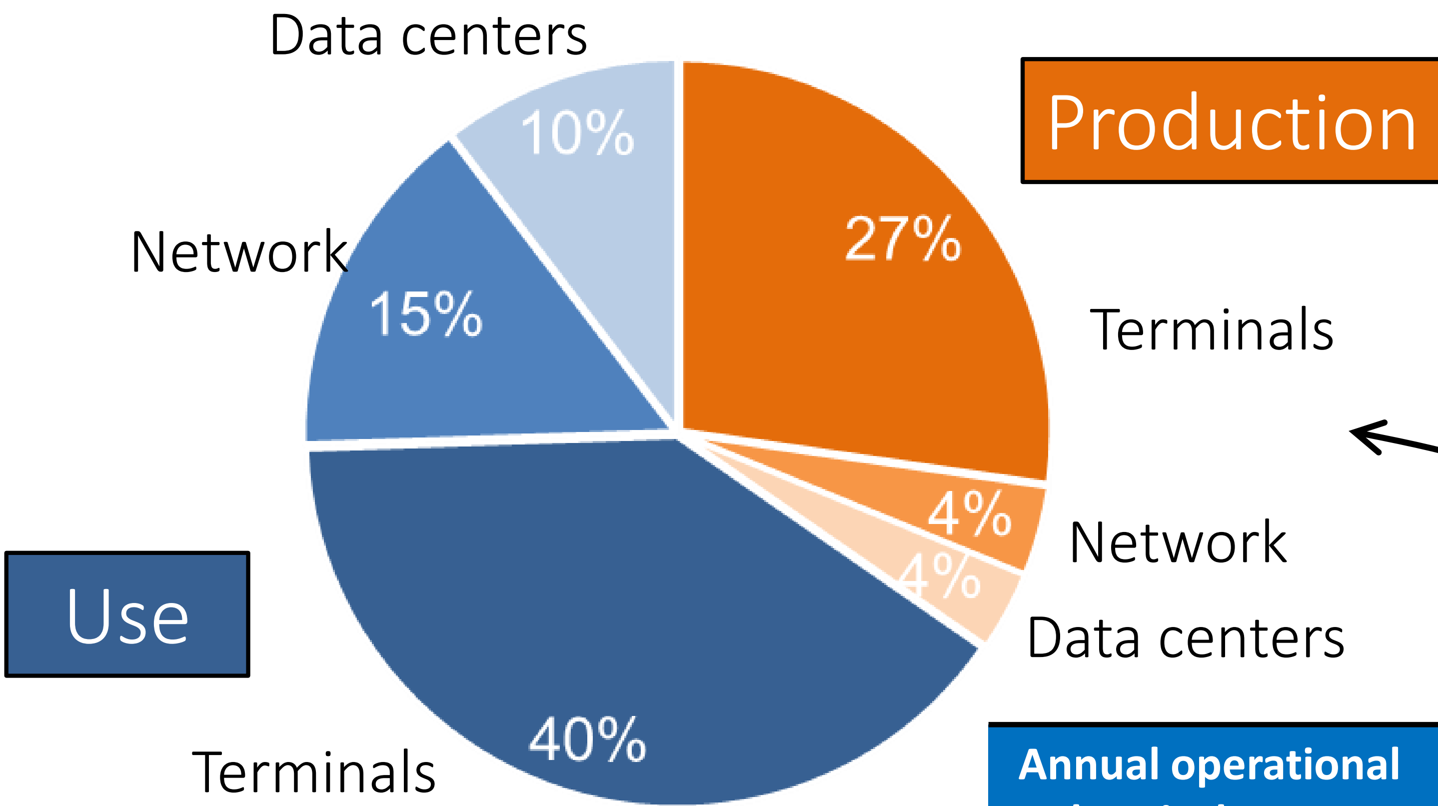
Backup slides

Life "cycle" of ICT equipments



[D. Bol, S. Boyd and D. Dornfeld, « Application-aware LCA of semiconductors: life-cycle energy of microprocessors from high-performance 32nm CPU to ultra-low-power 130nm MCU », in Proc. IEEE ISSST, 2011]

ICT carbon footprint (2015)



Annual operational electrical energy [final TWh]	Total annual GHG emissions [MT CO_2e]
1390	1200
6-7% of world footprint	2-4% of world footprint

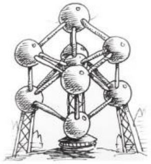
Source: Ericsson [J. Malmodin and D. Lunden, "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015", in MDPI Sustainability, 2018]

It's not only about energy and carbon

Coltan mine in North Kivu (Congo)
Copyright: Stefano Stranges

E-waste informal recycling area in Guiyu (China)

E-waste generated in 2018: 4M tons = 400 ×  (weight)

1500 ×  (weight)

Impact on technological progress

Accumulative capitalism (until 1970-1980)

Borrow (Debt)

Invest

Better production

Reimburse

Profit

Credibility indicator of the return-on-investment promises

Speculative capitalism (since 1970-1980)

Capitalization (Debt)

Invest in technology <u>innovation</u>

Stock value increase

Faith in future valorization

→ *Race to Innovation*

[Dallyn, 2011][Gomez, 2019]

Interactions socio-techniques

Jean-Baptiste
Fressoz

Exemple historique de la voiture individuelle aux États-Unis

- Mythe de l'appétence des humains pour l'automobile
- 1900-1920: beaucoup de réticence à l'arrivée des voitures dans les villes (accidents, odeurs, alternative des tramways)
- Projet politique: donner l'accès à la propriété en banlieue pour lutter comme le communisme
- Crédit à la consommation pour lutter contre l'absentéisme prof.
- Lobby pétrolier et production automobile

Niveaux d'action de la transition

<u>Transition planifiée :</u>

- Politique régionale, nationale, européenne
- Entreprises

<u>Transition citoyenne :</u>

- Initiatives individuelles : simplicité volontaire, décroissance, retour à la terre, petits gestes (régime végétarien, fin des voyages en avion, vélo, zéro déchet, habitats alternatifs)

- Initiatives collectives : villes en transition, potagers partagés, groupements d'achat, habitats groupés, covoiturage professionnel, bureaux sans poubelle