



## Projet SURFER : Les besoins en matériaux et métaux de la Transition Énergétique de la France

Daniel Monfort, Faustine Laurent, B Rodriguez, Frédéric Lai, Stéphanie Muller, Jacques Villeneuve

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## The SURFER project: the materials and metals needs of France's energy transition

Congrès international avniR 2019

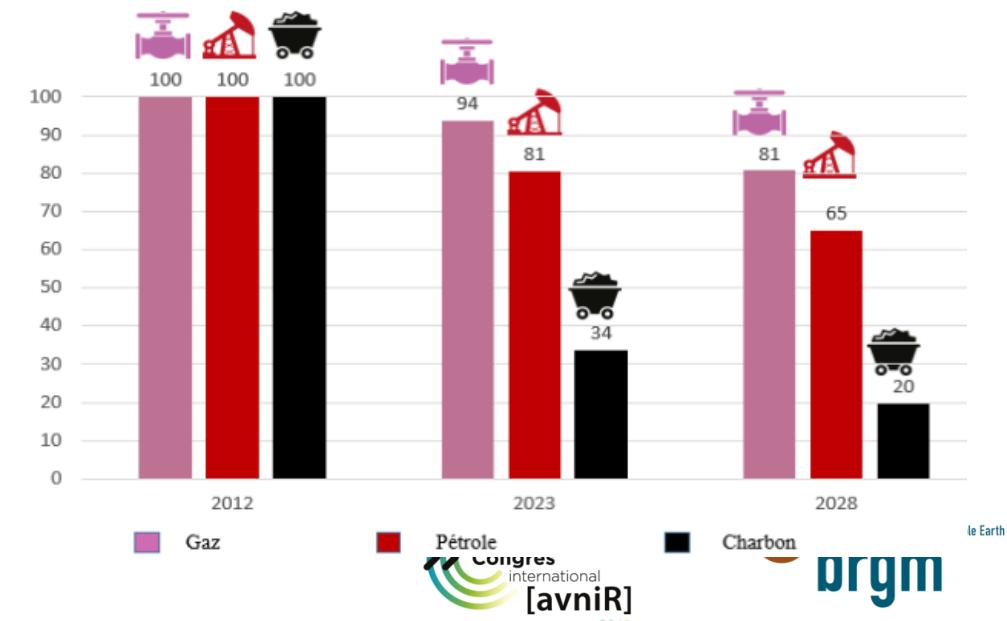
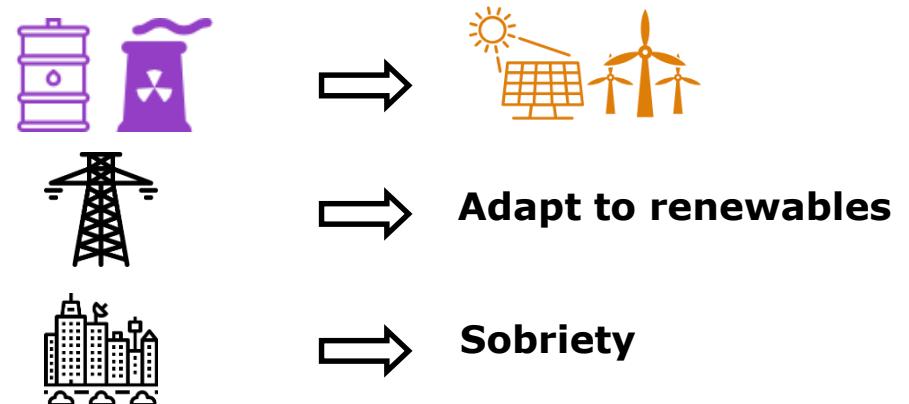
6<sup>th</sup> November 2019

D Monfort, F Laurent, B Rodriguez, F Lai, S Muller, J Villeneuve

## Context: Energetic transition – A needed step to tackle climate change

### Goals set by the French energetic transition act (August 2015)

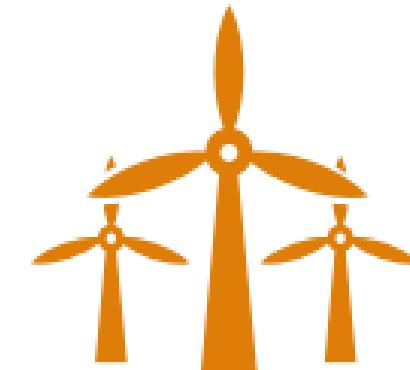
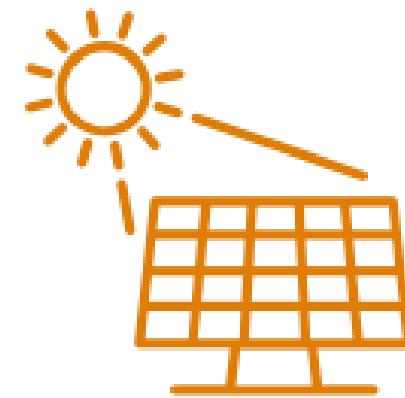
- By 2050:
  - **Reduction** of final energetic consumption, of the share of nuclear and primary fossil energy carriers
  - **Increase** of the renewable energy share in the final energetic consumption
- Examples in the *PPE*
  - **Sobriety**: Reduction of 7% in 2023 and 14% in 2028 (from 2012 level)
  - **Primary fossil energy**: Reduction of 20% in 2023 and 35% in 2028 (from 2012 level)
  - **Renewables**: 74 GW in 2023 (+50% from 2017 level) – 102 to 113 GW in 2028 (+100%)



## Context: Energetic transition – A needed step to tackle climate change but requires new infrastructures

### Some figures

- **Photovoltaic panels**
  - Almost 1 MWc by ha
  - Load factor +/- 15% (\*)
  - Almost 8 ha/MW eq
    - 5200 ha (52 km<sup>2</sup>, half of Paris area) to replace a 1 GW nuclear reactor operating at 75%(\*)
  
- **Windmills**
  - Almost 100t steel per MW
  - Load factor +/- 22% (\*)
    - Almost 1700 2 MW windmills to replace 1 GW nuclear reactor operating at 75%(\*) ~ 340000 t steel, 50 times the steel needed for the Eiffel tower
    - For a nuclear power plant: 30 to 60 t of steel /MW ~ 30000 to 60000 t steel per GW



**Do renewable energies require more raw materials (minerals and metals) than the actual energy mix?**

(\*) From : Bilan de l'énergie RTE

# Context: Energetic transition – A needed step to tackle climate change but requires new infrastructures

## Material requirements vs energy transition: a highly topical issue!

### PERSPE

#### Mineral supply requirement

Saleem H. Ali<sup>a,1,2</sup>, Damien Glenc<sup>b</sup>,  
Maria Amelia Enríquez<sup>b,3</sup>, Judith K.  
Richard Schodde<sup>c,3,4</sup>, Gabi Schneid

Successful delivery of the UN's Sustainable Development Goals will require technologies that utilize minerals to sustainably supply remain available to industry. The sourcing of minerals, trajectory effects of consumption, here interdisciplinarity perspective coming decades.

**THE IMPACT**  
A JOURNAL OF SUSTAINABLE  
DEVELOPMENT  
Edited by Emmanuel Hache

**Mineral supply requirement**

**10 January 2019**  
Issue 519  
Subscribe to free weekly News Alert

**Source:** Lapko, Y., Trianni, A., Naur, C. and Masi, D. (2018). In Pursuit of Closed-Loop Supply Chains for Critical Materials: An Exploratory Study in the Green Energy Sector. *Journal of Industrial Ecology*. DOI: 10.1111/jiec.12741 doi:10.1111/jiec.12741.

**Contact:** yulia.lapko@polimi.it

**Read more about:** Climate change and energy, Circular technologies, Resource efficiency, Sustainable business, Sustainable consumption and production, Waste

**1. For more information on the recovery of raw materials, see EC Directorate-General for Employment and Social Affairs, Entrepreneurship and SMEs (2013) Circular economy action plan for raw materials, ec.europa.eu/eurobarometer/2018 European innovation partnership on raw materials, doi: 10.2873/00298. [https://publications.europa.eu/esedoc/repositories/1177/pdf/eu-ec-2013-0006\\_01\\_en.pdf?setversion=2013-01-01&language=en](https://publications.europa.eu/esedoc/repositories/1177/pdf/eu-ec-2013-0006_01_en.pdf?setversion=2013-01-01&language=en)**

**2. The EU has a list of critical raw materials for the EU, which is regularly reviewed and updated: [http://ec.europa.eu/growth/european-innovation-partnership/critical-raw-materials-interest/critical\\_en](http://ec.europa.eu/growth/european-innovation-partnership/critical-raw-materials-interest/critical_en)**

**3. The EC is funding several projects to develop the substitution of lithium (e.g. on transportation infrastructure applications) or its sustainable production via innovative extraction methods. These recycling technologies. These research programmes include H2020 projects such as EUREC and INFINITY, which focus on substitution of lithium. Related projects include LIFE RECYCLED, PHOTOLE and LIFE-MISTER.**

**4. Corresponding author:  
E-mail address: gondia.sokhna.seck@ifpen.fr (Gondia Sol Samuel Carcanague)**

**5. Received 7 November 2018; Received in revised form 13 February 2019; Available online 13 February 2019; 0306-2619/ © 2019 Elsevier Ltd. All rights reserved**

**6. DOI: 10.1016/j.impact.2018.12.001**

**7. ISSN: 0960-1481**

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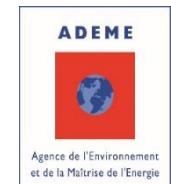
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# The SURFER project: materials and metals requirements for the French energetic transition

## Project's ambition

- **Temporal assessment of direct and indirect materials requirements**
  - Raw materials consumption for energy transition?
  - Requirements in terms of energy, water, land?
- **Feasibility of the energy transition**
  - What is the « weight » of these requirements within the national consumption?
- **What impacts?**
  - How many, where, when?
  - From a dependency to fossil energies to a dependency to metals? When?
- 4 years project – December 2016 – December 2020

**SURFER**



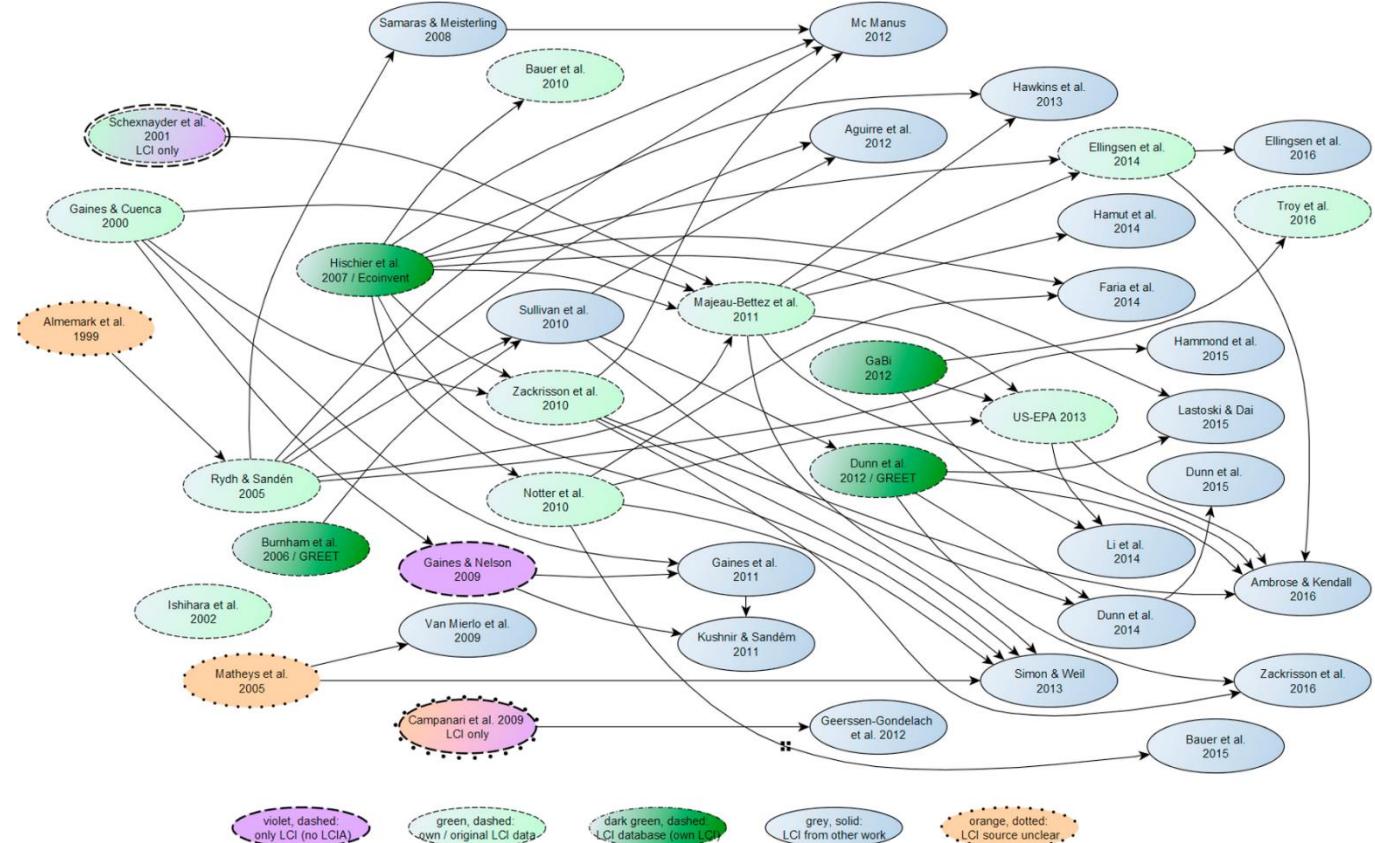
# Assessing the direct material requirements – Material intensity

## Concept of Material intensity

- Materials contained within the energy production infrastructures for a given installed capacity/power
  - e.g. *t of steel within a wind turbine for 1 kW installed capacity*
- Amount of fuels (fossil, nuclear...) consumed for energy production
  - e.g. *kg of uranium for producing 1 kWh*
- Materials contained within the fuels supply infrastructures (production + transport)
  - e.g. *t of steel within the uranium mining and processing infrastructures*

**One goal of SURFER:** build a database gathering the « material intensities » of different energy technologies

## Literature as a source for material intensity, but...



Peters et al., 2017, The environmental impact of Li-Ion batteries and the role of key parameters – A review

# Assessing the direct material requirements – Material intensity

From the SURFER database...

A	B	C	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
ID	TECHNOLOGY KEY	TECHNOLOGY SUBKEY	U_V_RELATIONSHIP	DATA_SCOPE	IC_STEP	VALUE_TYP	RAW_VALU	KEPT_VALU	VALUE_UNIT	HARMONISED VALUE UNI	VALUE_IS	UNIT_IS	REFERENCE_VA_LUE	REFERENCE_UN_IT	REFERENCE_VA_LUE_IS	REFERENCE_UN_IT_IS	MAT_INTENS
0	Combustion	Coal power pl	m-p	Direct	Manufacture	Single datum	1.96E+05	1.96E+05	kg	kg	1.96E+02	t	344439	kW	344439	MW	5.69E-0
0	Combustion	Coal power pl	m-p	Direct	Manufacture	Single datum	1.71E+05	1.71E+05	kg	kg	1.71E+02	t	344439	kW	344439	MW	4.96E-0
0	Combustion	Coal power pl	m-p	Direct	Manufacture	Single datum	1.73E+05	1.73E+05	kg	kg	1.73E+02	t	344439	kW	344439	MW	5.02E-0
																	344439 MW
																	6.18E-0
																	344439 MW
																	1.65E-0
																	344439 MW
																	1.74E-0
																	344439 MW
																	4.27E-0
																	344439 MW
																	2.59E-0
																	4.49E-0
																	-1.43E-0
																	1 MW
																	6.80E-0
																	1 MW
																	1.95E+0
																	6.82E+0
																	1 MW
																	2.64E+0
																	1 MW
																	4.20E+0
																	1 MW
																	1.59E+0
																	6.20E+0
																	5.07E+0
																	2.10E+0

Number of analyzed references per energy technology

Technology	References
Wood boiler	5
Heat pumps	15
Solar heaters	8
Coal plants	7
Anaerobic digestion	1
Batteries	8
Electric grid & smart grid	36
Gas power plants	17
Hydroelectrics	15
Nuclear	36
Wind power	173
PV	60

Multiple sources of data imply a lot of **heterogeneity** regarding material content to analyze...

**Harmonization procedure** (for each technology type)

## 1. Basic treatments

- Elimination of non original data and replicates
- Standardization of materials (e.g., steel alloys)
- Conversion in SI units

## 2. Material intensities (MI) calculation

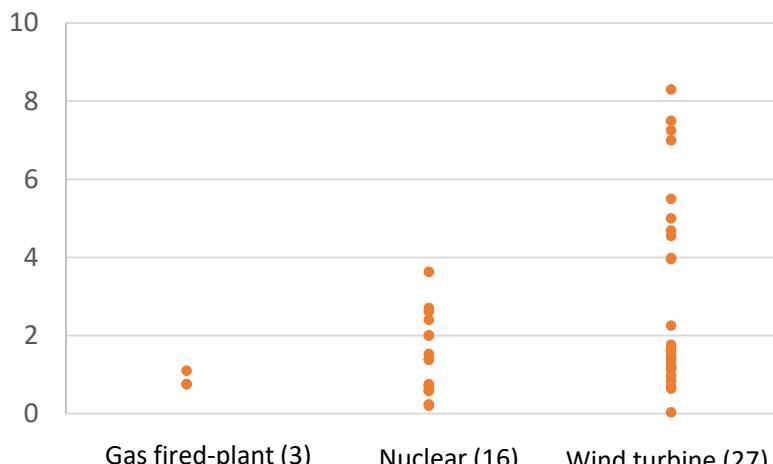
- Aggregation of kg per substance and per component
- Divide by a reference value (e.g. capacity)
- Return MI (in kg/MW)

## Assessing the direct material requirements – Material intensity

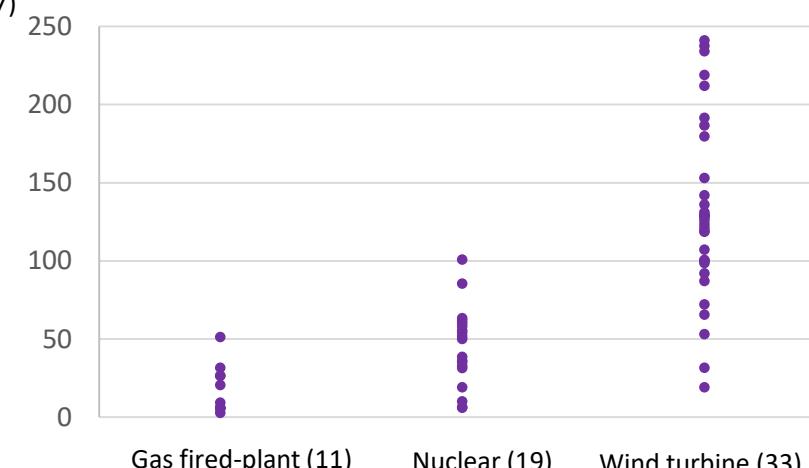
### From the SURFER database... to THE material intensity

Multiple sources of data imply **variability** within the harmonized MI

copper MI (t/MW)



steel MI (t/MW)



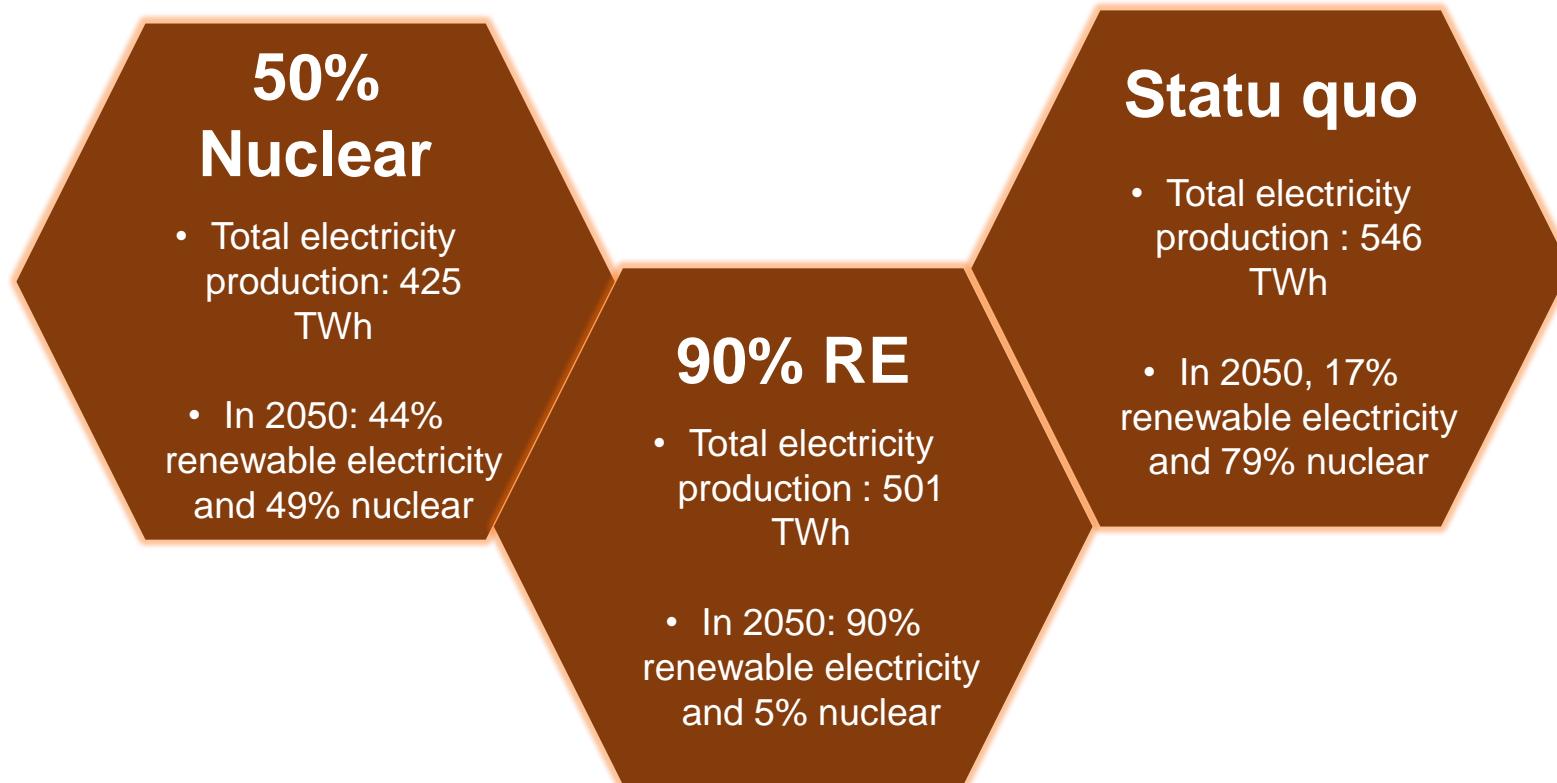
### Procedure

- Elimination of outliers
- Comparison with industrial data
- Validation by experts

## Applying these material intensities to the deployment of energetic scenarios

### Different energetic scenarios

- Scenarios based on « Visions 2035-2050 » from ADEME



# Applying these material intensities to the deployment of energetic scenarios

## Example for the deployment of wind turbines

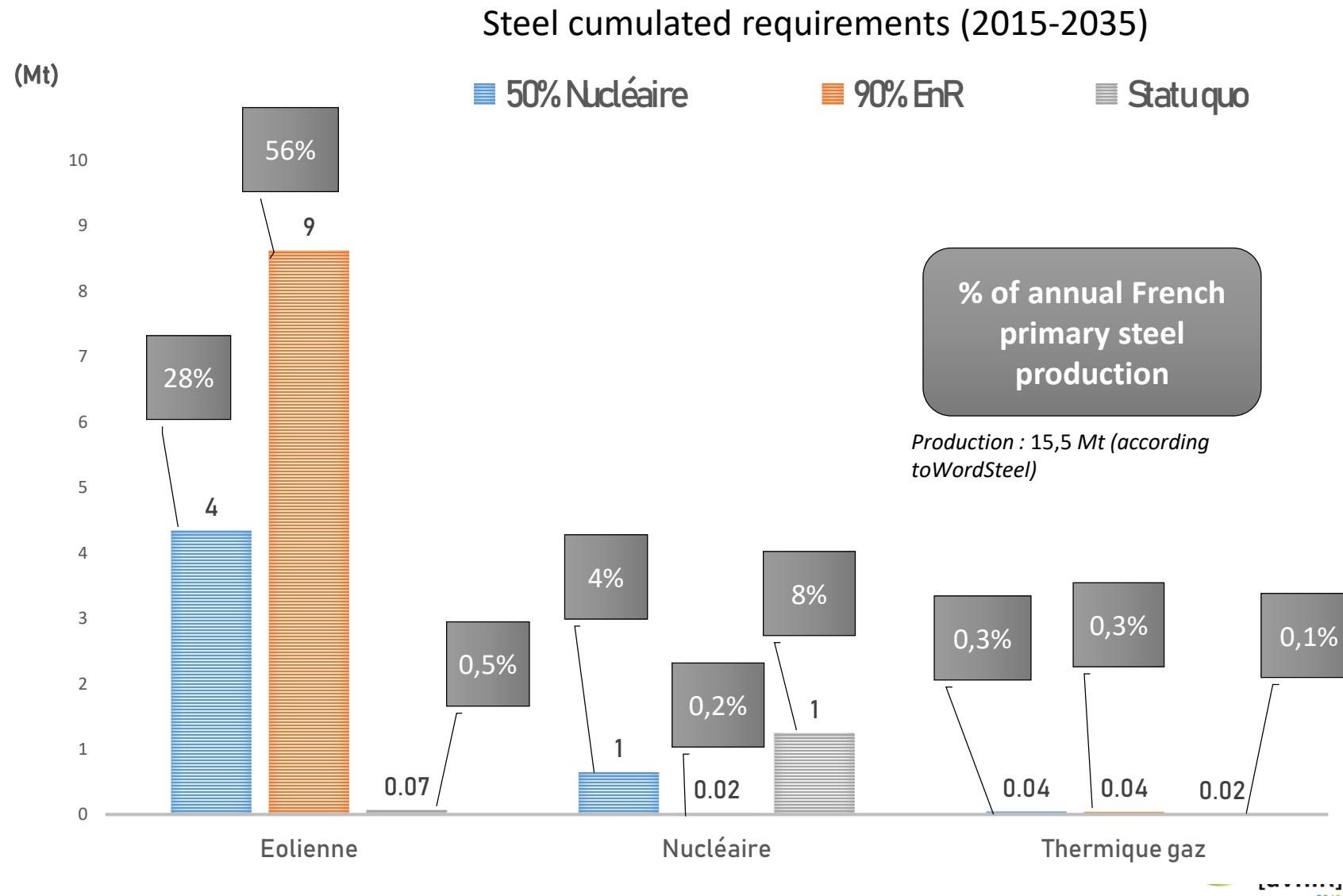
- Definition of three types of windmill parks

- Scenarios

MODEL 1																						
Parameter		Unit	Power (MW)		2000	2001	2002	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Wind farm	Grid connection	m per farm	Installed capacity (new)	94	35	1 360	1 360	1 360	1 360	1 360	743	743	743	743	743	743	743	743	-	200	-	200
	Power	MW	Installed capacity (repowering)			-	94	35	90	174	359	750	748	1 077	1 247	1 190	950	822				
	Number of wind turbines		Total installed capacity	-	94	35	1 360	1 360	1 454	1 395	1 450	917	1 102	1 493	1 491	1 820	1 990	1 933	750	622		
	Number of substations		Accumulated installed capacity	0	94	129	16 360	17 720	19 080	20 440	21 800	22 543	23 286	24 029	24 771	25 514	26 257	27 000	26 800	26 600	26 400	
	Wind turbine spacing		Number of wind farm	*change only the percentage*																		
Wind turbine	Lifespan	years	Model 1	90%	90%	80%	80%	80%	70%	70%	70%	70%	70%	50%	50%	50%	50%	50%	50%	50%	50%	
	Power	W	Total installed capacity per farm model	77	77	73	70	73	40	48	65	65	80	62	60	23	19					
	Height	m	Model 2	10%	10%	10%	10%	10%	15%	15%	15%	15%	15%	30%	30%	30%	30%	30%	30%	30%	30%	
	Transformer distance	m per	Total installed capacity per farm model	4	4	4	4	4	4	5	6	6	8	17	16	6	5					
	Rotor diameter		Model 3	0%	0%	10%	10%	10%	15%	15%	15%	15%	15%	20%	20%	20%	20%	20%	20%	20%	20%	
	Internal cables	Copper	Total installed capacity per farm model	0	0	3	3	3	3	3	5	5	6	8	8	3	3					
		Aluminium	Total material consumption/year	input																		
	External cables	Copper	IM*total installed capacity (t)																			
		Aluminium	Concrete	6,26E+05	6,26E+05	6,66E+05	6,39E+05	6,64E+05	4,14E+05	4,98E+05	6,75E+05	6,74E+05	8,23E+05	8,68E+05	8,43E+05	3,27E+05	2,71E+05	1,84E+05				
	Foundations	Gravity base	Steel and Iron	1,34E+05	1,34E+05	1,38E+05	1,32E+05	1,37E+05	8,43E+04	1,01E+05	1,37E+05	1,37E+05	1,67E+05	1,74E+05	1,69E+05	6,56E+04	5,44E+04	3,68E+04				
Wind farm	Tower	Concrete	Copper	4,35E+03	4,35E+03	4,65E+03	4,46E+03	4,64E+03	2,93E+03	3,59E+03	4,78E+03	4,77E+03	5,82E+03	6,37E+03	6,19E+03	2,40E+03	1,99E+03	1,35E+03				
		Steel	Aluminium	3,26E+03	3,26E+03	3,49E+03	3,35E+03	3,48E+03	2,20E+03	2,64E+03	3,58E+03	3,58E+03	4,37E+03	4,78E+03	4,64E+03	1,80E+03	1,49E+03	1,01E+03				
	Grid connection	m per	Number of wind farm																			
	Power	W	Model 1	920	997	954	1 022	1 090	986	1 019	1 051	1 084	1 116	821	844	838	831	814				
	Number of wind turbines		Model 2	45	49	53	57	61	94	97	100	103	106	219	225	223	222	214				
	Number of substations		Model 3	0	0	40	43	45	70	73	75	77	80	109	113	112	111	103				
	Wind turbine spacing		Total material consumption/year	stock																		
	Lifespan	years	IM*Accumulated installed capacity (t)																			
	Power	W	Concrete	7,53E+06	8,15E+06	8,74E+06	9,36E+06	9,98E+06	1,02E+07	1,05E+07	1,09E+07	1,12E+07	1,15E+07	1,14E+07	1,18E+07	1,17E+07	1,16E+07	1,15E+07				
	Height	m	Steel and Iron	1,61E+06	1,74E+06	1,80E+06	1,93E+06	2,06E+06	2,07E+06	2,14E+06	2,21E+06	2,28E+06	2,34E+06	2,29E+06	2,36E+06	2,34E+06	2,32E+06	2,31E+06				
Wind turbine	Transformer distance	m per	Copper	5,24E+04	5,67E+04	6,11E+04	6,54E+04	6,98E+04	7,21E+04	7,45E+04	7,69E+04	7,93E+04	8,16E+04	8,40E+04	8,64E+04	8,58E+04	8,51E+04	8,45E+04				
	Rotor diameter		Aluminium	3,93E+04	4,25E+04	4,58E+04	4,91E+04	5,23E+04	5,41E+04	5,59E+04	5,77E+04	5,95E+04	6,12E+04	6,30E+04	6,48E+04	6,43E+04	6,38E+04	6,34E+04				
	Internal cables	Copper	Number of wind farm	0,0	0,0	4,7	1,8	4,5	7,6	15,7	32,8	32,7	47,1	39,0	37,2	29,7	25,7	19,7				
		Aluminium	Model 1	0,0	0,0	0,3	0,1	0,3	0,7	1,5	3,1	3,1	4,5	10,4	9,9	7,9	6,9	5,5				
	External cables	Copper	Model 2	0,0	0,0	0,2	0,1	0,2	0,5	1,1	2,3	3,4	5,2	5,0	4,0	3,4	2,2	1,7				
		Aluminium	Model 3	0,0	0,0	0,2	0,1	0,2	0,5	1,1	2,3	3,4	5,2	5,0	4,0	3,4	2,2	1,7				
	Foundations	Gravity base	Total material from dismantling/year	output																		
	Tower	Concrete	IM*Installed capacity (repowering) (t)																			
		Steel	Concrete	0,00E+00	0,00E+00	4,31E+04	1,60E+04	4,12E+04	7,86E+04	1,62E+05	3,39E+05	3,38E+05	4,87E+05	5,44E+05	5,19E+05	4,14E+05	3,58E+05	2,91E+05				
	Power	W	Steel and Iron	0,00E+00	0,00E+00	8,89E+03	3,31E+03	8,51E+03	1,60E+04	3,30E+04	6,89E+04	6,87E+04	9,90E+04	1,09E+05	1,04E+05	8,30E+04	7,18E+04	6,09E+04				
	Height	m	Copper	0,00E+00	0,00E+00	3,01E+02	1,12E+02	2,88E+02	5,57E+02	1,15E+03	2,40E+03	2,39E+03	3,45E+03	3,99E+03	3,81E+03	3,04E+03	2,63E+03	2,04E+03				
	Transformer distance	m per	Aluminium	0,00E+00	0,00E+00	2,26E+02	8,40E+01	2,16E+02	4,18E+02	8,62E+02	1,80E+03	1,80E+03	2,58E+03	2,99E+03	2,86E+03	2,28E+03	1,97E+03					
	Rotor diameter		Number of wind farm	0,0	0,0	0,2	0,1	0,2	0,5	1,1	2,3	3,4	5,2	5,0	4,0	3,4	2,2	1,7				
	Internal cables	Copper	Model 1	0,0	0,0	0,3	0,1	0,3	0,7	1,5	3,1	3,1	4,5	10,4	9,9	7,9	6,9	5,5				
		Aluminium	Model 2	0,0	0,0	0,2	0,1	0,2	0,5	1,1	2,3	3,4	5,2	5,0	4,0	3,4	2,2	1,7				
	External cables	Copper	Model 3	0,0	0,0	0,2	0,1	0,2	0,5	1,1	2,3	3,4	5,2	5,0	4,0	3,4	2,2	1,7				
	Foundations	Gravity base	Total material from dismantling/year	output																		
	Tower	Concrete	IM*Installed capacity (repowering) (t)																			
		Steel	Concrete	0,00E+00	0,00E+00	4,31E+04	1,60E+04	4,12E+04	7,86E+04	1,62E+05	3,39E+05	3,38E+05	4,87E+05	5,44E+05	5,19E+05	4,14E+05	3,58E+05	2,91E+05				
	Power	W	Steel and Iron	0,00E+00	0,00E+00	8,89E+03	3,31E+03	8,51E+03	1,60E+04	3,30E+04	6,89E+04	6,87E+04	9,90E+04	1,09E+05	1,04E+05	8,30E+04	7,18E+04	6,09E+04				
	Height	m	Copper	0,00E+00	0,00E+00	3,01E+02	1,12E+02	2,88E+02	5,57E+02	1,15E+03	2,40E+03	2,39E+03	3,45E+03	3,99E+03	3,81E+03	3,04E+03	2,63E+03	2,04E+03				
	Transformer distance	m per	Aluminium	0,00E+00	0,00E+00	2,26E+02	8,40E+01	2,16E+02	4,18E+02	8,62E+02	1,80E+03	1,80E+03	2,58E+03	2,99E+03	2,86E+03	2,28E+03	1,97E+03					
	Rotor diameter		Number of wind farm	0,0	0,0	0,2	0,1	0,2	0,5	1,1	2,3	3,4	5,2	5,0	4,0	3,4	2,2	1,7				
	Internal cables	Copper	Model 1	0,0	0,0	0,3	0,1	0,3	0,7	1,5	3,1	3,1	4,5	10,4	9,9	7,9	6,9	5,5				
		Aluminium	Model 2	0,0	0,0	0,2	0,1	0,2	0,5	1,1	2,3	3,4	5,2	5,0	4,0	3,4	2,2	1,7				
	External cables	Copper	Model 3	0,0	0,0	0,2	0,1	0,2	0,5	1,1	2,3	3,4	5,2	5,0	4,0	3,4	2,2	1,7				
	Foundations	Gravity base	Total material from dismantling/year	output																		

## Applying these material intensities to the deployment of energetic scenarios

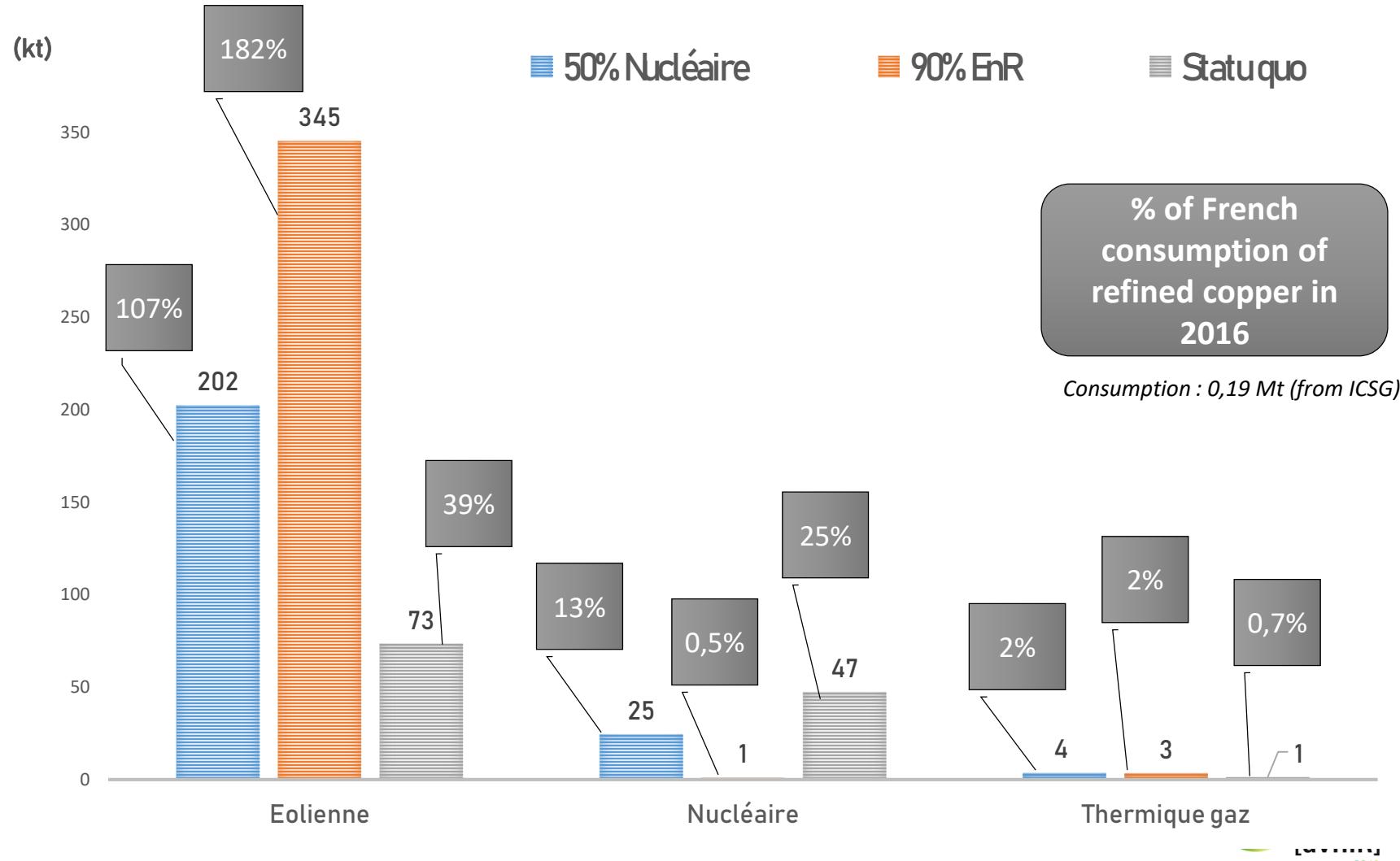
### Some results for wind turbines, gas-fired plants and nuclear plants



## Applying these material intensities to the deployment of energetic scenarios

### Some results for wind turbines, gas-fired plants and nuclear plants

Copper cumulated requirements (2015-2035)



# How to consider indirect material requirements and material cycle?

- **Indirect material requirements**
  - Application of life cycle approaches
- **Material cycle – how to consider dismanteling?**
  - Industrial reconversion
  - Two possible approaches for recycling
    - ✓ Closed-loop recycling
      - Recycling without the same product system
      - Recycling without any changes to inherent properties
    - ✓ Open-loop recycling
      - Recycling into different product systems
      - Recycling with changes to inherent properties
  - Two important notions to consider
    - ✓ Recycled content
    - ✓ End-of-life recycling input rate (EOL-RIR)

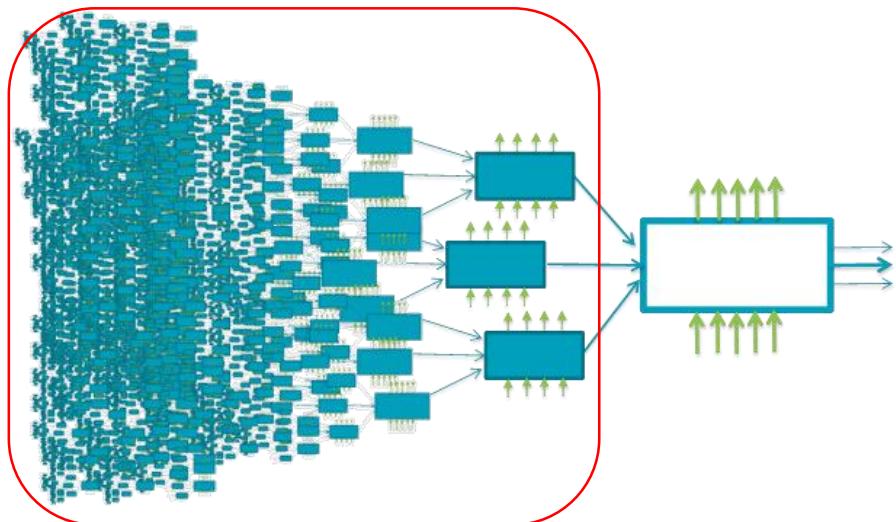
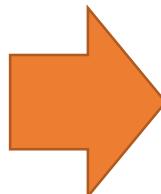
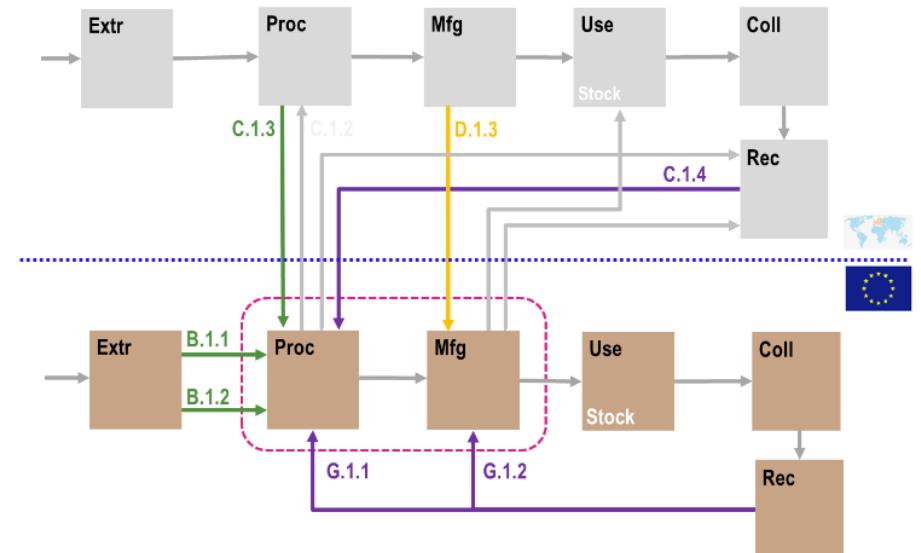


Figure 1 System boundaries and material flows included in the calculation of the EOL-RIR<sup>7</sup>.



Extr: Extraction; Proc: Processing; Mfg: Manufacturing; Coll: Collection; Rec: Recycling

## Conclusions

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- **Challenges raised by the SURFER project**
  - Data collection and harmonization
  - Assumptions and evolutions to take into account (lifespan, recycling rate,...)
  - Modelling of scenarios
- **Still some work to do**
  - Assessment of the total materials requirements
  - Assessment of the environmental implications of these requirements (energy, water, land)
  - Contextualization to French consumption
  - Materials criticity assessment





Thank you for your attention

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