UCL

The new CGE model UCL ENGAGE-materials and a case study on steel

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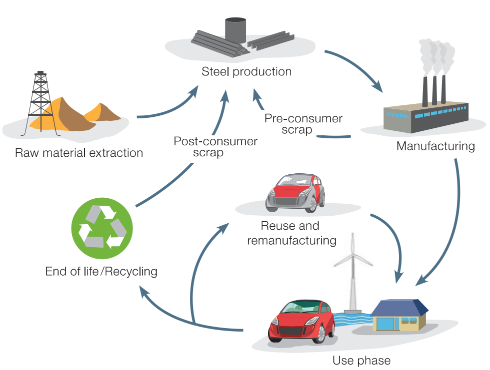
MICA Mineral Intelligence Capacity Analysis

Macro-Economic Models / CGE

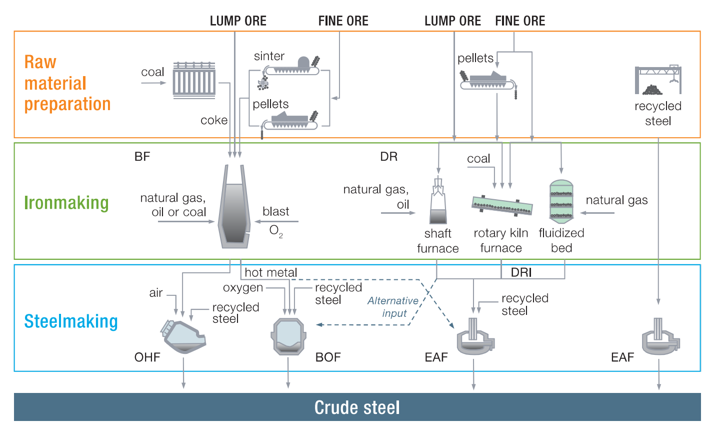
- Relevant to analyse the role of minerals in economies nationally and at an international scale, value added during production and consumption, and assess socio-economic impacts of changes in markets and policies
- Surprisingly little experience
  - Most macro-economic models do neither capture physical data nor disaggregate relevant sectors
  - Extensions to energy better developed, as well as energy system modelling
- Few models used to analyse RE/CE (GINFORS / Pantha Rhei, E3ME, GTEM, EXIOMOD)
- Computable General Equilibrium models (CGE) advantageous in representing advanced standard economics, used to model policy impacts, can apply GTAP database on international trade

Steel in the economy

- Steel is the key material for construction and automotive industries and, thus for industrialization. World steel production grew roughly tenfold from 1950 till 2015, with China now producing roughly half of world steel.
- Ambivalent environmental dimensions: (i) Steelmaking is a large source of greenhouse gas emissions. (ii) Steel is 100% recyclable and therefore considered a permanent material with high functionality for a circular economy. Europe is the leading exporter of scrap steel worldwide, both Asia and Europe are trading hubs for scrap steel.



Steel's life cycle



Steel production routes

Source: World Steel Association (2012). Sustainable steel: at the core of a green economy

ENGAGE overview at UCL ISR

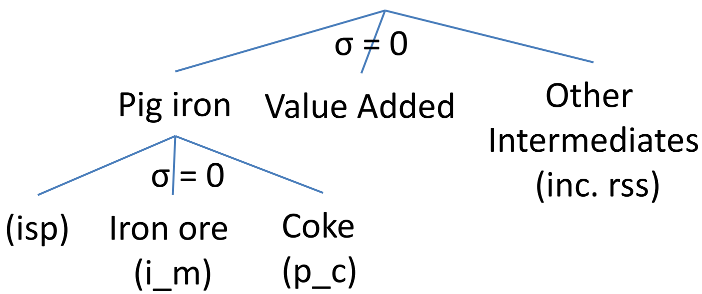
1. Split 'Other mining' sector (omn) in GTAP into 3 types
    - Iron and steel mining (i_m)
    - Non-ferrous mining (n_m)
    - Other mining (o_m)
2. Split 'Iron and steel' (i_s) and 'non-ferrous metals' (nfm) production sectors in GTAP into primary and secondary
    - Secondary iron and steel is split into 2 distinct production types: iron and steel for treatment (sst) and re-processing of secondary steel into new steel (rss)
3. Specify production functions in the model for primary/secondary sectors
4. Run basic scenarios and sensitivity analysis of key parameters
5. Run policy scenarios

ENGAGE – Material model – Steel routes

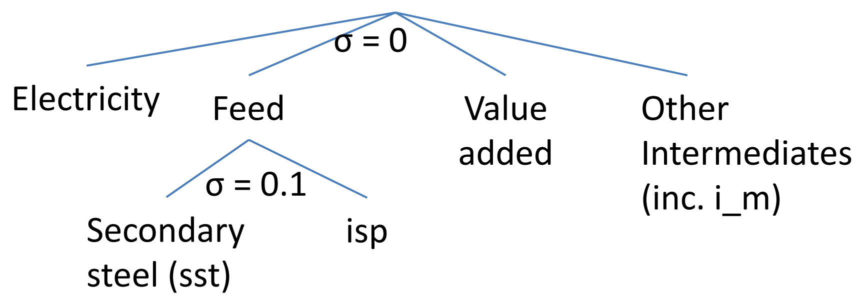
Environmental Global Applied General Equilibrium (ENGAGE)

Multi-region, multi-sector dynamic CGE model of the world economy

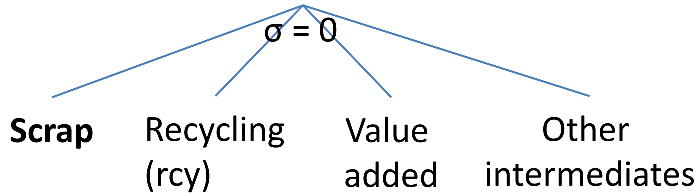
Primary steel (isp)



Re-processed steel (rss)



Secondary steel for treatment (sst)



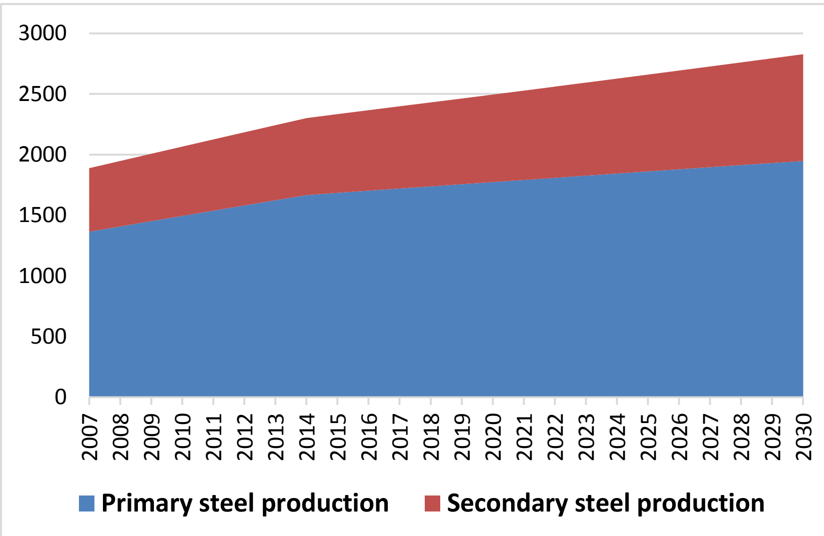
ENGAGE – Material model

Steel specification in ENGAGE

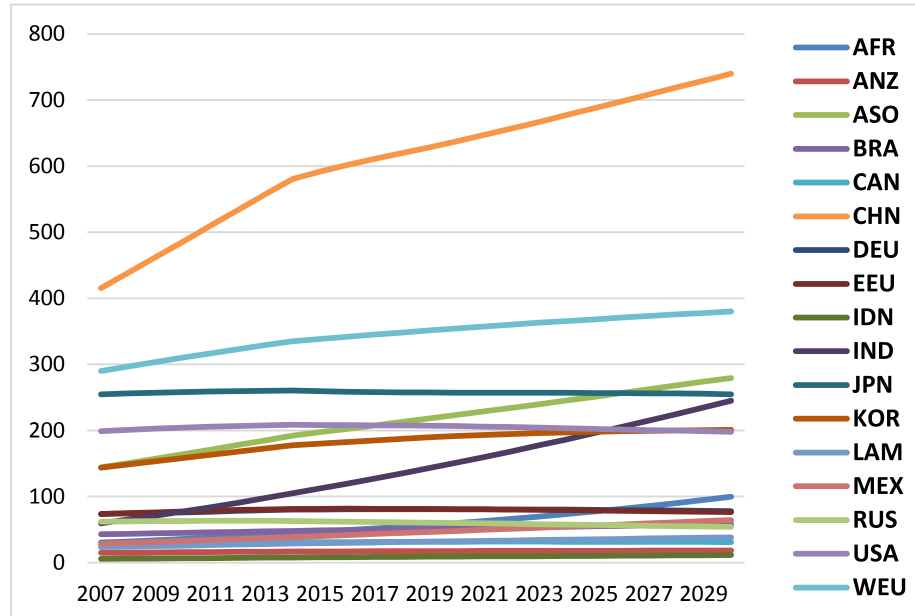
- Secondary steel - the value of scrap is derived from that of Capital– the capital investment in steel treatment reflect the shadow value of steel scrap
- Substitution of steel coming from *isp* and *rss* can be industry specific
- Scenario opportunity for scrap availability – boost in overall or sector-specific recycling rates/quotas – through EXIOBASE supply and use data

Baseline scenario

World steel production (million USD)



Regional steel production (million USD)

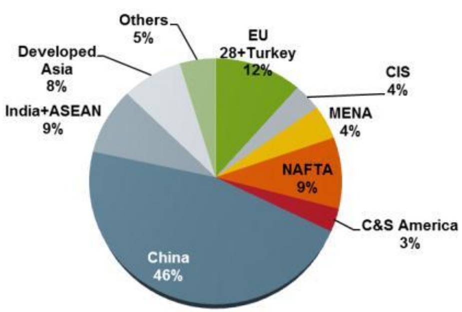


Steel demand outlook till 2030

2014

1,537MT

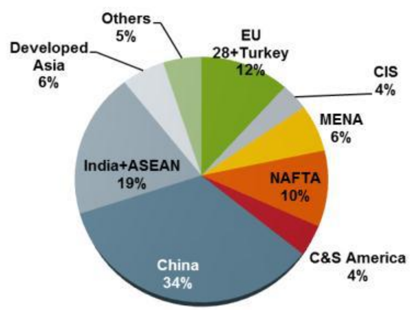
(finished steel basis)



2030

1,992 MT

(finished steel basis)



⇒ **Steady saturation in China**

⇒ **India and ASO emerge as a fast growing regions**

⇒ **WSA 30% (ENGAGE 23%) growth to 2030**

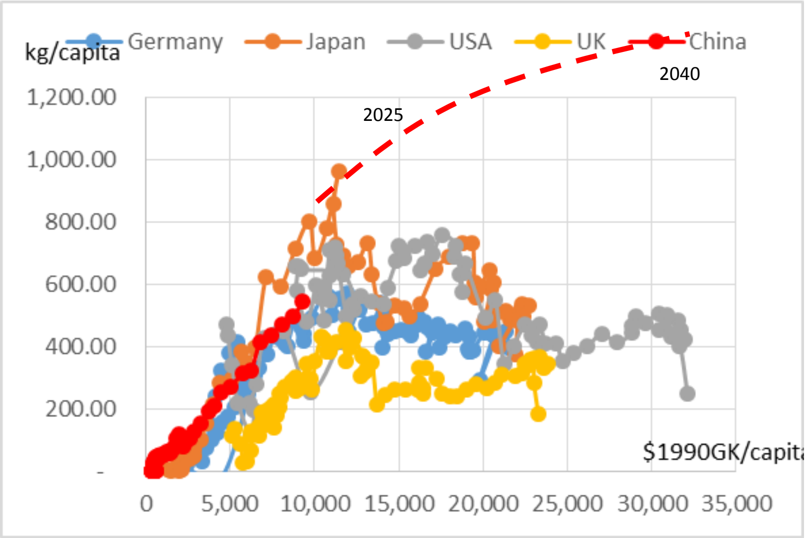
Source: World Steel Association (2015). Global steel market output

Extrapolation or Saturation - Two scenarios for China:

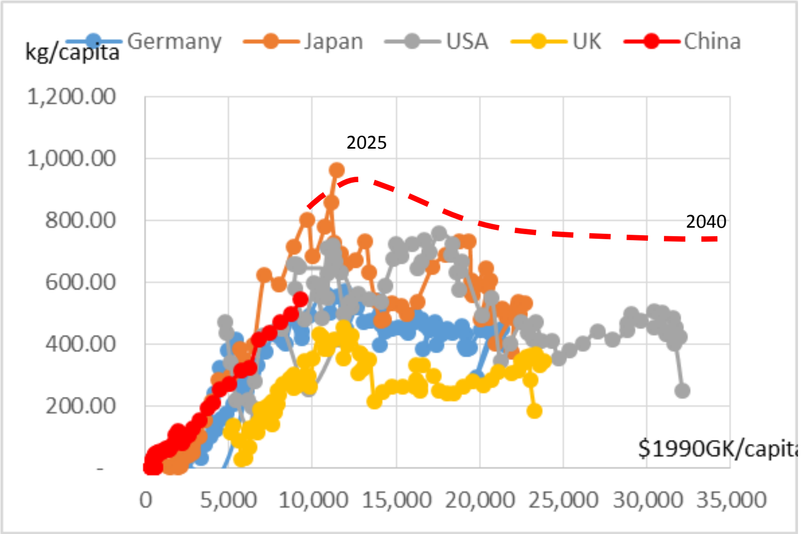
- Extrapolating future demand from the previous years: doubling demand by 2040
- Expecting a saturation to occur: stagnating and lower demand

Data as Apparent Domestic Consumption of steel per capita and Income per capita over time

Extrapolation



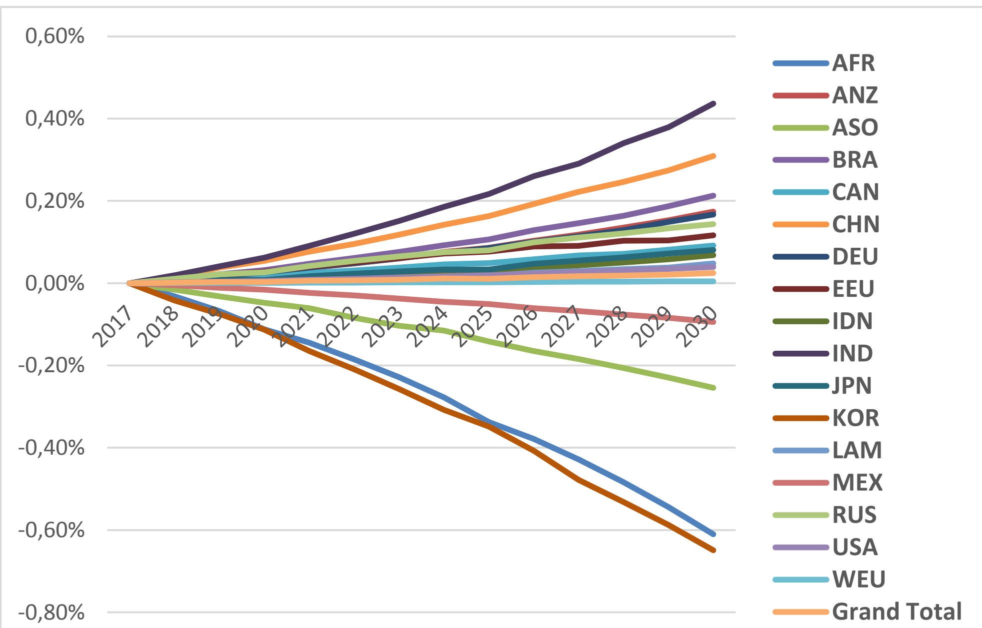
Saturation

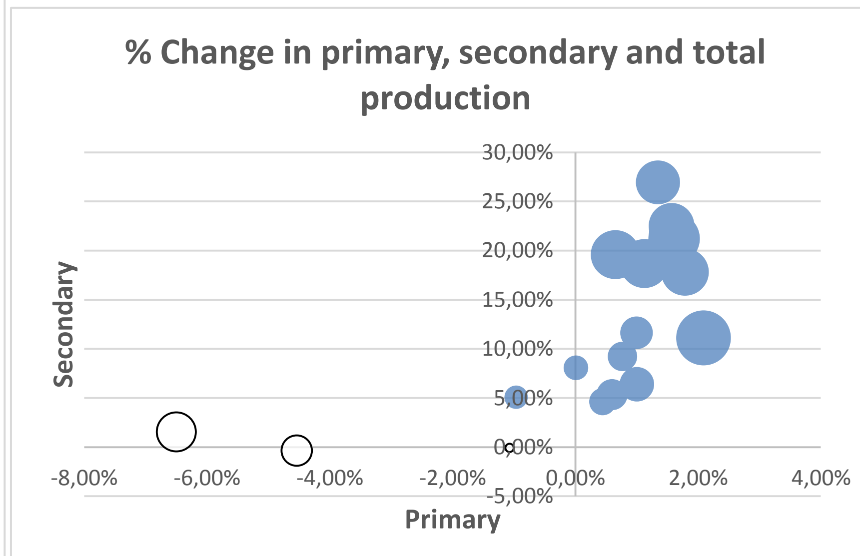


Towards a policy scenario: Boosting secondary supply

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Scrap	0.00%	4.98%	10.30%	15.99%	22.08%	28.59%	35.56%	43.02%	50.98%	59.49%	68.60%	78.35%	88.79%	100.00%
Secondary production	0.00%	0.35%	0.73%	1.11%	1.56%	2.03%	2.52%	3.05%	3.60%	4.25%	4.85%	5.52%	6.27%	7.08%
Primary production	0.00%	-0.01%	-0.01%	-0.02%	-0.04%	-0.04%	-0.06%	-0.07%	-0.08%	-0.09%	-0.11%	-0.12%	-0.13%	-0.15%
Total production	0.00%	0.09%	0.20%	0.31%	0.43%	0.56%	0.71%	0.86%	1.03%	1.22%	1.40%	1.61%	1.85%	2.10%

Regional GDP (%change wrt BAU)

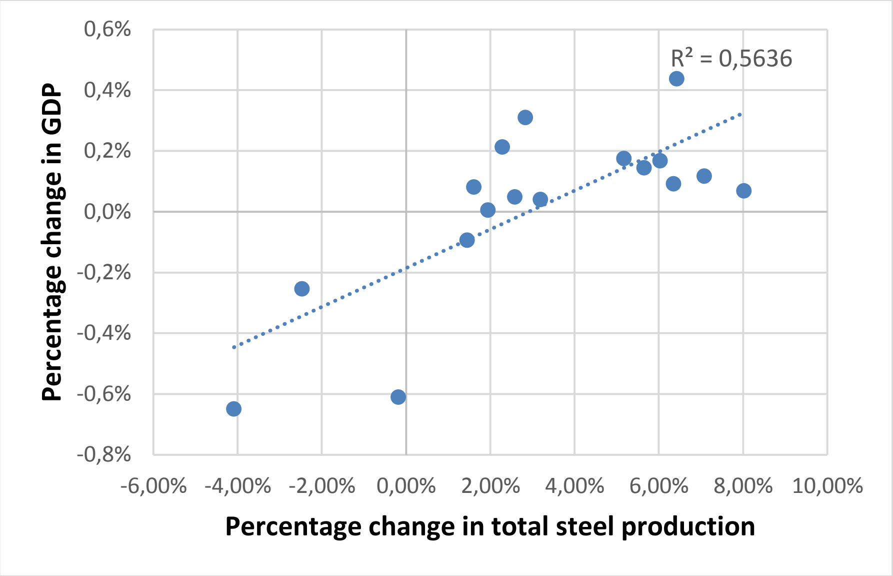




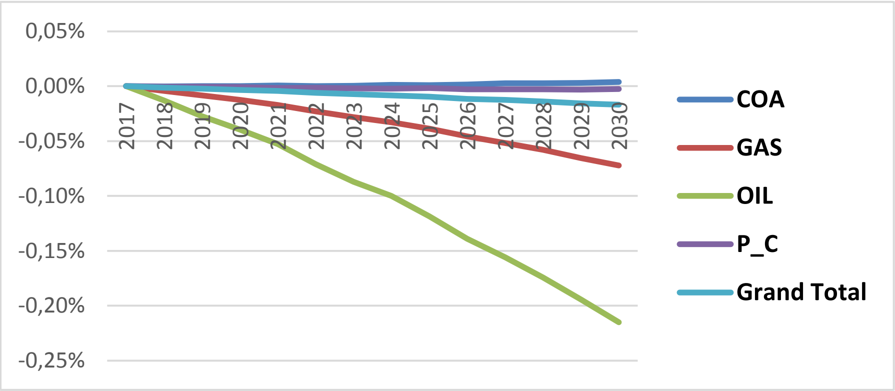
Policy scenario

Regional production 2030 (% change wrt base)

	Primary	Secondary	Total
AFR	-1.07%	-0.07%	-0.18%
ANZ	1.35%	26.94%	5.17%
ASO	-4.54%	-0.37%	-2.47%
BRA	0.77%	9.23%	2.28%
CAN	1.13%	18.67%	6.35%
CHN	1.00%	11.63%	2.83%
DEU	1.79%	17.82%	6.03%
EEU	1.61%	21.23%	7.08%
IDN	2.09%	11.12%	8.02%
IND	0.65%	19.59%	6.43%
JPN	0.01%	8.07%	1.61%
KOR	-6.50%	1.55%	-4.09%
LAM	0.60%	5.34%	2.58%
MEX	-0.96%	5.08%	1.45%
RUS	1.57%	22.50%	5.65%
USA	1.00%	6.39%	3.19%
WEU	0.45%	4.63%	1.95%



Emissions (%change wrt BAU)



Conclusions & Outlook

- UCL ENGAGE Materials offers useful insights; yet it needs further work (data, etc)
- Steel results encouraging; moderately positive impacts on GDP and emissions; needs more
  - Sensitivity analysis
  - Calculations of saturation levels
  - A more nuanced policy scenario
  - More detailed and accurate representation of technologies along the supply chain (Elasticities, links/constraints between physical and monetary data, etc.)

Planned future activities

- Publish paper (submitted to IEEP)
- Calibrate the model (Summer 2017)
- Develop steel scenario (Summer / Autumn 2017)
- Discuss interim results 15 Sep
- Incorporate feedback and finalise (end 2017/early 2018)

Selected references

- Bohringer, C. and Rutherford, T. (2015), The Circular Economy – an Economic Impact Assessment. Report to SUN-IZA
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- Hatfield Dodds et al. (2017), Assessing global resource use and greenhouse emissions to 2050, with ambitious resource efficiency and climate mitigation policies, Journal of Cleaner Production 144: 403- 414.
- Meyer, B., Distelkamp, M. and Beringer, T., (2015) Report about integrated scenario interpretation: GINFORS/LPJml results. Deliverable D3.7a for the FP7 project POLFREE (Policy Options for a Resource Efficient Europe)
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- Pauliuk et al (2013b), Steel all over the world: Estimating in-use stocks of iron for 200 countries, Resources, Conservation and Recycling, 71, 2013, 22-30
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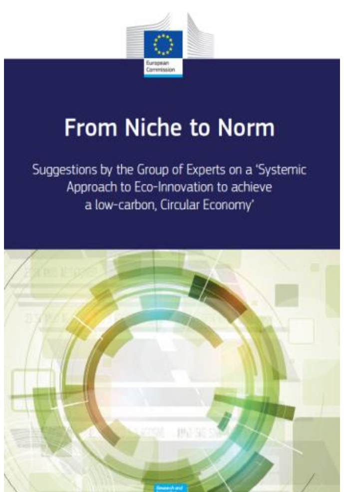

Thank you

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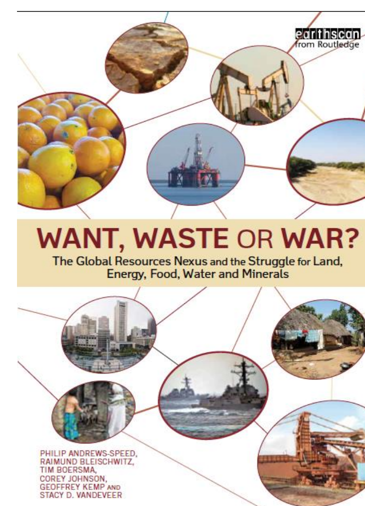
www.bartlett.ucl.ac.uk/sustainable

New MSc at: http://www.bartlett.ucl.ac.uk/sustainable/programmes/msc-sres



Existing modelling results on resource efficiency and circular economy

Bohringer and Rutherford (2015) - for the Ellen MacArthur Foundation on the circular economy.

- Benefits of circular economy show GDP could be 11% higher in 2030 and 20% higher in 2050 than the baseline development scenario. However, their model assumes exogenous technological change in transport, housing and food.

European Commission (2014) “Assessment of scenarios and option for a resource efficient Europe”

Meyer et al (2015)

- GINFORS model shows resource efficiency policies to reduce raw material consumption to 5 tonnes per capita, combined with other environmental targets, could be achieved with increased growth and employment.

CE and BioIS (2014)

- E3ME results suggest that resource productivity improvements of between 2 to 2.5% can be achieved with net positive effects on GDP. However, with higher levels of ambition there are net costs productivity improvements. They suggest around 2 million extra jobs can be created with a 2% per year improvement in resource productivity.

Schandl *et al* (2015) -

Global resource extraction from 80 to 183 billion tonnes in 2050 BAU can be reduced to 90 (or 130) with a high (or medium) carbon price

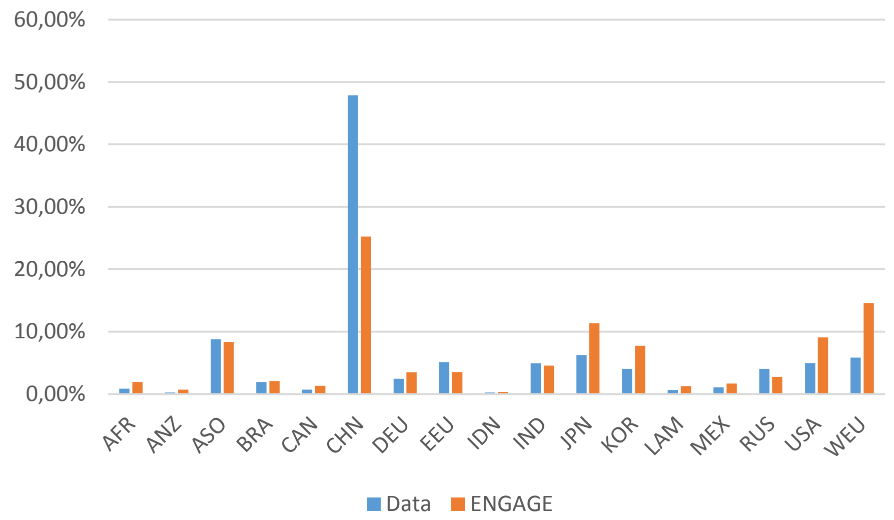
Resource efficiency and circular economy

Modelling literature review

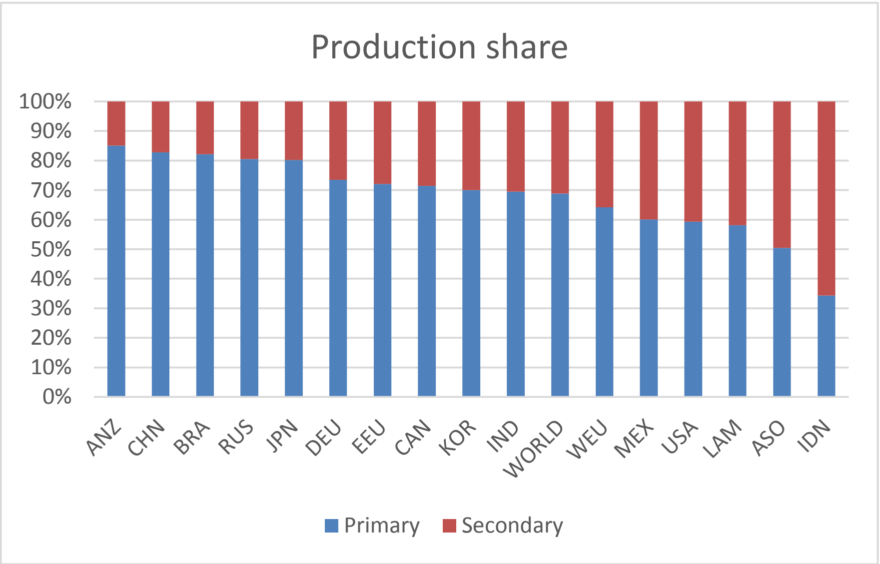
Model	Type	Database	Year(s)	No. Sectors	Resources	No. Regions	Main applications
EXIOMOD	CGE/IO	EXIOBASE	2004	127	11 extraction, 2 recycling, 3 waste, 48 raw materials	44	All environental applications
Ellen MacArthur	CGE	GTAP	2007	16	coal, crude oil, natural gas, refined oil, electricity	5	Transport, Housing, energy and food
GINFORS	Macro-econometric	WIOD	1995-2011	35 industries, 59 products	5 biomass, 4 fossil fuels, minerals construction, minerals industrial, minerals metal	38	Resource efficiency
E3ME	Macro-econometric	EE-MRIO from Eurostat and AMECO plus others	1970-2012	69 for EU; 43 for RoW	Materials module calculates RMC, DMI and TMR	All EU individually plus 11 others a RoW	Energy and resource efficiency. Hard linked materials module
GIAM	CGE	GTAP and Eora	2007	21	Soft-linked to separate MEFISTO material flow model	13	Energy and resource efficiency

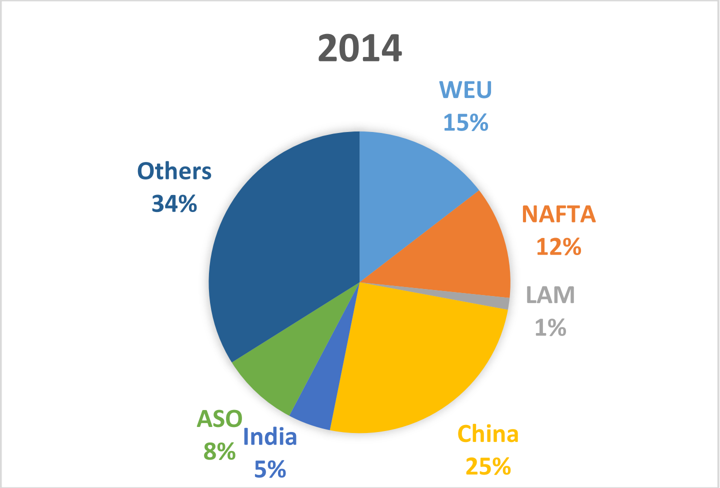
Baseline scenario

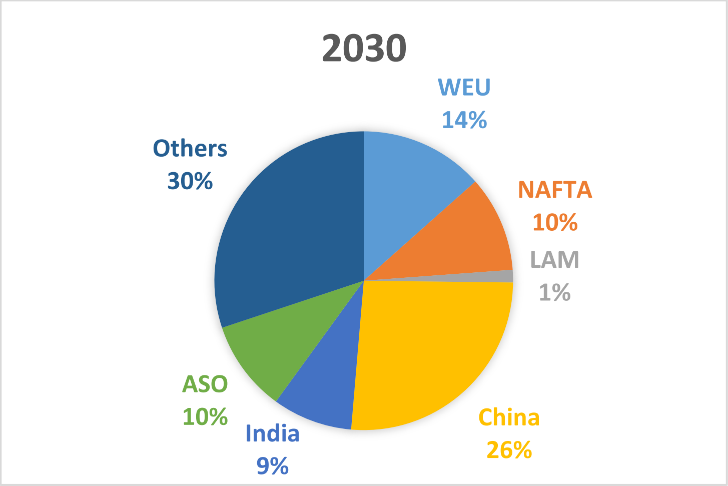
Region share in production 2014



2030 ENGAGE

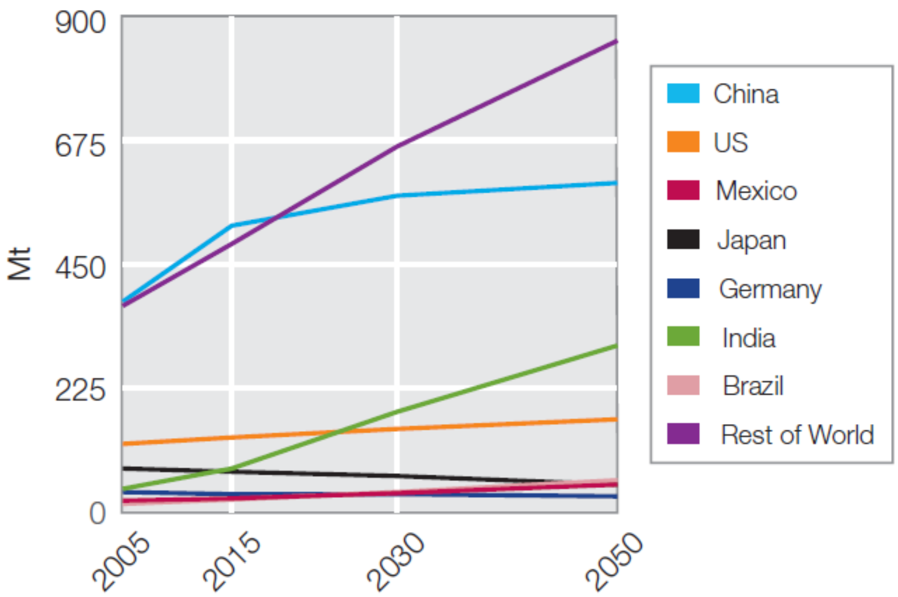




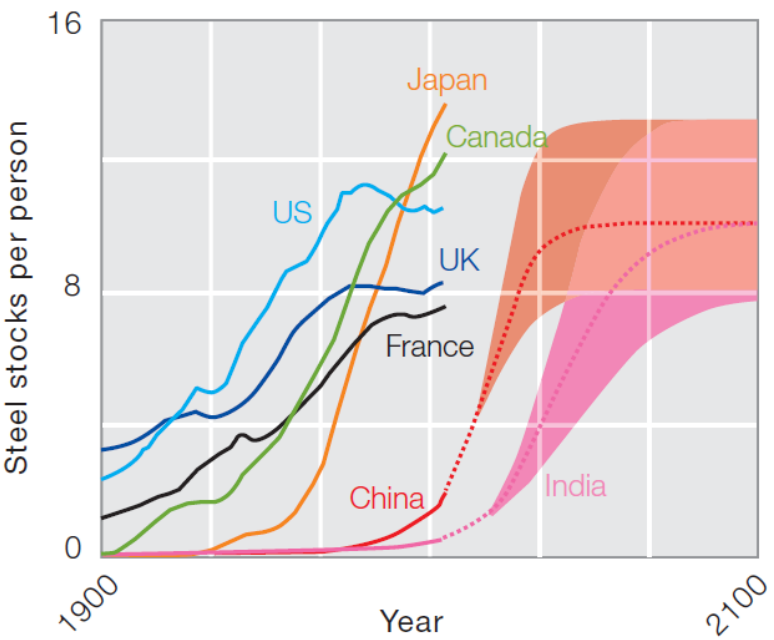


Steel production

Past and forecast steel consumption



Past and forecast steel stocks



Source: World Steel Association (2012). Sustainable steel: at the core of a green economy

ENGAGE–Material Model

Regions (17)

Regions (17)	
China	CHN
Japan	JPN
India	IND
USA	USA
Russia	RUS
South Korea	KOR
Brazil	BRA
Mexico	MEX
Canada	CAN
Australia	ANZ
Indonesia	IDN
Germany	DEU
Western Europe	WEU
Eastern Europe	EEU
Asia and Oceania	ASO
Latin America	LAM
Africa	AFR

Sectors (35)

Mining related sectors (15)		Energy related (13)	
Iron mining	i_m	Coal	coa
Non-ferrous mining	n_m	Crude oil	oil
Other minerals mining	o_m	Gas	gas
Iron and steel primary production	isp	Petroleum & Coke	p_c
Re-processing of secondary steel into new steel	rss	Transmission and distribution	tnd
Secondary steel for treatment	sst	Nuclear power	nup
Non-ferrous primary	nfp	Coal-fired power	cfp
Non-metallic minerals	nmm	Gas-fired power	gfp
Metal products	mtp	Wind power	wip
Motor vehicles and transport equipment	mvt	Hydro power	hyp
Electronic equipment	ele	Solar power	sop
Machinery and other equipment	mae	Oil-fired power	ofp
Recycling	rcy	Other power	otp
Construction	cns		
Transport	tra		
Other sectors (6)			
Agriculture and food	agr		
Wood products	wop		
Paper products	ppp		
Chemical products	crp		
Other manufacture	oma		
Services	ser		

Mining sector data

- **Issues**
  - ☑ Physical data seems consistent between EXIOBASE and our estimates from USGS (likely same data)
    - However, value data from EXIOBASE seems inconsistent for large mining producers e.g. iron ore mining in China relatively small in value terms. Requires independent estimation and potential re-estimation of OMN split

- **Methodology**
  - Check for national accounts data for monetary values of iron and steel, copper, aluminium and other mining sectors
    - Where full data is available use the national accounts to split these regions.
    - Where data is available for only one or two sectors e.g. only iron mining is given for AUS but all other mining is aggregated together, use this data and split others based on other estimates/assumptions
    - Where no data is available calculate from bottom-up using average world price

Mining sector data

UPDATED mining monetary value shares for splitting

Source	Country	Iron ore		Other mining		GTAP OMN TVOM $m 2007
		EXIOBASE	ENGAGE	EXIOBASE	ENGAGE	
National Accounts 2007	Australia	4%	39%	96%	61%	53,609
National Accounts 2005	Brazil	45%	66%	55%	34%	32,390
National Accounts 2007	Canada	2%	9%	99%	91%	19,065
National Accounts 2007	China	7%	36%	93%	64%	121,248
National Accounts 2005	India	26%	25%	74%	75%	16,365
USGS and price estimates	Russia	2%	44%	98%	56%	15,576
National Accounts 2007	USA	0.3%	5%	99.7%	95%	48,041

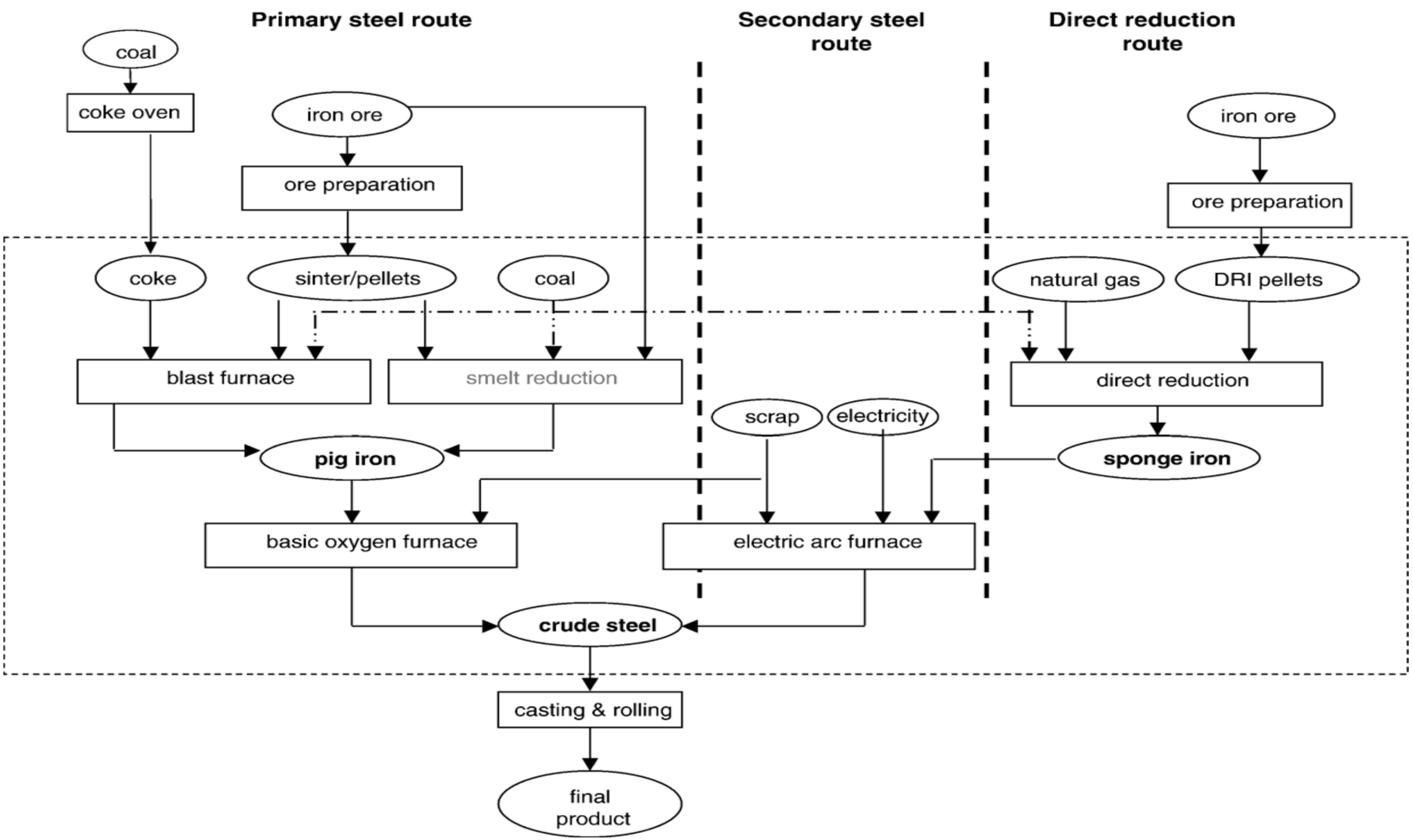
Mining sector data

COST STRUCTURE Iron mining sector (i_m)

Sector	AUS	CHI	BRA
Oil	0.7%	1.6%	0.0%
Iron mining	1.4%	11.5%	9.0%
Other mining	15.7%	0.0%	2.2%
Petroleum coal	**8.3%**	5.1%	**5.2%**
Chemicals	1.6%	4.3%	1.0%
Metal products	0.7%	4.0%	2.0%
Electrical equip	0.8%	7.1%	2.3%
Electricity	0.7%	**16.0%**	3.3%
Construction	7.0%	0.0%	3.4%
Transport	1.1%	3.1%	10.3%
Other business	5.0%	2.1%	7.5%
Trade	3.1%	1.1%	5.2%
Labour	6.3%	**12.1%**	5.5%
Output Tax	1.8%	5.6%	3.1%
Capital	**40.4%**	15.5%	**38.1%**
Total	**94.61%**	**89.18%**	**98.15%**

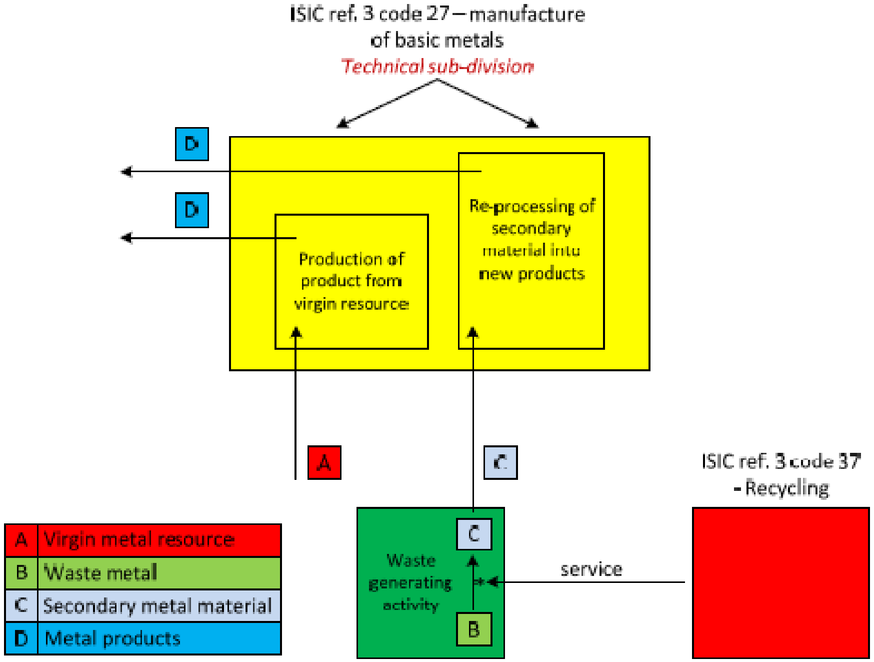
Primary and secondary steel production

Iron and steel production routes (Schumacher and Sands 2007)



Primary and secondary steel production

Metal waste treatment in EXIOBASE



For metals

- Recycling activity only deals with collection i.e. no monetary flows reflecting the value of scrap and no scrap physical quantities generated
- Secondary metal sectors are considered the "waste" users whilst other sectors (automotive etc.) are "waste" suppliers

⇒ Secondary metal sectors do the conversion of "waste metals" into "secondary metal materials" only assisted by the recycling activity

⇒ These sectors comprise both (1) the waste conversion and (2) the re-processing of secondary metals into basic metal products

Primary and secondary steel production

Secondary steel specification: EXIOBASE -> ENGAGE

	Waste treatment service:	Source:
1	Manure (conventional treatment)	FAOSTAT(2013); IPCC (2006); own elaborations;
2	Manure (biogas treatment)	FAOSTAT(2013); IPCC (2006); AEBIOM (2009); own elaborations;
3	Secondary paper for treatment, Re-processing of secondary paper into new pulp	EUROSTAT (2012); EPA (2008); WRAP (2011); Hyder consulting (2009); OECD (2010); Perele and Solovyeva (2011); DETEC-FOEN (2008); Ecolamancha (2008) ; own elaborations;
4	Wood material for treatment, Re-processing of secondary wood material into new wood material	EUROSTAT (2012); EPA (2008); Hyder consulting (2009); FAOSTAT(2013); Ecolamancha (2008) ; own elaborations;
5	Secondary plastic for treatment, Re-processing of secondary plastic into new plastic	EUROSTAT (2012); EPA (2008); Hyder consulting (2009); OECD (2010); CEMPRE (2010); Statistics Canada(2008); Perele R. and Solovyeva S. (2011); DETEC-FOEN (2008); Ecolamancha (2008) ; own elaborations;
6	Secondary glass for treatment, Re-processing of secondary glass into new glass	EUROSTAT (2012); EPA (2008); Hyder consulting (2009); CEMPRE (2010); Statistics Canada(2008); DETEC-FOEN (2008); Ecolamancha (2008) ; own elaborations;
7	Ash for treatment, Re-processing of ash into clinker	Smith I. (2005); own elaborations;
8	Secondary construction material for treatment, Re-processing of secondary construction material into aggregates	UEPG (2008); EPA (2003); Statistics Canada(2008); Hyder consulting (2009); BGS (2012); own elaborations;
9	Secondary steel for treatment, Re-processing of secondary steel into new steel	Worldsteel Association (2010); USGS (2012);

Re-processing of secondary steel into new steel	Basic iron and steel and of ferro-alloys and first products thereof - negative input	Ecoinvent process: Steel, electric, un- and low-alloyed, at plant/RER U
	Aggregated fuels	Ecoinvent process: Steel, electric, un- and low-alloyed, at plant/RER U
	Aggregated electricity	Ecoinvent process: Steel, electric, un- and low-alloyed, at plant/RER U

For steel:

- "*Secondary steel for treatment; Reprocessing of secondary steel into new steel*" – as single activity (*iss*) from EXIOBASE monetary flows

=> This sector needs to be split into

  - Secondary steel for treatment (waste conversion) - **sst**
  - Re-processing – **rss**

by assuming :

- that all own-demand in the *iss* sector is the output of the *sst* activity
- All recycling costs of *iss* are attributed to *sst*
- All treatment outputs *sst* go into reprocessing *rss*

Production - Cost Structure

ISP

	AUS	CHN	USA
i_m	1.4%	10.5%	0.5%
n_m	6.6%	9.4%	2.7%
o_m	13.4%	2.0%	0.9%
p_c	4.1%	7.2%	3.6%
nmm	0.5%	2.5%	2.3%
isp	14.6%	24.5%	9.6%
rss	3.3%	3.1%	6.0%
ome	0.6%	4.3%	6.0%
ely	2.2%	2.5%	3.1%
trd	3.6%	2.2%	8.3%
otp	7.7%	1.4%	4.0%
obs	4.7%	0.7%	4.4%
Labor	15%	8%	27%
Capital	11%	9%	8%
Total	88.5%	88.3%	86.7%

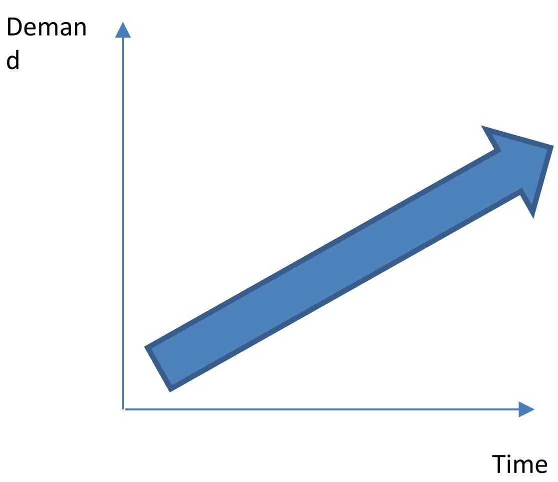
SST

	AUS	CHN	USA
Rcy	1.6%	24%	0.01%
Capital	98.6%	76.0%	99.98%
Total	100%	100%	100%

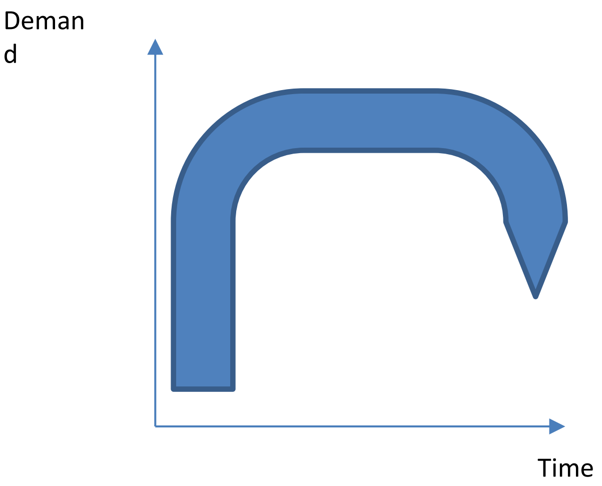
RSS

	AUS	CHN	USA
n_m	6.1%	9.8%	0.9%
o_m	12.2%	1.6%	0.2%
p_c	3.2%	1.9%	0.9%
nmm	0.4%	2.7%	0.6%
isp	13.4%	27.9%	16.6%
sst	3.0%	3.5%	9.0%
ome	0.3%	4.7%	10.2%
ely	9.3%	14.2%	3.9%
trd	6.1%	3.0%	8.3%
otp	10.3%	1.9%	5.7%
obs	4.5%	0.8%	4.5%
Labor	15%	10%	27%
Capital	5%	7%	0%
Total	88.9%	88.7%	87.4%

China's Future Demand for Resources: Insatiable or Saturated?



Analysts often derive future outlooks from extrapolating past years. This approach suggests China will double demand for resources by the year 2040



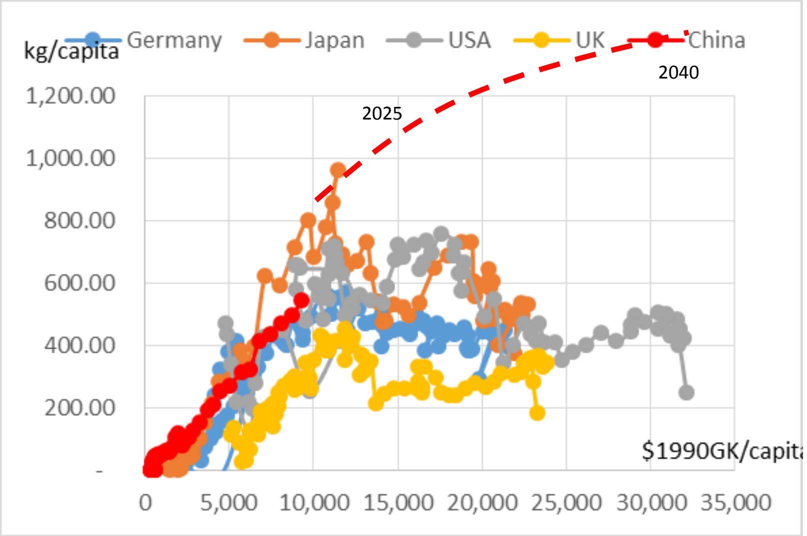
Evidence suggests a saturation effect: a stage of development when the intensity in the per capita use of materials decreases. This approach suggests China will lower demand for resources by the year 2030/2040.

Two scenarios for China:

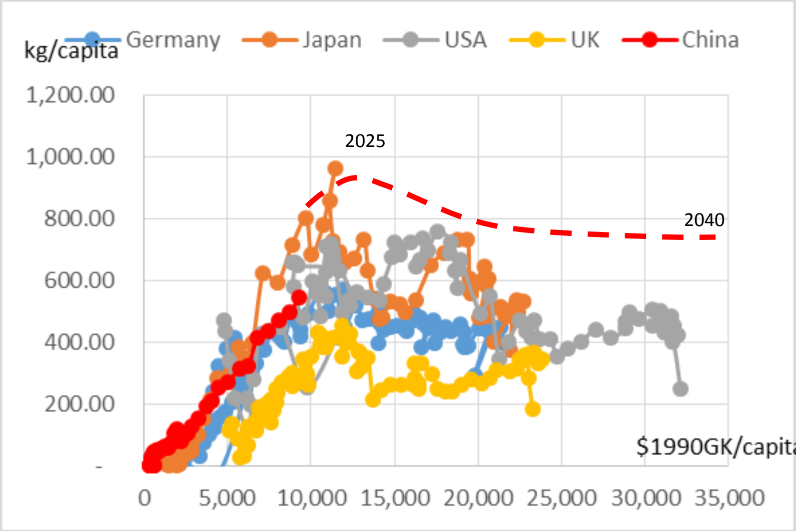
- Extrapolating future demand from the previous years: doubling demand by 2040
- Expecting a saturation to occur: stagnating and lower demand

Data as Apparent Domestic Consumption of steel per capita and Income per capita over time

Extrapolation



Saturation



Historic evolution has been following a sequence of saturation stages for resource consumption and development of anthropogenic stocks in the built environment
1) rapid accumulation
2) slow down of consumption
3) Stocks starting to saturate
4) Steady state
5) Material efficiency adjustments
Data for steel in the US over time (1900 – 2013)