The Rebound Effect of Resource Efficiency

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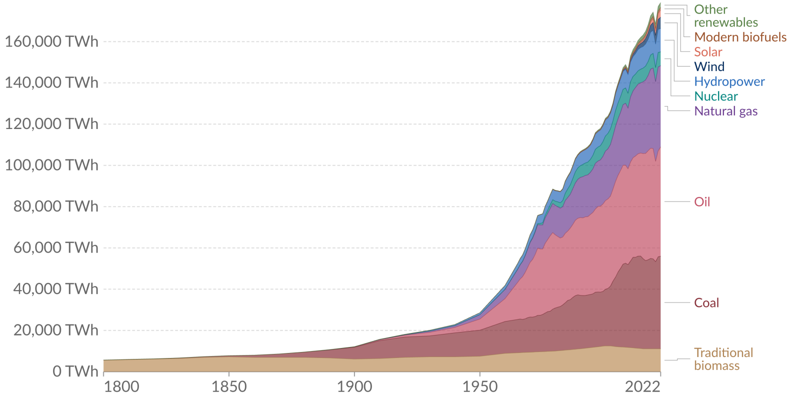
Climate Mitigation Policies

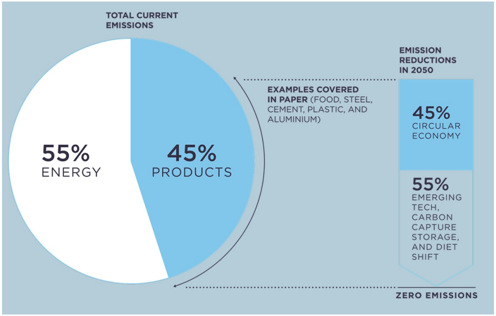
Figure: Global Energy Consumption by Source



Source: Ritchie and Pablo Rosado (2020)

Energy Efficiency for Mitigation?

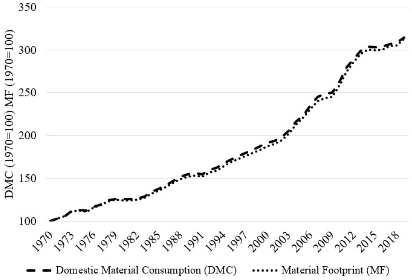
Figure: Tackling Emissions



Source: Ellen MacArthur Foundation (2019)

- Energy-based solutions alone can only reduce emissions by 55% and other solutions are required to achieve deeper emission reductions.

Material Consumption from 1970 to 2019



Source: Global Material Flows Database (2022)

- The OECD projects that global material use will be doubled in 2060, compared to 2011.
- Non-metallic minerals and metals will represent more than 60% of this growing demand.

Growing Demand for Materials

Actual (2021) and Projected (2050) Demand under IRENA's 1.5°C Scenario

Material	Demand in 2021 (Mt/year)	Demand in 2050 (Mt/year)	Source
Cu Copper	30 Mt/yr	50-70 Mt/yr	Elshkaki *et al.* (2016); ICGS (2021); INSG (2021)
Ni Nickel	2.77 Mt/yr	5-8 Mt/yr	Elshkaki *et al.* (2017)
Li Lithium	0.3 Mt/yr	2-4 Mt/yr	Moore and Bullard (2021)
Nd Neodymium	0.03 Mt/yr	0.2-0.5 Mt/yr	Barrera (2021); Joint Research Centre (2020, 2021); Deetman *et al.* (2021)

Source: International Renewable Energy Agency (2022)

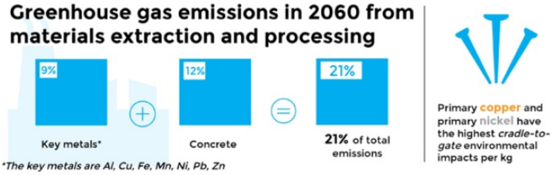
Economically vital

Source: Canada Mining

- Tungsten for smartphones, gallium for many light-emitting diodes (LEDs), copper for electronics, and silicon metal for semiconductors.
- For example, 50 different metals in different quantities are needed to produce a standard smartphone (EC, 2018).

Environmental Risk

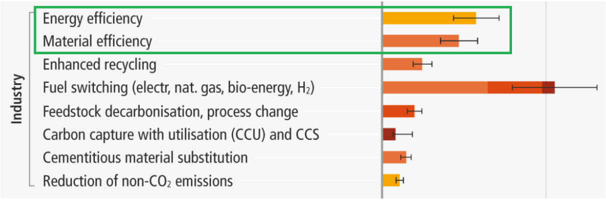
- Growing demand for materials does not come for free but at environmental cost.



Source: OECD (2019)

Material Efficiency

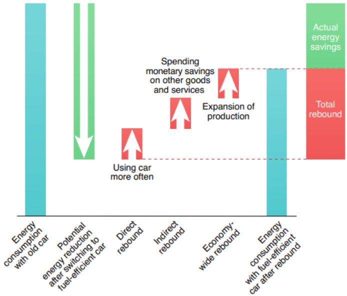
- IEA (2021) defines material efficiency as the strategies that reduce material demand or switch to lower-emission materials or production routes.



Source: IPCC (2022)

- Only energy efficiency may not be sufficient, we need more than energy efficiency!

Rebound Effect



- The rebound effect refers to various mechanisms that may offset potential resource savings resulting from improvements in resource efficiency.
- Specifically, rebound effects occur when the benefits gained from resource efficiency enhancements are partially or completely offset by increased consumption or production activities.

What do we do?

Purpose

- We comparatively investigate the material and energy efficiency performances, as well as their rebound effects.
- The European Union (EU) member countries and their main trading partners
- 1995-2019

Contribution

- This is the first study to comparatively assess the material and energy efficiency performances for the EU member countries and their main trading partners.

How do we do?

- Material intensity is still one of the most frequently used proxies for material efficiency.
    - defined as the ratio of material consumption to gross domestic product
    - only considers inputs itself
    - ignores other factors affecting material efficiency, such as structure of economy, input prices and so on.
- To address this deficiency, what we are looking for is to calculate a material efficiency based on the main determinants of material demand
- A frontier approach: Stochastic Frontier Analysis

Stochastic Frontier Analysis

- The earliest SFA panel data models mainly focus on controlling country effects.

$$lnDMC = f(x;\beta) + v + u \tag{1}$$

- To capture efficiency, they make country effects (fixed or random) one-sided and interpret them as efficiency.

$$ME = exp(-u) \tag{2}$$

- The rebound effect is calculated as follows

$$R = 1 + \epsilon_{ME}^{DMC}; \text{ where } \epsilon_{ME}^{DMC} = \frac{dlnDMC}{dlnME} = \frac{dlnDMC}{dlnexp(-u)} = -\frac{dlnDMC}{du}$$

- Backfire ($R > 1$); full rebound ($R = 1$); partial rebound ($1 > R > 0$); zero rebound ($R = 0$); super-conservation ($R < 0$)

SFA Model with the Rebound Effect

$$lnDMC = f(x;\beta) + v + (1 - R)u \tag{3}$$

$$lnDMC = f(x;\beta) + v + [1 - R(\lambda' Z)]u \tag{4}$$

- where $R(\lambda' Z)$ is the function that describes the rebound effect:
  - Z is a vector of variables that affect the level of the rebound effect
  - λ is a vector of corresponding coefficients

Model Specifications

- **Material model**

$$lnDMC_{it} = \alpha_0 + \beta_1 lnGDP_{it} + \beta_2 lnPOP_{it} + \beta_3 lnAREA_t + \beta_4 lnISH_{it} + \beta_5 lnSSH_{it} + \beta_6 lnMP_{it} + \beta_7 lnEC_{it} + \beta_8 lnTO_{it} + \beta_9 UMDT + [1 - R(\lambda' Z_{it})] + v_{it} + u_{it}$$

- **Energy model**

$$lnEC_{it} = \alpha_0 + \beta_1 lnGDP_{it} + \beta_2 lnPOP_{it} + \beta_3 lnAREA_t + \beta_4 lnISH_{it} + \beta_5 lnSSH_{it} + \beta_6 lnEP_{it} + \beta_7 lnDMC_{it} + \beta_8 lnTO_{it} + \beta_9 UEDT + [1 - R(\lambda' Z_{it})] + v_{it} + u_{it}$$

- **The $\lambda' Z$ functions for both material and energy**

$$\lambda' Z_{it} = \lambda_{GDP\_P} lnGDPP_{it} + \lambda_{MP} lnMP_{it} + \lambda_{CO} lnCOGDP_{it} + \lambda_{ISH} lnISH_{it} + \lambda_T lnUMDT$$

$$\lambda' Z_{it} = \lambda_{GDP\_P} lnGDPP_{it} + \lambda_{EP} lnEP_{it} + \lambda_{CO} lnCOGDP_{it} + \lambda_{ISH} lnISH_{it} + \lambda_T lnUEDT$$

What determines materials and energy demand?

(a) Drivers of material demand frontier and rebound effect			(b) Drivers of energy demand frontier and rebound effect		
Variables	**Coefficient**	**Std. err.**	**Variables**	**Coefficient**	**Std. err.**
			Frontier		
lnGDP	1.1814***	0.0999	lnGDP	1.1266***	0.0483
lnPOP	-0.6922***	0.1133	lnPOP	-0.1457***	0.0464
lnAREA	0.3440***	0.0426	lnAREA	0.1806***	0.0329
lnISH	-0.3495***	0.1127	lnISH	-0.2596***	0.0766
lnSSH	-0.5146***	0.1985	lnSSH	0.0266	0.0708
lnMP	0.1277***	0.0299	lnEP	-0.0616***	0.0166
lnEC	-0.0724	0.0735	lnDMC	-0.0031	0.0122
lnTO	-0.1863***	0.0429	lnTO	-0.0252	0.0177
UMDT	0.0027	0.0034	UEDT	-0.0219***	0.0016
Constant	-3.0965*	1.8316	Constant	-29.0039***	0.8977

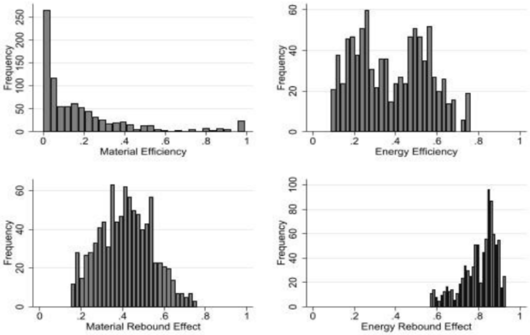
- A large part of the parameter estimates are statistically significant and show large similarities in terms of sign and magnitude.
- There is no very interesting outcome:
  - GDP has a positive significant effect on both energy and materials.
  - Larger areas require more energy and materials.

Rebound Effect: Determinants

(a) Drivers of material demand frontier and rebound effect			(b) Drivers of energy demand frontier and rebound effect		
Variables	**Coefficient**	**Std. err.**	**Variables**	**Coefficient**	**Std. err.**
		Rebound Effect			
lnGDPP	-0.0948	0.0632	lnGDPP	0.1968***	0.0189
lnMP	0.1852***	0.0436	lnEP	-0.0481***	0.012
lnCOGDP	-0.7763***	0.1783	lnCOGDP	-0.4773***	0.0664
lnISH	-0.3946***	0.0922	lnISH	-0.1664***	0.0579
UMDT	0.0086**	0.0043	UEDT	-0.0166***	0.0022
σ_u	1.1039**	0.4318	σ_u	3.0007***	0.4169
σ_v	-4.0628***	0.0493	σ_v	-5.9613***	0.0493

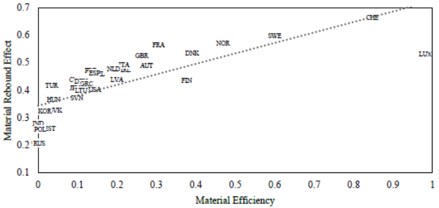
- There are some interesting outcomes:
  - Income per capita is statistically significant and positive for the energy rebound effect, yet it is for materials.
  - Energy price has a negative sign, but it is positive for materials.

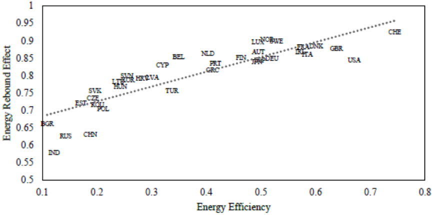
Resource Efficiency and Rebound Effect I



- Countries perform better in terms of energy efficiency.
- The energy rebound effect is higher than materials.

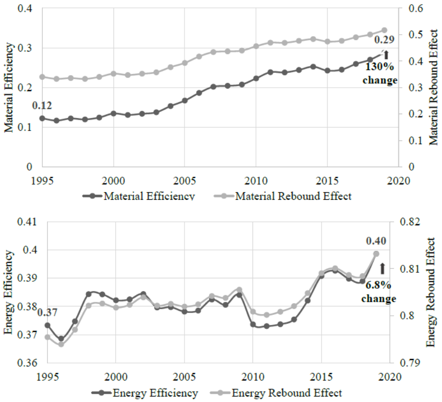
Resource Efficiency and Rebound Effect II





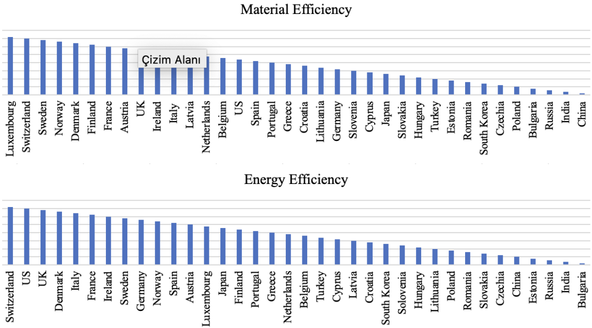
- There exists a positive relationship between efficiency and rebound effects: more efficiency leads to more rebound effects.

Resource Efficiency and Rebound Effect III



- Material efficiency scores are considerably low in the early period, yet improving significantly over the years.
- However, energy efficiency improvements have increased only by around 7% from 1995 to 2019, while this increase is around 130% for material efficiency.

Material and Energy Efficiency



- The most developed EU countries and their rich trading partners have the highest material efficiency scores.
- On the other hand, relatively less developed member countries and trading partners rank low.

Conclusion

- Both energy and material efficiency improvements are critical in meeting climate goals, yet they might have a rebound effect.
- Countries perform better in terms of energy efficiency, yet the rebound effect is also higher: positive link
- Material efficiency is lower, but improves over the years. There is significant room for efficiency improvements for low-scored countries.
- Developed EU countries and their rich trading partners generally ranked higher in material and energy efficiency scores, while less developed members and partner countries ranked lower.
- Our findings suggest that the EU's CBAM could have significant implications for trading partners with low-efficiency scores.
- Policymakers should consider potential rebound effects to ensure that they are effective and sustainable.
- Rebound effect of material efficiency is significantly lower than energy efficiency rebound, suggesting important opportunities for ME policies.

The End

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