Economic Brief

*"Even a single step makes a difference. And one after the other they become stamina.
Even a single word becomes stamina. When you repeat it again"* [1]

What if *technology was not the only way to implement green transition and, actually, elevating wisdom to collective standard could be more powerful?*

What if *renewable energy generation also had a 'dark side' calling for careful consideration and compensations, in order to avoid making the same mistake done with nuclear and fossil in the past?*

What if *green transition was, in the end a story of mismatches? Between demand and supply of materials, among competing uses of soil and water, between continuous demand and intermittent generation, between information needed to take wise decisions and (much more limited) information sometimes accurately distilled, between time horizons relevant for different actors (investors, industry, local communities and policymakers) and so on?*

1. Introduction

One aspect we have not tackled in our previous edition (Issue #30) on the green transition concerns **'green bottlenecks'**, namely "*the fact that wind farms, solar farms and battery-powered vehicles are now cost-competitive does not mean they can be built at whatever pace politicians choose. They require raw materials —sometimes […] in prodigious amounts— siting permits, infrastructure for transmission, recharging and the like. They also need lots of capital. And the necessary materials, sites and capital are all, to various extents in different places, in short supply*".[2] And all this comes before considering that they require available labour with matching skills, as well as social acceptability with regard to locational choices.

Raw materials - There are signals of supply-side pressures in relation to raw materials, in particular scarcity of some metals such as those needed for electric vehicles or balsa wood used in the production of wind-turbine blades. Scarcity has in most cases an impact on prices of those materials. Beyond materials, also land constraints (namely for the siting of equipment for renewable energy generation) threatens to slow down the green transition.

But also land and water - Shortages may also arise in relation to land and water, also for legitimate regulatory reasons. Wind turbines and solar panels require land and may generate collateral damages (read 'negative externalities'), for instance in terms of pauperising fertile soil (in the case of solar farms), or disrupting living wildlife environment (in the case of wind turbines). This clearly calls for discernment driving location choices, let alone possible and fully understandable regulatory limitations in the choice of such locations, towards e.g. well exposed but poorly fertile (or even rocky) land for solar panels, or locations far away from wildlife sanctuaries for wind turbines. Water also brings a high potential for conflict, namely when considering competing alternative utilisations. On one side, for instance, mining of raw materials crucial for the green transition (such as lithium or rare earth metals) or hydrogen electrolysis, both requiring massive amounts of water. On the other side, local communities for which water is essential, a particularly sensitive issue in regions where water

[1] Translation from the song "Resistenza" (stamina).
[2] See The Economist.

already tends to be scarce. Still, these adverse environmental impacts, once put in a **life-cycle perspective** may fade in comparison to the historical and still persisting impact of fossil fuels (for some aspects on a par with nuclear). Section 3 will develop these points.

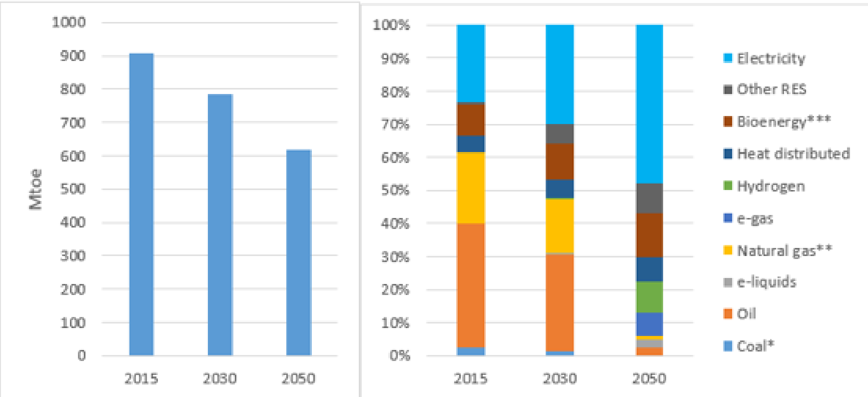
And capital - Another possible bottleneck for the green transition concerns capital. "*Renewable projects have low operating costs (the sun and wind are free) but require a lot of capital upfront. And in many emerging markets capital is expensive. The average cost of capital for a wind project in Indonesia is about four times that of one in Germany*".[3] This may be part of the explanation (on top of different environmental sensibility) for the existence of different (and sometimes very different) levels of stringency in environmental regulatory standards in different parts of the world (see Section 2).

Shortages and supply-side pressure call for careful consideration in view of possible drawbacks and for preparing in advance to undertake mitigating efforts. For instance, it is clear that the network of cross-border supply chains remains skewed towards a few rich countries (plus China). In order to address underinvestment in other parts of the world, "*western governments also have a duty to provide cheap financing to lift investment in poorer countries*". Nonetheless, shortages and supply-side pressure also witness the fact that decarbonisation is at last shifting from theory to reality, even if the energy transition has barely begun, as investment already undertaken "*is less than 10% complete (measured by the share of cumulative energy-investment needed by 2050 that has already taken place)*". However, "*a powerful push is now needed to help make the revolution happen [as]* ***today only 22% of the world's greenhouse-gas emissions are covered by pricing schemes, and those schemes are not joined up****.* ***Green bottlenecks are a sign that decarbonisation is at last shifting from being a theoretical idea to a reality***" [emphasis added].[4]

2. Graph(s) of the week

Green transition is ongoing. This is a fact! - Related EU objectives in terms of Green-House Gases (GHG) abatement (55% by 2030 and overall climate neutrality by 2050) have implications on both energy demand and supply sides. **Concerning energy demand, industry is an important component, but not the only one**. Other sectors must contribute as well, namely transport, residential and agriculture. Concerning **energy supply side**, there is a need for a massive shift from fossil sources towards decarbonised electricity, bioenergy and other energy carriers (e-fuels and hydrogen), all are generated from electricity.

Figure 1 – Final energy demand by energy carrier (total and composition)



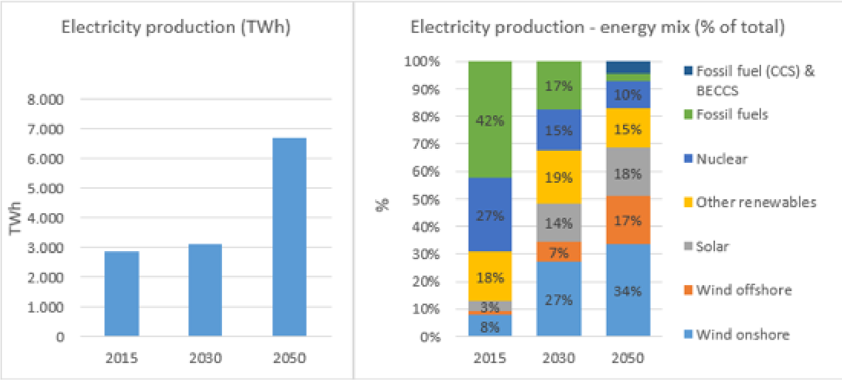
Source: SWD(2020) 176. Results for the "MIX" scenario therein.
Notes: (*) Includes peat, shale oil (**) Includes manufactured gases (***) Solid biomass, biogas, liquid biofuels, waste.

Figure 1 shows that the share of electricity within total energy demand is expected to increase substantially (right pane, blue segment).[5] The very significant expected increase in the demand for electricity by 2050 (see Figure 2, left pane), in connection with the decarbonisation ambitions, has obvious

[3] See The Economist.
[4] See The Economist.
[5] Both Figures 1 and 2 are based on the Impact Assessment accompanying the 2030 Climate Target Plan (SWD(2020) 176). The Impact Assessment supporting the July 2021 package (SWD(2021) 611) provides an updated analysis, but the substance does not change in terms of an energy mix shifting towards renewables and of a decrease of overall energy demand (but increase of the share of electricity therein).

implications in terms of the breakdown of electricity generation at the 2050 horizon (see Figure 2, right pane).

Figure 2 – Projected electricity production



Source: SWD(2020) 176. Results for the "MIX" scenario therein.
Note: "Other renewables" mainly includes hydroelectric power and electricity generation from biomass.

The transition will inevitably rely on specific equipment for generation and storage of renewable electricity. All this equipment implies energy consumption upstream (for the extraction of raw materials and all along the respective supply chains)[6] with a significant potential for strategic dependencies. However, **materials and related possible dependencies are only one element** in building scenarios for the estimation of generation capacity. Among them, availability of suitable areas (also considering alternative land use and possible restrictions), raw generation potentials (e.g. wind speeds, solar irradiation) and the range of available technologies.[7]

Renewables alone are not 'the' solution but only part of it - There are two important issues to address, in relation to renewables: (i) the gap between total energy demand and supply of renewable energy and (ii) the intermittent character inherent to energy sources like wind and solar. On (i), natural gas may play a role as a transitional energy source, but should not become an excuse to slow down the pace of transition or for forgetting to redirect sufficient energy resources towards the production of equipment needed for ramping up renewable energy generation. Both (i) and (ii) are also often invoked to make the case for ramping up nuclear power generation. On top of all this, **energy generation is not the end of the story and energy savings are at least as important**.

The elephant in the room – Nuclear generation has merits comparable to those of wind and solar in terms of marginal cost but without the drawback of discontinuities in generation. These are major arguments of supporters of its inclusion in the 'EU Taxonomy' as a sustainable source of decarbonised electricity. Despite these merits, there may well be important flaws in various other respects. Therefore, it would be indispensable to seriously consider (contrary to the past) all upfront investments (especially when taxpayers' money is involved, as often the case in the past) and negative externalities (both in terms of risks of running nuclear power plants and in terms of disposal of radioactive material of any sort). The good news could be that the range of technologies is evolving also for nuclear generation. The 'closed fuel loop' characterising 4th generation nuclear power plants, allowing to generate less radioactive waste, could be part of the reply to concerns related to negative externalities. However, most of the issues raised in relation to nuclear power plants remain only very partially addressed in practice (with nuclear waste that keeps on being dumped in relatively unpopulated areas of the planet). Small Modular Reactors (SMR), still in development and expected to be commercialised within the next decade, may also address some of the shortcomings relating to the large-scale nuclear power plants, namely in terms of nuclear safety and cost issues, opening up new applications in hard-to-abate industrial sectors or provide off-grid alternatives at mining sites. Still, **nuclear generation (and the same goes for natural gas), despite possible merits in supporting the transition process, remains hard to define as a sustainable source of 'green**

[6] In terms of energy consumption upstream, take the example of batteries. One TWh of battery capacity requires 50-65 TWh of electricity only for production, not including other steps of the supply chain, such as mining and processing of materials. With battery manufacturing capacity expected to reach 0.4-0.6 TWh by 2030, this would lead to 20-39 TWh of electricity demand for battery manufacturing alone.

[7] A forthcoming paper by Riera, Casini and Aparisi will discuss this at length. It will appear in the discussion paper series of GROW Chief Economist Team.

energy', when one considers that "*the principle of green energy is that it does not need fuel and does not produce waste*".[8]

A recent McKinsey article argues that, overall, "*there is no set, predefined solution to the net-zero equations. […] there are dozens of critical questions that need to be addressed and hundreds of solution elements to be considered and combined together. The solution process can, therefore, only be iterative and proceed in parallel with a better understanding of the equations, their constraints, and the means to removing these constraints. It is not hard to imagine that the solution process would be fraught with challenges and setbacks. […] While humanity may be facing the most existential challenge in its history, the path is no different than in the previous ones: **probing inquiry, followed by collective will and determined action***".

Matching generation with usage: storage and (smart interconnected) grids – One important element of complexity resides in the intrinsic discontinuity of renewable (wind and solar) energy supply, which calls for storage facilities (from rechargeable batteries to hydroelectric dams and conversion to/from hydrogen[9]) allowing to buffer electricity production and consumption. Storage does no longer represent just one option to improve the overall economics of the system (as in the case of fossil-based systems) but it has become a functional necessity. **Neglecting its importance would make of storage yet another bottleneck impacting the projected increase of renewable electricity generation in Europe**.

Storage capacity is not only a matter of buffering discontinuous renewable supply, but also a matter of efficiently addressing temporary shortages of renewable energy with surpluses eventually existing elsewhere. Indeed, a typical feature of renewable resources is that conditions are often more favourable to energy generation in regions with a low concentration of industrial facilities (i.e. where that energy is less needed). Therefore, linking efficiently energy carriers with consumption (especially industrial) through adequate infrastructure for storage and transport of electricity and hydrogen within and between regions is clearly paramount. More generally, **storage infrastructure, together with modern, secure, smart and interconnected energy network guaranteeing a seamless distribution is crucial for the security of energy supply at EU level**.

In this context, the **cross-border dimension** is extremely important and a **coordinated action at EU level** is indispensable in order to efficiently match resources and needs within the Single Market, at an affordable price.[10]

The pace of green transition - Transport and residential sector on one side and industry on the other side represent different challenges, in terms of needs of (and readiness to the use of) decarbonised electricity and of investment cycles. In all these sectors, electrification will be driven by demand growth. The electrification of the **transport** sector is **expected to be quite fast**, with the share of zero-emission or plug-in hybrid electric vehicles (EV) reaching 30% to 50% of the total vehicle stock by 2030. Similarly, concerning **residential** consumption (lighting, heating, cooling, hot water), 10% to 35% of all fossil heating is expected to be replaced by heat pumps and district heating, also by 2030. By contrast, the electrification of **industry** is **expected to follow a slow pace up to 2030**, mostly due to the long investment cycles of many energy intensive industries (EII) and low cost-

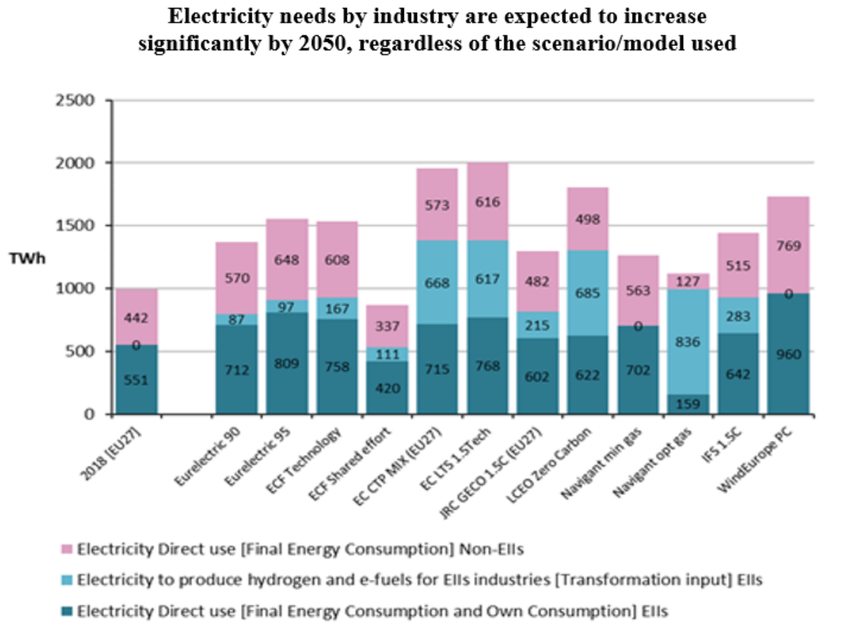
[8] Commissioner Frans Timmermans in a recent interview with L'Echo.

[9] Energy storage technologies differ in terms of character of storage they allow. Namely, batteries have fast reaction times and are easy to install but generally not economical for long-term storage. Moreover, the cost of storage tends to decrease with technological advances e.g. in terms of battery chemistries better adapted to seasonality and scale needs. In many respects, storage through conversion to/from hydrogen tends to be preferable in terms of cost, scaling and mobility, in particular as far as existing gas and oil storage systems can be adapted to use with hydrogen, thereby drastically decreasing investment in new infrastructure and cost of decommissioning old infrastructure.

[10] Equally essential in accommodating the existing geography of industry (and related energy demand) with energy generation is an adequate mapping of energy, industrial and other relevant infrastructure (e.g. roads, ports). This is the objective of the Energy and Industry Geography Lab [EIGL] recently launched and resulting from a joint effort by JRC and GROW.

efficiency (or even readiness) of breakthrough technologies.[11] In this decade, decarbonisation of industry will mostly consist of an increasing share of decarbonised electricity consumed in already electrified sectors. The transition pace for industry is **expected to accelerate after 2030 but, for that to happen, heavy investment is needed already now** to finance the groundwork towards a decarbonised industrial activity. By 2050, electricity needs for the industry are projected to increase significantly, including the electricity used to produce hydrogen and e-fuels used by the industry (see Figure 3).[12]

Figure 3 – Electricity use in industry: 2018 and 2050 (projections under different scenarios)



Source: Based on JRC (2020) "Towards net-zero emissions in the EU energy system by 2050 – Insights from scenarios in line with the 2030 and 2050 ambitions of the European Green Deal".

An investment gap – Investment is needed on different fronts: renewable energy sources, energy storage, grids and industrial transformation. The pace of investment is currently too slow to meet announced objectives. In the EU, the gap between planned and required installation of renewable capacity is equivalent to 28 TWh of electricity generation per year.[13] Similarly, also for the EU, the investment gap in renewables is estimated to be 33 billion EUR a year up to 2050.[14] Private investment is still insufficient (despite efforts to catalyse it also via a variety of financial programmes at EU level) and this is not the only limiting factor in upscaling renewables uptake. Other factors are gaps in an adequate planning and deployment of electricity infrastructures, in the availability of sites and related permits[15] and in the availability of adequately skilled workers (at least at the locations where they are in demand).

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[11] SWD(2020) 176 (MIX scenario therein) and JRC (2020).

[12] Available estimates on electricity use in industry by 2050 differ significantly, reflecting different modelling assumptions and scenarios.

[13] This gap derives from comparing planned new wind and solar generation capacity installation (resulting from national energy and climate plans), which only adds up to 72 TWh/year, and required new capacity estimated by Agora Energiewende and EMBER (2021) to be 100 TWh/year in 2021-2030 (up from 38 TWh per year average growth in 2010-2020). To put the figure of 28 TWh/year gap in context, Scotland with a population a little over 5 million requires 25 TWh of electricity each year.

[14] IRENA (2020) evaluates to only 32 billion EUR the annual investments currently planned up to 2050, while annual investments should amount to 65 billion EUR to meet 2050 climate targets.

[15] Permit procedures, specific to each Member State, are often perceived as one of the biggest obstacles to the growth potential for renewable energy, as they are lengthy and complex (particularly the ones also involving environmental impact assessments). For sure there is an element of administrative sluggishness, which could be addressed for instance with the ongoing digitalisation of public administration. Still, permit procedures also have a reason to exist, for instance in order to allow a fair use of common goods like land and environment, arbitraging between competing needs (such as using fertile land for agriculture or for a solar farm that could be installed in different locations less suitable for agriculture).

The point is that for most of those investments, there is currently an insufficiently strong business case.[16] Investment by industry (especially EIIs like steel, cement and chemicals) is indispensable, and incentives to invest depend not only from cost considerations (eventually influenced by, and not limited to carbon pricing or taxation) but also from confidence that enough affordable (read, high volumes of competitively priced) low-carbon electricity will be available to match the increased demand from low-carbon production processes. EIIs are at the origin of many strategic value chains and produce goods that enable reducing emissions in other sectors of the economy, including (sustainable) transport, (sustainable) construction and (renewable) power generation (think of e.g. wind turbines and wings). Carbon emission cuts of 80-95% by 2050 are considered as possible for EIIs, under the right conditions,[17] through new technological pathways, most of which depend on (direct or indirect) electrification.

Is the gap only a matter of investors' mindset? - In order to spur investments in decarbonisation, a deep change in the values guiding investment decision-making would be necessary. This would involve a systemic change, such that private investment decisions are guided not only by market price signals, short-termism, and financial returns, but also by long-termism and the delivery of societal benefits that do not readily lend themselves to monetization (e.g. climate stability, ecological and social wellbeing). It involves companies taking on a greater responsibility for the delivery of wider societal benefits, which in turn, through demand side effects could enhance their reputation, credibility, market position and –ultimately– the robustness and sustainability of their economic affairs, i.e. their business case.

The fossil-fuel path dependency in which industry continues to be deeply embedded can be unlocked by enabling a shift in long-term visions related to sustainability across market players, though concerted effort and support from public policy is needed in order for this to occur. A shift in industrial production processes that would embrace low-carbon breakthrough technologies, infrastructural change, and product innovation does come at increased production costs. However, it is estimated that such increases in production costs of basic commodities (e.g. cement) delivered by hard-to-abate sectors represent a very small share of the overall selling price at the end of the value chain (e.g. residential building).[18] Furthermore, research suggests that it is technically and economically feasible to decarbonize industry within the longer term of the Paris agreement of achieving net zero GHG emissions by 2050.[19]

And public policy in all this? - Public policy has a role to play in changing the rules of the game and the ethical stances of businesses. The EU taxonomy is a good example in point. It provides a common framework for sustainability investments (a green classification system) translating EU's climate and environmental objectives (whilst meeting minimum social safeguards) into criteria for investment in specific economic activities. Although private and public investors are free to decide what to invest in, the EU taxonomy aims at acting, over time, as a catalyst for a change in the attitude of market participants towards sustainability values. Ultimately, a systemic profound change towards sustainability depends on reaching a tipping point whereby both private and public players view the

[16] See McKinsey (2020). The study argues that assuming current costs and incentives, as much as 95% of capital expenditures in industry lack a positive business case. Namely, they would still entail positive operating expenditures (instead of savings) on top of required capital investments.

[17] The Industrial Emissions Directive and its Best Available Techniques (BAT) reference documents (the so-called BREFs) set the mandatory environmental standards that EIIs have to meet. Recently, there has been a breakthrough in the stakeholder discussions for revising the environmental standards applicable to the Ferrous Metals Processing industry with the use of electricity from carbon-free energy sources qualified as BAT for the sector. It is likely that this will influence the upcoming review on the environmental standards for the other EII sectors.

[18] For instance, Rootzén-Johnsson (2016) show that the increase in total production costs due to deep reductions in CO_2 emissions from the cement industry will result in an increase in the end-use price (residential building) limited to 1%.

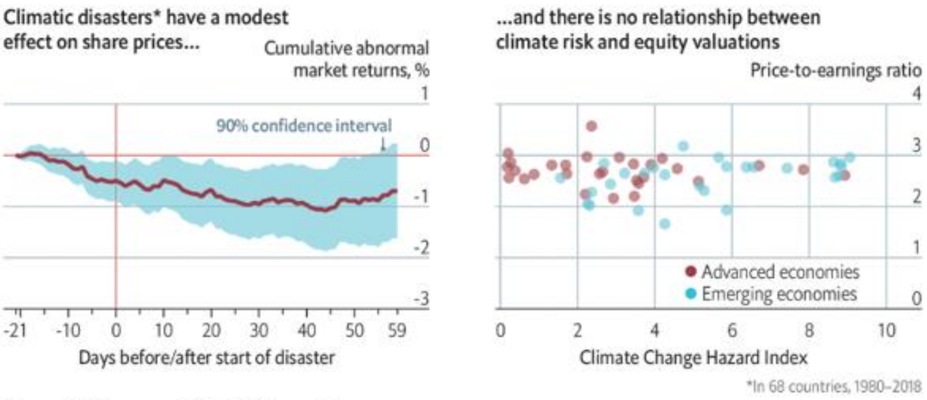
[19] See, for instance, Material Economics (2019).

risk of continuing on the current path of using fossil fuels as greater than the risk of innovation and investment in low-carbon, environmentally sustainable pathways.[20]

The role of finance – Green bonds and green finance are certainly important to support transition. This calls for an adequate rating system at firm level[21] but also, and perhaps more importantly, for a shift in the logic underlying investment decisions. No longer focusing on outperforming returns (even partially informed along ESG rating principles[22]) but at least in part as a matter of principle. Adequate incentive structures can of course support those principles and contribute to steer the interest of investors towards sustainable investing.

Based on IMF research,[23] investors appear not to price in climate-change risk (see Figure 4). Lack of data may be one obvious reason, as even if an increasing number of companies are **disclosing climate risk information**, many more do not.[24] Another reason is a **mismatch of time horizons** between how long investors keep stakes in companies' physical assets (hardly 20 years and often much less) and when the most devastating effects of climate change will materialise (30 years or so). It is possible, but hard to believe, that investors are simply ignoring climate change, at least on the basis of the fact (also in the IMF report) that investors in long-term sovereign bonds demand a premium from countries with high climate risk. It may be only a matter of time before equity investors do the same.

Figure 4 – Climatic disasters and share prices



Source: IMF, as reported by The Economist

In the end, **finance cannot be seen as a driver of climate action, but more likely as its enabler**.

[20] As also iterated by experts in the field, such as in Max Åhman's expert perspective on unlocking the 'hard-to-abate' sectors, published by the World Resources Institute. As stated in COM(2021) 952, "*While the private sector itself will have to take the main responsibility for investment, the role of the EU is to put the right regulatory and financial framework conditions in place. This includes stimulating demand through a number of measures included in the Fit-for-55 legislative package. In addition, the Recovery and Resilience Fund, InvestEU, and the new generation of EU programmes under the 2021-2027 EU budget offer a strong stimulus for addressing some of the challenges, by increasing available scale up capital, removing market barriers, and driving policy reforms*".

[21] See Ehlers et al (2020) (short and long version).

[22] ESG stand for Environmental, Social and Governance. This has virtually become the standard rating for ethical finance but, according to some critics, it represents a flawed metric, somehow feeding a sort of outperformance mirage. On this point, see e.g. Financial Times - ETF Hub. A couple of opinions follow, cherry-picked from the article. "*Most ESG investing is a ruse to launder reputations, maximise fees and assuage guilt […] ESG outperformance disappears when adjusted for risk, sector bias and quality factors*" (Sony Kapoor, managing director of the Nordic Institute for Finance, Technology and Sustainability). "*If people "want to invest [in ESG] purely because it will drive performance then I think it is bad news. If they want to outperform they should target factors that achieve that goal. If they are open to non-financial reasons then they should go ahead*" (Vitali Kalesnik, director of research in Europe at Research Affiliates).

[23] As reported in The Economist.

[24] For more on this, one of next editions will cover corporate purpose and due diligence.

3. Must read of the week

A recent McKinsey article argues that the deployment of technology and maintenance (or creation) of supply chains and support infrastructure (often on a massive scale) is possible only if sufficient natural resources are available. As already also mentioned in the Section 1, three types of natural resources will be especially critical: raw materials, land and water.

Raw materials are not just a matter of those used in large quantities today (such as copper and nickel) but also of those that are still considered relatively niche (such as lithium, cobalt, and rare-earth metals) and that will inevitably see a substantial increase in use as a result of the green transition. Scaling up production will almost inevitably make constraints in provisioning (and related capacity) more binding and lead to temporary shortages and price increases.

Land is crucial to building out renewables' capacity. "*Compared with fossil fuels, renewables require more area per unit of energy output. Replacing a typical gas plant of approximately 1 gigawatt with solar power generating the same amount of electricity, for example, would raise total land use from about 350 acres to approximately 40,000 acres. Even counting the land associated with the entire fossil-power value chain—for example, extraction, transportation, and storage of fossil fuels—total land use would still increase by a factor of five to ten. Land is also crucial for carbon stores and sinks such as forests, peatlands, and mangroves. On the other hand, forest land can contribute to emissions if not well managed, for example, through deforestation or forest fires. This suggests that preserving and regenerating natural capital will need to go hand-in-hand with the technological solutions described above. Importantly, natural, high-quality sinks are largely concentrated in a few geographies, and land often has competing uses, including food production and housing development. Its proper management would therefore require careful planning*".

Researchers at Princeton University[25] estimate the land needed for solar and wind farms by 2030 in the US (on the pathway for reaching net-zero emissions by 2050) to be about 160,000 km^2. This is less than 2% of the overall surface of the United States, but this apparently small figure is actually the size of an entire state like Illinois and it implies a huge increase of the current installations. This reasoning obviously applies also for Europe and reasons for concern may amplify when considering the possible competition for fertile land between solar/wind farms and 'real' farming activities.[26] Logic would say that energy farms should target land not suitable for farming, but logic may end up hitting against higher installation costs and other plain business considerations. Moreover, installing solar and wind farms is not the end of the story. Disagreement may also arise concerning the siting of transmission lines from those solar and wind farms. The common denominator is that we are talking about public utilities benefiting the whole society, but for which a part of the population ends up bearing disproportionately high negative externalities without clear (or sufficient) compensatory measures.

Last but certainly not least, **water**. "*Building an economy that is fuelled in part by hydrogen will require large amounts of water. Water will also be crucial for extracting key minerals. The reliance on water would thus only increase under a net-zero transition, all while water is likely to be in shorter supply, both from increased demand for other uses and, in some geographies, from the reduced precipitation resulting from a changing climate*". Pushing this a bit further, one could even remind what Ismail Serageldin, vice-president of the World Bank, stated in 2009: "*The wars of the 21st century will be about water, unless we change the way we manage water*".[27]

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[25] As reported by The Economist.

[26] An example of this is a recent article in the Italian press reporting on Sicily possibly becoming an immense photovoltaic 'mirror' despite skyrocketing prices of land and opposition by farmers.

[27] Credit to the Financial Times for the citation. On a slightly different note, a recent book "*Water: A biography*" (see here for a presentation of the book by the author, Giorgio Boccaletti) elaborates on how far water is actually the most elemental substance on Earth and why a proper understanding of our relationship to—and fundamental reliance on— it is paramount.

Water is also extremely important in relation to electrolysis. On this, figures diverge a bit according to sources. Hydrogen Europe website advances figures that are quite reassuring. Namely, that the fresh water needed annually to support the 2030 hydrogen strategy would be slightly less than 0.5% of all annual freshwater resources of the EU, and less than 3% of all annual precipitation (i.e. rainfall) in the EU27. On top of that, the same source refers to the possibility to set up desalination plants at the electrolyser site in order make electrolysis no longer compete for fresh water with human consumption and/or irrigation. The additional cost of setting up desalination facilities may even be justified by the fact that they may even produce a surplus of desalinated water, with respect to the needs of the electrolysis site, which would end up benefiting human consumption and/or irrigation in the local area. Oilprice.com, unsurprisingly, is much less reassuring, highlighting that the water needed to produce green hydrogen is not just a matter of feeding the electrolyser, but also of other steps needed to provide water of adequate quality (i.e. purification of water) boosting water needs up to a "*ratio [that] is close to 20 tons of water for every 1 ton of hydrogen*", making "*the cost of water supply, storage, and purification […] not viable - not without significant government support*".

Potential dependencies – Having said about the importance of land and water, let's come back to raw materials, in order to dig deeper into implications in terms of dependencies. It is clear that projections in terms of requirements of critical raw materials to support massive installation of renewable energy equipment (like battery and energy storage, as well as wind turbines and solar panels) show a high potential for dependencies and shortages, especially if provisioning remains limited to mining activities (for the extraction of 'primary' raw materials) without designing processes with a sufficient degree of circularity. Namely by activating recycling activities complementary to mainstream production and allowing to maximise the use of "secondary" raw materials in place of 'primary' ones, thereby reducing the need for extraction (limiting, in passing, also related negative externalities / nuisances).

Take lithium used for batteries (with EU demand expected to increase 1500% by 2030 and 4500% by 2050), or graphite, cobalt and nickel projected to multiply as well, or again various raw materials used for photovoltaic applications and wind turbines (with EU demand expected to increase 100% - 200% by 2030 and up to 800% by 2050).[28] And this is not all, as we also need to consider demand by other global players (namely the US and China) that have also set plans for decarbonisation.[29] What is clear is that pressure on the supply of raw materials and related potential for dependencies and shortages, could slow down the green transition at a global level.

One specific problem for the EU (that other global players like China would not have) is that, overall, its total production of these materials is only 1% of needs.[30] This is not necessarily due to those raw

[28] The Staff Working Document on EU strategic dependencies and capacities [SWD(2021) 352], which is part of the updated EU industrial strategy, conducts a mapping exercise based on trade flows of around 5,000 products, with the objective of identifying goods where the EU is heavily dependent on foreign sources in strategic ecosystems. The mapping is based on three characteristics characterising dependence: (i) limited number of sources (read, concentration of foreign suppliers), (ii) proportion of extra-EU imports on total imports and (iii) possibility of substitution with internal EU production. The resulting list of strategic dependencies includes raw materials that are used in the deployment of green energy technologies.

[29] On how important this would be for having a chance of success is clearly shown in a very telling animation showing the evolution in carbon emissions at country level and the progressive exhaustion of the '1.5 degree budget'. A major point, discussed in a recent Carbon Brief, is some the ethical calculus related to climate action. This depends on some 'historical climate debt' of richer countries (with a more accomplished economic development) towards many lower-income countries (whose development still largely depend on richer countries). Incidentally, the former are historically responsible for climate change and the most successful among the latter (namely China and India) are major newcomers in the 'carbon race', further complicating the ethical calculus. David Leonhardt put it in The New York Times "*Leaders in China and India argue that when the U.S. and other countries were emerging from poverty in the past, they didn't have to worry about what kind of energy sources they were using*". But "*If China cares as little about the planet as England did during the Industrial Revolution, everybody will suffer*".

[30] European Commission (2020), Critical materials for strategic technologies and sectors in the EU - a foresight study.

materials not being available in the EU, but in some cases to externalities related to their extraction (for instance for neighbouring communities that would end up paying a disproportionate share of the cost of extraction) or to higher standards (i.e. extraction processes not compatible with EU social and environmental standards). Circularity (and related availability of "secondary" raw materials) could be a solution. However, its cost needs to remain aligned with alternatives, either by improving recycling technologies and logistics or by factoring in (and translate in monetary terms) the lower standards of production of imported raw materials (with due care to avoid conflicts related to WTO rules).

Focusing on the four technologies mentioned above (wind turbines, solar photovoltaic (PV), fuel cells and advanced (i.e. Li-ion) batteries) a number of dependencies can be identified. In terms of raw materials, for wind turbines it is possible to identify dependencies for aluminium (various products based on it), chromium, copper, iron, manganese, molybdenum, nickel and different types of permanent magnets (such as boron and some rare earths like neodymium and dysprosium). For solar PV: cadmium, copper, silicon, aluminium and silver. All this considering mature technology based on silicon-based wafers, rather than emerging 'thin-film' PV technologies that would provide much more efficient solutions in terms of light absorption efficiency. For fuel cells (needed to convert hydrogen directly to electricity without combustion): aluminium (again), titanium, vanadium, zirconium, magnesium, manganese, molybdenum, nickel and mica. Fuel cell technology is quite mature, but some challenges remain only partially addressed, such as the one related to the size for use in private cars (less of a constraint in public transportation, trucks, not to talk of maritime transportation, as discussed in EB#10) or large scale deployment in domestic and industrial segments, still limited for a number of reasons including but not limited to technical ones. For Li-ion batteries: aluminium (again), fluorspar, copper, lithium, nickel, manganese niobium, phosphorus and silicon.

In the end, out of the 137 products identified in SWD (2021) 352 as source of strategic dependencies, there are indications that around 1 out of 5 are linked to green energy technologies, with few additional products indirectly linked through the supply chain. On top of dependencies related to raw materials, additional bottlenecks may arise concerning intermediate products (as in the case of the middle-upstream parts of the solar PV value chain, i.e. module manufacturing) and/or specific technologies. On technological dependencies, there is an ongoing effort to extend the Advanced Technologies for Industry project (ATI), conducted in GROW for digital and manufacturing technologies, to identify green/clean technology dependencies also benefiting of indications from the Annual report on the competitiveness of clean energy technologies (2nd edition recently published).

Beyond shortages: life-cycle perspective – When considered over the whole life cycle, the picture about alternative energy generation solutions inevitably acquires an additional layer of complexity, even more so when we do not limit ourselves to renewables like wind and solar generation, or green hydrogen. This is because we are looking at input of materials (including structural bulk materials, such as cement, iron, etc. needed to build hydropower dams or offshore wind parks, or copper needed for cabling and connection to grid) as well as land occupation and water consumption (i) **all along the supply chain**, from mining of raw materials, through growing feedstock for biomass and cooling of nuclear plants, to pollution and eco-toxicity related to chemical releases (e.g. heavy metals, volatile organic compounds, particles), and (ii) **during the whole lifecycle**, again from mining of raw materials to electricity generation and distribution. A condensed survey is provided in Annex.

4. Op-ed

The green transition is not just a matter of political will or intellectual enlightenment (eventually fed by survival instinct of the human race). Actually, it goes well beyond that in view of the complex interactions among trading partners at global level, of multifaceted incentives and constraints at different levels of societies plagued by significant (and often increasing) inequalities and, last but not least, of multiple market failures. The green transition is at least as much a matter of adequate communication as a matter of capillarity in consistently spreading signals in all interstices of our economies and communities. Also for this reason, measures such as carbon pricing would be part of the solution and should not fall apart because of geopolitical frictions or rivalries. "*The key is the introduction of carbon prices which embed market signals into millions of everyday commercial decisions and give entrepreneurs and investors more visibility over a long-term horizon*". More generally, we are in "*a new phase in the green revolution. The engineering which allows the spinning* *blades of a single wind turbine to power a thousand homes, or uses lithium from desiccated lake beds to store power from sunlight in the floor of a sedan, is remarkable. But it has to be fed the materials it needs, found places to stand, integrated into the rest of the world's infrastructure and paid for. Innovation and investment in mining, pressure on the politics of land use and new catalysts for private investment, especially in emerging markets, are less iconic. But they are no less necessary*".[31]

And then there is COP26 … - The recent climate summit in Glasgow made the headlines (and rightly so). It is not reading and multimedia material that is missing, from debates during the event and reports one can read in the news. The overall impression (re-joining in this Kenneth Rogoff's column on Project Syndicate) is that there are reasonable doubts on "*whether political efforts to limit global warming to 1.5º Celsius will warm up as fast as scientists say the planet is*". As Jean Pisani-Ferry argues (in the same columns), this may lead to the collapse of the core mechanism of the 2015 Paris agreement, probably the most accomplished achievement up to date in tackling climate change. In the words of The Economist, COP26 could finally be "*both crucial and disappointing*".

The role of technology - One possible reason for this is the prevalent focus on what we could call the 'technological way' to sustainable development (which implies a persisting attitude aimed at bending and submitting nature to human needs), as compared to alternatives where prioritising respect for nature and its limits in significantly changes the design of possible solutions. For instance, if advances in terms of sustainability of productive processes are used to increase production, the total level of emissions may not decrease as much as expected. Moreover, as explained earlier, the extraction of raw materials that are crucial for the production of clean technologies equipment may generate externalities (in terms of emissions, waste and destruction of ecosystems and biodiversity) that may be hard to metabolise for normal natural cycles. No need to revert to 'Pachamama' rituals (though in many cases we should consider asking permission to Mother Nature, and not only to regulatory bodies), but internalising some more respect and consideration for the limits of nature (in terms of delicate equilibrium and overall finiteness) would certainly help. This is a matter of awareness that can only come from adequate education (conversely, missing awareness witnesses an important failure of the education system) and less consumeristic pressure. Somehow, the point is managing to **bring wisdom to become a collective standard**.

The role of tiny steps – We are back to the point of signals. In a recent article on the Financial Times,[32] Tim Harford argues that despite the fact that "*the world's supply chains are formidably complex, delivering products with a carbon footprint one could only guess at [...] the big picture is obvious enough*". In that framework, we come to the essence of what signals as those deriving from a carbon tax are for. "*It isn't just an incentive to change behaviour; it's a source of* ***information about which behaviour we most urgently need to change****. [...] It seems like a* ***huge leap*** *to decarbonise the world economy, but it is better understood as a* ***trillion tiny steps****. From frugal shopping to efficient logistics to renewable sources of electricity, carbon taxes gently steer us towards the greener solution every time, whether we are racked with guilt or blithely unconcerned. They should be at the centre of our fight against climate change*".

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31 See The Economist.

32 Published on FT Magazine (but also readable here), based on the book "*The Next Fifty Things That Made the Modern Economy*" of the same author.

ANNEX

A LIFE-CYCLE PERSPECTIVE

Solar PV and wind require numerous **materials**. Mostly metal, partly due to their technological requirements that use intensively copper, tin, manganese concentrate, and rare earth metals. An example is copper demand, which is associated with cabling and connection to grid, hence, with decentralized electricity production (UNEP, 2016). Solar PV and wind power have high copper demand (higher than concentrated solar power (CSP) and hydro, but also higher than coal and natural gas), with more than 1g of copper per kWh produced in 2010 (UNEP, 2016). The use of rare earth permanent magnets for wind technologies further increases the impact on metal depletion, whereas solar PV also uses important amounts of glass. On the other hand, CSP tower technologies and inefficient hydropower installations have high material requirements, when considering overall structural bulk materials (e.g. aluminium, iron, copper, and cement) per unit of generation. More specifically, the literature estimates that these require around 8-9g of bulk materials per kWh, whereas the remaining renewable technologies consume bulk material in the range of 1-4 g/kWh, with offshore wind power and trough CSP on the higher end, and roof PV on the lower end (see the landmark study of Hertwich et al 2015). Regarding **water** consumption, low-carbon technologies have diverse water use patterns. However, studies tend to point to hydropower, nuclear, and bioenergy as displaying the highest impact intensities (NETL, 2013; JRC, 2021). Relatively higher water consumption for nuclear is explained by the use of cooling water, whereas for biomass, in addition to the water consumed by the thermal power plants, very large amounts of water may be consumed during the production of the feedstock, depending on factors such as the type of crop, geographic location, local climate and crop management technique (JRC, 2021). Otherwise, geothermal and solar thermal consume relatively low volumes of water, whereas, wind power, due to its non-interference with natural water flows, does not have significant water consumption (NETL, 2013). In terms of **land**, the literature indicates that bioenergy (particularly solid biomass but also biogas), and, to some extent, solar (particularly CSP), as the electricity generation technologies that have the highest land occupation impacts amongst decarbonising sources (Bouman, 2020; JRC, 2021). For the case of CSP and ground solar PV, the plants themselves use most of the land occupied, whereas in the case of roof solar PV, the production of metals for the manufacture of the panels contributes the most to this environmental impact indicator (around 95% of the land occupied, see Stamford and Azapagic, 2012; Bouman, 2020; Hertwich et al, 2015). Land occupation by large reservoir based hydro and by wind onshore is also of significance (although part of the land dedicated to wind parks may be used for agriculture or left to wildlife), whereas offshore wind and nuclear have negligible impacts. Concerning water and land, there is an additional aspect related to **pollution.** Toxic chemical releases (e.g. heavy metals, volatile organic compounds, particles) during the lifecycle of electricity generation technologies also affect water and terrestrials ecosystems, for which the literature deploys various indicators. Overall, there is some convergence in the literature, on eutrophication and acidification impacts. This indicates that, amongst decarbonising technologies, nuclear energy tends to have the lowest impacts, whereas bioenergy is contributing the most to water and soil pollution when considering these environmental impact areas (e.g. JRC, 2021; Bouman, 2020). For eco-toxicity impacts, estimates vary considerably, especially for wind and solar as they depend more on the indicator considered, as well as on the type of technology assumed (JRC, 2021). For instance, some studies find that solar PV has the highest impact on freshwater eco-toxicity due to a variety of metal ions (mostly copper) and emissions of chlorine to water linked to mining and metal operation (Bouman, 2020). More specifically, solar PV may have an estimated freshwater eco-toxicity potential five times higher than other low-carbon technologies, e.g. around 50kg 1.4 DCB-eq[33] per MWh, as opposed to below 10kg 1.4 DCB-eq per MWh for CSP, hydro, wind, geothermal, and nuclear (Bouman, 2020). Other studies point not only to the production of photovoltaic cells as contributing the most, amongst renewables, to terrestrial and water eco-toxicity, but also to CSP towers playing some role in marine eco-toxicity, while wind, small hydro, CSP trough, and geothermal contribute the least (UNEP, 2016).

[33] The shortcut 'kg 1.4 DCB-eq' is a unit of measurement for eco-toxicity, where 'DCB-eq' stands for 'dichlorobenzene equivalent'.