

Shivenes Shammugam

## **Raw materials and energy transformation process**

Analysis of supply bottlenecks and  
implications on metal markets

**Raw materials and energy transformation process  
- Analysis of supply bottlenecks and implications  
on metal markets**

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## List of scientific publications

Some parts of this thesis have been developed as part of scientific papers in collaboration with co-authors. These papers serve as a basis for some chapters, but were also revised and expanded in terms of content and editorially amended as part of the thesis. Chapters containing longer text passages or result representations are marked accordingly. In each case, the author had a significant share of all essays in this thesis.

- Shammugam, S.; Gervais, E.; Schlegl, T.; Rathgeber, A. (2019a): Raw metal needs and supply risks for the development of wind energy in Germany until 2050. In *Journal of Cleaner Production* 221, pp. 738-752.  
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Chapter: 2.3.1, 6, 10.1
- Shammugam, S; Rathgeber, A; Schlegl, T (2019b): Causality between metal prices. Is joint consumption a more important determinant than joint production of main and by-product metals? In *Resources Policy* 61, pp. 49–66.  
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## I. List of metal abbreviations

Ag	Silver
Al	Aluminium
Au	Gold
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Dy	Dysprosium
Ga	Gallium
In	Indium
Li	Lithium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
Nd	Neodymium
Ni	Nickel
Pb	Lead
Pd	Palladium
Pt	Platinum
Sb	Antimony
Si	Silicon
Se	Selenium
Sn	Tin
St	Steel
Ta	Tantalum
Te	Tellurium
Ti	Titanium
V	Vanadium
Zn	Zinc

## II. List of general abbreviations

ADF	Augmented Dickey-Fuller
ARCH	Autoregressive conditional heteroscedasticity
BEV	Battery electric vehicles
BG	Breusch and Godfrey
BIC	Bayesian Information Criteria
BIPV	Building integrated photovoltaics
BMS	Battery management system
BOS	Balance of system
BSF	Back surface field
CdTe	Cadmium Telluride
CIGS	Copper-Indium-Gallium-Selenium
Con	Consumption
CPI	Consumer price index
CUSUM	Cumulative sum
CZTS	Copper-Zinc-Tin-Selenium
c-Si	Crystalline silicon
DFIG	Doubly-Fed Induction Generator
D/P ratio	Demand-to-production ratio
D/R ratio	Demand-to-reserve ratio
D/R <sub>base</sub> ratio	Demand-to-reserve base ratio
EEG	Renewable energy act
EESG-DD	Electrically-Excited Synchronous Generator-Direct-Drive
EV	Electric vehicles
FedFund	Federal Fund Rates
FEVD	Forecast error variance decomposition
GDP	Gross domestic product
GHG	Greenhouse gasses
GW	Gigawatt
GWh	Gigawatt hours
H <sub>0</sub>	Null-hypothesis
HEV	Hybrid electric vehicles
IRF	Impulse response function

KPSS	Kwiatkowski-Phillips-Schmidt-
kWh	Kilowatt hours
LCA	Life cycle analysis
Li-Air	Lithium-Air
Li-Ion	Lithium-Ion
Li-S	Lithium-Sulphur
LM	Lagrange Multiplier
LME	London Metal Exchange
MENA	Middle East & North Africa
MW	Megawatt
Na-S	Sodium-sulphur
NiMH	Nickel-metal hydride
OLS	Ordinary least squares
PGE	Platinum group elements
PHEV	Plug-in hybrid electric vehicle
PM	Permanent magnet
PMSG-DD	Permanent Magnet Synchronous Generator-Direct-Drive
PMSG-HS	Permanent Magnet Synchronous Generator – High Speed
PMSG-MS	Permanent Magnet Synchronous Generator-Middle Speed
Prod	Production
PV	Photovoltaic
REE	Rare earth elements
SCIG	Squirrel Cage Induction Generator Variable Speed
SLI	Starting, lighting, ignition
TCO	Transparent conducting oxides
TLB	Tension leg-buoy
TWh	Terawatt hours
VAR	Vector auto regression
VECM	Vector error correction model
VRF	Vanadium redox flow