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THE IMPACT OF FUTURE GENERATION ON CEMENT DEMAND: An Assessment based on Climate Scenarios

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ABSTRACT

Concrete is the most widely used manmade material in the world with an annual production of about 10 billion tons at the global level. It outpaces the use of historically important materials such as wood or stone in modern urbanism. Concrete is tightly linked to the energy transition. On one hand, as a structural material, concrete is used in multiple sectors among which the energy sector. Because the concrete content of a power plant may vary depending on the technology, the energy transition is expected to impact the future demand for concrete. On the other hand, concrete production is known to highly pollute the environment as one of its major components is cement, whose industry is one of the main emitters of carbon dioxide in the world. This dual aspect explains the aim of this study of understanding concrete (and therefore cement) demand under energy transition policies described in the 2017 IEA's Energy Transition Policy (ETP) report and quantifying CO₂ emissions stemming from cement production for the energy sector. Based on a simple model the study is conducted at the global and regional levels to take into account potential local disparities. The results demonstrate that the decarbonisation of the electricity sector will have a limited impact on the global cement demand, but that could be more challenging for some regions where new electricity mix require large concrete structures.

This model could be a useful decision-making tool for assessing the relative impact of any public energy transition scenarios on raw materials, such as cement, at the highest level of disaggregation, as well as a better sub-sectorial screening.

Keywords: Energy transition, concrete, cement, power production, construction materials

JEL Classification: Q42, Q51, Q53

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I. INTRODUCTION

1.1 Concrete requirements for power generation technologies

As a consequence of climate mitigation, we are witnessing new policies for energy transition aiming at reducing Greenhouse Gases (GHG) emissions and containing global warming in the wake of the Paris Agreement (COP21). Decision-making takes place in a complex and increasingly global context. Faced with technological, social and environmental challenges, climate scenarios are developed by major international organizations, such as the International Energy Agency (IEA) or the World Energy Council (WEC), and are important landmarks for policies but also for the industry. Climate scenarios are also developed by Non-governmental organizations (NGOs), such as the World Wide Fund for Nature (WWF) or Greenpeace, as well as private energy companies like BP or Shell. These scenarios all agree on the necessity to deploy more power plants based on variable renewable energy.

From 2008 to 2017 world renewable energy¹ capacity increased from 1 057 GW to 2 179 GW (IRENA, 2018a). In 2017 renewable energy capacity has still grown at record-high levels. Offshore wind investment, for example, has experienced a nearly four-fold increase from 2013 to 2016 and is poised to grow further (IRENA, 2018b). Nevertheless the total investment value in renewables dipped in dollar terms in 2016, due to the large drop in technology cost. Most renewable energy technologies, and other low-carbon technologies such as electric vehicles, require an important amount of mineral resources. Many studies have focused on these new material demands, especially on rare earth elements (Alonso et al., 2012 ; Baldi et al., 2014) or minor metals such as cadmium, chromium, cobalt, lithium, etc. to identify material bottlenecks and to analyse potential critical materials that could limit large-scale diffusion of low-carbon technologies (Moss et al., 2013 ; De Koning A. et al., 2018 ; Valero et al., 2018a). The energy required to extract and then to refine such resources are often pinpointed. Hodgkinson and Smith

¹ IRENA includes as renewable energy: hydropower, marine energy, wind energy, solar energy, bioenergy (solid biofuels and renewable waste, liquid biofuels, biogas) and geothermal energy

(2018) presented the link between the aim for a sustainable development and the need to carefully plan our resource extractions through a detailed policy framework. It encouraged and supported the widespread adoption of mitigation strategies in mining and mineral processing, recycling and closed-loop resource uses. They provided a synthetic roadmap of adaptation and mitigation strategies at the global scale for a climate-smart mining and recycling strategy to meet the Paris Agreement and the United Nations Sustainable Development Goals. Without any doubt, the energy transition to a low carbon economy will involve substantial amount of minor metals. It will also require an increased use of structural (or bulk) materials, such as aluminium, copper, nickel or cement (Vidal, 2017). Such materials may be less constrained by their available reserves than by their production process. Indeed, aluminium, iron and steel, or cement industries are known to be very energy intensive. Albeit the future aluminium, iron and steel demands for power generation have been examined in the literature (Kleijn et al., 2011 ; Elshkaki and Graedel, 2013 ; Månberger and Stenqvist, 2018 ; Valero et al., 2018b), relatively few studies tackled the interaction between the power sector transition and the subsequent cement demand. This is nonetheless an important issue as cement is often mentioned as a crucial material due to the large volume required in building energy technologies, but also because it has a high environmental impact. In addition, cement is one of the major components of concrete which is widely used in buildings and infrastructure. With a total production volume of about 6 billion m³ in 2017, concrete is the most commonly used building material (Unicem, 2018). Being heavier, more elastic and resistant than wood, stone and most construction materials, it has outpaced the use of these important historical materials in modern urbanism. Nowadays, 80% of individual housing and 90% of collective housing are constructed using concrete (Unicem, 2018). It is also crucial for building greater structures such as hospitals and factories, and in the construction of new transport infrastructures (roads, bridges, etc.). But concrete is also a key material in the energy sector that relies on the building of infrastructures for power plants and electrical connections. In the power sector, it is used in foundations building for nuclear power plants for example or as

pedestals or towers for wind turbines (Guezuraga et al., 2012 ; Wang et al., 2018 ; Yang et al., 2018). As an example, the European Pressurized Reactor (EPR)² at Flammanville (France) requires 400 000 m³ of concrete. Dams are also large concrete consumers (Song et al., 2016). The world largest concrete structure is the Three Gorges Dam in China with about 26 million cubic meters of concrete used³. In the energy sector, concrete is a key material for the building of power plants and can be also used for thermal energy storage (Laing et al., 2010).

In this article, we consider several exogenous energy transition scenarios and compare their impact on the demand for concrete and cement of the power sector. To quantify these demands, the concrete-content of each technology used has then to be known. A pooling of data has been done from different sources (Vidal (2017), EcoInvent (2017) and United Nations Environment Program (UNEP, 2016)) in order to assess the concrete needs in the power sector (Table 1). Those values are averages of material content per technology. Given the diversity of technical solutions and the variety of site-specific characteristics, these figures may not be representative for some regions and may differ inevitably from the real material inventory found in the literature or at a micro-level. To give an example, Zimmermann et al. (2013) studied the concrete demand from a large-scale deployment of wind energy in Germany and made the assumption that onshore wind turbines require more concrete per installed MW than offshore wind turbines, while offshore wind turbines require a higher percentage of steel for the construction. This regional assumption thus differs from our global assumptions on concrete demand for wind technologies.

² It is a third generation Pressurized Water Reactor (PWR) design.

³ <http://www.china-embassy.org/eng/zt/sxgc/t36512.htm>

Table 1: Concrete requirement for major power generation technologies

Technology	Concrete need (t/MW)	Source
Wind onshore ⁴	421	EcoInvent
Wind offshore ⁵	650	UNEP
Nuclear ⁶	523	EcoInvent
Fossil (peat)	509	EcoInvent
Fossil (oil)	244	EcoInvent
Fossil (coal) ⁷	252	Authors
Fossil (lignite)	510	EcoInvent
Natural gas (combined cycle)	36	EcoInvent
Natural gas (classical cycle)	4	EcoInvent
Geothermal	0	EcoInvent
Hydro (Pumped Storage) ⁸	3 000	Authors
Hydro (Run-of-river)	3 000	Authors
Concentrated solar power (CSP) ⁹	10	EcoInvent
Photovoltaic (PV) Solar	10	EcoInvent

Sources: EcoInvent Data, UNEP (2016), Vidal (2017)

In addition to power generation technologies, the transmission and distribution of electricity from the production site to individual consumers should be taken into account. Vidal (2017) tried quantifying the concrete demand required for interconnection although with a large range of uncertainties. The global estimated concrete content of connectivity could vary between 100 and 500 Mt/yr by extrapolating the material intensities of Harrison et al. (2010)¹⁰, which is more than ten times the concrete volume required for the power generation according to Vidal

⁴ The concrete content of wind onshore technology was determined by averaging the concrete contents of wind turbines with and without precast concrete towers of respectively 2.3 and 2 MW capacities.

⁵ The concrete content of wind offshore was determined through the UNEP data, of offshore wind turbine with 5MW capacity.

⁶ Concrete content average between 3 technologies: PHWR (pressurized heavy-water reactor), PWR (pressurized water reactor) and BWR (boiling water reactor).

⁷ Due to the lack of data on the bioenergy technology, the data corresponding to the fossil fired power plant was used to estimate the concrete content in the bioenergy.

⁸ The concrete content in the hydro technology was problematic to find, these values are average concrete contents for the some of the major dams in the world (Three Gorges, Hoover, Jinping I, Chevril, Gudril, Almenda). The order of magnitude is in accord with the interval presented by Vidal (2017).

⁹ CSP concrete demand is considered the same as PV.

¹⁰ Harrison et al. (2010) have largely taken their data for material embodied energy and carbon from the Inventory of Carbon and Energy, a database of construction materials compiled by the University of Bath (Hammond and Jones, 2008).

estimations¹¹. Harrison et al. (2010) have estimated that concrete represents 53% of the raw materials used to build the whole UK electricity transmission system¹². However, their results are inferred from specific indicators related to the technology activities and not from the technology installed capacities¹³. Therefore, due to a lack of accurate data at the world scale, the electrical transmission system as well as potential carbon capture units have not been taken into account in this paper. Consequently, in the remainder of this paper, technologies with and without carbon capture will be aggregated; for example coal and coal with CCS (carbon capture and storage) will be referred to as coal.

1.2 The use of scenarios to anticipate future concrete demand

The issue of future concrete demand from the power sector can be tackled at the global or regional level, based on existing scenarios (from the IEA for example) or supposed electrical mixes (Table 2). Future concrete demand will widely vary according to the assumptions made on technology concrete-content and the scenario considered. It was particularly emphasized by the French Alliance of Energy Research Coordination (ANCRE, 2015) that considered future annual concrete demand to fluctuate from 30 Mt/y to more than 100 Mt/y to meet the French energy transition scenarios in 2050. Taking into account the diversity of future electricity mixes worldwide, it is not reasonably possible to extrapolate the results at the global scale. One of the most consistent work from the literature has been conducted by Hertwich et al. (2015) using IEA scenarios (BLUE Map scenarios, 2010). By conducting an integrated life-cycle assessment of electricity supply scenarios the authors have estimated future requirements of aluminium, copper, cement or iron and underlined a potential concern on copper supply by 2050. However, a limit of their study is that some technologies: combined heat and power plants, bioenergy and nuclear which have a non-negligible impact in the future power sector mix, have been excluded due to more complicated life

¹¹ Between 7 Mt/yr (Blue Map, AIE ETP 2010) and 10 Mt/yr (García-Olivares et al., 2012) of concrete would be required at the global scale for the power generation by 2050.

¹² Transmission system includes overhead line, underground cable, substations and transformers.

¹³ The demand for materials is better assessed in terms of capacity than activity, since the capacities built but not used have still consumed materials.

cycle inventories (comprehensive assessment of the food system for bioenergy or conflicting results of competing assessment approaches in nuclear case). In addition, material requirements are based on activity and not directly on the capacity installed and could then lead to rough estimations¹⁴.

Table 2: Literature review on studies modelling future concrete or cement demand

Authors	Sector coverage	Geographic coverage	Data used	Methodology	Outcomes
Vidal (2017)	Power production and electrical connections	World	ETP BLUE Map scenarios and scenario extracted from Garcia-Olivarès et al. (2012)	Post-treatment of climatic scenarios results	Detailed analysis to raw materials dedicated to worldwide energy transition
De Marsily and Tardieu (2018)	Power sector	France	French scenario (30GW wind, 20GW PV)	Post-treatment of climatic scenarios results	Detailed analysis to raw materials dedicated to energy transition in France
Hertwich et al. (2015)	Power sector	World	ETP BLUE Map scenarios	Post-treatment of climatic scenarios results with THEMIS ¹⁵ model (Hybrid LCA and multiregional input-output)	Detailed analysis to raw materials for Power sector dedicated to worldwide energy transition

Source: authors

¹⁴ In the supporting information, authors described the matrix product used to calculate absolute emissions and resource, one of the term of which is a “matrix of emission or resource load intensities by activity”.

¹⁵ Technology Hybridized Environmental-economic Model with Integrated Scenarios. THEMIS is a hybrid LCA input-output framework.

Given its importance for building power plants, combined with its hefty carbon footprint makes concrete an important and challenging material for the energy transition. The aim of this article is thus to quantify the future concrete need for the power sector under several climate scenarios and address a better feedback of the electricity mix evolution in the light of future low carbon technology implementation. Our contribution to the existing literature is threefold. Firstly, the data used in this paper is the latest available (IEA - ETP 2017). Secondly, we take into account the decommissioning process of already installed power plants. And thirdly, the originality of our work lies on a global with a regionalized disaggregation approach of the cement demand with the consideration of all power sector technologies. This is due to the fact that the electricity mixes, as well as climate policies, differ significantly from one region to another.

As the main environmental challenge related to concrete use concerns cement production, the cement's manufacturing process and market are studied in Section 2. In section 3 the model developed to determine the evolution of concrete and cement demands from the power sector is described. Section 4 presents our main results at global and regional scale and related comments, while Section 5 summarizes our findings and provides policy recommendations and research perspectives.

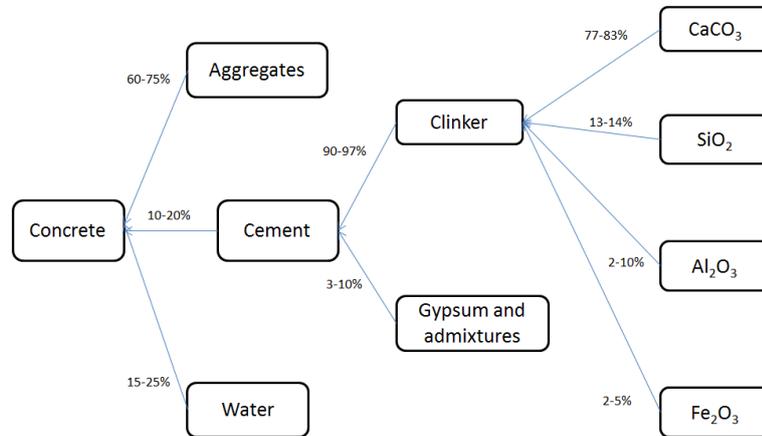
II. THE CEMENT SECTOR

Cement is an essential component of concrete. Chemically, concrete is a composite material containing several mineral materials. It is made up of inert materials called aggregates (sand, gravel, etc., 60 to 75% of composition), a binder (*i.e.* a material able to agglomerate, generally cement, but it can also be clay or bitumen, 10 to 20%); water and other admixtures that are used to modify the physical and chemical properties of the mixture (Figure 1). In current usage, as well as in the following work, the term concrete designates “cement concrete”¹⁶. As for cement, it is a manufactured compound that is

¹⁶ We can also speak of clay concrete if the binder used is clay or asphaltic concrete if the binder is bitumen.

classically composed of clinker¹⁷, gypsum and other admixtures (such as limestone, blast furnace slag, coal fly ash¹⁸, and natural pozzolanic materials).

Figure 1: Concrete and cement composition¹⁹



Source: authors (based on Ecocem France²⁰)

2.1 Overview of the cement market

The cement industry, along with the concrete demand, had a relatively fast development, largely explained by Chinese demand growth (Figure 2). Its production has increased by around 86% during the 2006-2013 period, a fast growth mainly explained by the growing urbanization of China. However, since 2013, Chinese cement production has stagnated due to a slowdown in the real estate market since 2014. Consequently, total cement production in the world reached a high in 2014 with an annual production about 4.1 billion tons (Gt) and registered a stagnation since then (USGS, 2018). This volume represents an annual increase of 23% compared to 2010, and 155% if compared to 2000. As seen in Figure 2, the 13 largest producing countries in 2017 (China, India, USA,

¹⁷ Clinker is produced by sintering limestone and aluminosilicate materials.

¹⁸ Generated by the burning coal and waste materials for the calcination.

¹⁹CaCO₃, or calcium carbonate, is the main component of limestone.

SiO₂, or silicium dioxide, is used in the form of silica.

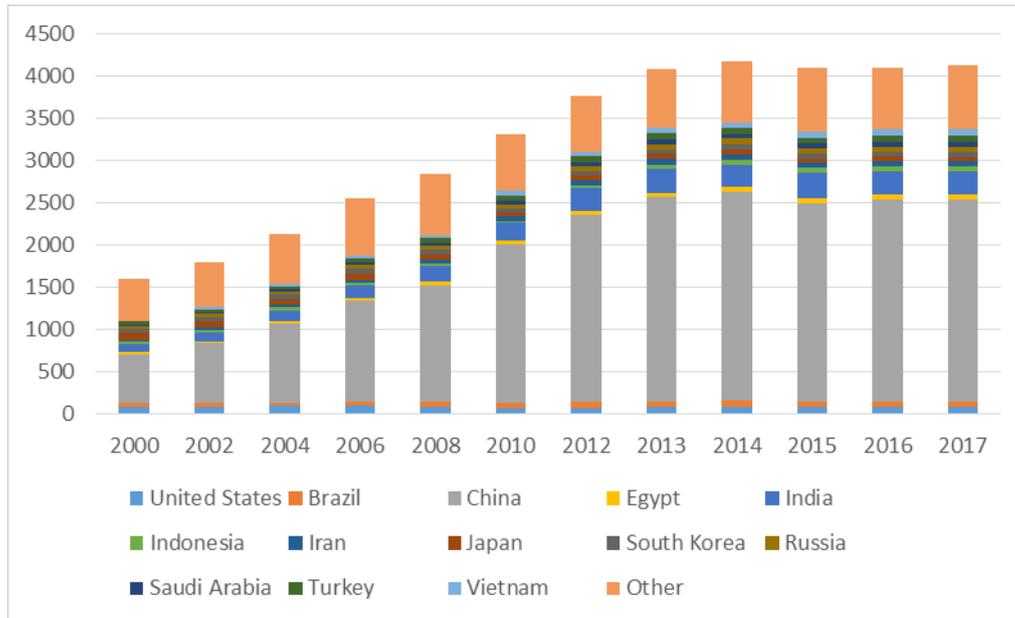
Al₂O₃, or aluminum oxide, is the natural oxide of aluminum, and is found in many minerals.

Fe₂O₃, or iron oxide, is one of the natural oxides of iron, and is found in many minerals.

²⁰ <http://www.ecocem.fr/fabrication-du-ciment/>

Turkey, Brazil, Russia, Iran, Indonesia, South Korea, Vietnam, Saudi Arabia, Japan and Egypt) account for 70% of world production while China alone accounts for almost 60% of the world production with 2.4 Gt in 2017.

Figure 2: Evolution of world cement production (million tons, Mt)



Sources: USGS (2017), Cement producer reports

Cement is a very local market. It involves only a small volume of international trade. According to Chatham House, only 179 million tons of cement were traded in the world in 2016 (3.6% of world production)²¹. It is easily explained by the fact that cement is a commodity that involves very high transport costs due to its heavy weight, relative to its market value. It is usually said that cement could not be economically hauled beyond 200 or at most 300 km²². Production activities are therefore generally located at a reasonable distance from operating activities in order to minimize transportation costs. Currently, the largest cement exporters are China, Turkey, Japan and Thailand while the largest importers are the United-States of America, Bangladesh and Sri Lanka and Singapore. In 2016 the largest trade flows were from Canada to the USA (4.5Mt), from

²¹ Including Portland cement, aluminous cement, slag cement, supersulphate cement and similar hydraulic cements: <https://comtrade.un.org/data/>

²² According to the European Cement Association: <https://cembureau.eu/cement-101/key-facts-figures/>

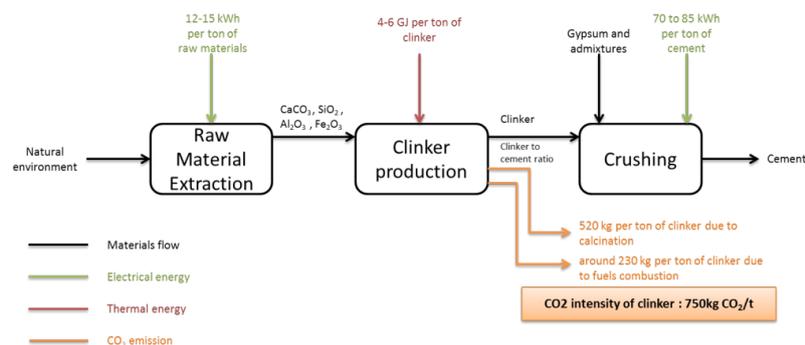
India to Sri Lanka (4.3Mt) from China and Thailand to Bangladesh (respectively 4.1Mt and 3.8Mt) and finally Japan to Singapore (3.5Mt), illustrating the predominance of border trade.

2.2 The cement manufacturing and environmental impact

The cement sector is currently the third-largest industrial energy consumer and the second-largest industrial CO₂ emitter globally (IEA, Technology Roadmap - cement, 2018). Cement production is therefore one of the most emitting industries worldwide with approximately 25-27% of the total industry emissions (i.e. 5-7% of the global CO₂ emissions) (Rodrigues and Joekes, 2010) and is responsible for 12 to 15% of industrial energy use in the world (Ali et al., 2011).

High GHG emissions are partly due to the high energy needs for the process, but also, intrinsically through chemical reactions in cement clinker production. Depending on the different production processes, the average energy intensity for cement production ranges from 4 to 6 GJ per t²³ of cement (Institut Français de l'énergie, de l'environnement et de la francophonie, 2001). Figure 3 outlines a simplified representation of the cement production process with energy inputs and emission outputs.

Figure 3: Cement manufacturing process, inputs and outputs



Source: Adapted from IFEP (2001)²⁴

²³ 1 GJ/t = 1 Giga Joules per ton = 10⁹ Joules per ton.

²⁴ French Institute of energy, environment and French-speaking world.

The high energy demand from cement production is mainly due to the cooking stage requiring temperatures up to 1600°C due to the endothermic nature of the calcination of calcium carbonate (about 2.80 GJ/t). In addition to the thermal energy, the cement manufacturing process requires electrical power used in both the raw materials extraction and the mixture crushing²⁵. In addition to GHG emissions from energy consumption, the decarbonation reaction releases a large amount of CO₂²⁶, which represents about 60% of the cement manufacturing emissions. Finally, the average CO₂ intensity of clinker is about 750kg CO₂/t clinker according to IFEP (2010) (Figure 3) and represents the main contribution to the high overall CO₂ intensity of the cement production.

There are different ways currently developed to achieve more environmentally friendly cements. The perspectives cover industrial optimization (energy consumption) and environmental impact mitigation (CO₂ emissions). In addition, some challenges are pinpointed upstream of the process. For instance, Kendall et al. (2008) linked the optimized production process to geologic and geographic constraints at the local scale, especially for limestone mining operations operated in densely populated areas, protected natural areas, or excessive overburden thickness. Then, during cement production the main options discussed to decrease the environmental impact of cement industry are to increase energy efficiency, develop CO₂ capture and sequestration (CCS), decrease the clinker to cement ratio, increase the recycling rate of cement, associate waste heat recovery or develop the use of alternative fuels²⁷ (Kendall et al. 2008, Ali et al., 2011; Hasabeigi et al., 2012; Rahman et al., 2013 ; Uson et al., 2013 ; Morrow et al., 2014 ; Ishak and Hashim, 2015 ; Salas et al., 2016 ; Shen et al., 2017; Leeson et al., 2017 ; Gartner et al., 2017 ;). Potential CO₂ reductions vary greatly from one region to another. At the global level, cement technology roadmap of the IEA plots path to cutting annual

²⁵ Depending on the type of technology used the extraction uses up 12 to 15 kWh per ton of mineral extracted, and the crushing steps consume around 20-25 kWh per ton of raw materials and 50 to 60 kWh per ton of cement. To sum up, each ton of cement produced can use up 80 to 100 kWh of electrical energy (0.29 to 0.36 GJ).

²⁶ $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$: the decomposition of calcium carbonate (limestone) into carbon dioxide and calcium oxide (lime).

²⁷ The main fuels used for clinker firing are today petroleum coke (used at about 40% of the calorific value consumed), coal and lignite (about 50%), some waste, heavy fuel oil and gas. Over the past decade, the share of traditional fuels, such as coal, fuel oil and gas, has tended to be reduced in favor of other more economically attractive fuels, such as petroleum coke, waste, and biomass (including meat and bone meal).

CO₂ emissions by 24% below current levels by 2050 by a combination of technology and policy solutions in a 2°C scenario²⁸, or a reduction of 32% of the global direct CO₂ intensity of cement (IEA, Technology Roadmap, 2018). It also recognises the need to consider CO₂ emissions reduction over the overall life cycle of cement, concrete and the built environment (conception and design life of construction for instance) to have the more CO₂ savings. If reduction potentials exist, we will discuss in the data section the limited role of these mitigation actions in reducing cement-related CO₂ emissions for power generation technologies, partly due to concrete specifications required for the energy sector.

III. METHODOLOGY

The methodology developed in this article aims at estimating the need for concrete (and therefore cement) to achieve the energy transition objectives in the power sector determined by the IEA climate scenarios. First, we will introduce the structure of the model before presenting the data considered and finally describe the scenarios used.

3.1 Model structure

In this article we developed a model whose schematic structure is given in Figure 4. The model has as exogenous input data (in red in Figure 4):

- The different power plants' concrete contents.
- CO₂ emission per unit mass: this factor varies according to the type of fuel used to supply the furnaces with thermal energy. It also has a lower limit due to the intrinsic production of carbon dioxide by the calcination reaction²⁹.

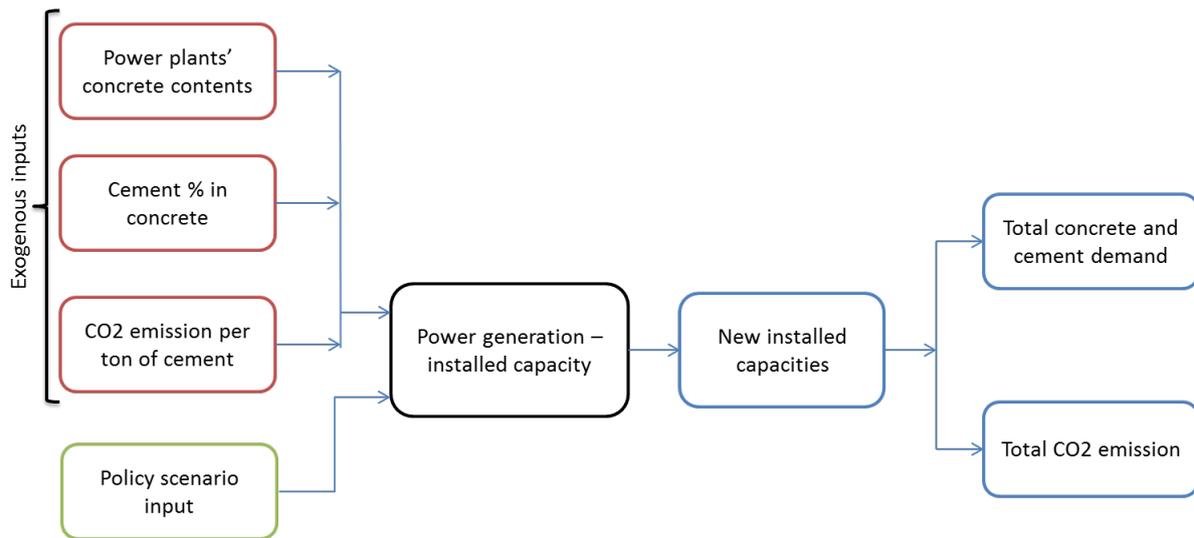
²⁸ 24% direct emission reductions of which 3% are due to thermal energy efficiency, 12% to fuel switching, 37% to reduction of clinker cement ratio, 48% to innovative technologies (including carbon capture), not included CO₂ reduction linked to heat waste recovery.

²⁹ Except if CCS technologies are considered.

- The percentage of cement in concrete: the composition of concrete is generally fixed, especially since the concrete chosen in all energy production technologies is high-performance concrete.

The values of these inputs are discussed in part 3.2.

Figure 4: Modelling future concrete needs



Source: authors

The model's outputs are (in blue in Figure 4):

- The cumulative amount of concrete required for deploying the electricity sector according to several climate scenarios considered.
- The quantity of CO₂ directly emitted to produce this quantity of concrete.

The model is using policy scenarios as inputs for the technology-mix in power sector and its evolution over time (in green on Figure 4):

The evolution of installed power capacities is given by 5-year intervals, both on a global and regional scale. The investments in new installed capacities are dependent on climate objectives and are provided in this article by the IEA (ETP, 2017). To obtain accurate results, it is also necessary to take into account the lifetime of a power plant. This parameter allows us to take into account the decommissioning process and its impact on future concrete demand. Indeed by only considering the additional capacities over time, without taking into account technologies lifespan, it leads to underestimate the required volume of concrete. We assume for any technologies with a lifespan of 35 years or less,

that they will be dismantled and potentially replaced once during the period 2014-2050. For technologies with a longer service life, particularly nuclear, decommissioning has been taken into account based on the timetable for nuclear power plants (Commissariat à l'Energie Atomique et aux Energies Renouvelables, 2015). The hydro technologies have too long lifetime to be dismantled in the 2014-2050 period. Due to this methodology, we can only evaluate a cumulative material demand over the period but we cannot provide an annual evolution of concrete demand for the electricity sector.

The cumulative new capacities denoted $C_{cum,i,j}$ are then calculated as follows:

$$C_{cum,i,j} = \sum_t C_{i,j}(t+1) - C_{i,j}(t) + C_{i,j,eol}(t+1)$$

Where:

- t represents the time period over which the cumulative amount of installed capacities is calculated. The first period runs from 2014 to 2025, then a 5-year interval is set. $t=\{2014; 2025; 2030; 2035; 2040; 2045; 2050\}$.
- $C_{i,j}(t)$ represents the installed capacity of the technology i at the end of the year t in the geographical area j , and $C_{cum,i,j}$ represents the cumulative installed capacity of the technology i that has been commissioned during the 2014-2050 period in the geographical area j .
- $C_{i,j,eol}(t)$ denotes the amount of installed capacity of the technology i in the geographical area j that is projected to be dismantled during the period t .

The demand for concrete from geographical zone j is denoted D_j and is expressed by:

$$D_j = \sum_i C_{cum,i,j} \cdot \alpha_i$$

Where:

- α_i is the concrete content in the technology i , expressed in t/MW of installed capacity.

The resulting demands for cement, water and aggregates, as well as the associated CO₂ emissions are determined as follows:

$$Cem_j = D_j \cdot \beta_{cem} ; Wat_j = D_j \cdot \beta_{wat} ; Agg_j = D_j \cdot \beta_{agg}$$

$$CO2_j = Cem_j \cdot \gamma_{cem}$$

Where:

- D_j represents the cumulative 2014-2050 demand for concrete in the power sector in the geographical area j.
- Cem_j , Wat_j and Agg_j respectively represent the cumulative 2014-2050 demand for cement, water and aggregates in the power generation sector in the geographical area j. β_k represents the proportion of the component k in concrete.
- $CO2_j$ represents the direct CO₂ emissions resulting from the manufacturing of the cement used in the power generation sector. γ_{cem} represents the CO₂ quantity emitted per ton of cement produced (CO₂ intensity).

3.2 Data

The lifetime values characterizing the different power generation technologies used to calculate the new capacities, taking into account decommissioning, are summarized in Table 3.

Table 3: Life expectancy of electricity generating technologies

Technology	Lifetime (years)
Wind Onshore	25
Wind Offshore	25
Nuclear	60
Hydro	150
Fossil	35
Solar	25
Geothermal	50
Bioenergy	30

Sources: Kannan et al. (2007), EDF Data, CEA Data (2015)

In order to quantify the global impact of concrete used in the power sector, the concrete-content of each technology used should also be known. They are mentioned in Table 1. The results presented in this article are produced by considering the technological state of the cement and the concrete industries. The parameters of the concrete production technology are presented in Table 4 and correspond to the exogenous inputs presented on the Figure 4 (red).

Table 4: Used values for concrete proportions and CO2 emissions

Parameter	Signification	Used Value
β_{cem}	Cement proportion in concrete	0.2
β_{wat}	Water proportion in concrete	0.15
β_{agg}	Aggregates proportion in concrete	0.65
γ_{cem}	CO ₂ intensity of cement (kg CO ₂ /ton cement)	540

Sources: Unicem³⁰ (2018), IEA (2018)

The CO₂ intensity of the cement used in this study for power generation is the world average given by the IEA (540 kg CO₂/t). Thereafter this study does not take into account the potential evolution of technological progress that may lower the environmental impact of the concrete use. Indeed, we could have implemented a dynamic composition of concrete or CO₂ intensity of cement over time (with a 5-year interval). Nevertheless due to the high performance required in the energy infrastructures (corrosive or high pressure environment) we assume the cement proportion in concrete has good probabilities to remain constant in the future. In addition we keep constant the cement CO₂ intensity as the impact of thermal energy efficiency is negligible in the cement roadmap of the IEA (as it accounts for only 3% of CO₂ savings in the cement industry by 2050). Furthermore the clinker-to-cement ratio evolution is not taken into account due to the high specifications of concrete for energy

³⁰ French Union of Quarry and Construction Materials Industries <https://www.unicem.fr/>

infrastructures. For the same reason the potential CO₂ savings due to a change in the fuel used during cement production is not considered due to the problematic of impurities from new fuels³¹. Otherwise this possible overestimation of future CO₂ emission due to constant parameters could be contrasted by an underestimation of some renewables technologies' needs in the future. Indeed this paper takes into account average concrete and cement needs from the current technological state-of-the-art. Further research in this field can be developed to determine the evolution of power generation technologies in order to further narrow down the uncertainty about future cement demands and get a more accurate estimation. Nevertheless to our understanding of the different power technologies, the average concrete demand could be higher than the anticipated one in this study due to the development of some renewable energy related technologies such as the tower design or foundations of wind turbines requiring more concrete (Zimmermann et al., 2013) or the evolutionary nuclear Generation III plants³² (Peterson et al., 2005). Additionally no recycling from dismantlement is taken into account due to the high performance of concrete required from energy technologies³³.

The major limitation of this work concerning the future environmental impact of concrete production is therefore the non-consideration of innovative technologies such as carbon capture and storage, which could decrease the CO₂ intensity of cement, while it is widely used by the IEA to achieve ambitious climate scenarios, as mentioned below.

3.3 Scenarios

With regard to the policy scenario input, the three scenarios studied thereafter have been considered. They are defined by the IEA on a global scale and for the entire energy system as follows:

³¹ Alternative fuels can pose process or quality use problems, mainly related to the chemical components they contain (Sb, As, Ba, etc). Their use could therefore be limited in some applications (Mungyeko and Pongo Pongo, 2014).

³² Evolutionary Generation III plants—EPR and Advanced boiling water reactor (ABWR)—use approximately 25% more steel and 70% more concrete than 1970's Light-water reactors.

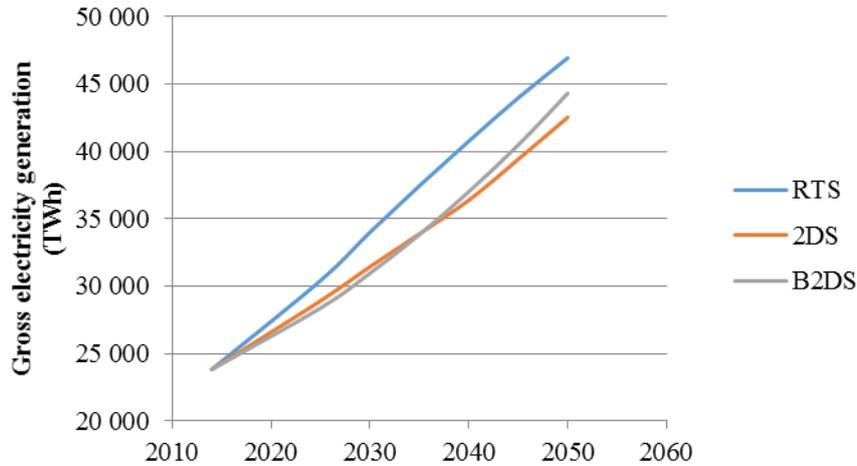
³³ Crushed recycled concrete could be used as the dry aggregate for brand new concrete. For wind turbine technologies recycled concrete could be used for example, as filling material but cannot be used as substitute for primary material in the technology.

- The RTS or *Reference Technology Scenario* is a scenario that provides a baseline which takes into account the energy policies as well as the commitments of different countries in terms of climate policy. The RTS scenario therefore reflects current climate ambitions, including Nationally Determined Contributions pledged under the Paris Agreement. In the RTS scenario, the share of electricity in final energy demand across all end-use sectors increase (from 18% today to 26% in the RTS by 2060 according to ETP scenarios). Consequently global electricity demand more than doubles between 2014 and 2060 while the CO₂ emissions stabilize after 2030.
- The 2DS scenario is a more ambitious scenario, which translates the climate objectives of limiting global warming to 2°C. Energy efficiency is the main factor (after the use of renewables) that contributes to CO₂ emissions reductions (39% of total CO₂ reduction in comparison with the RTS scenario emissions). This scenario involves also the use of CCS technologies to save 4.2 GtCO₂ in 2050 (16% savings)³⁴. In this scenario the global power sector reaches net-zero emissions in 2060.
- The B2DS scenario (Beyond 2°C scenario) is a scenario that limits global warming to less than 2°C. It explores how far deployment of technologies that are already available or in the innovation pipeline could take us beyond the 2DS. Technology improvements and deployment are pushed to their maximum practicable limits across the energy system in order to achieve net-zero emissions by 2060 and to stay net zero or below thereafter. It aims a 1.75°C global warming by 2100. Energy efficiency and CCS technology allow additional savings of 2.5 GtCO₂ and 3.1 GtCO₂ compared to the 2DS scenario. The global power sector reaches net-zero emissions by 2050 and then becomes net-negative (in particular due to the use of bioenergy with capture carbon and storage).

The power sector has a crucial role to play in achieving those objectives, as it is now the world's largest emitter of carbon dioxide and is growing rapidly worldwide. IEA ETP scenarios describe the changes in the amount of energy produced (Figure 5) and gross installed capacity for the power sector between 2014 and 2050 (Figure 6). Note that there is no information on potential decommissioning included in this latter graph which represents only the total capacity installed at a given time.

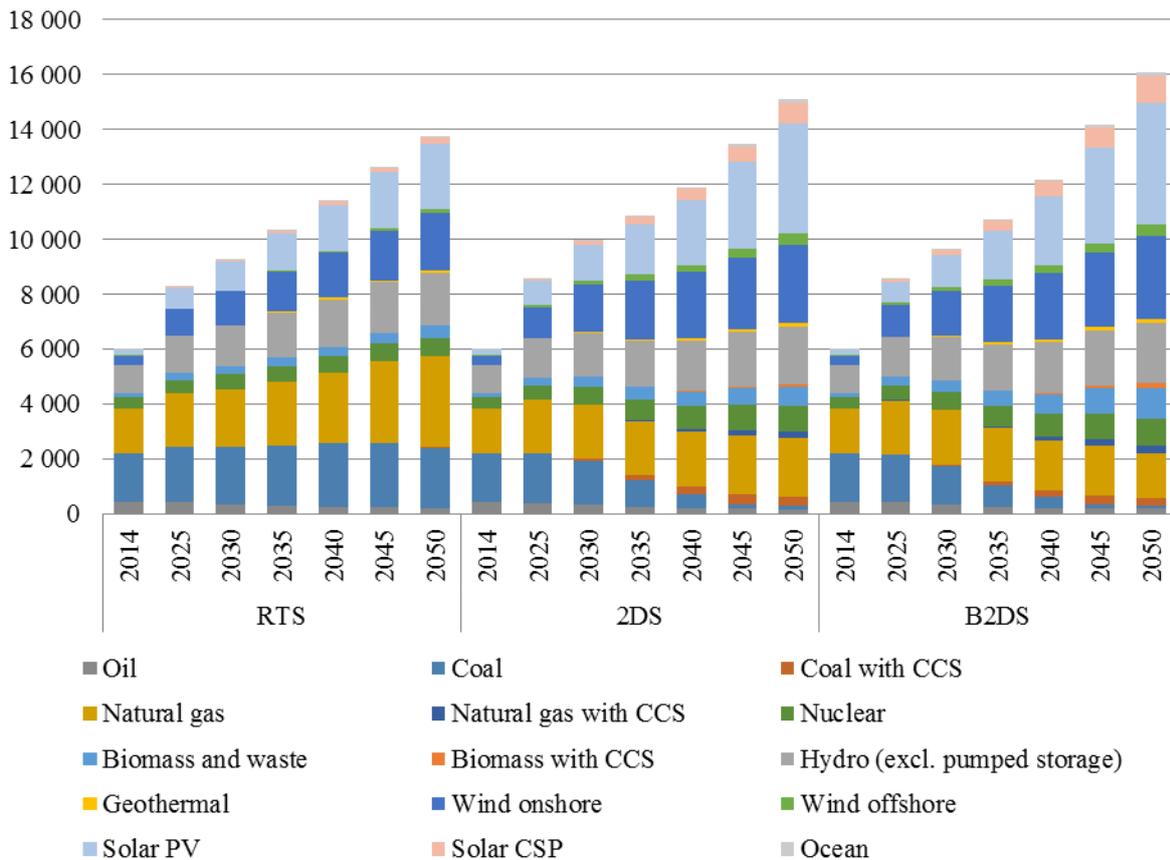
³⁴ <https://www.iea.org/etp2017/summary/>

Figure 5: Evolution of gross electricity generation (TWh) in the 2014-2050 period



Source: IEA - ETP 2017

Figure 6: Evolution of installed capacities for climatic scenario (GW) - Breakdown according to technologies



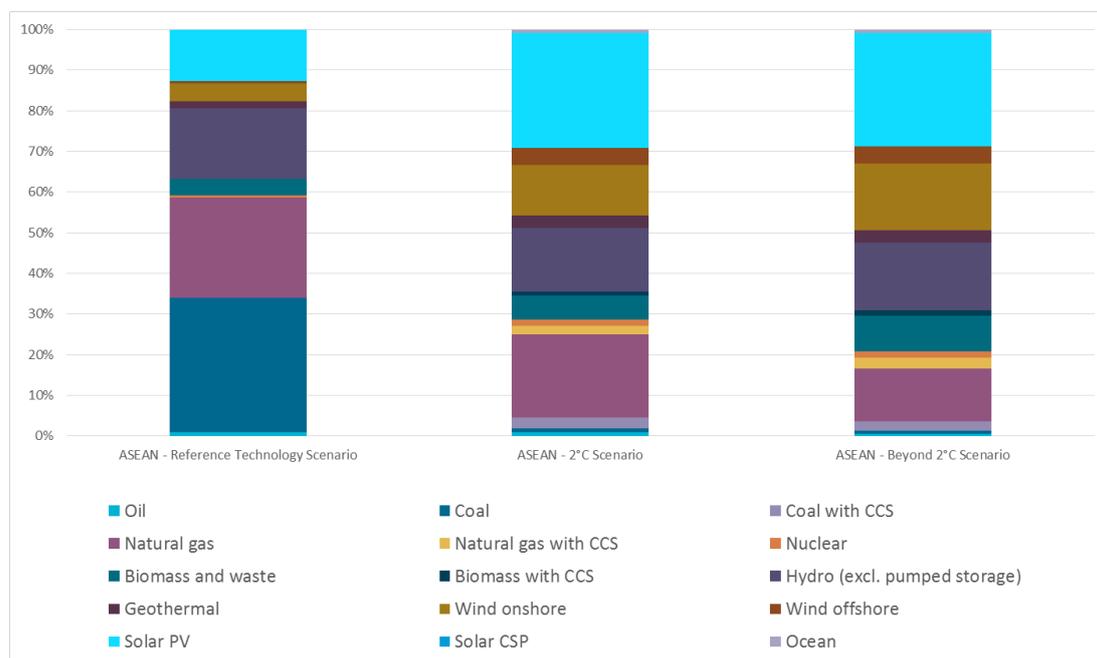
Source: IEA - ETP 2017

The consequence of switching from the RTS scenario to a 2°C or below 2°C scenario is that, despite the gradual decrease in the total amount of electricity generated worldwide³⁵ (Figure 5), there is an overall increase in the total gross installed capacity by 2050 (respectively 10% and 17% compared to the RTS). This increase is explained by the fact that the energy transition scenarios imply an increase in the share of variable renewable energies, whose load factors³⁶ are in average lower than fossil or nuclear energies (25% for wind onshore, 40% for wind offshore and 15% for PV solar in opposition to 81% for nuclear, 80% for coal and 35% for natural gas). This difference in the average load factor inevitably implies an increase in the total installed capacity worldwide compared to the RTS scenario. Obviously, the share of fossil-fuel based generation power (oil, coal with or without CCS) strongly decreases in the two most ambitious climatic scenarios (2DS and B2DS) while the shares of low carbon technologies (nuclear, hydro, biomass, wind, solar, etc.) become predominant to meet the climate objectives at the global level. Data are also regionalised, allowing carrying out studies at more local scales. It shows in particular that marginal abatement efforts can have a major impact on the technology mix of the electricity sector for some regions (as illustrated with the shift from the use of natural gas to onshore wind or biomass and waste between the 2DS and 2BDS scenarios for The Association of Southeast Asian Nations as displayed in Figure 7).

³⁵ Respectively -9.4% and -5.6% in the 2DS and B2DS compared to the RTS, due to hypothesis on strong innovation (especially energy efficiency).

³⁶ The load factor of a power plant is the ratio between the actual electrical energy produced over a given period and the energy it would have produced if it had operated at its rated power during the same period.

Figure 7: Share of the different technologies in the ASEAN region’s electricity mix in 2050 (in terms of installed capacity)



Source: IEA – ETP 2017

Regional disaggregation and impact on local demand for cement will be discussed in the second part of the results section.

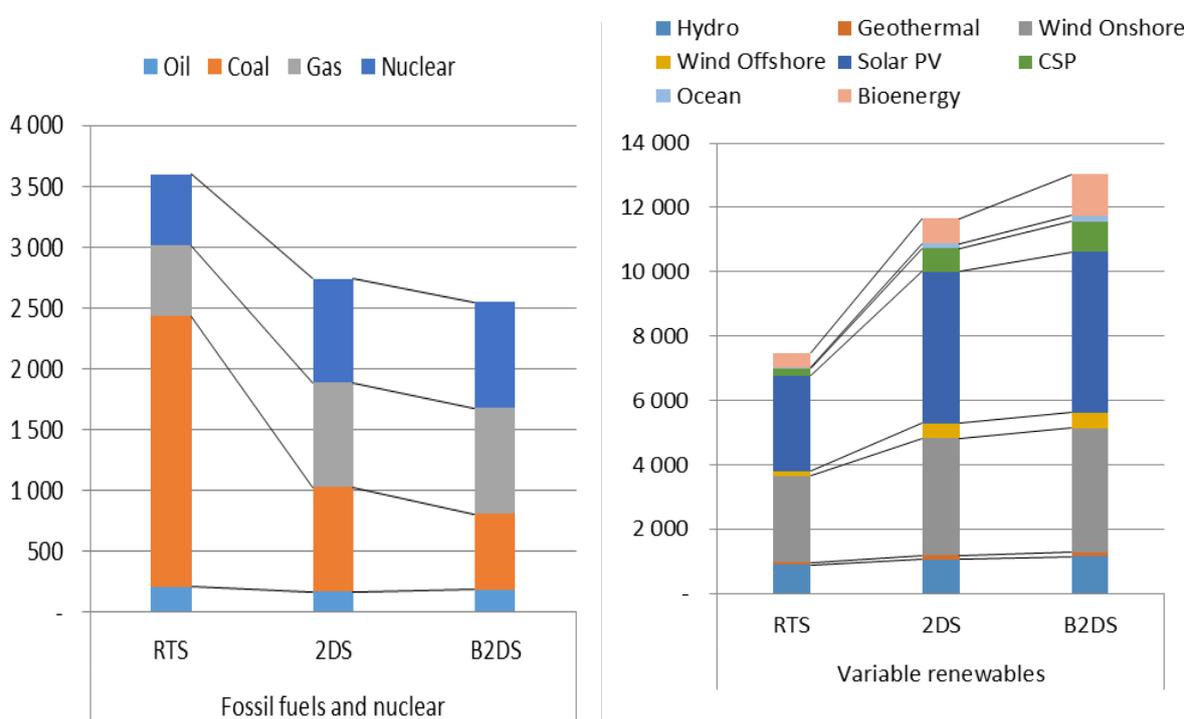
IV. RESULTS AND DISCUSSION

4.1 Global cement demand by 2050 for the power generation sector

Using the ETP data and implementing decommissioning, thanks to the lifetime of already installed technologies, the model allows us to calculate the global cumulative new installed capacity between 2014 and 2050, for each climate scenario. In Figure 8, we observe a 3.5 fold decrease in new coal capacities between the RTS and B2DS while new gas capacities will decrease by 42% and new oil capacities will remain roughly constant. On the other hand, the cumulative installed capacities of variable renewable energy plants are expected to significantly increase, respectively by about 56% and 74% in the 2DS and the B2DS, compared to the RTS levels. Finally, the cumulative new installed

capacities of nuclear power at the global scale are also expected to increase by 50% between the Beyond 2°C scenario and the RTS. Disaggregation between fossil technologies is also necessary due to the difference in the concrete content of these technologies (very low for natural gas system even in combined cycle, Table 1). Consequently, the impact of fossil fuel technologies on concrete demand is expected to be lower in the B2DS than in the RTS while it is the opposite result we obtain for renewable and nuclear capacities.

Figure 8: Cumulative new installed capacity (GW) by scenario between 2014 and 2050: breakdown by technology



Source: authors

According to these results, and to the concrete contents per technology presented in the above-mentioned methodology, the model provides concrete, cement, water and aggregates volume demands, as well as the total CO₂ emission due to the cement manufacturing process. The cumulative cement demand in each of the three scenarios, at a global level, are given in Table 5. The GHG emissions associated with these production levels are given in the rightmost column.

Table 5: Cumulative cement demand by 2050 and associated CO₂ emissions

Scenario	Cumulative cement demand (2014-2050)	Cumulative direct CO ₂ emission (2014-2050)
Reference Technology Scenario (RTS)	1 016 Mt (ref.)	549 Mt
2 Degree Scenario (2DS)	1 205 Mt (+19%)	650 Mt
Beyond 2 degrees Scenario (B2DS)	1 300 Mt (+28%)	702 Mt

Source: authors

First, we observe an increase in cement demand from the transformation of the power sector for the energy transition. This is true in both ambitious scenarios (2DS and B2DS) as the cumulative cement demand increases by 19% and 28% in the 2DS and B2DS scenarios, respectively, compared to the RTS scenario. This is the direct consequence of higher cumulative installed capacities with high concrete-content technologies, such as hydropower or wind power technologies. Without decommissioning, the cement demand was 25 to 30% lower than the results presented in the previous table, depending on the scenarios. Overall our results are higher than those obtained by Hertwich, et al. (2015) whose cement requirement for the power sector was 520 Mt by 2050 according to the BLUE Map scenario (2010). The difference is explained in part by a more ambitious global GHG reduction in the ETP 2017 and the larger scope of power generation technologies considered here (nuclear, biomass and oil power plants). Indeed the BLUE scenario described in the ETP 2010 assumes that global energy-related CO₂ emissions are reduced to half the 2005 levels by 2050. In terms of renewables electricity production, the Blue Map scenario is then closer to the current RTS scenario than the 2DS or B2DS.

In order to put into perspective the figures of future global cement demand, we can compare them with current production. In the more stringent scenario (B2DS), the cumulative cement volume required from 2014 to 2050 is about 1.3 billion tons, which is around 32% of the 2017 global cement production (4.1 billion tons according to USGS). As global population rises and urbanization grows, global cement production is expected to increase by 12 to 23% by 2050 according to the IEA (Technology Roadmap - Cement,

2018). The cumulative future cement production worldwide could thus range between 160 and 167 billion tons on the period 2014-2050. Consequently, the estimated share of cement allocated to the energy transition for the power generation sector in all scenarios would only represent 0.8% of world cement production by 2050. The vast majority of the future volume produced is therefore expected to be allocated to improve infrastructure, build housing, factories, etc. along demography growth and living conditions improvements. Indeed, according to the UN estimations (World Urbanization prospects, 2017), urban population is expected to represent 65% of the world's population by 2050, reaching 6.70 billion urban dwellers by 2050.

Regarding to other concrete constituents, the same conclusions can be drawn. The increase in cement demand goes naturally with an increase in both construction aggregates and water demand which remain negligible in respect to the global demand (all sectors included). According to our assumptions (Table 4) the cumulative amount of concrete needed for low carbon electricity generation will require about 3.9 Gt of construction aggregates in the 2°C scenario (around 3,3 Gt in the RTS and 4.2 Gt in the B2DS), as shown in Table 6, while the world annual construction aggregates demand was around 53 Gt in 2017. Besides, concrete demand from the power generation sector does not significantly impact the stress on global water demand by 2050 in regard to the annual 4 000 Mt water consumption for the concrete production; even if this demand at the regional scale can be more challenging (but this point is not discussed here).

Table 6: Cumulative aggregates demand by 2050

Scenario	Cumulative aggregate demand (2014-2050)	Cumulative water demand (2014-2050)
Reference Technology Scenario (RTS)	3 301 Mt (ref.)	762 Mt
2 Degree Scenario (2DS)	3 915 Mt (+22%)	903 Mt
Beyond 2 degrees Scenario (B2DS)	4 225 Mt (+31%)	975 Mt

Source: authors

Finally in terms of CO₂ emissions, direct emissions due to cement production for power generation technologies are really small compare to the indirect CO₂ savings induced by the new global power mix (cumulative direct emissions from the power sector -without including CCS- decrease by 40% between the RTS scenario and the B2DS scenarios on the period 2014-2050). It does not allow us to conclude on the net carbon impact of the deployment of new technologies because many other materials are needed and are also responsible for significant CO₂ emissions. The low amount of GHG emissions that is imputable to concrete production for the power sector indicates however that it is very unlikely that carbon pricing instruments will hamper the diffusion of low-carbon technologies, despite their higher concrete-content compare to conventional ones. This result holds at the global scale. The next subsection shows nonetheless how concrete can have a greater role at the regional level.

4.2 Regional cement demand by 2050 for the power generation sector

While the weight of the electricity sector in the aggregated concrete demand is relatively small, national specificities make concrete more important for energy transition in some countries than in others. Indeed, cement and concrete are local markets, so it is difficult to relocate the negative externalities associated with their production. The cement volumes required to implement the new electricity mix by 2050 on a regional scale can therefore be assimilated to future internal production from these regions. This regionalization is presented in Table 7.

Table 7: Cumulative cement demand for the power sector by 2050

Country / Region	RTS	2DS	2DS/RTS	B2DS	B2DS/RTS
China	286	295	3%	298	4%
India	117	152	30%	161	37%
USA	83	105	26%	115	38%
EU	82	90	10%	91	11%

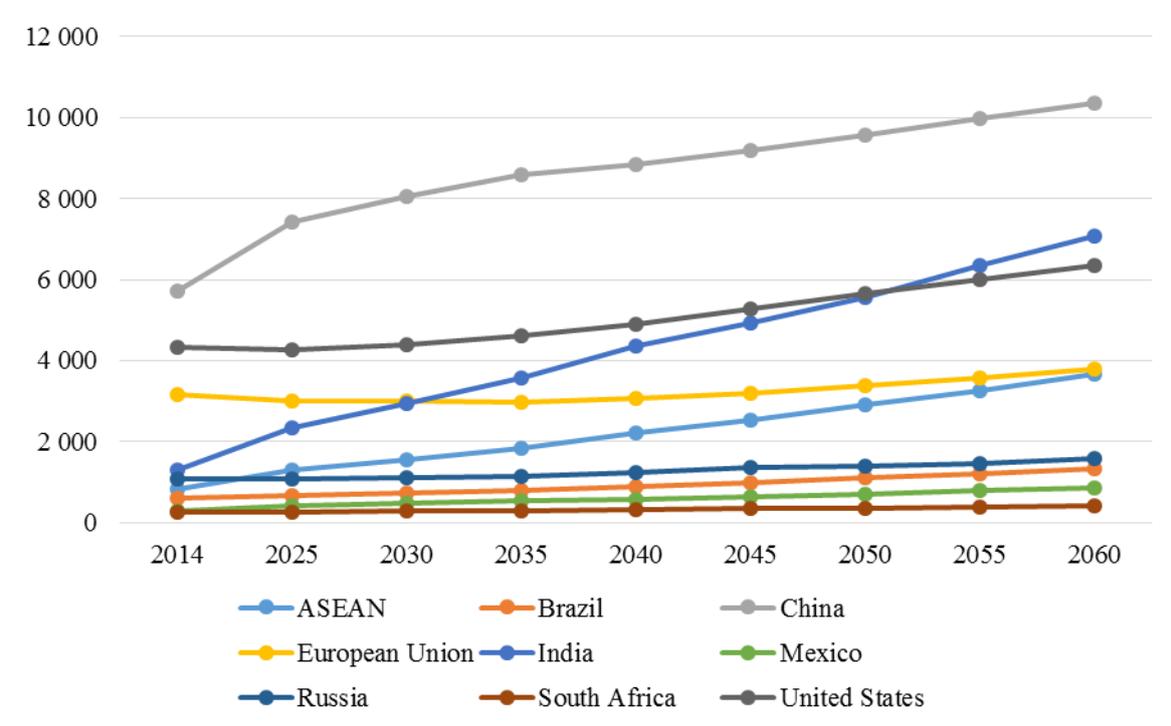
ASEAN	70	93	34%	120	72%
Brazil	47	43	-6%	48	4%
Russia	25	42	68%	48	90%
Mexico	7	12	66%	14	83%
South Africa	6	9	34%	8	31%
OECD	244	291	19%	305	25%
Non OECD	775	927	20%	1 005	30%

Source: authors

First noticeable point is the high consumption of developing countries, whose electrification of the economy will increase in the coming decades. This is particularly the case for China, India or, more generally, the ASEAN countries³⁷. According to the IEA, electricity production will increase by 67% in China between 2014 and 2050, 332% in India and 246% in ASEAN countries (Figure 9).

³⁷ Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei, Vietnam, Laos, Burma, Cambodia

Figure 9: Gross electricity generation per region (TWh) between 2014 and 2060 in the B2DS scenario

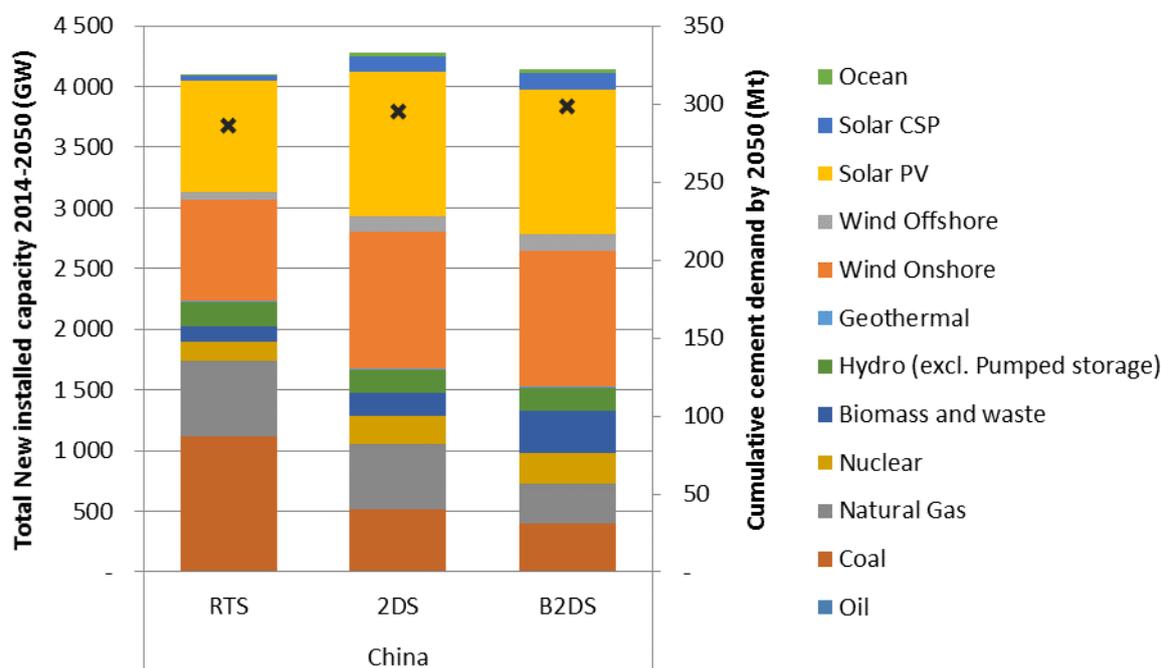


Source: IEA – ETP (2017)

IEA does not provide an African vision (excluding South Africa) in the ETP (2017), but the continent is also expected to witness a strong electrification in the medium term.

If we focus on a country level, we observe quite contrasting differences in future cement demand. Surprisingly, China's cement demand will remain relatively stable between the 3 scenarios considered by 2050 (RTS, 2DS (+3%) or B2DS (+4%)) (Figure 10). In both the 2DS and the B2DS, approx. 66% of the demand for cement is imputable to the deployment of hydro technologies. Wind capacities are also partly responsible (about 37%) although their cement content is lower per installed MW. It is important to note that by 2050 the installation of new coal-fired power plant capacity (with or without CCS), hydro and wind technologies, as well as nuclear plants will account for about 95% of cement consumption in all scenarios. The evolution of solar capacities will increase significantly but will have a modest impact on cement demand.

Figure 10: New Chinese cumulative electric capacities by 2050 (2014-2050)



Source: authors

Cement consumption is directly related to the amount of new installed capacities but more importantly to the electricity mix considered. This is illustrated in particular by calculating the cement intensity of the installed GW in the different scenarios for a given country (Table 8).

Table 8: Comparative cement demand and CO₂ emissions per installed capacity (cumulative between 2014-2050)

	Cumulative installed capacity (2014-2050) (GW)			Cement demand per capacity installed (Mt/GW)			CO ₂ emitted from cement manufacturing per capacity installed (Mt/GW)		
	RTS	2DS	B2DS	RTS	2DS	B2DS	RTS	2DS	B2DS
China	4 094	4 276	4 142	70	69	72	38	37	39

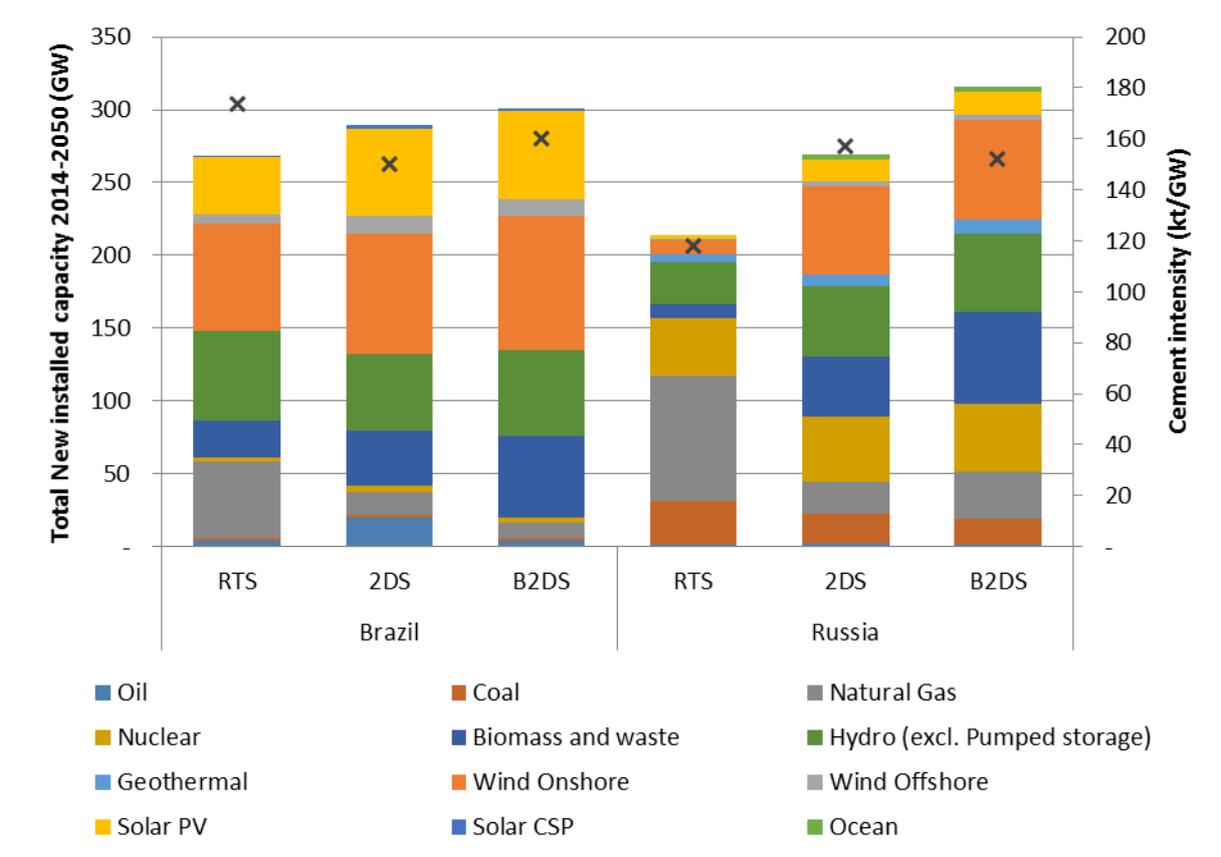
India	1 626	2 304	2 346	72	66	68	39	36	37
USA	1 861	2 247	2 318	45	47	50	24	25	27
EU	1 294	1 354	1 448	64	67	63	34	36	34
ASEAN	671	952	1 107	104	98	108	56	53	58
Brazil	268	290	301	174	150	160	94	81	87
Russia	214	269	316	118	157	152	64	85	82
Mexico	219	255	283	34	49	48	18	26	26
South Africa	121	164	158	53	53	54	29	29	29
World	13 801	15 800	16 629	74	76	78	40	41	42

Source: authors

It can be observed, on a global scale, that the intensity of cement for electrical technologies by 2050 remains relatively stable, from 74 to 78 kt of cement per GW installed. Nevertheless, and it is worthy of note, this intensity varies widely from one region to another. It results in local carbon intensities, linked to this cement production, that are significantly higher than the world average. While Mexico has a very low cement consumption electricity mix (48 kt/GW in B2DS), Brazil has the highest one (160 kt/GW, B2DS), followed by Russia (152 kt/GW, B2DS) and ASEAN (108 kt/GW, B2DS) that have a relatively high emissive mixes compared to cement demand. The US also stands out for the low cement intensity of its new electricity mix (50 kt/GW). These differences can be explained by the choice of power generation technologies. Mexico or the US have strong solar capacities (PV or CSP) by 2050, while Brazil will have a strong installed hydropower capacity.

The second point to consider is that within the same geographical area, cement intensities can vary positively or negatively depending on the scenario considered. For example, in Russia there is a 29% increase in cement consumption per installed GW between the RTS and B2DS scenario, while in Brazil there is a 7.7% reduction. The electricity mixes of these two countries are shown in Figure 11.

Figure 11: Cumulative new power installed capacity in Brazil and Russia from 2014 to 2050 (GW)



Source: authors

For Russia, the cement (and the corresponding CO₂) intensity of the average installed electrical power is higher for the B2DS than for the RTS scenario due to new capacities in hydropower (+64% to 85% of GW installed compared to RTS) and onshore wind (+494 to 582% compared to RTS), which require large volumes of concrete. On the contrary, Brazil's CO₂ content has decreased from 94 kt CO₂/GW to 87 kt CO₂/GW due to the development of energy technologies with lower concrete content (solar PV in particular). Nevertheless, total cement demand remains relatively stable between the

three Brazilian scenarios, offset in the two climate scenarios by the installation of additional capacities.

We have therefore just illustrated the regional disparities in cement demand for future power mixes according to the scenarios of the ETP 2017. In the previous section, we showed that on a global scale the cement volumes required to make the energy transition in the electricity sector were low, with a cumulative volume over the period 2014-2050 equivalent to less than 35% of cement production in 2017. Table 9 uses the same reasoning for the few countries where data were available (in the case of the most restrictive B2DS scenario). Conducting this exercise demonstrates that albeit the decarbonisation of the power sector will only have a limited impact on the production of cement at the global scale, this result cannot be generalized for every country and the energy transition will have a greater impact on the cement market in several countries.

Table 9: Ratio of cement demand for future power sector and national production

Country/Region	Cumulative cement by 2050 [Mt] (B2DS) (1)	2017 cement production [Mt] (2)	Ratio (1)/(2)
China	298	2400	12%
India	161	270	59%
USA	115	85.3	135%
EU	91	169.9*	54%
Brazil	48	54	89%
Russia	48	58	83%
Mexico	14	39.6	34%

South Africa	8	13*	65%
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Source : USGS (2018), *USGS (2015)

For China, which has a cement production capacity greater than its needs (about 10% overcapacity³⁸), the demand for cement in the electricity sector should not be a concern. That's why, when looking at the results on a global scale, the large Chinese cement volumes mask in reality a local disparity. Indeed cement volumes required for the future power sector are not negligible in the rest of the world relative to their current cement volume production and capacities. Especially in other developing countries such as Brazil, India or Russia. Even in the US, it will also take more than a year of national production to meet the entire demand for a B2DS scenario. In Africa, even if not quantified, the demand for cement for the construction of the power plants could also represent a major challenge. In regards to the continent's urbanization growth rate (the highest in the world) and the growing population, this ratio should not be neglected. The African cement industry is expanding rapidly, especially in countries such as Ethiopia, Nigeria, and Tanzania³⁹. Nevertheless, with the presence of one predominant actor on the market (Dangote which represents more than 35% of the continent cement capacities, about 45Mt) in addition to the capital intensity of the cement industry (usually above \$175M per million tonnes of annual capacity, equivalent to around 3 years of turnover⁴⁰), as well as the transport cost and the high energy intensity of the process, the important development of this industry will remain challenging in the future to meet the cement demand both in the sector power and the buildings sector for the African continent.

For Africa, as well as for India, another issue for the cement industry is related to "power availability" that includes cut in the electricity, shortage of coal, inadequate availability of wagons for transport, limited availability of furnace oil, etc. In India, about 65% of the electrical energy requirements for cement manufacture in the country are met through

³⁸ <https://www.reuters.com/article/us-china-commodities-cement/china-prohibits-glass-cement-capacity-expansion-in-2018-idUSKBN1FW066>

³⁹ <https://www.bloomberg.com/professional/blog/africas-cement-industry-is-expanding-fast/>

⁴⁰ The European Cement Association – Key Facts & Figures

coal power plants (predominantly coal-fired) installed at cement manufacturing facilities (installed to reduce cost of energy and to ensure steady power availability). The Indian cement industry has nearly 4,000 MW of installed captive (i.e. dedicated to the cement plant) power capacity, including coal-based plants, but also diesel generating sets and wind turbines to overcome rising power costs and uncertainty over supply. Captive power plants will continue to grow as long as steady and continuous grid power is not available at a competitive cost. However, it represents an additional cost for new cement plant projects. In addition, those countries often have cement plants with high CO₂ intensity compared with others countries. In India, the overall CO₂ emission is 866 kg/ton of clinker produced. The IEA have estimated that the additional investment required to reduce growth in CO₂ emissions of the Indian cement industry by 2050 is between \$US 34 to \$ 100 billion, or 20% to 30% higher than in a business-as-usual scenario (IEA, 2013).

V. CONCLUDING REMARKS

In this article, the future concrete and cement demand has been quantified. By studying different energy transition scenarios, as well as the cement manufacturing process and power plants' concrete needs, we show that the cumulative cement demand for the power generation sector over the 2014-2050 period will not exceed 1.3 Gt. At the global scale we observe an increase in cement demand from the electricity sector in response to the energy transition (+19 or 28% for 2DS and B2DS compared to the RTS scenario). Nevertheless even in the most stringent scenario (B2DS) the cumulative cement volume required from 2014 to 2050 is only about 32% of the 2017 global cement production. As the power sector related demand will most likely not exceed a few percent of the total demand for cement, it appears that the power sector will not substantially contribute to a material shortage in cement or specific environmental externalities.

At the local level, a high cement consumption is observed for developing countries, whose electrification of the economy will increase in the coming decades and so lead to a high growth rate of the total electricity consumption (such as in India). If the cement consumption is of course directly related to the number of new installed capacities, it is

mostly a consequence of the future electrical mix. At the global level, it can be observed that the cement intensity of power generation technologies by 2050 remains stable, while it is significantly higher in some regions or countries (such as Russia, ASEAN countries or Brazil). Cement is in some cases an important material for the energy transition in the electricity sector (especially where are developed hydro, wind or nuclear power plants) while it is used more rarely in other mixes (solar-based mix). As cement production is highly CO₂-emitting and difficult to relocate, it is necessary for national policies to implement means of mitigating GHG emissions in a systemic way across all sectors of the economy (industrial, electricity, etc.) so that their global climate policy would be consistent with ambitious reduction targets. Finally, we have also found that while the volume of cement required at the global level for the electricity sector is negligible in regards to global cement production, it can represent a significant part of local production (especially in developing areas such as Africa, India, Brazil or Russia, but also in the US). This latter result demonstrates the importance of forecasting how energy transition can increase the risk of material production bottleneck, even for material such as cement that are not considered to be critical.

In the future, sensitivity analyses could be conducted, such as investigating through our model the impact of a reduction in CO₂ emission from the production process, especially at the regional level to check the adequacy with local climate policies in terms of GHG emissions (especially with Nationally Determined Contributions). Other perspectives of our outcomes could be then the analyses of crediting mechanisms in developing or developed countries such as Clean Development Mechanism (CDM) or Joint Implementation (JI) to encourage investments in emissions reductions where they are least expensive. In other words, the outcomes of our model could be useful for policy makers to transform current concepts of sectorial agreements into effective international policy instruments that will promote the rapid and cost-effective deployment of best available technologies (BATs) and innovation. More extensively, an analysis of a global carbon tax could make it possible to assess the potential competitiveness in different regions of the world according to IEA scenarios and thus, to encourage as well trade in order to pool emission mitigation efforts.

Finally energy transition could certainly lead to great impact on some other materials demand as Renewable Energy Technologies (RETs) and fossil-based technologies in power sector require large amount of minerals. The analyses of other raw materials demand according to the future uncertainty of the power sector development within IEA scenarios could also be an asset for further researches. ■

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THE IMPACT OF FUTURE GENERATION ON CEMENT DEMAND: An Assessment based on Climate Scenarios

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This article is part of the GENERATE (Renewable Energies Geopolitics and Future Studies on Energy Transition) Project.

GENERATE (Renewable Energies Geopolitics and Future Studies on Energy Transition) is a two years research project (2018-2020) on the Geopolitics of Renewable Energy, on behalf of the French National Research Agency, in a consortium with IFP Energies Nouvelles. The purpose of the project GENERATE is to analyse the geopolitical consequences of a spread of renewable energies worldwide. This project will focus particularly on three major issues, namely (1) the criticality of energy transition materials for energy technologies (electric vehicle, solar panel, wind turbine, etc.). (2) the new geography of patents for the renewable energy technologies and (3) the oil producing countries development model, and their places on the international energy scene.

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