Back to 2050

1.5°C is more feasible than we think.

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In this report, we review scenarios toward full decarbonization of the economy by 2050. Our key finding is that transformations of consumption patterns, driven by an inevitable appetite for human progress, and fueled by innovation and changes in behavior, lead to a less carbon-intensive economy. We thus argue that the only way to remain on a decarbonization trajectory consistent with a 1.5-degree global warming target, and carry out a transformation which has no precedent in history, is to accelerate the modernization of the economy. The climate change challenge can only be resolved if it is founded on human progress, and not at its expense. A 1.5-degree trajectory might be more feasible than we think.

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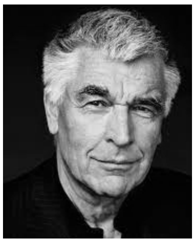

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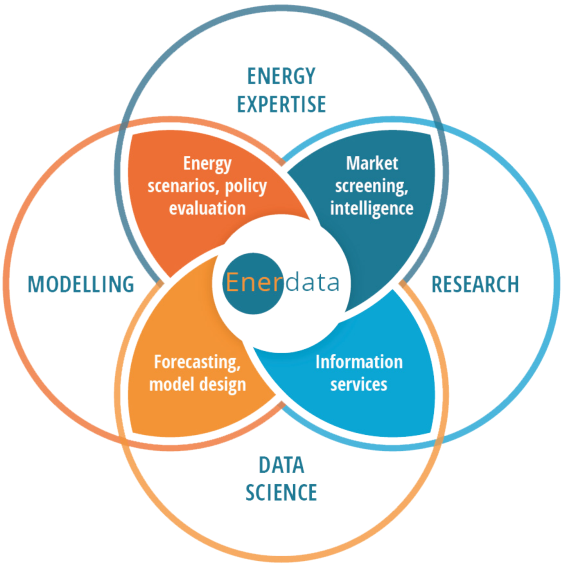

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Together, let's accelerate the decarbonisation of our society and build a more sustainable world.

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[1] The POLES model has been initially developed by IEPE (Institute for Economics and Energy Policy), now GAEL lab (Grenoble Applied Economics Lab). The version of the model used for this report is the POLES model version owned and run by Enerdata, named POLES-Enerdata.

List of tables and figures as they appear

Executive summary

On August 9, 2021, the Intergovernmental Panel on Climate Change issued the first chapter of the highly anticipated 6th assessment report, fully due in 2022. The conclusions are clearer than ever: global warming is man-made and the window of opportunity to change the course on which the world appears to be set on is closing rapidly. The UN Secretary General Antonio Guterres called this report a “Code Red for Humanity”. The target is clear. To keep global warming limited to 1.5 degree (compared to preindustrial levels), carbon dioxide emissions must be zeroed by 2050, and reduced by 30-50 percent by 2030 (while other greenhouse gas emissions must also be significantly abated). The bulk of these emissions comes from energy. A transition toward a net-zero economy is thus also an energy transition of momentous proportions. The pace and extent of its unfolding has simply no precedent in history: it has to happen within a time frame twice shorter than in the past, and on a global scale.

How this can realistically be achieved is thus the main question, and despite a flurry of scenarios to 2050, the momentum is still not here. In fact, 2021 will mark a major rebound in global emissions, as the economy recovers from the Covid-19 pandemic. Yes, nothing has really changed yet.

This report is another contribution to this question and proposes an alternative approach. It builds on key findings from the study of past energy transitions. History indeed reveals that what drives energy transitions is actually the way this energy is used and consumed. Energy transitions happen because new energy resources bring about positive changes in consumption patterns, or because new consumption patterns emerge and call for innovations in energy use. **Energy supply has always chased energy demand**. What this means is that the only way to realize a transformation of the energy system of such magnitude is to design a transition which makes sense for the consumer, hence drive adoption – rather than resistance – at an accelerated pace.

This is what we have done. And our conclusion is clear: **the best way – not to say the only way – to get to net-zero by 2050 is to modernize the economy at rapid pace, building upon innovations and behavioral changes** that – for many of them – will support the climate change agenda, although not always rapidly enough, and that – for some of them – need to be closely watched and possibly mitigated. **There is no needed arbitrage between human progress and climate change mitigation. In fact, there will be no climate change mitigation if it does not build on human progress**.

Would someone have imagined back in 1990 (30 years ago) that half the global population would today walk in the streets with 100,000 times the computing capacity of the guiding system that landed Apollo 11 on the Moon in 1969? How does this inform us about what to expect for 2050 (30 years down the road)? Yes, in 2050, we will live in a different world. In this report, 12 key transformations have been reviewed and their impact on the energy system modelled. These key transformations are all largely inevitable, as they bring considerable benefits to consumers, in terms of access to services, convenience, and quality of life.

12 Transformations

Buildings
Transport
Industry

Policy shifts
Sharing Economy
Access vs Ownership
Sufficiency

New Energy technologies
New Digital technologies
New Nano- and Bio-technologies

Distributed Generation and Storage
Superior Space Conditioning technologies
Road transport electrification
Transport as a Service Multimodal systems
Digitalized industries Best Available technologies
New industrial processes
Virtual environments
Construction disruption
Autonomous Vehicles
New fuels
Circularity
Distributed Manufacturing

- Lower costs
- Larger housing
- More comfort
- New urban forms

- Lower costs
- Less pollution
- Less congestion
- Convenience

- Customized, accessible and affordable goods
- Productivity
- Decoupled resource / growth

Figure 1 – 12 transformations to 2050

The only question is the pace and the extent of their unfolding by 2050. Two scenarios have been modelled

- The scenario *"New Normal"* essentially looks at the natural unfolding of such transformations in consumption, without further policy changes, and considering business as usual market conditions.
- The scenario *"Back to 2050"*, central to this report, explores to which extent a "climate & consumer-centric" policy shift can help reach the target of cutting emissions by 30-50 percent by 2030, on a course to net-zero by 2050.

The key finding of this detailed modelling is that **a pathway to 1.5-degree is more feasible than we think**. In the *"New Normal"*, we find that the economy, as it modernizes, becomes less carbon intensive and decarbonizes faster than often anticipated, albeit not at the right pace. By 2050, emissions in this scenario drop 30 percent compared to current levels (no additional policies).

Accelerating these positive transformations of consumption, in other words accelerating modernization through a consumer-centric policy shift, helps reach a net-zero economy by 2050 (scenario *"Back to 2050"*).

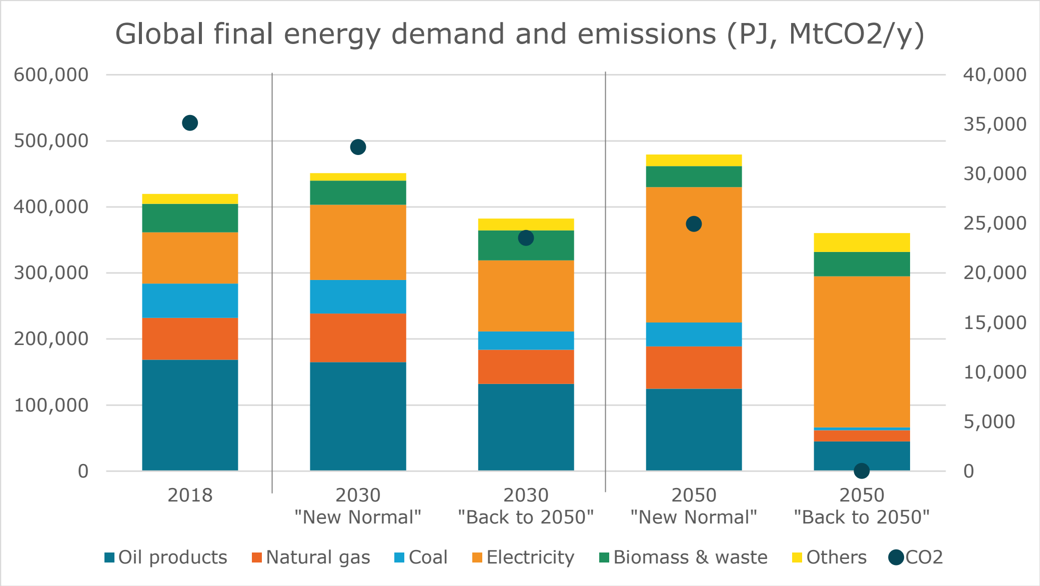

Figure 2 – Global final energy demand and emissions across 2 scenarios

Final energy demand in this scenario drops 15 percent compared to current levels. It stabilizes in urban environments but drops 20 percent industry and over 30 percent in mobility. The energy system also electrifies, with a share of electricity which climbs from 18 percent (in 2018) to 60 percent by 2050. Total electricity demand increases 3 times, and 20 percent of it is actually delivered by distributed solutions. The share of electricity reaches 80 percent in buildings and industry, and 40 percent in mobility: a different world.

Net carbon emissions are reduced 30 percent by 2030 and zeroed by 2050. In 2050, there are still 5,500 million tons of annual residual emissions, which are compensated by Carbon Capture, Utilization and Storage (CCUS) and other negative emission solutions (Direct Air Capture, Nature Based solutions)[2].

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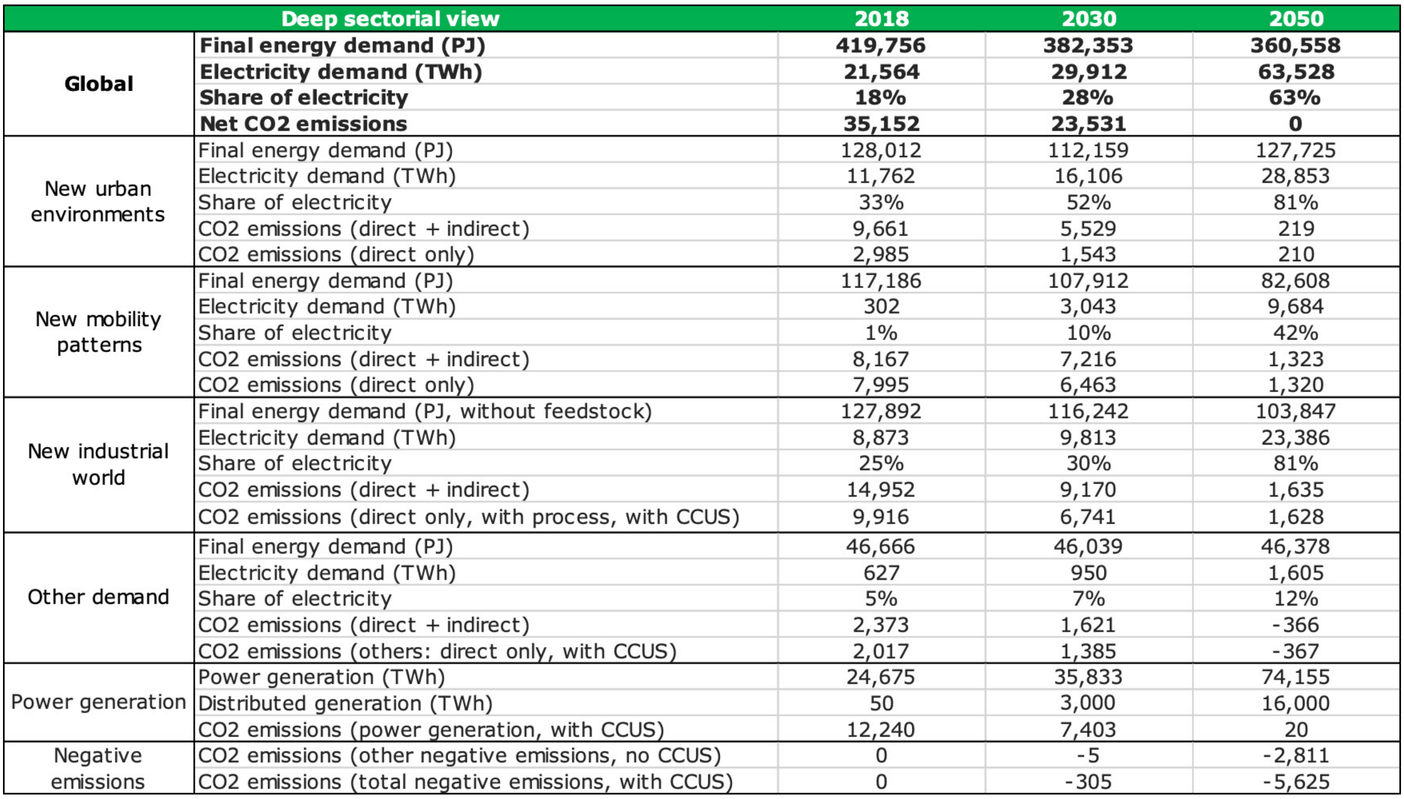
[2] The scope of emissions reviewed in this report covers energy-related emissions and industrial process emissions, or a baseline of around 35,000 million tons of carbon dioxide per year.



Deep sectorial view		2018	2030	2050
Global	**Final energy demand (PJ)**	**419,756**	**382,353**	**360,558**
	Electricity demand (TWh)	**21,564**	**29,912**	**63,528**
	Share of electricity	**18%**	**28%**	**63%**
	Net CO2 emissions	**35,152**	**23,531**	**0**
New urban environments	Final energy demand (PJ)	128,012	112,159	127,725
	Electricity demand (TWh)	11,762	16,106	28,853
	Share of electricity	33%	52%	81%
	CO2 emissions (direct + indirect)	9,661	5,529	219
	CO2 emissions (direct only)	2,985	1,543	210
New mobility patterns	Final energy demand (PJ)	117,186	107,912	82,608
	Electricity demand (TWh)	302	3,043	9,684
	Share of electricity	1%	10%	42%
	CO2 emissions (direct + indirect)	8,167	7,216	1,323
	CO2 emissions (direct only)	7,995	6,463	1,320
New industrial world	Final energy demand (PJ, without feedstock)	127,892	116,242	103,847
	Electricity demand (TWh)	8,873	9,813	23,386
	Share of electricity	25%	30%	81%
	CO2 emissions (direct + indirect)	14,952	9,170	1,635
	CO2 emissions (direct only, with process, with CCUS)	9,916	6,741	1,628
Other demand	Final energy demand (PJ)	46,666	46,039	46,378
	Electricity demand (TWh)	627	950	1,605
	Share of electricity	5%	7%	12%
	CO2 emissions (direct + indirect)	2,373	1,621	-366
	CO2 emissions (others: direct only, with CCUS)	2,017	1,385	-367
Power generation	Power generation (TWh)	24,675	35,833	74,155
	Distributed generation (TWh)	50	3,000	16,000
	CO2 emissions (power generation, with CCUS)	12,240	7,403	20
Negative emissions	CO2 emissions (other negative emissions, no CCUS)	0	-5	-2,811
	CO2 emissions (total negative emissions, with CCUS)	0	-305	-5,625

Figure 3 – Deep sectorial view

In the route to net-zero (scenario *"Back to 2050"*), **the decarbonization of demand accounts for half of global abatement**, with supply decarbonization (notably power generation) accounting for the rest. On the demand side, the effort is almost equally split between demand optimization (changing consumption patterns) and process changes (which include notably the electrification of the energy system).

Demand optimization includes behavior transformations such as sufficiency in buildings, modal shifts in transport, circularity and the impact of other sectorial transformations in industry, as well as energy efficiency measures on the stock. Process changes include the electrification of mobility, building and industrial heat, as well as the switch to other fuels, and the deployment of carbon capture, utilization and storage (CCUS), although the latter has a relatively minor impact compared to others.

More importantly, these transformations of demand come at net benefit for consumers, bridging climate change mitigation and human progress.

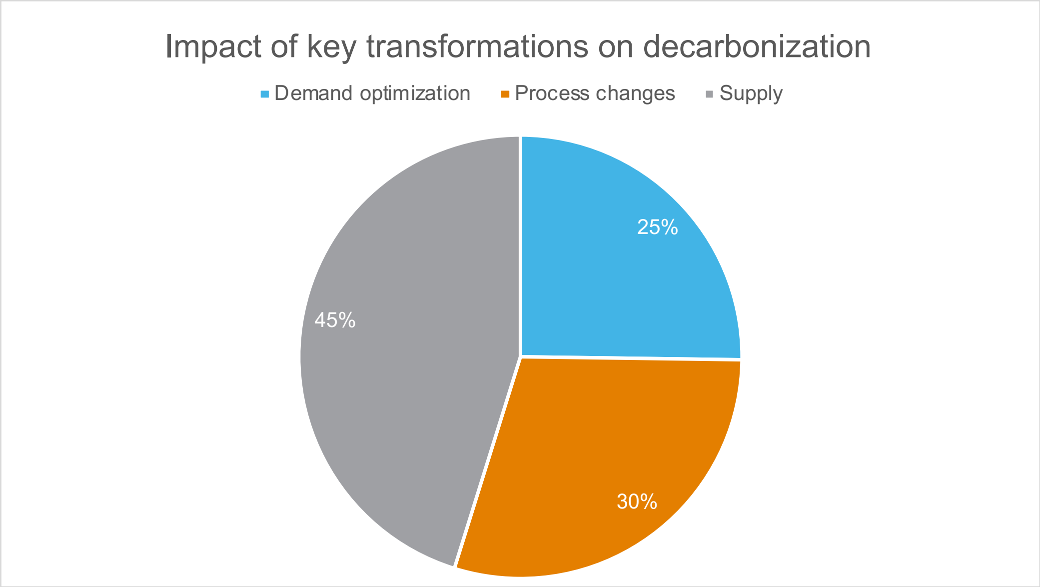


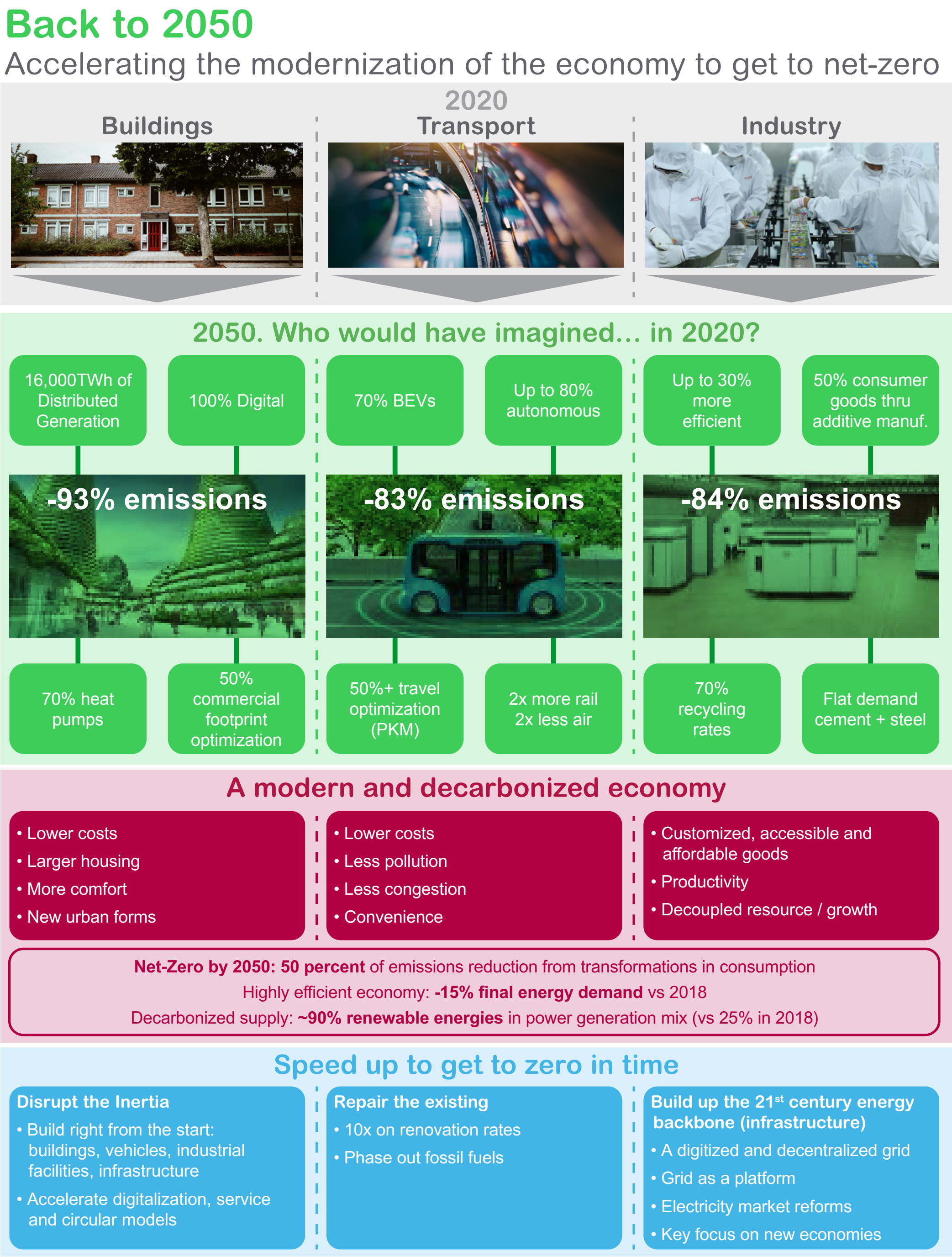
Figure 4 – Impact of key transformations on overall decarbonization, scenario *"Back to 2050"*

The accelerated modernization of urban environments, mobility patterns and industrial footprints thus charts a feasible pathway to a 2050 net-zero economy. As this transition is also consumer-centric, hence inclusive, we argue this pathway is also more realistic. Rapid adoption of decarbonized uses can only happen if it comes with human progress. Technologies, innovations and changing behaviors all make this possible. The key question therefore is whether the roadblocks to an accelerated adoption will be removed in time, or not.

In fact, a policy shift is required, from a pure "infrastructure-centric" focus to a complementary "consumer-centric" focus. This policy shift is not meant to discard the necessary and fundamental effort on infrastructure buildup, but rather complement it with key measures that will unlock a rapid and inclusive decarbonization of the economy on the consumer side. It is based on 3 pillars

- **Disrupt the inertia of the current system**: everything that is built new should now be built with the 2050 end-game in mind. There is no time for keeping up with the historic model. Policies can play a fundamental role in forcing these shifts, faster than it would otherwise pervade the economy.
- **Repair the existing**: a massive effort is required to modernize the existing stock of assets (buildings, mobility, industrial facilities and machines, etc.), at a much faster rate than natural evolutions. In fact, as 100 percent of the stock needs to be refurbished by 2050, the annual rate of renovation must increase by an order of magnitude compared to current levels (when accounting for those renovations that truly focus on deep decarbonization). Policies will also play a fundamental role in enabling this turnaround quickly.
- **Build up the twenty-first century energy backbone**: a fundamental effort is required to expand and strengthen the current power system infrastructure, in particular the grid. This is notably a critical point for new economies which will at large define the global trajectory toward zero emissions post 2030. This infrastructure also needs to take stock of the new paradigm of a more distributed energy landscape, where the grid effectively acts as a platform on which all other transformations build up. Finally, this transformation of the energy infrastructure must go along with a fundamental redesign of energy markets, which are today built for a fossil fuels economy.

The COP26 of November 2021 is in this regard a critical milestone. By 2022, a major overhaul must take place, with a no-regret move away from coal, stringent standards on new build, clear renovation programs at regional level, and a fundamental rework of market design.



Back to 2050

Accelerating the modernization of the economy to get to net-zero

2020

Buildings	Transport	Industry

2050. Who would have imagined… in 2020?

Buildings		Transport		Industry	
16,000TWh of Distributed Generation	100% Digital	70% BEVs	Up to 80% autonomous	Up to 30% more efficient	50% consumer goods thru additive manuf.
-93% emissions		-83% emissions		-84% emissions	
70% heat pumps	50% commercial footprint optimization	50%+ travel optimization (PKM)	2x more rail 2x less air	70% recycling rates	Flat demand cement + steel

A modern and decarbonized economy

- Lower costs
- Larger housing
- More comfort
- New urban forms

- Lower costs
- Less pollution
- Less congestion
- Convenience

- Customized, accessible and affordable goods
- Productivity
- Decoupled resource / growth

Net-Zero by 2050: 50 percent of emissions reduction from transformations in consumption
Highly efficient economy: **-15% final energy demand** vs 2018
Decarbonized supply: **~90% renewable energies** in power generation mix (vs 25% in 2018)

Speed up to get to zero in time

Disrupt the Inertia
- Build right from the start: buildings, vehicles, industrial facilities, infrastructure
- Accelerate digitalization, service and circular models

Repair the existing
- 10x on renovation rates
- Phase out fossil fuels

Build up the 21st century energy backbone (infrastructure)
- A digitized and decentralized grid
- Grid as a platform
- Electricity market reforms
- Key focus on new economies

Figure 5 – Back to 2050, a scenario to net zero by 2050

If done right, a net-zero economy is achievable by 2050, and with it will also come human progress. It requires however to embrace the future with clear resolve. We acknowledge that many uncertainties remain on the pace and extent of such developments, and that more work is required to further refine some of the assumptions taken. This is also why we have tried to provide maximum transparency on this work, so that its underlying assumptions can be further debated. After all, scenarios are as good as their assumptions. We hope nevertheless that this effort will help steer the conversation toward the consumer side of the energy system and provide new insights to all those who focus on building practical pathways to our common goal.

Chapter 1 – The climate imperative calls for a new approach to the energy transition

A new approach to the energy transition is needed

On August 9, 2021, the Intergovernmental Panel on Climate Change (IPCC) released the highly anticipated contribution from the first working group on the physical science basis on climate change. This report is due to be integrated in the full 6th assessment report (AR6) in 2022, which will also integrate other contributions on climate change impacts and mitigation pathways[3].

This report, which will come 8 years after the previous one (AR5, 2014), shows tremendous progress in understanding the mechanics of our planet's climate. And it starts with a clear statement, which straightforwardness is unusual in scientific publications.

> *It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.*

After decades of research on the impact of human activities on climate change, and a growing understanding of natural effects and feedback loops, the global scientific community now considers unequivocal (certain!) that currently observed global warming is man-made. The pace of change is also unprecedented and its impact likely to materialize rapidly[4]. The time window is thus closing upon us. Little time remains to transform our economy, and prepare for an inevitable adaptation, which extent we need to limit as much as possible[5].

In a 2018 publication, the IPCC also demonstrated that net emissions of carbon dioxide must be zeroed by mid-century (with significant abatement on other greenhouse gases), while they also must be reduced by 30-50 percent by 2030, for the world to remain on a trajectory consistent with a long-term 1.5-degree global warming ambition[6].

This is the target to reach. There are however several impediments to the rapid transition described by the IPCC. For one, many economies around the world have not yet reached the levels of wealth and development of their industrialized counterparts. The energy demand per capita in lowest income countries of the world ranges at 10 times lower levels than those of affluent economies[7], and the world has still nearly one billion people with no access to a modern source of energy such as electricity. As these economies develop and further integrate within the global network of exchanges, their energy demand will go up. In addition, global population will continue to increase, by over 2 billion people by 2050, further fueling energy demand growth, and this will at large happen in these economies[8].

Second, if transitions have happened in the past, they always took 60-70 years to materialize in full, and on parts of the energy system only[9]. What the IPCC describes here is a transition which is twice shorter, and all at once, an undertaking which has clearly no precedent. Such a brutal transformation of our energy system implies *a priori* many sectors being caught in the line of fire, not to say an entire generation. The question of making that transition "inclusive" has thus been taking center stage in the last years, and the difficulty to come with a clear path forward has led to much public dithering.

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[3] IPCC (2021), Climate Change 2021, the Physical Science Basis

[4] See annex for more details.

[5] IPCC (2018), Global Warming of 1.5°C; Schneider Electric (2021), The 2030 imperative: a race against time

[6] Schneider Electric (2021), The 2030 imperative: a race against time

[7] Compared to the United States here. Europe has much lower energy per capita demand, yet the difference remains significant, at around 5-6 times.

[8] Petit V. (2021), The Future of the Global Order

[9] Petit V. (2021), The Age of Fire is Over

Finally, climate transformations are already here. Extreme heat waves and wildfires, floods and droughts are more frequent than ever, and with these come a lot of new adaptation issues which the world has barely anticipated yet.

This research is another contribution to this effort. Its approach departs and complements other studies with a key focus on the contribution of the "consumer-side" of the energy system into the overall decarbonization of the economy. It also builds on key learnings from past energy transitions.

The main finding of this report is that accelerating the modernization of our global economy is the key success factor of a rapid and inclusive decarbonization.

The History of past energy transitions informs us on what such a new approach could look like.

The history of energy transitions is full of powerful learnings, and they have been explored through many research efforts[10].

Figures 6 to 8 reproduce two long-term analyses of the history of energy transitions in the United States and the United Kingdom since 1800[11]. The detailed study which underlines these analyses complements other efforts and leads to 3 main conclusions which define the history of modern energy transitions.

Energy transitions take time and build on the existing system in place

The pace of past transitions is measured in decades. This has to do with the fact that new energy resources are adopted in certain sectors of activity first, and that their deployment depends on how rapidly the infrastructure to supply them is developed. The longer it takes, the longer the adoption. When the infrastructure finally comes online, then transitions in adjacent sectors are often quicker.

New energy sources build on the existing infrastructure in place, before this infrastructure also transforms, benefiting from adjacent progress and innovation. This was the case for the transportation of coal in the early stages of its development, initially carried by animals or cabotage, before railroad systems began to be deployed post 1850. This is also the case for modern solar panels manufacturing, using conventional power generation today (carbon intensive), before decarbonized electricity picks up the pace[12].

Energy transitions overlap

Energy transitions have happened in the past, and they will continue to do so in the future, a natural course of things which owes to the perpetual quest of humanity to improve its condition. One energy source has never replaced all the others at once. This is because these are used in certain sectors, not in others, with substitutions which do not materialize at the same time.

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[10] See notably Hall et al (2016), The Future of National Infrastructure; Petit V. (2021), The Age of Fire is Over; Rhodes R. (2018), Energy. A Human History; Smil V. (2017), Energy and Civilization; Shell (2014), The Colours of Energy. Essays on the Future of Energy in Society; Suits et al (2020), Energy Transitions in U.S. History, 1800–2019

[11] For the United Kingdom: Hall et al (2016), The Future of National Infrastructure; For the United States, Suits et al (2020), Energy Transitions in U.S. History, 1800–2019

[12] Petit V. (2021), The Age of Fire is Over; Suits et al (2020), Energy Transitions in U.S. History, 1800–2019

The history of coal use in the United States is in this regards emblematic. It began to be used in industrial applications, and helped kickstart the industrial development of the nation, before to further penetrate households (as a substitute to wood for heating and cooking) thanks to railroad development (after the Civil War), which enabled mass access to this new energy source. Coal was then in part displaced by oil, gas, or electricity across all sectors of activity, with different timelines for each sector, yet it remained in use for electricity generation[13]. Modern coal-fired power plants still resemble the steam engines of the 19th century (despite considerable improvements on the efficiency in coal use).

Energy transitions are a byproduct of innovation

The most important lesson of past energy transitions is however that these are not only a product of new energy sources, but rather of innovations in the way to use energy. Vaclav Smil summarized it in simple words

> *As far as fuels are concerned, history would have taken a different course if coal had been used merely as a substitute for wood in open fireplaces, or if crude oil had remained limited to kerosene for lighting. In most cases it has not been the access to abundant energy resources or to particular prime movers that made the long-term difference. Decisive factors were rather the quest for innovation and the commitment to deploying and perfecting new resources and techniques and finding new uses*[14].

Energy transitions have happened in the past because these new energy sources were used in new ways and provided greater benefits, be it supplying an existing service at a fraction of its past cost, delivering it with greater convenience, or enabling a new service which did not exist before.

Why all this matter?

This short review of the history of energy transitions provides ground-breaking evidence that energy transitions are primarily driven by the complex development of how energy is actually used. **The supply of energy chases existing or new consumption patterns**. Transitions take time because new energy sources often require new infrastructure and because new patterns of use emerge only when the economics make sense, and not across all sectors at once. And these transitions tend to overlap over time as more innovation leads to new improvements in a variety of services.

There is an obvious reason to this: humanity seeks wealth and abundance. This may take multiple forms, but ultimately new energy sources are only as good as they provide new means toward this goal. Then, adoption accelerates, and the energy system (the way energy is supplied to consumption) transforms.

We can already foresee three critical consequences to this

- **In 2050, we will live in a different world**. Consumption patterns will continue to evolve in the medium term, fueled by innovation and by new behaviors. The future system will be different than present, as the present one differs from the past.
- **Adoption of new energy uses will be the key driver of rapid transformation**. In the current context, where a global transition is due in half the time traditional ones take to materialize, a renewed focus on the “demand-side” of the energy system is thus more important than ever.

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[13] Petit V. (2021), The Age of Fire is Over; Suits et al (2020), Energy Transitions in U.S. History, 1800–2019

[14] Smil V. (2017), Energy and Civilization

- The development of a new supply infrastructure to fuel these evolving consumption patterns will prove key in the race to a net-zero economy by 2050.

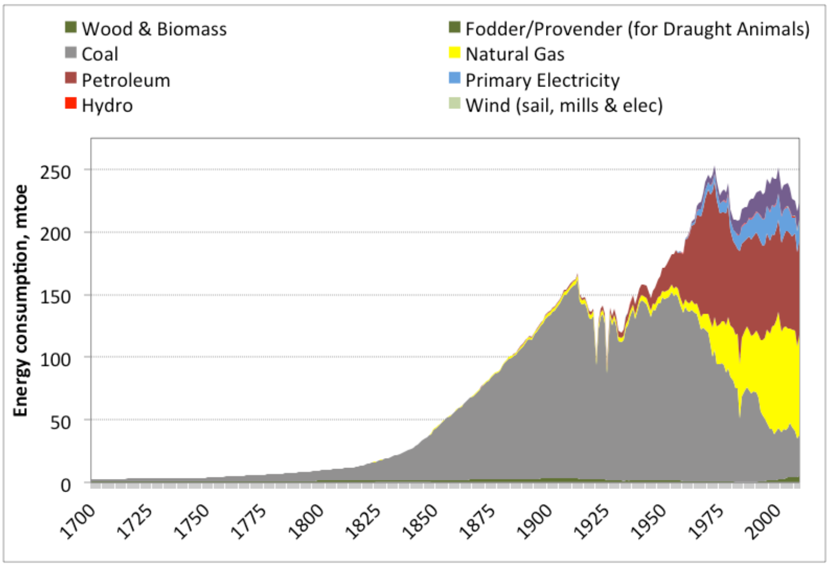

Figure 6 – The United Kingdom energy system 1800 to today[15]

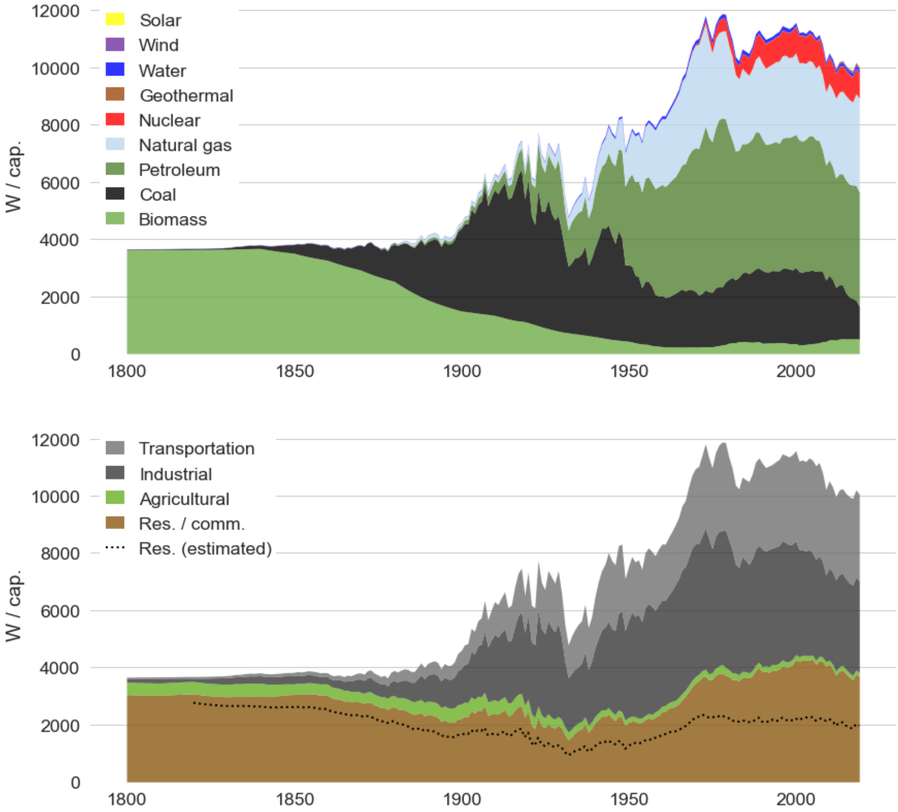

Figure 7 – The US energy system 1800-2019[16]

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[15] Hall et al (2016), The Future of National Infrastructure

[16] Suits et al (2020), Energy Transitions in U.S. History, 1800–2019

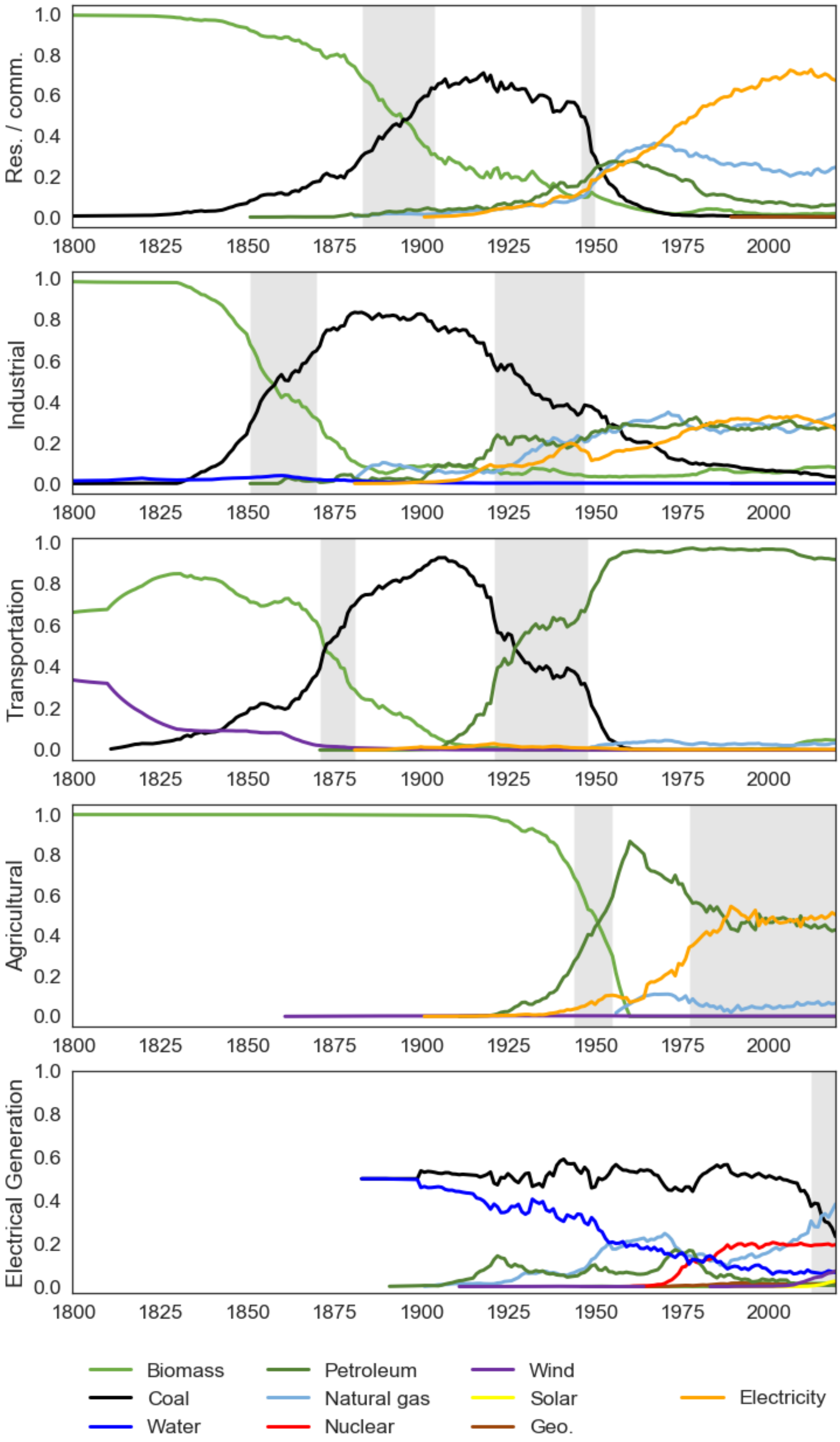

Figure 8 – Transitions at play, in the United States[17]

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[17] Suits et al (2020), Energy Transitions in U.S. History, 1800–2019

We must prepare for the future system, not only patch the existing one

Future consumption patterns will thus be a fundamental driver of the upcoming energy transition. The future energy system will not resemble the present one and there is considerable value to understand what are those new patterns of consumption which, for those that are intrinsically positive for the climate agenda, need to be accelerated, and conversely, for those that are not, require strong attention and be mitigated.

There is limited body of work on this matter and we believe now is time to shed greater light on the topic[18]. The following report is thus an exploration of how a variety of innovations and behavioral changes are likely to transform the energy system going forward; how some of these transformations are found to be highly positive to climate change mitigation and should be accelerated, while others would require significant attention as they have the potential to derail our global collective effort toward zeroing greenhouse gas emissions by mid-century. In other words, the following exercise departs from other studies, traditionally centered around the energy supply infrastructure. **Its focus is to frame the energy transition from the standpoint and through the lens of the consumer (or the end-user)**. We consider this approach to be an important complement to current prospective efforts, as well as a key lever for a rapid and successful transformation in the context of climate change mitigation.

We hope this effort, despite its imperfections, to be an insightful contribution to the debates at hand.

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[18] Arbib et al (2021), Rethinking Climate Change; Grubler et al (2018), A low energy demand scenario for meeting the 1.5°C Target and Sustainable Development Goals without Negative Emission Technologies; Energy Transitions Commission (2020), Making Mission Possible; Petit V. (2021), The Age of Fire is Over

Chapter 2 – In 2050, we will live in a different world

Technology and Culture two foundational drivers of change

These transformations of the demand for energy will happen for two main reasons: on the one hand, new technologies, including new energy sources (but not only!), provide the platform for innovative development in the way we deal with the current services and goods we consume. On the other hand, our societies continue to transform, and with them appetites for different living styles, which have obviously a significant and direct impact to our economic activity, hence the energy we use.

A new technology toolbox at hand

First driver of transformation: technology. The beginning of the twenty-first century may arguably be considered one of the most dynamic eras of technology innovation, one that can be compared to the mid- to late 1800s industrial revolutions (steel manufacturing, nitrogen fertilizers, railways, telegraphs, automobiles, etc.). Modern technology innovation now builds on 3 fundamental areas of research

- Digital technologies: the staggering development of internet in the last 2 decades has mostly consisted so far in connecting people to people. Now comes the time to connect machines to people, and soon machines to machines. The number of connected objects already dwarfs that of connected “humans”. Data generation and transmission capabilities increase every few years by an order of magnitude (and nothing indicates it will stop any time soon), computing power continues to improve, while new developments such as artificial intelligence or quantum computing suggest giant leaps could be at reach.
- Nano- and bio-technologies: working at subatomic scale has now become common practice, and this because its cost has reduced by several orders of magnitude in less than a decade, a learning rate which has no equivalent. And this is opening a whole new array of uses in a variety of sectors. Developing and finding new cures to diseases, manufacturing nano-scale robots, inventing new materials with predesigned properties, are all developments which seem to be on the cusp of emerging[19]. Such a feat would never have been possible without digital technologies (and notably computing power), and it will impact many sectors of activity, and in particular energy.
- Energy technologies: new renewable energy sources have made great strides in the last decades. Solar photovoltaics (PV) costs have fallen by as much as 80% in just a decade, and they are expected to continue to fall rapidly[20]. Wind power follows similar trends. At the same time, storage technologies have begun to emerge, a classical example of an innovation which started in one sector before to pervade others. Lithium-ion batteries were first developed to fuel the growing energy needs of modern consumer electronics, before to be scaled up to automotive (leading to the Electric Vehicle – EV – phenomenon), and ultimately to enter household’s energy systems. There are two key things to understand with these new energy technologies
    - They have increasing learning rates: the more the technology develops, the lower the costs (or the higher the efficiency, which leads to the same result). This is in direct opposition with traditional fossil fuels (which extraction gets more difficult, thus costly over time).

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[19] See notably Hockfield S. (2019), The Age of Living Machines

[20] NREL (2021), Documenting a Decade of Cost Declines for PV Systems; NREL (2021), 2021 Electricity ATB Technologies and Data Overview

- They are still in infancy: current solar modules deployed worldwide are – for the most part – first generation technologies. Scientists already work on new technologies (third generation) which efficiency and cost could be further game changers[21]. And these new technologies leverage the power of nano- and bio-technologies discussed above, alongside access to significant computing capabilities to design at will new materials, composites, and architectures.

A new toolbox for innovation is thus emerging, and it will fuel most of innovation going forward, building on digital, nano- and bio-technologies and new energy sources. Already significant paradigm shifts are at reach with current technologies, but much more is to come. As we project ourselves in 30 years and beyond, it is a must – despite the inherent uncertainties of such a thought experiment – to take stock of these dynamics.

A new generation in charge

Today's generations in charge belong to Generation X (1965-1980) and Generation Y (1981-1996). They have specific views (and often antinomic ones) of the world they live in, this is well known and has spilled already a lot of ink. A more insidious trait is that – and this is the nature of things – these generations tend to predict the future through the same lens than the one which governs their present views.

The reality, however, is that by 2050, the generations in charge will be Generation Z (1997-2012), Alpha (2010s to mid-2020s), and even Beta (mid-2020s to late 2030s). And the appetites of these generations are likely to significantly differ from those of past generations, as always verified in the past. While research on Generation Z is rather well documented, that of Generation Alpha (and Beta) is only emerging[22].

Behavioral patterns of future generations essentially stem from 2 main root causes: the environment they live in, and the way they interpret, reject or are influenced by the generation which has preceded them. In other words, what defines success for them? There are many ways to approach this and there will certainly be more research in the coming years on the subject. At a high-level, however, we want to retain here 3 main patterns

- A generation of entrepreneurs: Generation Alpha is likely the first one to truly have accessed from early age to a full range of digital capabilities, and to near-universal access to information. With this comes significant flexibility in learning, working and contributing to a variety of self-fulfilling activities. This world of opportunities is therefore likely to translate into a growing appetite for individual entrepreneurship, which may take a whole range of new forms (from traditional enterprises to more social-oriented activities).
- A generation of activists: unlike the relative apathy of the past generations to some of the most pressing challenges the world is confronted to, this generation is more likely to take up on these issues, while at the same time being growingly confronted to them, as they unfold. Global warming is the first one of them, but access to food and health, or inequalities, will also be significant reasons of engagement, self-awareness and adjustment, and again a channel for entrepreneurship.

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[21] For more, see notably Petit V. (2021), The Age of Fire is Over

[22] Interesting insights from Aggrawal S. (2019), The Less Known Alpha Generation; Business Wire (2019), Generation Alpha: New Study Shows How Being the Most Diverse Generation Yet Impacts Their Behaviors Now & In the Future; Chatfield T. (2014), What our descendants will deplore about us; McCrindle and Fell (2020), Understanding Generation Alpha; Vermot-Desroches G. (2018), Le Printemps des Millenials

- A generation of individuals: although this statement could be heavily challenged, this generation is also likely to live in a world where abundance prevails over scarcity, at least relatively to past generations. And with this is likely to come demand for instantaneous fulfillment, customized content and services, alongside extraordinary flexibility. This is likely to challenge the traditional ownership paradigm which has been the defining factor of wealth identity in the last decades, as well as redefine traditional bonds.

What also matters is that these developments are likely to differ from one region to another. An obvious but understated reality is that these generations will primarily come from new economies. 4 regions of the world (Eastern, Middle and Western Africa, and Southern Asia) will make up 75% of the global increase in population (Figure 9). **The Generations Alpha (and Beta) will be of African and Asian origin**. And these populations also turn out to be the ones most likely to experience some of the greatest impacts from the global issues mentioned above[23].

World population	2015	2050	Annual growth	Share of total change
Africa and Middle East	**1,620,235**	**2,871,778**	**1.9%**	**65%**
Eastern Africa	445,406	851,218	2.2%	21%
Middle Africa	179,595	382,640	2.6%	10%
Southern Africa	67,504	87,379	0.9%	1%
Western Africa	401,861	796,494	2.3%	20%
Northern Africa	246,233	371,545	1.4%	6%
Western Asia	**279,637**	**382,502**	**1.0%**	**5%**
Central and Southern Asia	**2,014,709**	**2,496,417**	**0.7%**	**25%**
Central Asia	74,339	100,250	1.0%	1%
Southern Asia	1,940,370	2,396,167	0.7%	23%
Eastern and South Eastern Asia	**2,346,709**	**2,411,344**	**0.1%**	**3%**
Eastern Asia	1,678,090	1,617,342	-0.1%	-3%
South-Eastern Asia	668,620	794,002	0.6%	6%
South America	**653,962**	**762,432**	**0.5%**	**6%**
Pacific	**42,678**	**57,376**	**1.0%**	**1%**
Europe	**747,636**	**710,486**	**-0.2%**	**-2%**
North America	**368,870**	**425,200**	**0.5%**	**3%**
World	**7,794,799**	**9,735,034**	**0.7%**	

Figure 9 – Global population evolution[24]

The overwhelming conclusion of this is that there is little chance that the coming evolutions of our economy (and the ultimate pathway to decarbonization) build on common wisdom stemming from affluent economies and older generations. How could this look like then?

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[23] United Nations (2019), World Population Prospects; Petit V. (2021), The Future of the Global Order

[24] Ibid

A day in 2050

April 2, 2050, 12pm, Conakry, Guinea

- Very well, says Aberash. Time for me to hit the road then. We'll stop here and reconvene in two days when I am done with this step of the project.

She closes the video call and all three participants drop off her wall screen. She lies back on her chair and stretches a little. She has recently added this new spacious office as an annex to her home. The previous, which came with the original design, was really too small. This was easy, she just had to use the mobile additive manufacturing machine from 3D-Company for a couple of days. She had borrowed the plans on the construction platform of 3D-Company which provides a whole set of standard designs for such types of annexes and spent a nice week-end with her husband customizing it to her taste. She feels good here, it is exactly what she was looking for.

The chatbot rings a bell.

- Your car will be here in thirty minutes, it says. You still need to complete the file and send it to the foreman's group.

Not much time to rest today. As the local site manager of the multinational ModernInfrastructure company, headquarter in France, she must get this large infrastructure dike investment happen. It is a very important project for Guinea, and could prevent further flooding of nearby communities, which have been hit hard just a year ago, an event which was one in half a century. Unfortunately, the Global Climate Modelling Forecast has already predicted a similar event to happen within the next coming five years, with a 30% probability for this year.

Fortunately, with her colleagues, she is nearly done. She looks once again at the 3D perspectives of the supporting infrastructure they have been working on for a month. She is happy with the results, it has been fully optimized to resist the pressure and force of a similar flood, and is completely adjusted to the planes and slopes on which it needs to be deployed. There is no time to waste as the massive infrastructure printing machine has just arrived to Guinea. The machine travels the world and every day without use costs a lot to the company. The machine is due in a week in Mauritania. The most difficult part, the design, is complete anyway. They just need to get the construction going now. It will only take a few days. That's the easy part.

She clicks on "send" and wraps up her stuff. She still has time for a quick coffee before to get going. It's a one-hour ride to the site, she will finally be able to relax a little while the machine takes her there.

April 2, 2050, 12pm, Paris area, France

Jean closes the video screen. That was an efficient call, and he is extremely satisfied with the results. The financial parameters of the project are very strong. It will be a good project, and profitable to the fund of private investors IS company has brought on board.

If only there were more projects like this, his life would be easier! He is working in parallel on four other projects at the moment, each with different companies. You have to say, though, that on this one ModernInfrastructure company has brought very good talents. Not sure how their HR team has managed to build such a database of resources, but not all groups are so successful.

He turns to his chatbot and asks it to get a coffee prepared and turn on his 3D printer. Time to get to more fulfilling stuff!

The kids will be back from school in one hour, and he still need to get some boots printed before they can go on their little excursion this afternoon. Yesterday, they stayed up late to customize them, and they insisted that – this time – he would have them ready before the hike! He gets on the files and verifies once again everything in order. He received yesterday all the materials needed and prepared the printer so that he would just have to launch it today.

Done! He hears the noise of the machine in the garage purring. It will take only half an hour to get these two pair of boots done. They will be super excited, they love these little walks in the forest nearby. He tries to go every day. At the moment, he can handle most of his projects early morning, so he enjoys the time in the afternoon. His wife, as a teacher, still has to get to school every once in a while, and she will not be with them this time.

The forest is brand new. He remembers twenty years ago when it was still a vast field for livestock. But we don’t eat natural meat anymore (his children do not even believe we had such barbaric practices in the past!), so the community planted a new forest instead, and designed it purposely to make it a nice recreational area. He enjoys this as much as his kids, even if every time he needs to get another pair of boots done!

April 2, 2050, 6pm, Shangai, China

Fen stands up. That was a great call. She is very happy with the feedback from Aberash on the design of the dike. The few tweeks she inserted into the open-AI algorithm of ModernInfrastructure company proved to be very useful. As the software engineer of the project, she was a little unsure these last modifications would yield the expected result, but now she is relieved. She will finally be able to put this project behind her and move onto something else. She has already been contacted to work on another interesting project for a food company in Australia. The project looks fascinating. Nothing on infrastructure this time! She prefers food engineering. That was her major at the university and she always wanted to get back to it.

But first things first, she has a party tonight. Her smartphone rings, and the chatbot instantaneously relays the message

- We are likely to get a short storm tonight, Fen. However, you need not to worry. It will only last from 8 to 9pm. The home system is fully charged, you have three days of energy autonomy. Also, your car is just back and plugged in.

She did not even hear her car coming back. She bought it last month and immediately lend it to the major TaaS actor in Southern Shanghai. In practice, she does not use it, but it yields quite a good amount of money every month, a nice complementary source of revenue. Tonight, she heads south with her friends to a new village near the sea. They will take one of these new large autonomous vehicles that have been designed for such road trips. The car first comes pick her up around 6.30pm and then will go on and pick up the others. They ordered some food and wine in the car. The trip is likely to be as exciting as the venue. She cannot wait!

April 2, 2050, 6am, Boston area, United States

What an energetic meeting! Mark wonders how Aberash manages such a complex project, and he truly admires the passion she put in building this dike. He knows how important it is. Last year, he was involved in a similar project nearby Denver, Colorado, and this time he even had a chance to go there to see by himself. As an architect, he does not get to travel too often, so he was very grateful with the opportunity. That also helped him better understand his role in a project like this one.

He looks at his watch and smiles. Yes, he still has one! His grand-father gave it to him, so he keeps it as a relic. It's convenient, even though he cannot wear it too often otherwise his body sensor loses data points and then he gets a call from the medical center. He does not have too much time anyhow. He needs to get to the community vegetable garden. For over two years now, the people of the village he lives in, outside Boston, have created this common to grow fresher vegetables. They carefully looked into their genetic composition to best address the specificities of the land and weather they have here. He loves this time together, even though everyone has its say on the colors and taste of the next generation they will grow: endless conversations, but that brought them closer to one another over time. Today he will only be able to stay in the morning though, as he has a busy afternoon in Boston, with two classes to teach at Boston University afterward.

And before to get going, he still needs to ship the set of clothes he decided he did not want to wear anymore. He barely wore them once. In a few clicks it is done. He puts them in the package and place it out on his garden loan. The drone will come pick it up in the afternoon and should also deliver the laundry he has shipped yesterday.

The chatbot rings

- Before you leave, Mark, do we also fill up the fridge? Same batch as usual?

He almost forgot! Yes, he confirms. That way he will also have something to eat tonight. He loves to cook, even though not many people are doing it anymore. Yet, after all, he still wears a watch!

Our consumption patterns will evolve, and this will change our contemporary frame of reference

The future will not resemble the past. Thru the combined effect of growing technology capabilities, changing cultures and priorities, major transformations to global living standards will lead to different patterns of consumption, and this will have a major impact on the energy system.

Figure 10 summarizes 12 of those transformations which impact on the energy system we have decided to explore in this issue. This should be regarded as a starting point, in no way an exhaustive assessment.

This selection results from a larger research effort and an extensive review of current literature. We consider their likelihood to unfold greater than others, because of their relative readiness but also (and more importantly) of the potential benefits they could bring[25].

Our argument is that, for most of them, such transformations are inevitable as they bring greater wealth and abundance to people. The question however will be that of the extent of their unfolding, and the pace at which they could materialize. This is what we will test through the different scenarios developed in this report.

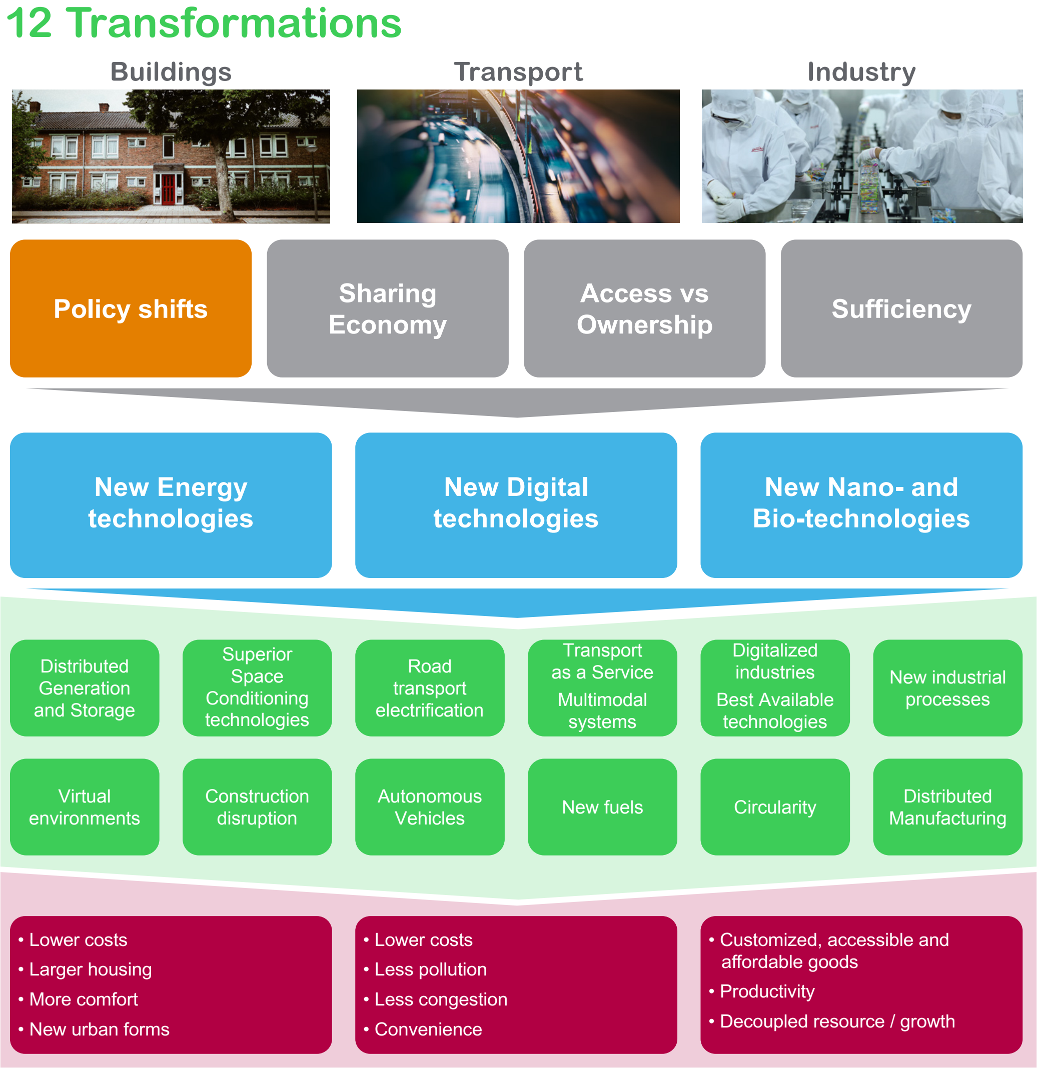

Figure 10 – 12 transformations to 2050

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[25] More details available in annex on our assessment

New living environments

A major development in buildings will be the inevitable digitalization of our living environments. This is obvious. What is less obvious are its consequences. We argue this trend will trigger a whole new range of activities, which for part of them, have already begun to emerge: home office, online shopping, etc. This transformation will ripple through all sectors and redefine our traditional anticipations on building footprint evolutions. More residential, more time in households, and inevitable impacts on the commercial sectors, both on their actual footprint and configurations.

Digitalization will also pervade the construction sector, an industry which has made limited productivity gains in the last decades, therefore prey for disruption[26]. A significant potential exists. 15 percent of materials is wasted in construction, overspecification typically drives 20-30 percent extra materials supply, and advanced construction designs and modular approaches could offer even larger benefits[27]. This could have significant impacts on the various industries which supply construction with materials[28] (steel, cement, bricks, glass, plastics, etc.). A significant productivity disruption in the construction industry could lead to reduced costs of housing, a new form of abundance.

One of the key unanticipated effects of such evolutions could be different urbanization patterns, and the emergence of new urban forms. More affordable housing provides the opportunity for greater space, while many of daily commute and mobility needs could be significantly optimized. This would clearly have an impact on city footprints and overall demand for energy.

This may not ultimately be a synonym of efficient use of space and energy and could in fact drive rebound effects (i.e. more demand in housing). Yet, this is also likely to be compensated by the native capabilities of digital controls (which will be here no matter what) to optimize energy demand, another aspect of these technologies overlooked in most current analyses[29], as well as growing self-awareness of the environmental impact of our living standards, fueling sufficiency in use.

Another major unappreciated development of buildings in the coming decades is the inevitable rise of distributed generation (and storage). A recent study from BloombergNEF[30] showed unequivocally the rising competitiveness of such solutions, making their deployment largely inevitable in the coming decades. While storage often comes as a key question, one has to realize that energy storage can take multiple forms, some of them being already available at near-zero marginal costs within building assets (e.g. water tanks, etc.), and, needless to say, growingly actionable by the digital infrastructure in place[31]. Are there already many of the appliances we purchase which do not integrate a form of native connectivity? And when this is not the case, how long before it becomes mainstream? This transformation toward a “Prosumer” model will significantly transform grid operations and play a major role in redefining how energy exchanges are orchestrated over an entire grid. Drivers to such a transition are also not only economic. A generation of activists and individual entrepreneurs is likely to see in such a model a new form of fulfilling, while for many regions of the world, the reliability of existing power grids remains an issue, which such developments help address.

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[26] Cilia J. (2019), The Construction Labor Shortage: Will Developers Deploy Robotics?; McKinsey (2017), Reinventing construction: a route to higher productivity

[27] Lovins A. (2021), Profitably Decarbonizing Heavy Transport and Industrial Heat: Transforming These “Harder-to-Abate” Sectors Is Not Uniquely Hard and Can Be Lucrative; Material Economics (2018), The Circular Economy. A powerful force for climate mitigation

[28] Not accounting for further innovation on materials themselves.

[29] Schneider Electric (b) (2021), Cracking the Energy Efficiency case in Buildings

[30] BloombergNEF (2021), Realizing the Potential of Customer-Sited Solar

[31] See chapter 7 for more details

This new abundance of near-zero marginal cost energy will also trigger further transformations of the energy demand within buildings, and notably for the bulk of it, space conditioning (heating, cooling), leading to further electrification. This will be fostered by a new generation of heating and cooling technologies, with growing performance levels and likely better designs. Heat pumps are already 3-5 times more efficient than traditional boilers, and they are already competitive in many regions of the world, while their performance is expected to continue to increase over the coming decades[32]. As well, the (very relative) attractiveness of a boiler or furnace which sits in a basement is likely to be increasingly challenged by modern conditioning systems with superior design[33] and embedded connectivity.

New mobility patterns

Electrification of mobility (EV) will become a reality sooner than often anticipated. In 2014, Tony Seba[34] predicted a disruption by 2030. What may have appeared at the time to some as a fancy idea has almost turned into a prophecy. Everywhere, governments have taken actions to decarbonize road transport globally. The United States has pledged to make half of the new vehicle fleet electric by 2030. In Europe, a proposition is on the table to phase out internal combustion engines by 2035[35]. And who has a chance to travel to Shenzen, China, has a unique opportunity of a trip in a not so distant future. At the same time, BloombergNEF[36] estimates EVs to reach cost parity by 2025 globally, with some regions coming sooner than others, while costs will continue to go down in time. In fact, Seba argues that by nature EVs are less expensive since there are 100 times fewer parts in electric powertrains, and electric motors enjoy yields 3-4 times those of gasoline cars. Over time, they will thus be less costly to purchase, less costly to run, and less costly to maintain. And yes, they are also more fun to drive (no pollution, smoother driving, no noise, etc.). In fact, all what was needed was the capacity to store enough energy to run the car for several hundreds of miles. EVs have not yet similar driving range as gasoline cars, but technology progress on batteries[37] suggests they may in fact exceed conventional cars' autonomy within a few years. When they do, this is another pain point of the current system which disappears: will the next generations enjoy as much as we did to wait in long queues at the gasoline station? After all, electricity is today the most ubiquitous form of energy.

A second transformation is on its way, that of transport as a service. Several companies in the field have already redefined the way mobility can be provided as a service, removing many of the frictions that existed in the past, one of them even joining the global dictionary: uberization. There were indeed better alternatives than having to hail a taxi in a congested street on a rainy day. Many cities have also the ambition to limit the number of cars, in an attempt to resolve congestion and pollution issues. Transport as a service, alongside multimodal transport systems, makes it possible. And if owning a car has been an important sign of success and material wealth in the past, will it hold with future generations? Or will they prefer the convenience of digitally enabled, rapid and comfortable mobility services?

How accessible and affordable these services are has however remained an open question until now, but the rapid development of service offers, particularly in dense urban areas, makes the prospect of their further development highly likely. Can we question that this development will not further accelerate by 2050? In addition,

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[32] Schneider Electric (c) (2021), Building Heat Decarbonization; BloombergNEF (2020), Heating Unit Economics Calculator

[33] See for instance Redwell (2021), Using Redwell picture heating to put your own stamp on your home

[34] Seba T. (2014), Clean Disruption of Energy and Transportation

[35] Shepardson D., Mason J. (2021), Biden seeks to make half of new U.S. auto fleet electric by 2030; Carey N., Steitz C. (2021), EU proposes effective ban for new fossil-fuel cars from 2035

[36] BloombergNEF (2019), New Energy Outlook

[37] Bloch et al (2019), Breakthrough Batteries: Powering the Era of Clean Electrification

autonomous vehicles could add significant value to this development. Level 5 autonomy[38], when it becomes widely available, could both increase availability of transport as a service and reduce its costs. Several sources have notably estimated that autonomous transport as a service could reduce costs of mobility 5-10 times[39]. Sources differ on the timing, but it always happens before 2040[40]. The relative reluctance that continues to prevail over autonomous vehicles has also to do with the fear of accidents. A zero-accident level 5 system will certainly take decades to come. Let's remember however that several workarounds exist to make it safer, simply by reviewing traffic rules, and that, unfortunately, there are today 3,700 road crash deaths per day in the world, a reference point which a machine is likely to outperform within less than a decade, when this is not already the case[41]. And once again, the relative lack of interest already observed from current generations for driving may accelerate adoption. It may even appear to them as another irresponsible adventure to have let people drive tons of metals at high speeds in the first place!

All these developments could lead to a dramatic reduction on costs of mobility, making such a transition largely inevitable. This could however also lead to rebound effects in total demand for mobility services. In fact, two trends compete at the same time. A growing recourse to public or shared mobility services could reduce total kilometers travelled, while lower costs of transportation could boost the appetite for travelling. And in the context of new urban forms, possibly less "verticalized" cities than often anticipated, a rebound is in fact possible.

Other mobility patterns (ship, rail, aviation) will follow a different journey. Sufficiency[42] could yield a reduction in travels. This is particularly noticeable for business purposes. At the same time however, less physical interactions from remote connectivity and greater flexibility in work could boost demand for tourism and recreation. As well, the transformation of these modes of transport is less likely to rely on electrification at this stage (or only in part), but more on new fuels developments. These are likely to come as a result of major policy shifts and innovation.

New industrial world

Inevitably, the digitalization of our economy will pervade the industry sector as well, as it has already started. It is already well established that these new technologies offer a key recourse to declining productivity levels[43]. A quantitative study from 2016 has shown that – in the case of the automotive sector, one of the most automated sector already – the deployment of digital technologies could lead to double the Return on Capital Employed (ROCE) and profitability, and raise plants' utilization by more than a third[44]. The development of digital technologies spans across all categories of activity. It helps optimize facility operations and supply chains, but also facilitates customer interaction (and increase loyalty), and even more importantly further advances product designs. The potential of these technologies is thus spectacular, and we are only at the dawn of the transformations that they will inevitably yield.

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[38] Level 5 autonomy is the highest level of vehicle autonomy. Until level 4, a driver sits behind the steering wheel. Level 5 autonomy implies no driving seat and no steering wheel.

[39] Arbib J. & Seba T. (2017), Rethinking Transportation 2020–2030; Keeney (2017), The Future of Transport is Autonomous Mobility-as-a-Service

[40] Hamblen M. (2020), Self-driving vehicles will emerge, but only gradually, IDC says; Hyatt K. (2021), Elon Musk says Tesla's Full Self-Driving tech will have Level 5 autonomy by the end of 2021; Litman T. (2021), Autonomous Vehicle Implementation Predictions; Metz C. (2021), The Costly Pursuit of Self-Driving Cars Continues On. And On. And On

[41] Association for Safe International Road Travel (2021), Road Safety Facts

[42] Sufficiency is a change of behavior toward more frugality in use. It can be driven by technology or by self-adjustments and cultural evolutions.

[43] Immelt J. (2016), Digital Industrial Transformation. Presentation at the GE Oil & Gas annual meeting of 2016; McKinsey (2017), A Future That Works: Automation, Employment and Productivity

[44] Roland Berger (2016), Think Act beyond Mainstream. The Industrie 4.0 Transition Quantified

They will also be crucial in accelerating adoption of best available technologies. Multiple studies and practical examples have shown the potential to significantly optimize energy and resource demand[45]. Benefits could range between 10-20 percent across sectors and industries, with cutting-edge technology developments helping to lift these savings to 35 percent and above, with highly competitive paybacks. Industries show thus significant potential to continue improving the efficiency of their operations going forward, and digital technologies will play a crucial role in enabling this to happen.

Going further, as industries renovate to become more efficient, they are also more likely to see their processes evolve. In fact, the global push for decarbonization has led to renewed innovation in industrial processes, and a whole range of new developments is on the cusp of emerging. Direct reduction of iron, low-clinker cement, new mining techniques, or alternative materials and synthetic or bio-chemicals are all on the agenda of major players in these industries. And as these developments provide further differentiation, they will contribute to changing the overall industry landscape, in forms that have so far not received their full share of attention[46]. These transformations will also not only concern heavy industries but the whole array of manufacturing activities. Some studies have notably shown a significant potential for competitive switch to electrification, well above 80 percent across most sectors[47]. Often, the electrification of industrial processes is found to also bring additional benefits in terms of operational flexibility and final product quality[48]. Electrification of industrial processes is thus largely inevitable, a natural development with a growingly affordable and plentiful electricity resource. Ultimately, it is key to realize that, despite major productivity gains in the twentieth century (without which modern wealth would not have been possible), the foundations of our modern processes have in fact not evolved in over a century and owe to the remarkable innovations of the late nineteenth century. In a world where digital technologies redefine the boundaries of what can be computed (and therefore engineered), where nano- and bio-technologies redefine the historic table of elements, and where energy technologies redefine the volume of accessible energy (the technical retrievable potential of renewable energies is 25 times that of our current use[49]), it is not hard to predict major breakthroughs are at reach.

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[45] Allwood et al (2013), Material efficiency: providing materi-al services with less material production; Gutowski et al (2013), The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand; Schneider Electric (2019), Global Digital Transformation Benefits Report; International Energy Agency (2017), Digitalization and Energy; Petit V. (2017), The Energy Transition. An overview of the true challenge of the 21st century

[46] See notably Philibert C. (2017), Renewable Energy for Industry

[47] Beyond Zero Emissions (2018), Electrifying Industry; Madeddu et al (2020), The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat).

[48] Agora Energiewende & AFRY management consulting (2021), No-regret hydrogen: Charting early steps for H_2 infrastructure in Europe

[49] REN21 (2017), 2017 Renewables Global Futures Report: Great Debates towards 100% Renewable Energy

Competitive electrification

The general consensus that prevails is that the electrification of the economy will come at an additional cost for society. This statement is largely misconstrued, for four main reasons.

1. Relative energy costs are also (and often most essentially) a reflection of taxation schemes on various energy resources. In Europe for instance, there is in average 4 times more taxes (in absolute value) on electricity than on natural gas[50].
2. The competitiveness of various energy resources is assessed in final energy demand terms, while the actual measure to follow is the useful energy, or the unit of energy effectively used to provide a given service (motion, heat). Electric powertrains are 3 times more efficient than traditional combustion engines. Electric heat pumps are 3-5 times more efficient than gas boilers. And standard electric heating systems (for high-temperature heating) are generally 10-20 percent more efficient (without accounting for side benefits in terms of quality and process speed).
3. Current electricity costs (i.e. without taxes) are today a reflection of fossil fuel costs, since power generation is essentially fossil-fuel based. With transformation yields well below 70 percent (and often closer to 40 percent), electricity prices are higher than basic fuel costs. This paradigm is now put in check with the emergence of renewable energies which have no fuel costs and are projected to fall well below their fossil counterparts.
4. A significant share of retail electricity costs is that of the grid infrastructure. Distributed generation offers a new competitive source of energy which costs are by nature much lower since they do not integrate any grid infrastructure cost (even if they supply only part of final energy demand).

When real costs per unit of final energy are taken into account, a key finding is that electric solutions are often competitive with their fossil fuel counterparts or on the verge of becoming so. This obviously varies significantly across sectors and regions, with mobility and buildings heating as obvious first targets[51].

Beyond industrial operations, circularity will also kick in and play a more significant role than often projected. Climate change and environment degradation are obviously primary drivers of change for industries under scrutiny, but resource dependencies play also a fundamental role in reassessing how to best use and re-use (or recycle) resources. Beyond, optimizing product lifecycles and more importantly developing new service-oriented offers represent a key opportunity for greater customer loyalty, fostered again by changing appetites from new generations, more eager to access reliable and affordable – not to say free – services rather than purchasing expensive products. Some studies, once again, have demonstrated that there is economic value to adopt circular approaches, and that ultimately it will increase productivity and differentiation, in short provide a competitive advantage to those who adopt them[52]. The development of circularity is thus only a matter of time. New product designs will play a key role in making this transition economically attractive, and modern digital design tools provide already the right platform for such unfolding. When it comes to decarbonizing the economy, it is also worth to realize that circularity could play a defining role. Over 40 percent of total greenhouse gas emissions would be related to supply chains[53] globally. One of the key hurdles to the development of effective

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[50] Eurostat (2020), Data For Households

[51] See annex for more details

[52] Ellen Mac Arthur Foundation (2013, 2014), Towards the Circular Economy Volume 1-3; Lacy et al (2020), The Circular Economy Handbook: Realizing the Circular Advantage

[53] Material Economics (2018), The Circular Economy. A powerful force for climate mitigation; Science Based Targets, Navigant, Gold Standard (2018), Value change in the value chain: best practices in scope 3 greenhouse gas management

circular loops in the economy has to do with the overall orchestrating and scaling up of these new supply chains[54]. Yet, digital technologies are a powerful enabler of such transformations, and one can expect them to have largely reached maturity by 2050.

Another important transformation will be that of distributed manufacturing. Additive manufacturing is a well-known technology that has long been used for industrial prototyping. In recent years, however, its deployment has expanded to a whole range of new uses. It is now commonly used for spare parts manufacturing. It has been used in pilot projects as an industrial platform for specific machine designs. And it has even found its early adopters in the mass consumer market. Some even believe additive manufacturing to be on the cusp of revolutionizing the construction sector. A key limit of its deployment thus far has been the lack of digital infrastructure to share at scale design tools and resources. This is now changed and will continue to improve in the coming decades. As it materializes, it is likely to reshuffle at least those sectors where it makes most sense (low quantities, highly customizable). This could be a renewed source of wealth and abundance, if near-free design alongside affordable and widely available raw materials (from circular supply chains) could enable customized manufacturing, at home or in proximity manufacturing centers. And this could also be cause for a rebound in demand for goods of all types, and energy intensity of manufacturing[55]. Why change of running shoes only once in a year if you can “print” new ones next door every month for a fraction of the price?

The industrial world is thus also prey to significant transformations, fueled by technologies and cultural changes, and these changes are likely to significantly impact the energy system as we have known and anticipated it thus far.

Sector integration

All these innovations will have a significant impact on consumption. Since they come at a net benefit for consumers and meet growing appetites of new generations, they are also likely to be largely inevitable, the extent of which remaining to be understood in the time scale we contemplate in this report.

As well, none of these innovations are to be taken in isolation. Their unfolding indeed helps reframe the traditional conventions we have used for decades on energy demand. Historically, energy uses were split and evaluated separately across three main sectors: buildings, industry and mobility. There was reason to this: they could be monitored, and they followed different patterns of development. Now, the development of all these innovations will progressively reshuffle this historical articulation. In short, boundaries are blurring.

The Building / Mobility nexus

An obvious reality of the development of EVs is that charging will mostly happen in buildings. Range anxiety and overall lack of charging infrastructure have so far provided ground for the development of fast-charging stations across the countryside and within cities, in an attempt to replicate the existing system (a gas station) and reassure adopters on their ability to charge. If no charging capability exists within a

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[54] It is also critical to note that there are limits to certain developments, notably on materials’ recycling. See notably Labbé, J. (2016), Les limites physiques de la contribution du recyclage à l’approvisionnement en métaux. See annex for more details on assumptions.

[55] AMFG (2020), How Sustainable is Industrial 3D Printing?; Flaudi J., Van Sice C. (2020), State of Knowledge on the Environmental Impacts of Metal Additive Manufacturing; Gebler M., Schoot Uiterkamp A., Visser C. (2015), A global sustainability perspective on 3D printing technologies; Goodrich M. (2013), 3 D Printing: The Greener Choice; Gonzales C. (2021), Is 3D Printing the Future of Manufacturing?; Groot, A. (2018). The Future At Nike: 3D Printing Customized Shoes At Home; Jezard A. (2018), One-Quarter of Dubai’s Buildings Will Be 3D Printed by 2025; Reichental A. (2020), When it comes to 3D printing, how much sustainability is enough?; Schwaar C. (2021), 7 Ways 3D Printing Helps You Become Sustainable; Warren T. (2018), This Cheap 3D-Printed Home Is a Start for the 1 Billion Who Lack Shelter

home or a commercial building, and if there are no available charging stations, then adoption of EV is likely to be increasingly difficult, beyond early adopters.

Yet, range anxiety will fade away, fueled in part by growing range from EVs, with significant progress expected in this decade. As well, the charging infrastructure begins to be deployed, both in commercial and residential buildings, albeit not without key questions on the grid infrastructure. As these problems get solved, it is easy to picture that the bulk of charging will in fact ultimately happen within buildings of all forms, a trend confirmed by most forecasts[56]. And as it materializes, it will become more difficult to differentiate energy demand patterns between buildings and mobility. Mobility might well become another flexible load pattern of buildings of the future. In fact, their contribution to overall building energy demand flexibility could be a massive opportunity for cost savings[57].

The Building / Industry nexus

Building and industrial energy convergence is another interesting prospect. Provided the deployment of distributed manufacturing materializes, the traditional setting of industries could also be revisited. If more goods can be manufactured at home, or at least within proximity manufacturing centers, then the footprint of some industries could find itself displaced in several ways. There again, new dynamics of energy demand may materialize which we have only begun to understand.

The Building / Grid nexus

One of the key technological building blocks we discussed is solar photovoltaics (PV). To date, there has been very limited prospective efforts on the potential deployment of distributed energy resources on the rooftops of buildings and facilities, not to say this topic has been largely ignored. The main paradigm has remained that of large utility-scale farms, which essentially replicate the conventional power plants as we know them.

Yet, there is a considerable potential for distributed generation. A good proxy is the comprehensive study of Deng et al which came up to a global potential around 8 percent of final energy demand, with a 2050 projection of around 25 percent. The International Energy Agency comes close with 9,000GW of potential estimated today (which translates into a similar percentage). Other studies vary in scope and assumptions but yield similar results. The study from Apur and Egis on downtown Paris potential yields lower results, while that of Taminiau and Byrne for New York comes at higher levels. Google also estimated a total potential of 39 percent for the United States[58]. The bottom line is that the potential contribution of distributed energy is generally significant at global level, even if no silver bullet[59]. And this new energy source turns out to be extremely competitive with grid-sourced supply or is on the verge of being so across most regions of the world, making their adoption largely inevitable, as described in a recent publication from BloombergNEF[60].

A key sensitivity metric which helps explain the differences across forecasts is the actual suitability of rooftops to accommodate distributed generation. This is often constrained by design, or competing against other equipment (eg. HVAC, ventilation,

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[56] BloombergNEF (b) (2021), Electric Vehicle Outlook

[57] Schneider Electric (d) (2021), Electric Vehicle Smart Charging in Buildings

[58] Apur & Egis (2015), Analyse de potentiel solaire. Toitures du Grand Paris; Deng Y. et al (2015), Quantifying a realistic, worldwide wind and solar electricity supply; Google (2016), Reaching our solar potential, one rooftop at a time; ©OECD/IEA (2019), Renewables 2019. Analysis and Forecast to 2024; Petit V. (2021), The Age of Fire is Over; Taminiau J. and Byrne J. (2020), City-scale urban sustainability: Spatiotemporal mapping of distributed solar power for New York City

[59] See chapter 7 and annex for more details on the forecast presented in this report.

[60] BloombergNEF (2021), Realizing the potential of customer-sited solar

etc.). Accounting for all these limitations, the potential remains nevertheless significant. What is even more important is that, with growing attractiveness of this new energy resource, hence consumer-led demand, building designs will evolve to enable greater integration of these energies in modern construction assets, lifting the potential upwards, as portrayed by Deng et al, and as many recent examples suggest[61].

The inevitable development of distributed energy will thus also blur the frontiers between centralized infrastructure and "beyond the meter" assets such as buildings or facilities.

Circularity

The development of circular supply chains and business models will also considerably reshuffle how industry operates. As mentioned above, 40 percent of greenhouse gas emissions stem from material flows across industries. What applies to greenhouse gas also applies to materials and industrial outputs. Circularity, in this regard, is a game changer, which could have profound impact on both the footprint of certain operations as well as the way they effectively engage and trade. The traditional linear flow from mining to manufacturing and disposal which we use to delineate industrial operations might well be challenged with growing circular activities. Numerous leaders in heavy industrial activities have already taken stock of this and developed relevant strategies[62].

Regional distribution of consumption

A last aspect of these blurring frontiers is also the way energy demand spreads across regions. With global trade of goods soaring in the last decades, industrial footprints have evolved and so has their energy demand (and related carbon emissions). In fact, we can picture trade of goods and materials as massive exchanges of energy resources (their "embodied" energy). Many of the innovations we covered above also picture a world with significant reallocation of these footprints. In this issue, we will only focus on global results, but subsequent releases of this scenario will highlight regional developments and we will come back on this point.

Collateral effects and leapfrog

Beyond a redefinition of sectors, transformations in one sector also influence transformations in others. There is no better example than the development of lithium-ion storage which we described above.

The same can be expected from digital technologies. The development of more virtual environments within households has already an impact on office, shopping and recreation practices, fostering a transformation of the commercial building sector. The development of circular value chains with digital technologies will impact modern industrial footprints, alongside consumption habits and patterns. It has already started with many sharing platforms emerging in the last few years, and this is only a beginning. Digital technologies, together with circular supply chains, also create the foundations for the development of distributed manufacturing applications for the mass-market, with ripple effects on consumption, and possibly unanticipated rebound effects[63].

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[61] See for instance the Fraunhofer study on Integrated Photovoltaics, estimating a potential of above 1,000GW in buildings in Germany. Fraunhofer (2021), Integrated Photovoltaics – Areas for the Energy Transformation

[62] An inspiring example: Vicat (cement company) works at reusing the important carbon emissions of its process to produce green methanol through the combination of carbon dioxide and green hydrogen, an activity traditionally devoted to petrochemical organizations. Vicat (2021), Low-carbon trajectory: Vicat and Hynamics unveil Hynovi project

[63] See notably Groot, A. (2018), The Future At Nike: 3D Printing Customized Shoes At Home

The accelerated development of renewable energy sources (and storage) will also transform sectors beyond the energy infrastructure. As shared by Dorr and Seba[64], excessive availability of near-free energy could push a significant share of modern industries to shift toward electrification as a result. The energy system would shift from a "demand-following" model (supply adjusts to inelastic demand) to a "supply-following" model (demand adjusts to inelastic supply), providing major economic benefits to those embracing it, and all this greatly enabled by end-to-end digital capabilities across the value chain[65].

Finally, some of these transformations might as well compete with one another, blurring further the evolution of the energy system. In cities, a rebound in housing demand could be mitigated by increased sufficiency from new generations and possibly different demand for housing designs and stock. In mobility, lower costs of transportation are likely to increase demand, but again models based on sharing (carpooling, public transport systems) could undermine this trend. Finally, in industry, circularity business models, fueled by sufficiency, would lead to decrease in demand, but this pattern could be challenged by the rising availability of distributed manufacturing.

Energy transitions take time, overlap and are driven by a multitude of evolutions in services and consumption. The future energy system will be the complex product of such entanglements.

What will it look like?

The world in 2050 will be different from what we traditionally anticipate.
12 transformations provide a first glimpse of these changes. Though likely incomplete, it enables us to trigger a first experiment in assessing their impact on the overall energy system.

We have used this frame to reassess energy demand to 2050. The quantitative analysis has taken stock of the wide disparity of cases, modelling the unfolding of these various transformations across 13 sectors and 11 regions.

Granularity of the modelling exercise				
Sectors reviewed	**Buildings** - Residential (specific outlook on individual versus collective residential) - Commercial	**Mobility** - Passenger vehicles - Buses, 2-wheelers - Road freight - Aviation - Shipping	**Heavy Industry** - Steel - Cement - Chemicals	**Manufacturing Industry** - Automotive - Machinery - Other industries (specific outlook on consumer goods)
Regions reviewed	**Asia** - China, India, South East Asia, Pacific, Other Asia	**Middle East Africa** - Africa, Middle East	**Europe and Eurasia** - Europe, Eurasia	**Americas** - North America, Latin America

Figure 11 – Granularity of modelling

This granularity has enabled to refine projections, notably regarding adoption[66]. In this report, only global results are provided. Regional perspectives will be the object of subsequent publications.

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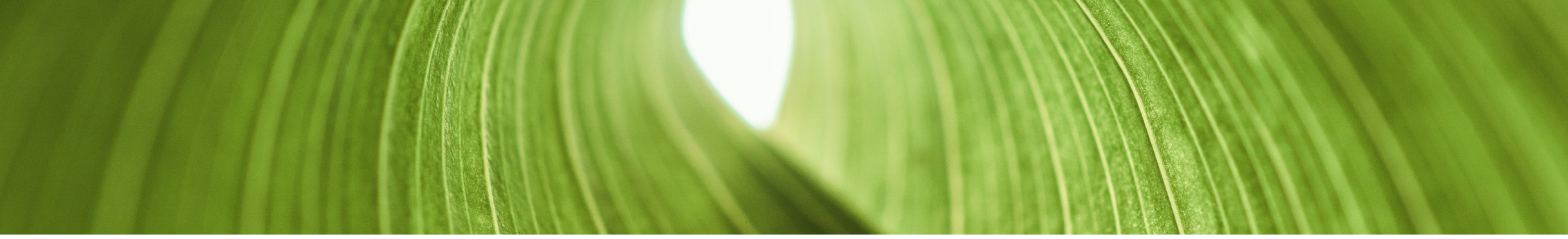
[64] Dorr A., Seba T. (2020), Rethinking Energy 2020–2030

[65] See chapter 7 for more details

[66] All quantitative assumptions are available in annex.

Two scenarios have also been developed, to take stock of the different cases of adoption.

- The *“New Normal”* scenario aims at identifying normal patterns of change, with no significant evolution in the policy context nor in market conditions. The intent is to highlight possible differences with the way energy demand is traditionally forecasted.
- *”Back to 2050”* is our central and backcasted 1.5-degree scenario, targeting a 30-50 percent reduction of carbon dioxide emissions by 2030 and a net-zero economy by 2050. The key objective is to explore the potential contribution of these (beneficial) transformations of consumption patterns into reaching a net-zero economy by 2050. **Would the solution to global decarbonization be to accelerate our transformation toward a modern (and inclusive) future?**



Chapter 3 – A 1.5-degree trajectory might be more feasible than we think

The main argument of this report is that a successful decarbonization strategy must take stock of the two key driving forces of energy transitions: **transformations of consumption patterns, and the development of the necessary infrastructure to supply them**.

In other words, while the traditional paradigm of existing decarbonization pathways is centered around infrastructure, the purpose of this report is to complement them with a consumer centric lens, a new approach full of learnings as the future demand side of the energy system will not resemble the past, and that this is that demand which decarbonization pathways must prepare for. The other merit of such approach is that it reconciles decarbonization and social progress, by accelerating natural evolutions which are intrinsically good for both the climate and the population.

Both our scenarios look at the same transformations, albeit with different paces of unfolding. While the scenario *“New Normal”* focuses on natural evolutions, the scenario *”Back to 2050”* frames a favorable policy environment which, having taken stock of the potential of a more consumer-centric approach, drives a rapid decarbonization of the economy.

The energy system is growing naturally more efficient

Final energy demand only increases by 15 percent by 2050 in the *“New Normal”* and decreases by 15 percent in *”Back to 2050”*, compared to a baseline which grows (all other things being equal) by over 70 percent (Figure 12). Ongoing evolutions of consumption thus tend to **mitigate the rise in energy demand to much lower levels than often anticipated**. In other words, the global economy grows more efficient, thanks to the (inevitable) adoption of modern technologies across all sectors. Pushing the envelope in *“Back to 2050”* helps stabilize demand further.

The share of electricity grows from around 20 percent to date to 40 percent in the *“New Normal”* and 60 percent in *“Back to 2050”*. **The electrification of the economy is thus largely inevitable**, and a key finding of this analysis is that its development is probably underestimated. While oil and coal demand decreases across all scenarios (by 30 percent in *”New Normal”*, and 70-90% in *“Back to 2050”*), the demand for natural gas stabilizes in the former, fueled by growing demand in areas where little innovation on electrification technologies has happened (lack of policies triggering innovation). It however falls in a scenario consistent with a near-total decarbonization of the economy (by 70 percent in *“Back to 2050”*).

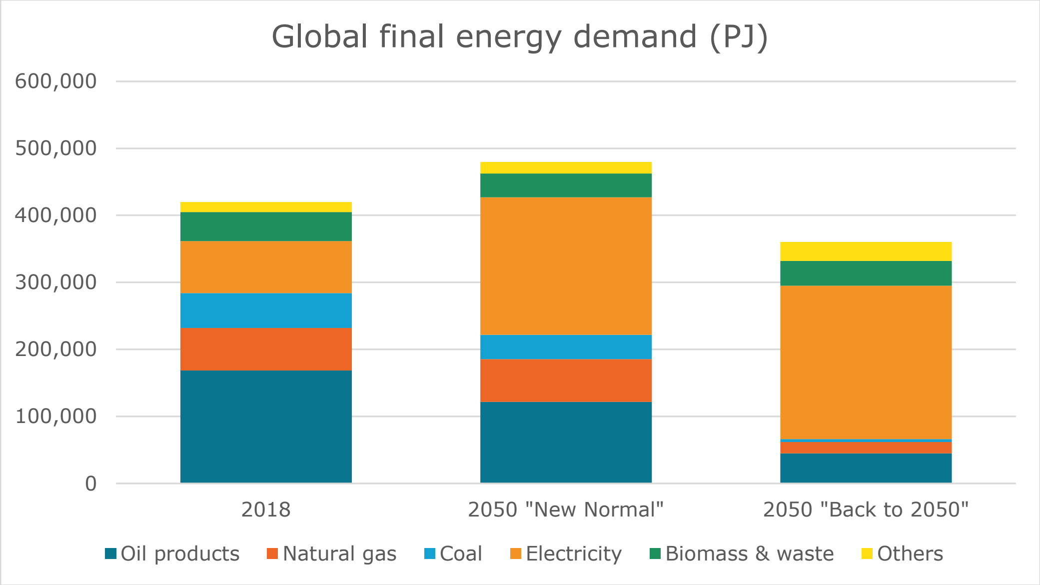


Figure 12 – Final energy demand and emissions[67]

The economy is becoming less carbon intensive, and a net-zero economy is achievable by 2050

We look here at carbon dioxide emissions from energy and industrial process emissions, or a baseline of around 35,000MtCO2 per year. In other words, we focus on all sectors of economic activity outside of AFOLU (Agriculture, Forestry and Land Use). We also do not look at non-carbon dioxide emissions. This scope of review corresponds to around 70 percent of global greenhouse gas emissions.

A first key finding is that carbon dioxide emissions decline by 30 percent in 2050 in a scenario with no reinforcement of the current policy framework (Figure 13). In other words, **a 30 percent abatement of carbon dioxide emissions is driven by the natural adoption of more competitive and modern services and goods[68]**. This is because positive transformations in consumption patterns are intrinsically less carbon intensive. They account for 50 percent of the global abatement. The remaining decarbonization of the economy comes from the energy supply system (out of which power generation forms the bulk of the issue), which emissions drop by 30 percent (without additional policies).

In *"Back to 2050"*, the decarbonization of the economy reaches 85 percent, down to around 5,500 $MtCO_2$ per year, which require to be compensated by negative emissions (Carbon Capture, Utilization and Storage on key industrial facilities, Direct Air Capture and Nature Based solutions). As large as this volume may look at first glance, it sits at the lower end of most existing range estimates[69]. **It is thus possible to reach a net zero economy by 2050 by focusing on accelerating positive transformations in consumption: a more efficient, electrified and competitive economy**. In this scenario, transformations on the demand side indeed account for 50 percent of total decarbonization, while the near complete decarbonization of the power sector accounts for the rest (as well as a significant reduction on other energy resources).

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[67] We decided not to use 2020 as a baseline due to the major impacts of Covid-19 on energy demand during that year and consider 2018 (or 2019) to be a closer estimate of a true baseline.

[68] This ratio is over 50 percent if we compare it to 2050 baseline emissions, evaluated from the natural increase in economic activity (and population), all other things being equal. See annex for more details.

[69] See chapter 7 for more details

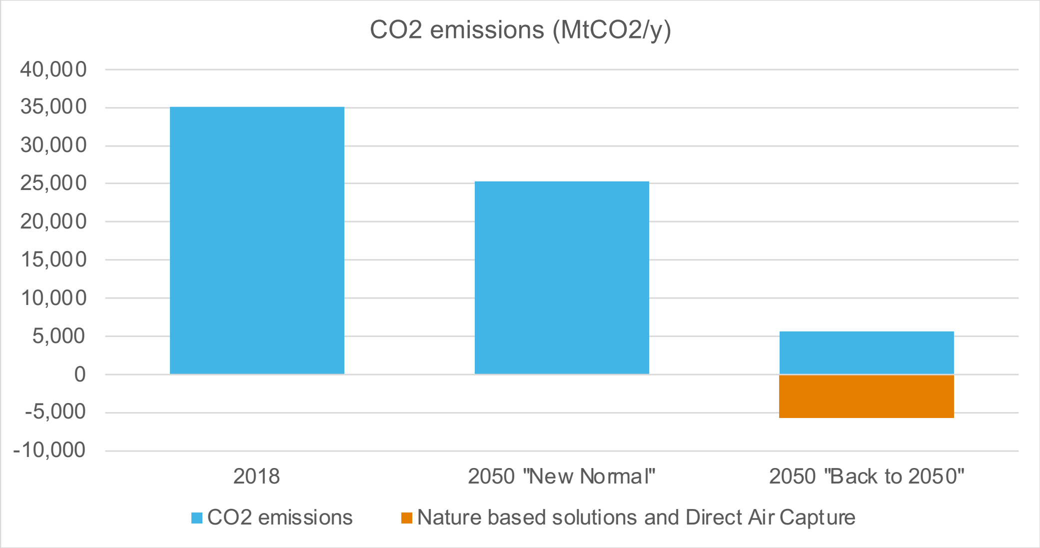

Figure 13 – CO2 emissions

2030 is a key milestone

Global emissions need to be reduced 30-50 percent by 2030 for the world to remain on a trajectory globally compatible with a long-term 1.5-degree global warming[70]. A deeper look at our central scenario *("Back to 2050")* shows that emissions are reduced by around 30 percent by 2030, a pathway consistent with the above imperative (Figure 14). In this scenario, transformations of the demand side of the energy system account for 50 percent of the total abatement, with the other half coming from the supply side of the energy system. **A significant focus on the transformation of the demand side is thus critical for a proper decarbonization of the economy**.

The challenge to get there is however daunting. Global final energy demand drops 9 percent by 2030 in this scenario. Electricity demand rises 50 percent, while the demand for oil and gas drops 15-20 percent, and that of coal by around 50 percent (across both industry and power generation). Such a transformation thus requires a significant acceleration of the transformation of global consumption patterns toward the future model, across all sectors of activity (cities, mobility and industry). While the effort to 2050 is equally as important across affluent and new economies by 2050 (with different patterns of development), the bulk of the effort to 2030 revolves around affluent economies[71], as they represent above 70 percent of global emissions.

This challenge may also be rewarding, however, as it essentially represents an investment into new consumption patterns which inherently benefit consumers, as described in chapter 2. **This new narrative on an inclusive and rapid decarbonization of the economy through its accelerated modernization is the main argument of this report.**

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[70] Schneider Electric (2021), The 2030 imperative: a race against time

[71] OECD countries and China.

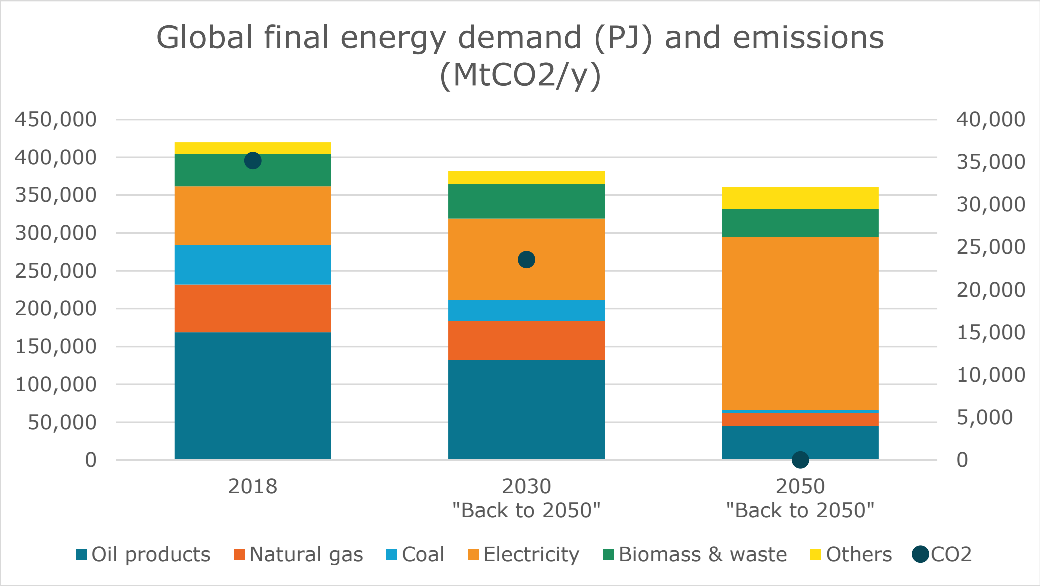

Figure 14 – Route to zero emissions[72]

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[72] Emission levels include negative emissions in this graph.

Chapter 4 – Sectorial deep dive – New urban forms drive a new energy system in cities

New urban forms change energy uses

Figure 15 highlights key evolutions in the building stock. The baseline corresponds to current levels of building footprint (the baseline is square meters of surface – sqm). The share of new constructions, aggregated energy intensity improvements and the penetration of electric solutions are also presented.

Two disruptions fundamentally change the urbanization landscape to 2050: a positive productivity disruption in the construction industry and an increased virtualization of living environments (enabling new models of remote engagement for work, shopping and recreation). These two disruptions lead to the emergence of new urban forms, driven by lower costs of housing and lesser needs for commute. These yield a rebound in the demand for residential space and a lower footprint than anticipated for commercial activities. The extent of this unfolding however varies across our two scenarios. In *"Back to 2050"*, the natural rebound effect on residential demand is mitigated through policies (while going full swing in the *"New Normal"* in key regions currently urbanizing, with an aggregated growth of nearly 20 percent). The development of home office is also significantly encouraged in the scenario *"Back to 2050"*, compared to the *"New Normal"*, where its unfolding is more diverse across regions[73].

The building stock also continues to evolve. The share of new buildings corresponds to around 65-70 percent for residential and 50-55 percent for services[74]. While rates of new construction are relatively similar across both scenarios (despite differences due to the above developments), renovation rates vary significantly (current levels for the scenario *"New Normal"*, accelerated renovation programs in *"Back to 2050"*). Performance standards are also different across scenarios, with more stringent requirements in the scenario *"Back to 2050"* for both new build and renovation. Renovation performance (energy intensity reduction compared to current levels) are also lower than what can be reached with new building standards[75]. These efficiency gains in energy use are also largely supported by the natural penetration of digital technologies within living environments which bring better control of occupancy (on top of other services), hence energy efficiency. This forms the bulk of the savings in the existing stock in the *"New Normal"*, and acts as a complement to more traditional (yet expensive) renovation measures in the scenario *"Back to 2050"*. Sufficiency practices also contribute and vary only slightly across scenarios.

Finally, the significant penetration of distributed generation discussed above essentially occurs in buildings[76]. As it provides access to highly competitive electricity, a significant shift toward electrification takes place, for both heating and cooking. This happens in the *"New Normal"* primarily in new constructions, and to a lower extent in the existing stock (mostly for oil and coal heating as part of natural modernization of the stock). This is however accelerated in the scenario *"Back to 2050"*, where heat pump penetration reaches around 70 percent of the stock across both residential and services.

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[73] These figures are expressed in percentage of current activity. Residential footprint currently corresponds to 80 percent of the total footprint. The impact of rebound in residential demand is thus much larger in square meter terms than that of services, despite a lower percentage. See annex for more details.

[74] This obviously varies significantly across regions as these figures correspond to a globally aggregated mix. The share of new buildings is much lower in affluent economies, and higher in new economies.

[75] See annex for details on assumptions. We have taken different performance levels for renovation and new constructions, with different assumptions across scenarios and regions.

[76] See chapter 7 and annex for details on estimates of distributed generation.

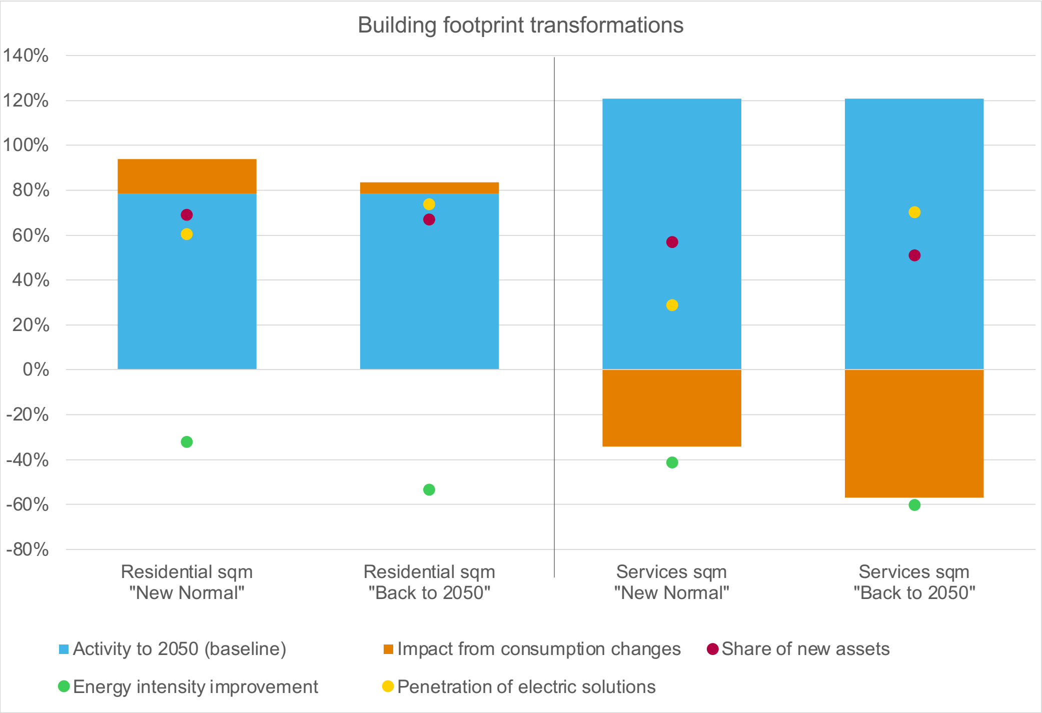

Figure 15 – Building development patterns

New energy uses drive a new energy system

The final energy mix evolves as a result of these transformations in consumption patterns (Figure 16). Since less effort occurs on the existing stock in the *"New Normal"*, the transition to more efficient buildings and electrified heating and cooking solutions is less pronounced. In the scenario *"Back to 2050"*, these transformations accelerate in the existing stock and fossil fuels, including natural gas, are substituted almost entirely. The significant share of traditional biomass in buildings today is progressively substituted by electrification across all regions. This is accelerated in the scenario *"Back to 2050"* and complemented in select regions by a partial migration to biogases. While direct heating (both district and renewable heating) increases slightly at global level, there is virtually no role for hydrogen in buildings. The share of electrification increases substantially as a result, driven by growing and inevitable competitiveness of electrified heating solutions, up to 60-75 percent in residential (respectively scenario *"New Normal"*, *"Back to 2050"*) and 70-85 percent in services[77].

By 2050, **direct emissions from the building sector drop 50 percent in the *"New Normal"* and are nearly zeroed in the scenario *"Back to 2050"*** (210 $MtCO_2$ per year), from a 2018 base of nearly 3,000 $MtCO_2$ per year.

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[77] Schneider Electric (c) (2021), Building Heat Decarbonization. The combination of increased distributed generation (lower costs of electricity) and learning rates on heat pumps makes the case of electrified heating obvious in most regions of the world by 2050.

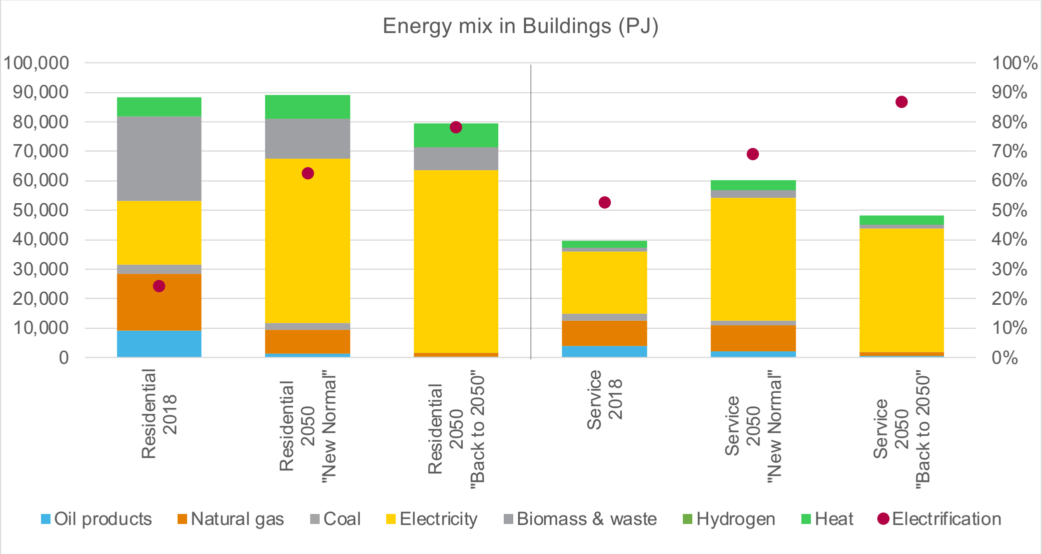

Figure 16 – Building energy mix, per segment[78]

How robust is this scenario?

The primary intent of this exercise is to show how changes in traditional demand patterns ultimately reshape the energy system, and their potentially significant contribution to the global decarbonization agenda. It is however based on many assumptions on rates of adoption, which are themselves the output of key tipping points and policies (in the scenario *"Back to 2050"*).

While we do not believe in a role for hydrogen heating in buildings, the role of biomass is highly prey for challenge. Traditional biomass for heating is likely to be progressively substituted by more efficient electric or direct renewable heating solutions. Biogases (integrated here) could also play a complementary role, possibly larger than anticipated, depending on locally available resources.

Our scenario considers however that ultimately electrified heating and cooking solutions are a more compelling alternative, as explained earlier. This however assumes several things to happen in parallel

- The development of a robust power infrastructure, notably in new economies, and potential upgrades and reinforcement in affluent ones[79].
- Accelerated learning rates and technology improvements on heat pumps which will ultimately make electrified heating an obvious consumer choice, a prospect we consider highly likely with demand growth[80].
- Evolutions in taxation systems across different energy resources. Current energy taxation schemes are indeed highly favoring fossil fuel resources globally, making the case currently more difficult for electrification. How policy frameworks will evolve in this regard remains a major question[81].

Finally, our scenario *"Back to 2050"* assumes a significant renovation effort on the existing stock, the only way to achieve near total decarbonization of the building stock by 2050.

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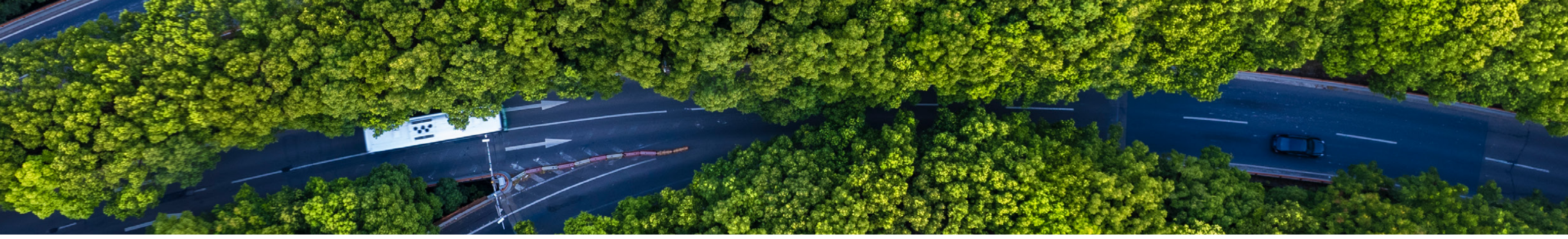
[78] Heat corresponds to both district heating and direct heating solutions (such as solar heating for instance).

[79] See chapter 7 for more details.

[80] See notably our study on building heat decarbonization and the impact of taxation on electrified heating competitiveness. Schneider Electric (c) (2021), Building Heat Decarbonization

[81] Ibid



Chapter 5 – Sectorial deep dive – New mobility patterns drive a new energy system

New mobility patterns change energy uses

Figure 17 summarizes key evolutions in demand for mobility uses. The unit of activity is kilometers travelled[82].

Passengers' transportation is increasing thanks to increased access to mobility in most new economies of the world (activity level is rising). The demand for road mobility services is impacted by lesser commute, but the cost disruption in the sector from electrification, transport as a service and the rise of autonomous vehicles leads to a rebound in demand (and a natural trend toward individual based transportation), aggravated by a more distributed footprint of urban landscapes. This rebound in demand is however compensated by further modal shifts which are significantly encouraged in the scenario *"Back to 2050"* with policies that notably promote the use of public transportation within cities. While the baseline accounts for a near doubling of kilometers travelled, we estimate only a minor reduction to that baseline in the *"New Normal"*, but a 50 percent abatement in our policy-driven scenario.

Road freight demand is essentially impacted by the reconfiguration of industrial footprints stemming from circularity, distributed manufacturing, and optimization of logistic flows.

In the rail and aviation sectors, the demand for services is impacted by behavioral changes, notably with a reduction of domestic and international business travels. We have not taken any specific assumption on the evolution of tourism to 2050 compared to baseline. In the scenario *"Back to 2050"* however, policies further encourage the switch from domestic air travels to rail, in an attempt to accelerate decarbonization. This leads to a material reduction in demand for aviation, compensated by rail activity.

Electric Vehicles (EVs) reach around 50-70 percent of the global fleet by 2050 (respectively scenarios *"New Normal"* and *"Back to 2050"*), for both private transport and road freight. In fact, this relatively conservative penetration rate has to do with slower than anticipated ramp up of the EV charging infrastructure (in the absence of policies) and a significant discrepancy between affluent economies (already equipped with a large and resilient power infrastructure) and others, which essentially continue to rely on traditional combustion engines (with a large market of second-hand vehicles). This issue is mitigated in the scenario *"Back to 2050"*, as international support accelerates the development of the infrastructure in new economies. The share of EV in road freight is also estimated to be similar to that of private transportation. We indeed estimate the progress on batteries and logistic flows redesign to accommodate EVs in fleets will prove more competitive over time than the development of alternative infrastructure (such as hydrogen refueling stations). With significant targets on decarbonization in the scenario *"Back to 2050"*, further innovation in air and shipping leads to short-haul services to be partially electrified as well.

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[82] For private transport, we use passenger kilometers travelled (PKM). For freight, tons kilometers travelled (TKM).

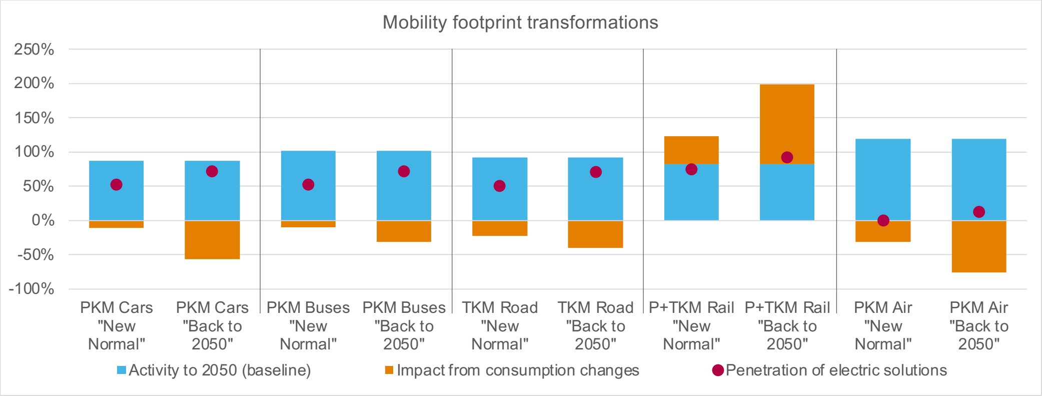

Figure 17 – Mobility development patterns

New energy uses drive a new energy system

The final energy mix is a direct consequence of these innovations in mobility patterns (Figure 18). Despite a significant growth in service level across all scenarios, the energy demand of road mobility reduces. This is essentially due to the electrification of the system, which increases up to 30 percent in the *”New Normal”* and 55 percent in the scenario *“Back to 2050”*. In the latter, this is also further accelerated by an optimization of service demand, as discussed above. The role of biofuels and hydrogen remains minor (at global level) across all scenarios. Oil demand drops 45 percent in the *“New Normal”* (from natural electrification of the fleet given compelling economics), and 80 percent in the scenario *“Back to 2050”*. The key question is whether new economies will switch to EVs in the time frame to 2050.

The demand for other services continues to increase, albeit at slower pace than anticipated. Rail continues its natural electrification, and only small portions of the network which are not easy to electrify continue to run on fossil fuels by 2050. Aviation and Shipping show no significant transformation in the *”New Normal”*, in the absence of key policies to push decarbonization. In the scenario *“Back to 2050”* however, decarbonization of these sectors is almost complete. While aviation shifts to biofuels, shipping is switching to hydrogen-based ammonia. Upcoming innovations also enable partial electrification of short-haul niche markets in both segments.

By 2050, **direct emissions from the mobility sector drop 25 percent in the *”New Normal”* and 85 percent in the scenario** *“Back to 2050”* (1,300 $MtCO_2$ per year), from a 2018 base of nearly 8,000 $MtCO_2$ per year.

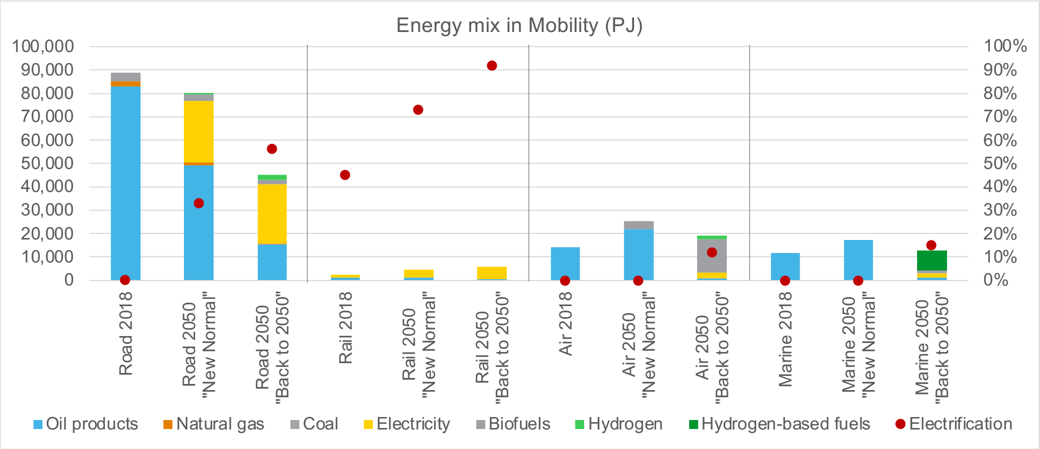

Figure 18 – Mobility energy mix, per segment

How robust is this scenario?

The primary intent of this exercise is to show how changes in traditional demand patterns ultimately reshape the energy system, and their potentially significant contribution to the global decarbonization agenda. It is however based on many assumptions on rates of adoption, which are themselves the output of key tipping points and policies (in the scenario *"Back to 2050"*).

One of the key questions at hand is the expected progress on battery technologies, fueling EV adoption. While there is generally high confidence in the potential of upcoming breakthroughs in this industry, the full electrification of road freight could stumble on more limited developments than expected. This could leave room for alternative decarbonization fuels (such as hydrogen) to emerge in the upper part of the chain (long-haul freight). We however believe a more natural development route could likely revolve around new logistic flows adapting to more competitive EV powertrains, a topic on which there is limited research to date.

Adoption of EV is also constrained by the development of a proper charging infrastructure, a highly relevant issue in new economies as well as in affluent economies, though to a lower extent[83]. This shift to EVs could also be further hampered by deflationary pressure on oil prices (from lower demand), and delay further the switch. Globally coordinated policies on this matter would thus play a critical role.

The demand in biofuels in our forecast essentially stems from aviation transition to zero-carbon fuels. These assumptions are derived from the work of the Energy Transitions Commission[84]. This is however still an object of debate. Other approaches favor hydrogen fuel cells (but there are mainly at pilot stage), synthetic kerosene (from the combination of hydrogen and carbon dioxide, although the cost of such solution remains a question), or simply running on fossil fuels combined with offset programs (negative emissions, or bio-offsets).

Finally, the accelerated demand for rail transport could stumble on few key roadblocks. One of them is obviously the necessary development of the infrastructure in regions with limited footprint. Another is the exact carbon footprint impact of developing railroad systems when accounting for the necessary material requirements (notably steel) and associated "embodied" carbon emissions. It should be noted however that a significant share of this growth in demand happens within cities and remains a very powerful solution to mitigate congestion from individual transportation. More research is likely required on this front.

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[83] See chapter 7 for more details.

[84] Energy Transitions Commission (2018), Mission Possible.

Chapter 6 – Sectorial deep dive – Industry decoupling drives a new energy system

Industry decoupling changes energy uses

The industrial sector is the cornerstone of access to modern living standards and is as a result significantly impacted by many of the transformations discussed (Figure 19).

First, the development of a competitive sharing economy, fueled by new appetites from generations Z and alpha, and competitive service-oriented business models (for machines, mobility, buildings, etc.) all contribute to a reduction in demand for virgin goods, across all sectors of activity. This has as a result a significant impact on the demand for primary materials (steel, minerals, chemicals) and we assume their unfolding likely across all scenarios (albeit with slightly different assumptions on adoption). The rise of distributed manufacturing however leads to a slight rebound in demand for consumer goods, but it has only a minor impact on the demand for primary materials due to greater resource efficiency.

The disruption in the construction industry (alongside new building designs) and in the mobility sector also significantly limit the demand for virgin steel, cement and plastics. Two thirds of the demand for steel indeed come from the construction and automotive sector, and the bulk of cement demand is associated with construction.

All these innovations lead to a natural decoupling of industrial production versus access to goods. This decoupling is more pronounced in the scenario *"Back to 2050"*, due to ambitious policies which accelerate their competitive unfolding in the time frame to 2050. In this scenario, the actual demand for steel and cement flattens, that of consumer goods is in retreat, while the demand for other capital goods only grows by 20 percent.

Recycling rates for steel and plastics are also significantly improved, notably in our central scenario (*"Back to 2050"*) where policies push for further adoption, and as new supply chains and digital traceability tools develop at scale. This is particularly relevant in affluent economies where stocks are nearly saturated (for steel mainly) by 2050[85].

With several rounds of upgrades on industrial facilities, the overall sector is making further strides in improving its energy and resource intensity as well, through the progressive implementation of best available technologies and digital solutions, an evolution which is accelerated in the scenario *"Back to 2050"* thanks to clear policy incentives[86]. Energy intensity improvements are however negatively impacted by the rise of distributed manufacturing in the consumer goods sector due to higher energy intensity levels of additive manufacturing[87].

These industrial facilities also take greater stock of the major opportunity of highly affordable (yet intermittent) renewable electricity and progressively electrify their operations. This is more relevant for the chemical sector, and manufacturing (including food and beverage production), for which competitive electrified heating[88] is reached sooner than in other sectors. Once again, policies further accelerate these natural trends in the scenario *"Back to 2050"*.

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[85] Assumptions on rates of recycling take into account the available potential from materials reaching end of life as well as their actual recyclability levels at end use. More details are available in annex. See also notably Labbé, J. (2016), Les limites physiques de la contribution du recyclage à l'approvisionnement en métaux.

[86] The total share of new assets is declining in the scenario "Back to 2050", because of lower demand and increased recycling.

[87] See annex for more details.

[88] This is due to both the ability to electrify heating systems in current operational setups as well as the ability to make production more flexible (and take the opportunity to access highly affordable electricity as a result). See chapter 7 and annex for more details.

Finally, while limited innovation on current processes takes place in the *”New Normal”* (lack of incentives), a significant shift toward new processing techniques occurs in the scenario *“Back to 2050”*, further reshaping industrial operations[89].

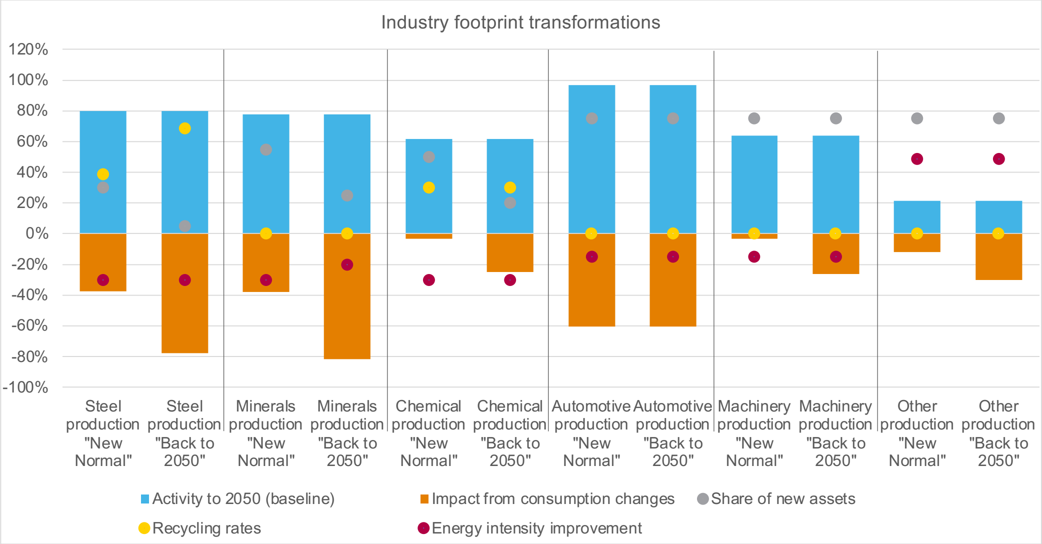

Figure 19 – Industry development patterns

New energy uses drive a new energy system

Figure 20 highlights how these key transformations in use reshape the energy mix across all segments. This graph only shows energy uses and does not take into account feedstock.

A first key point is the stabilization (and even reduction) of energy demand across most industries, and particularly in primary material industries such as steel, minerals and chemicals. This stabilization is less pronounced in manufacturing (others) due to the impact of distributed manufacturing (which shows higher energy intensities) which mitigates efficiency gains.

All sectors also tend to electrify. This is due to both the growing competitiveness of electrified heating as well as the rise of recycling in primary materials (particularly on steel and to a lower extent on plastics), and this is accelerated in the scenario *“Back to 2050”* with ambitious policies to decarbonize industry and the switch to new industrial processes[90]. Overall electrification of industry rises up to 40-65 percent of final energy demand across scenarios (and 50-80 percent if we exclude feedstock). In the scenario *“Back to 2050”*, electrification reaches 95 percent in manufacturing, 85 percent in chemicals, 60 percent in steel, and a lower 30 percent in cement, what is commonly assumed to be the maximum economically achievable[91].

Hydrogen demand for high-temperature heating purposes (not feedstock) remains limited to steel and minerals. For minerals notably, it competes with natural gas which continues to be in use in 2050 in the sector.

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[89] For steel, the adoption of Direct Reduction of Iron; for cement, low-clinker technologies and CCUS (Carbon Capture Utilization and Storage); for chemicals the development of synthetic and biosourced fuels, etc. We have not taken any assumption on the development of additive practices in the manufacturing sector at this stage. See annex for more details.

[90] See annex for more details.

[91] Madeddu et al (2020), The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat).

By 2050, **direct emissions from the industry sector drop 20 percent in the *"New Normal"* and 75 percent in the scenario** *"Back to 2050"* (2,500 $MtCO_2$ per year), from a 2018 base of nearly 10,000 $MtCO_2$ per year (including process emissions).

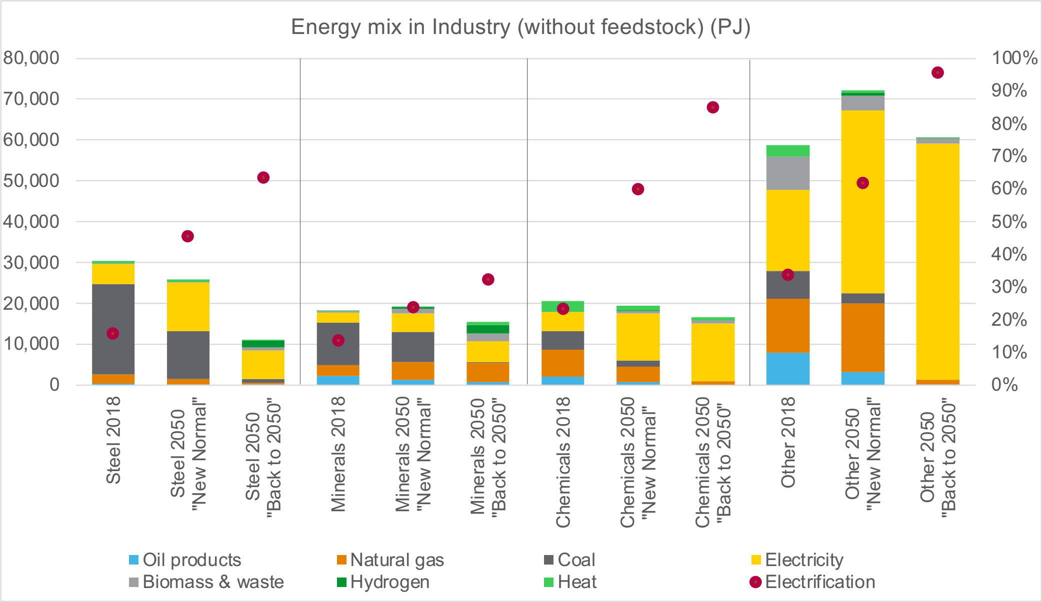

Figure 20 – Industry energy mix, per segment[92]

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[92] Figure 21 only represents energy use, feedstock is not accounted for.

How robust is this scenario?

The primary intent of this exercise is to show how changes in traditional demand patterns ultimately reshape the energy system, and their potentially significant contribution to the global decarbonization agenda. It is however based on many assumptions on rates of adoption, which are themselves the output of key tipping points and policies (in the scenario *"Back to 2050"*).

A first discussion could revolve around the actual development of a true circular economy: new business models, the development of the sharing economy, and a significant increase in recycling. These developments could be hampered for some time if new product designs fail to embed circular approaches and if supply chains take more time to develop, all issues proper policy incentives can help accelerate. We believe however our forecast to be rather conservative, as manufacturing is a more concentrated market than real-estate or mobility (and highly inter-dependent). We thus argue that changes in industry are likely to be faster than generally anticipated.

A second question could revolve around the rates of electrification in various industry sectors. While we have assumed competitive electrification to be at reach across many sectors with the development of highly affordable renewable energies (provided storage helps capture these intermittent flows[93]), high-temperature heating solutions still show low technical readiness levels. Our assumptions are based on external studies and essentially focus on these areas where solutions are known and technologies already available. However, a key question will be the necessary development of the supporting power infrastructure (power grids), which could limit the pace of development[94]. An alternative could be the provision of hydrogen for industrial heating, particularly in large industrial setups (and clusters) where significant production exists already (mainly for feedstock). We estimate however that the economics of direct electrification are likely to be more compelling, but this clearly remains an open question to date[95].

Our estimate of the potential of biomass in industry is also very limited, particularly when compared to other external scenarios[96]. We generally estimate biomass supply availability is a key concern going forward for its use as an energy resource[97]. In chemicals, however, it could be further used as a feedstock to produce bio-sourced products (e.g. bioplastics). As this develops, biomass waste could lead way to its use as an alternative for heating purposes, further raising its share in the final energy mix of the segment.

Finally, the development of carbon capture, utilization and storage (CCUS) in cement, necessary to abate industrial process emissions, could be further extended to also address energy-related emissions (and notably the use of coal), challenging our projection of a switch away from coal. As discussed in chapter 2, innovations on the use of carbon dioxide at the back of cement facilities could lead way to alternative models, such as notably the production of a variety of chemicals.

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[93] See chapter 7 and annex for more details.

[94] Ibid

[95] Ibid

[96] Notably the International Energy Agency Net Zero Emissions scenario. © OECD/IEA (2021), Net Zero by 2050

[97] While biomass is traditionally considered a zero-carbon resource, we should also remember that burning biomass generates significant volumes of carbon dioxide in the atmosphere and is as well a key contributor to ambient air pollution.

Chapter 7 – Sectorial deep dive – A new infrastructure at the heart of the transition

The final energy system will be more electric, with a share of electricity rising from around 20 percent to 40-60 percent of the total mix by 2050 (across both scenarios). **Electricity demand will rise around 3 times current levels as a result**. This significant increase is likely one of the defining aspects of the upcoming energy transition and a trend which has made overwhelming consensus worldwide. As the world modernizes and decarbonizes, it also becomes more electric. Yet, the way all this electricity will be supplied and delivered will also be the object of significant innovations and transformations of the traditional paradigm of the twentieth century power infrastructure.

A new power system emerges, inexorably

Our modelling exercise suggests global power generation increases from 25,000TWh to 65,000-74,000TWh by 2050 (across both scenarios). Due to growing competitiveness of renewable energies, the power generation mix also evolves toward more renewable energies, which account for 70 percent of the mix by 2050 in the *"New Normal"* and 85 percent in the scenario *"Back to 2050"*, compared to 25 percent today (including all renewable energies, notably hydroelectricity, Figure 21).

While coal is progressively abandoned (at a slower pace in the *"New Normal"*), the fate of natural gas and nuclear essentially depends on policies in place. Natural gas keeps its share in the *"New Normal"* (doubling in volume) and its demand is halved in the scenario *"Back to 2050"*, while the demand for nuclear power remains stable in volume in the *"New Normal"* and increases in the scenario "Back to 2050", up to around 7 percent of the global mix by 2050 (or twice current volumes of production). The bulk of the increase in renewable energies comes from wind and solar photovoltaic (PV) which shares increase from a few percent up to respectively 34 percent and 38 percent.

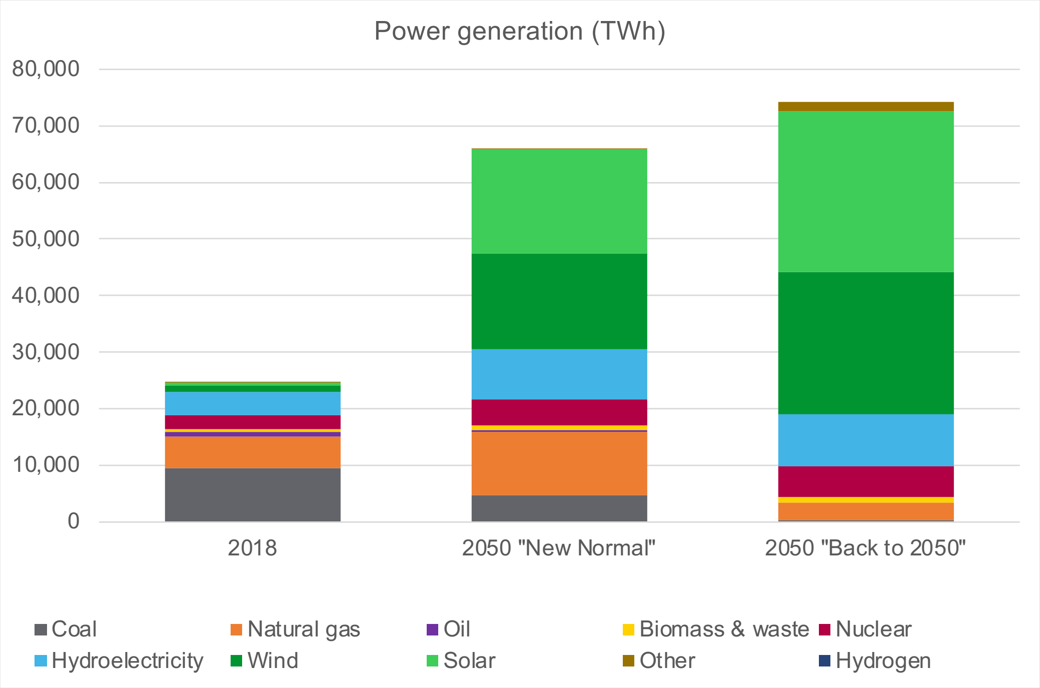

Figure 21 – Power generation

Major role for distributed generation

Another key finding of this review is the share of distributed solar generation which represents the largest opportunity for solar development to 2050. Land use constraints and reluctance from neighboring communities indeed slow down the development of utility-scale solar once most accessible sites have been used. In parallel, the obvious economic rationale of distributed generation progressively materializes worldwide, notably in new constructions. Consequently, solar PV begins to be integrated broadly in new constructions and building designs evolve to increase its potential. With improved economics, solar PV then begins to pervade the existing stock. Full adoption is well on its way by 2050[98]. By then, **distributed generation reaches up to 8,000TWh in the *"New Normal"* and 16,000TWh[99] in the scenario *"Back to 2050"*** (Figure 22).

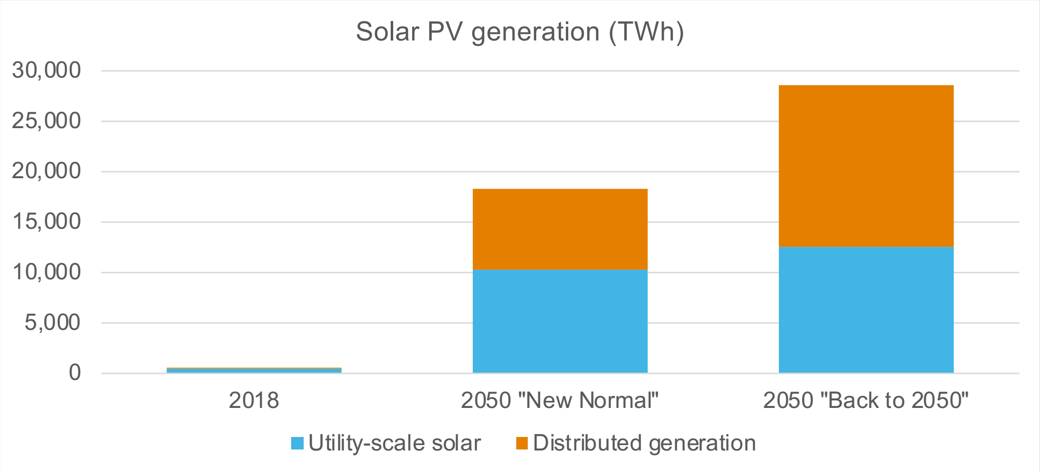

Figure 22 – Solar PV generation

A new energy supply paradigm

Existing models on energy (and electricity) supply all follow the same approach. They match demand with supply and look at how to optimize utilization of supply assets in order to keep infrastructure costs as low as possible. Historically, fossil-fuel based power plants have operated as "dispatchable" resources to fuel an inelastic demand. The main objective has been to maximize utilization. Yet, the history of power capacity utilization has shown that installations generally operate at much lower utilization levels than theoretically possible[100]. This has created many concerns on the true Levelized Cost of Electricity of new investments and prompted questions on costs of electricity going forward and possible risks of assets stranding[101].

The emergence of a large share of solar and wind energy is putting this debate back front and center. Since these resources are by nature intermittent, their capacity factor is low, typically below 20 percent for solar and around (or above) 30 percent for wind[102]. The Levelized Cost of Electricity for these resources is however low (and getting lower), because of relatively low upfront costs (compared to a conventional plant) and very limited operational expenses (low maintenance costs, no fuel costs). In practice, renewable resources are prioritized in a pure merit-order dispatching system. They have historically been prioritized by regulation (as costs were high),

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[98] See annex for more details on this forecast.

[99] This is twice current estimates from the International Energy Agency. © OECD/IEA (2021), Net Zero by 2050.

[100] See for instance Energy Information Agency (2021), Capacity Factors for Utility Scale Generators Primarily Using Fossil Fuels; Digest of UK Energy Statistics (2021), Plant Loads, Demand and Efficiency (5.10)

[101] Dorr A. and Seba T. (2021), Rethinking Energy. The Great Stranding: How inaccurate Mainstream LCOE Estimates are Creating a Trillion-Dollar Bubble in Conventional Energy Assets

[102] This is highly dependent on location, daily weather patterns and season. For wind notably, offshore resources offer considerably higher capacity factors than onshore systems.

but their growing competitiveness makes them now prioritized even without such measures.

The overall power system is thus moving toward a low-utilization system, which is at odds with current wisdom, and poses key questions on the actual Levelized Cost of Electricity going forward. There is however a major difference between conventional and renewable resources. Since renewable resources are intermittent, their production is not flexible (not “dispatchable”). If there is excess supply at the time of production, the energy is wasted (curtailment), and the actual utilization lowered (hence the cost of electricity is higher). This is particularly of concern for solar PV. Since conventional resources are “dispatchable”, they operate on demand, and their capacity factor is a function of whether more affordable resources are available at the time of operation, or not. As they get progressively substituted by renewable energies (at times of important supply), their average capacity factor is lowered (increasing the cost of electricity).

Hence comes the need for storage. If excess supply of intermittent renewable energy can effectively be stored, then overall capacity factors of various resources can be optimized again, thus costs. This is because there is no large-scale storage capacity (either at grid level or beyond the meter) today that the transition to renewable energies is essentially thought out to come at a cost, and why electricity prices are expected to be on an increasing course.

Yet, once again, considerable research is taking place in the sector. Batteries (notably from EVs) have made the news in recent years, but many additional technologies either already exist or are on the verge of coming to market. Research on grid-scale storage solutions is at its climax and we can safely anticipate that, combined with battery, they will bring solutions to the issue[103]. Behind the meter, a considerable potential also exists, and solutions are well known. As the bulk of energy demand is thermal conditioning (heating, cooling), in both buildings and facilities, thermal storage has long proven to be a highly affordable solution. There again, key innovations look at optimizing building design and facility operations to take provisions for larger thermal storage capacities. The electrification of heating does not necessarily require to be backed up by batteries, and cooling demand could also be stored through thermal storage solutions.

In addition, the flexibility potential of load demand has so far largely remained untapped, despite a significant potential, notably in industry[104], helping to access energy (and run operations) at times where plentiful near-zero marginal cost resources are available, a possible game changer for many industries.

As all these developments materialize, the full potential of highly affordable renewable energies (at their maximum capacity factor) can then be harvested, pushing down energy prices as a result, and leading to lower costs of energy compared to current.

This has even prompted new philosophies of supply systems development[105]. The essence of these new concepts is to oversize the supply capacity (compared to current needs) and use oversized energy storage systems (that are affordable to build, with no or limited maintenance costs) and flexible demand approaches to maximize the use of a plentiful low cost energy resource. In such development, the cost of energy drops by an even more significant factor compared to our current “dispatchable” paradigm, which relies largely on (increasing) fuel costs.

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103 Hart D., Bonvillian W., Austin N. (2021), Energy storage for the grid; © OECD/IEA (2021), Energy Storage; Princeton (2021), Grid-scale electricity storage; University of Michigan (2021), US Grid Energy Storage Factsheet. Many of these research efforts look at developing storage capacities which are not only affordable, but also capable to store vast quantities of energy, possibly across seasons.

104 Philibert C. (2017), Renewable Energy for Industry

105 See notably the work from Dorr and Seba. Dorr A., Seba T. (2020), Rethinking Energy 2020–2030

This is because of these trends that we have taken key assumptions on electrification of the stock, notably in industry. **Highly affordable electricity could make the electrification case more compelling than often anticipated[106]**. As penetration increases, such evolution of the power system would also have very significant consequences on the way energy ends up being valued and traded.

Sector integration and a new grid infrastructure

The other change of paradigm in infrastructure will be the future development of grids, the backbone of modern energy supply. In the initial chapter of this report, we alluded to the critical role of infrastructure development in accelerating the unfolding of innovations, hence energy transitions. The development of a resilient grid infrastructure backbone, capable to meet new patterns of electricity use, will thus play a fundamental role going forward. Failing to develop such infrastructure in time also means slowing down the transition to a net-zero carbon economy.

Yet, these developments take multiple forms.

New urban forms drive a new grid development paradigm

There are several transformations that reshape the landscape of urban centers: a more distributed urban stock, more efficiency in the build environment (with different patterns between existing renovated buildings and new constructions), the rise of distributed generation in buildings, electric mobility (with EV charging in buildings), and the electrification of heating and cooking. These transformations significantly reshape energy demand in buildings and invite to reflect on the traditional taxonomy of current energy systems, what is also referred to as sector integration. The key point is that buildings become the epicenter of many new activities and that electrification serves as their energy backbone.

Activity growth leads to a near tripling of electricity demand (from a baseline of around 12,000TWh). Electrification (heating, cooking) adds another 5,000TWh, to which needs to be added the extra demand for mobility electrification at around 6,300TWh[107]. At the same time, energy efficiency (including sufficiency) provides 14,500TWh of savings and distributed generation 16,000TWh of energy, taming part of this extra demand. Figure 23 provides a perspective of these different elements.

A first key conclusion is that a considerable potential exists to mitigate the additional electricity demand within the building stock from electrification and mobility by a greater recourse to both energy efficiency and distributed generation.

In practice however, these transitions will take different forms between the existing stock and new constructions. Indeed, 75 percent of the potential of distributed generation is in new constructions[108]. As well, new constructions will naturally take stock of these new uses, and the corresponding infrastructure will be developed, from the start, to accommodate them. The potential of distributed generation is so important in new buildings that it could offset a sizeable share of the load. The energy effectively transiting through the grid could be much lower than in a conventional case, while bidirectional exchanges would also become the norm. Provided most of the energy from distributed generation can be stored efficiently, and load flexibility be further harvested through smart controls (notably for heat and mobility), the overall

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[106] See more details in annex on how this could be the case in various sectors.

[107] For mobility, we have assumed 90 percent of EV charging is done within buildings. BloombergNEF (b) (2021), Electric Vehicle Outlook. We have not modelled here the impact of distributed manufacturing but part of it could also materialize in building premises, as discussed in chapter 2. See annex for more details on its impact.

[108] See annex for details.

infrastructure capacity could thus be significantly optimized. In such case, **buildings would also become energy centers (an integral part of the infrastructure, also servicing mobility and some industrial services), fundamentally changing the purpose of the grid**.

The case in the existing infrastructure (serving the existing stock) is however likely to be different, and under more pressure to cope with increases in demand. Both distributed generation and efficiency will prove key in mitigating the size of the issue, but since the potential of distributed generation is lower on the existing stock, energy efficiency will play a more fundamental role, while load flexibility will also become paramount. As infrastructure upgrades in cities prove long and expensive, they represent a potential roadblock to a rapid transition, which can only be mitigated by a significant effort on the renovation and the digitalization of the existing stock.

Taking it a step further, the future development of infrastructure in new urban forms could also mix both existing and new buildings to optimize the potential of distributed generation at the district level. In such a case, commercial buildings should certainly be a key point of focus, because of faster stock turnover rates.

Obviously, quantified analyses of such impacts can only be assessed in capacity terms (and not in energy terms), a study we have not done in this issue. Yet, we consider these highlights to remain robust in line of the evidence. This obviously assumes a significant potential for distributed storage, which we have already argued is largely achievable in the time frame to 2050. As well, situations are likely to differ very significantly from one area to another, making global perspectives very challengeable. It remains nevertheless that a significant focus on an efficient infrastructure development, taking stock of the abatement potential “behind the meter”, will prove key in enabling a rapid shift toward decarbonized cities.

New industrial footprints drive a new grid development paradigm

In the scenario *“Back to 2050”*, the scale of transformation is massive from an energy standpoint and yields significant impacts on the grid infrastructure. Overall, electricity demand increases by 50 percent in steel, two-fold in minerals, and three-fold in chemicals and manufacturing. This massive increase in electricity demand (around 15,000TWh) calls for significant grid infrastructure development.

Energy efficiency will play a critical role to mitigate demand for industrial heat as it electrifies. Yet, current low levels of electricity demand yield a lower potential for energy efficiency measures (on electric systems) to mitigate the additional stress on the existing grid infrastructure[109] (Figure 23). In short, the current infrastructure is currently not sized to cope with such an increase. While new facilities may be built right from the start with the appropriate grid infrastructure, the issue may become prominent for the facilities already in operation, particularly in segments with slow stock turnover.

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[109] Energy efficiency on heating loads will be a key enabler to limit the rise of electricity demand when switching to electric processes. However, due to the low baseline of electricity demand (25 percent of total energy demand in industry), efficiency on current electric loads will have a limited impact on creating space for additional electrification.

Highly efficient heat pumps can substitute fossil fuels with performance levels (COP) well above 100 percent in some industrial sectors (as for buildings), hence mitigate the need for additional electricity, but the situation is more complex for high-temperature heating processes, where heat pumps are not suitable and efficiency gains less relevant, leading to a significant rise in electricity demand.

The development of local distributed generation capacities could play a crucial role in mitigating this rise. We have not modelled it specifically here, as it mostly relates to connecting directly large industrial facilities to utility-scale renewable farms. In fact, some large industries may decide to develop their own energy production facilities (provided space is available), but the question is to which extent such provisions could supply the actual load demand. Industrial clusters (regrouping a variety of large industrial facilities and distributed energy resources) offer an interesting solution to the future development of the sector, by taking stock of such issues in grid development, and many projects have begun to develop[110]. As well, distributed storage (notably thermal) and flexibility in production[111] could once again help optimize the potential of such approaches by increasing the harvesting of renewable resources.

Traditional grid development will however remain compulsory in the sector, and a successful transition to a more decarbonized industry will ultimately depend on how fast and well the infrastructure develops. Lagging developments could significantly slow it down.

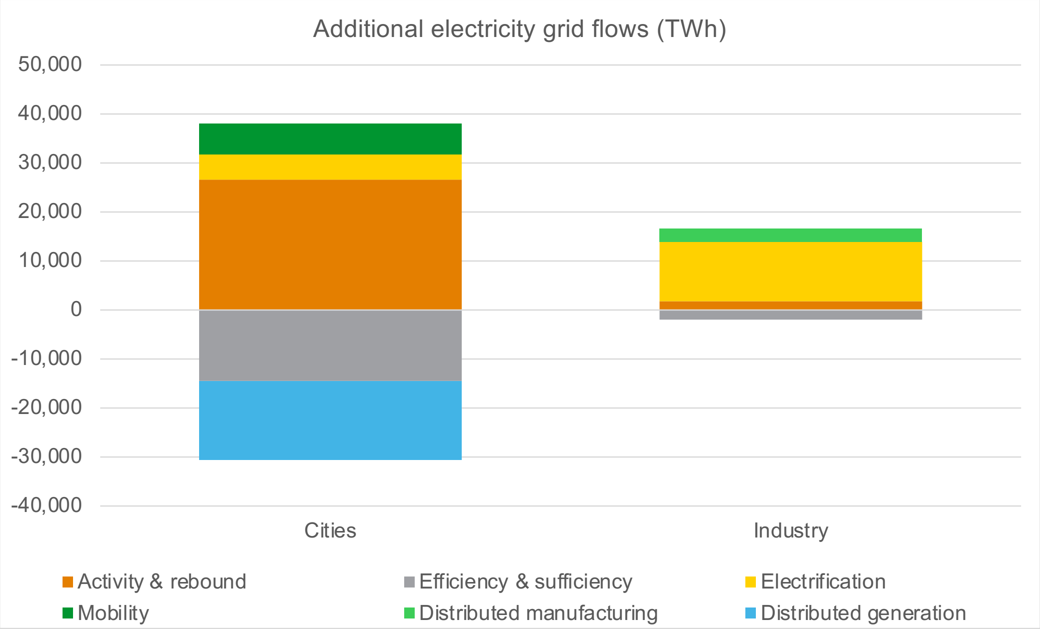

Figure 23 – A new infrastructure paradigm, scenario *"Back to 2050"*[112]

Transitional impacts

The history of energy transitions has shown that they always rely on the proper infrastructure to be put in place to ramp up, once innovations have emerged. Most innovations discussed above have already begun to emerge, but their future unfolding will depend on how well and at which pace the future grid infrastructure will be developed. One of the key findings of this short review is that **the infrastructure must not only be thought in terms of the traditional transmission and distribution grids, but also integrate the vast array of distributed generation, storage and energy efficiency, as building and facilities grow over time into energy centers**.

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[110] Snieckus D. (2021), German steel giant Salzgitter goes green with pioneering wind-plus-hydrogen pilot; Bailey M.P. (2021), Major Green Ammonia and Hydrogen Project Announced in Morocco

[111] A number of industrial processes are indeed highly flexible, notably the production of hydrogen (for feedstock). See notably Philibert C. (2017), Renewable Energy for Industry.

[112] We have included the additional impact of distributed manufacturing in industry on this graph, in order to be consistent with our approach throughout the report. As alluded to in chapter 2, however, part of this demand could in fact materialize in building premises.

When it comes to meeting a 1.5-degree trajectory, the key question – beyond accelerating the emergence of these transformations – will thus be the development of this future infrastructure. **Failing to apprehend the true potential of resources "behind the meter" as an integral part of a future collaborative infrastructure could thus delay this transition by some time, while making its development cost likely more significant than it really needs to be**.

Other infrastructure needs

Hydrogen

Hydrogen plays an important role in the energy transition, both as a feedstock and an energy resource. In our central scenario *("Back to 2050")*, demand for hydrogen grows from 90 million tons a year up to nearly 280 million tons by 2050, or a 3-fold increase.

This increase, as significant as it is, is however much lower than many scenarios. On the higher end of the spectrum, BloombergNEF sees a potential of up to 1,200 million tons by 2050 (with scenarios ranging between 200-1,200 million tons), and the Energy Transitions Commission a potential of 500-800 million tons. The International Energy Agency estimates in its Net Zero Emissions (NZE) scenario a potential of 530 million tons. On the other side of the spectrum, IRENA sees a contribution of 240 million tons[113]. Such discrepancies across forecasts highlight the significant uncertainty on the scale of hydrogen infrastructure development.

Figure 24 compares the forecast from the scenario *"Back to 2050"* to that of the International Energy Agency Net Zero Emissions scenario. Overall demand by 2050 is twice lower. While the forecasts are relatively similar in terms of industrial demand (energy and feedstock), at around 170-180 million tons per year, the scenario *"Back to 2050"* projects a demand of "only" 100 million tons in mobility, nearly half of that of the NZE. This is essentially coming from a lesser use of synthetic fuels in aviation and more importantly a lower penetration of hydrogen fuel cell vehicles in road transport, which converges instead toward electric powertrains. Finally, the scenario *"Back to 2050"* does not anticipate any use for hydrogen in buildings, nor in the power sector[114] (mainly due to very poor efficiency levels of conversion).

In terms of electricity demand, the required power generation for green hydrogen production reaches 14,500TWh in the NZE and 9,200TWh in the scenario *"Back to 2050"*, both with significant impacts on power generation. This corresponds to two-thirds of green hydrogen in the scenario *"Back to 2050"*.

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[113] BloombergNEF (c) (2021), New Energy Outlook; Energy Transitions Commission (b) (2021), Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy; IRENA (2020). Global Renewables Outlook: Energy Transformation 2050; © OECD/IEA (2021), Net Zero by 2050

[114] One of the key questions regarding the use of hydrogen in power generation revolves around its use for long-term seasonal energy storage. Given low efficiency levels of conversion, we consider in this report that other storage solutions (many of them being currently considered or at pilot stage) could ultimately prevail, as being intrinsically more competitive. As well, the exact needs of seasonal storage remain a highly regional topic which requires more research.

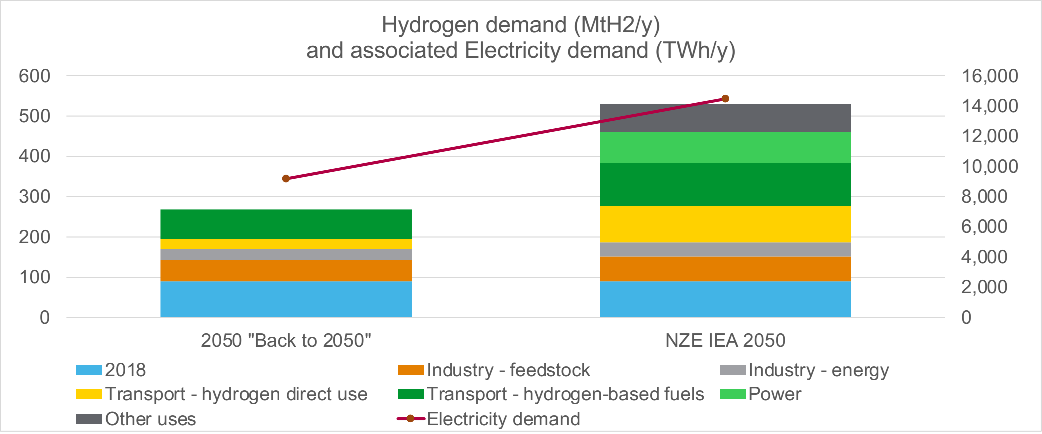

Figure 24 – Hydrogen demand

Biomass supply

The scenario *"Back to 2050"* is also very conservative when it comes to biomass demand, given current uncertainties on how rapidly and sustainably supply can be scaled, and the necessary arbitrages in many regions of the world with other land uses, notably agriculture.

Overall consumption of biomass ranges today around 43,000 petajoules, mainly stemming from traditional biomass use in new economies for heating, cooking and lighting. This type of use is expected to drop significantly in the decades to come as modern forms of energy (notably electricity) develop. The scenario estimates around 9,000 petajoules demand by 2050, a five-fold reduction from current levels.

Yet, increases in other forms of biomass use, for building heating, biofuels, and industrial heat, yield a 2050 forecast of nearly 48,000 petajoules, a figure globally consistent with current demand, which requires however the development of a sizeable biomass industry.

This figure sits well in the boundaries of what is traditionally considered the true sustainable potential of biomass supply for energy and industry, ranging between 30,000 and 50,000 petajoules per year[115].

Bridging the gap toward net-zero

Around 5,500 million tons of carbon dioxide remain in 2050 in the scenario *"Back to 2050"* (Figure 25). These emissions need to be further compensated by negative emissions, essentially coming from carbon capture, utilization and storage (CCUS) and other negative emissions such as nature-based solutions and direct air capture.

We find that CCUS reaches nearly 3,000 million tons. The power sector is entirely decarbonized (after accounting for CCUS). For industry, when accounting for industrial energy emissions, and industrial process emissions, there remains around 1,600 million tons to be abated (after accounting for CCUS). The mobility sector also continues to generate 1,300 million tons of carbon dioxide (and the building stock around 200 million tons[116]). These residual emissions can be further offseted by the recourse to nature-based solutions and direct air capture.

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[115] Energy Transitions Commission (2021), Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible

[116] Other transformations, once CCUS is accounted for, also yield nearly 400 million tons of negative emissions.

While the true potential (and cost) of direct air capture remains to be fully confirmed, nature-based solutions could also provide for such abatement. Several studies have shown that their potential is greater than what is accounted for in this forecast[117].

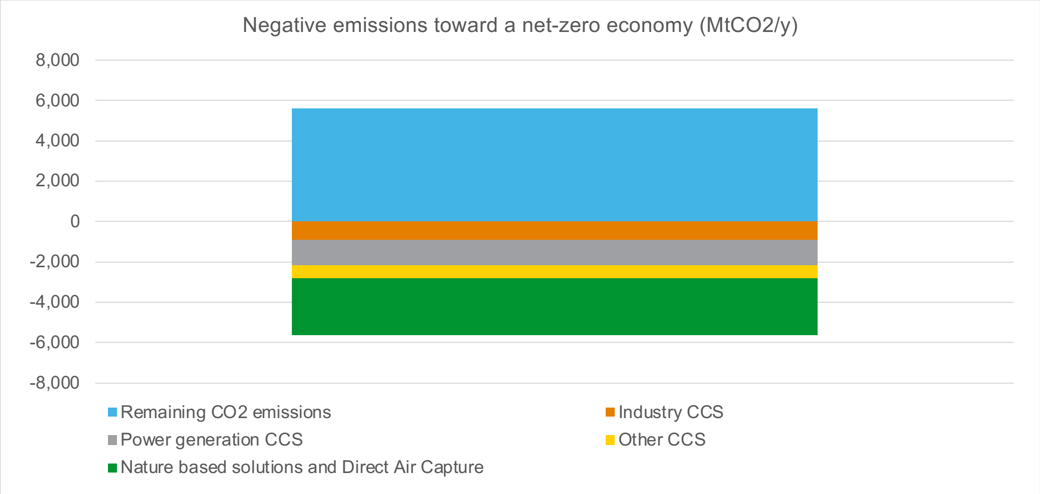

Figure 25 – Negative emissions

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[117] Energy Transitions Commission (2020), Making Mission Possible; IIASA & IAMC (2018-2019), IAMC 1.5°C Scenario Explorer hosted by IIASA; IPCC (2018), Global Warming of 1.5°C; Arbib et al. (2021), Rethinking Climate Change

Chapter 8 – Major drivers of change to watch

A consumer-centric approach to make it to zero

This report has illustrated that key transformations in consumption patterns will reshape the future energy system in ways that are often overlooked. Their development is largely inevitable due to the inherent benefits they bring, and for many of them are also positive contributors to climate change mitigation, hence our argument that the modernization of the economy plays a key role in overall decarbonization by 2050. We focus here on the scenario *"Back to 2050"* and assess the contribution of each driver to overall decarbonization. In buildings, direct emissions drop from nearly 3,000 million tons to around 210 million tons by 2050. The baseline shows an increase in emissions of around 30 percent. This includes a 10 percent impact from rebound effects. There are three critical contributors to the decarbonization of the sector. Efficiency measures on the existing stock and new building standards provide significant abatement. This is further accelerated by sufficiency (about a third of the total abatement of this category). These measures help bring back emissions to their current levels by 2050. Then, electrification helps further reduce emissions, and is further complemented by other fuel switch (e.g. to heat or modern biomass). Overall, one third of the abatement comes from efficiency and sufficiency, 50 percent from electrification and the rest from other fuels switching (Figure 26).

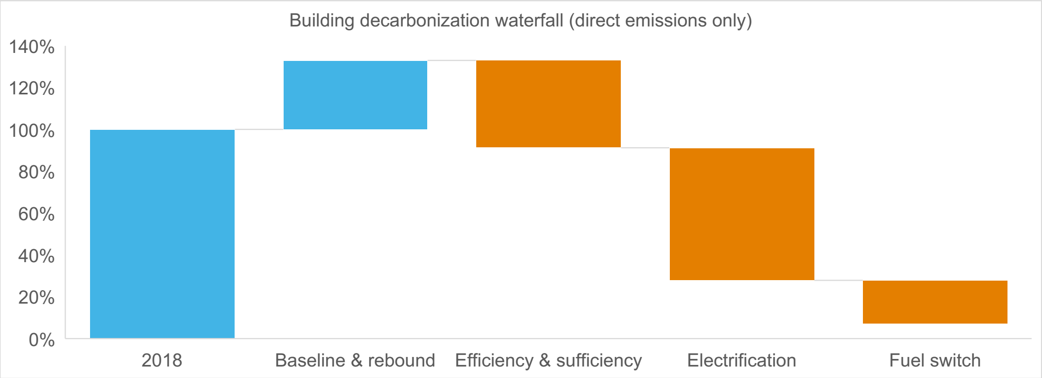

Figure 26 – key drivers of change in buildings

Figure 27 shows a similar waterfall for the mobility sector. There, modal shifts play a crucial role in total abatement, helping to stabilize emissions of the sector despite a growth in activity (and rebound effects from lower costs of mobility). Modal shifts account for 50 percent of total abatement in the sector. Electrification of the stock contributes around one third of total abatement, and is further complemented by adoption of new fuels (notably for aviation and shipping). By 2050, emissions from the sector drop from nearly 8,000 million tons to 1,300 million tons.

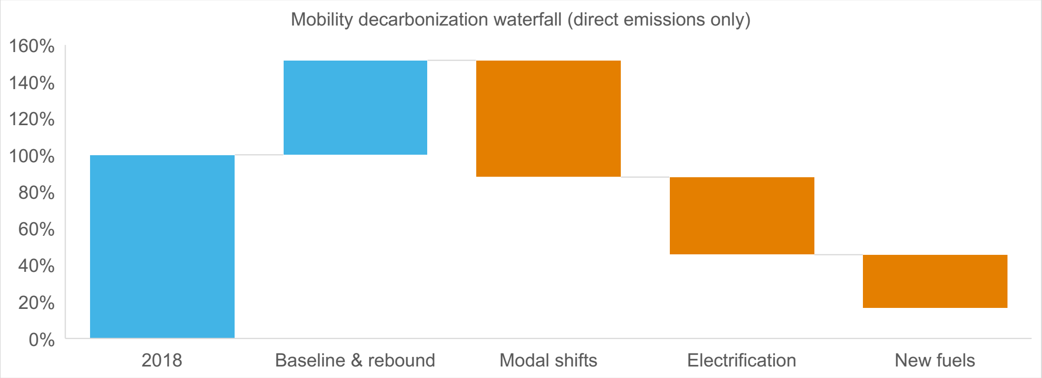

Figure 27 – key drivers of change in mobility

In industry, emissions drop from nearly 10,000 million tons (including process emissions) to 2,500 million tons (and 1,600 million tons if we include the deployment of carbon capture, utilization and storage systems). The first key driver is circularity and efficiency. It includes the development of a sharing economy, the impact of circularity measures from other sectors (construction, automotive), and the progressive upgrade of industrial processes toward greater energy and resource efficiency. Overall, this driver helps maintain emissions at current level despite a baseline growth of around 50 percent (including rebound effects, notably from distributed manufacturing), and contribute nearly half of the total abatement in the sector by 2050. The second key driver is electrification, contributing around one third of the decarbonization of the sector. It is further complemented by the recourse to alternative fuels where electrification is not achievable in the time frame to 2050, and a lower contribution of carbon, capture, utilization and storage (CCUS)(Figure 28).

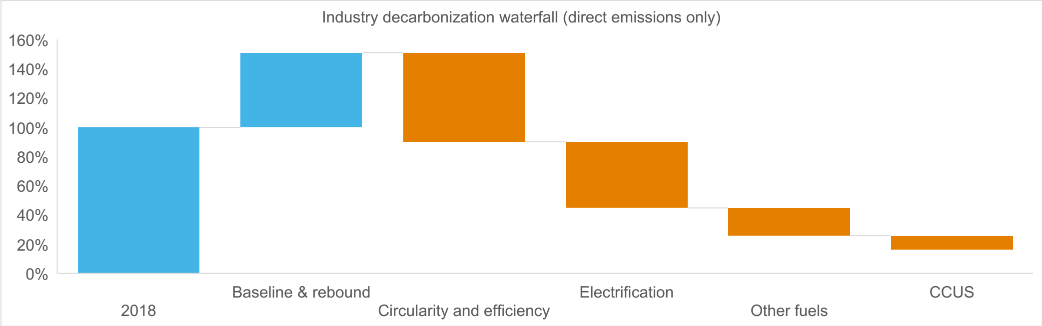

Figure 28 – key drivers of change in industry

A key takeaway from this review shows that both demand side optimization (efficiency, circularity, behavior changes such as sufficiency) and process changes (electrification) are equally important in the decarbonization of the demand side of the energy system. Demand side optimization helps mitigate the natural increase in emissions from growth in activity (and economic wealth): the economy is becoming more efficient. Process changes (notably electrification) contribute to decarbonize the rest. Both these opportunities should thus be pursued in parallel. Moreover, they both come with net benefits to consumers. An increasingly efficient economy is also synonym of greater access to services and goods, while electrification is proven to come at greater convenience and costs across multiple sectors, as discussed in chapter 2. Finally, efficiency measures and reductions in demand make the case for accelerated clean electrification more compelling over time, as they help reduce the need for significant infrastructure buildup.

These levels of abatement account for around half of the global decarbonization target. The rest comes from the decarbonization of the existing supply side, notably power generation, which represents the vast majority of the effort (90 percent of total). This decarbonization will accelerate as older power plants reach end of life and since renewable energies have become competitive compared to their fossil fuel counterparts. In the scenario *"Back to 2050"*, emissions drop 10-fold from around 12,200 million tons in 2018 to 1,300 million tons in 2050 (and carbon neutral with the implementation of carbon capture, utilization and storage systems – CCUS), while the rest of the supply system becomes carbon negative, thanks to CCUS.

What a sensitivity analysis tells us about our assumptions

As every scenario planning exercise, this report is also a prospective effort, fundamentally based on key assumptions, which are detailed in annex with as much transparency as possible. Beyond the results and findings of this report, it is thus also critical to understand the sensitivity of the quantitative assessment to some of these key assumptions.

Overall, we find that 3 key transformations hold a significant potential for rapid decarbonization. First, a radical **transformation of urban centers** has to take place. This includes both a large renovation effort on buildings, as well as a major optimization of urban mobility through public transportation, carpooling, and other on-demand mobility services (enabled as well by growingly autonomous transportation). The modernization of urban environments will thus play a critical role, and a lack of such development could significantly slow down the decarbonization of the sector. These transformations have also ripple effects on industry (demand for automotive, steel and plastics). This is further amplified by a **circularity disruption**, notably in the construction industry, which leads to a large optimization of demand for steel, plastics and minerals. Would this disruption take more time to materialize at scale, the decarbonization of industry could also be hampered. Finally, **electrification of end-uses** (industrial and building heat, cooking, mobility, etc.) plays a critical role. Our assumptions are particularly ambitious in buildings and industry (80 percent electrification). While technically and economically achievable within the time frame to 2050, lower rates of transformations could also limit the overall potential of decarbonization.

Chapter 9 – The 2030 imperative

Achieving a 1.5-degree compatible trajectory on greenhouse gas emissions does not only require reaching a net-zero economy by 2050, but as well to curb the shape of emissions significantly in the coming decade. Studies have demonstrated that emissions need to be reduced by 30-50 percent by 2030, for the world to stand a chance to stay on such course. This is also estimated to require an effort 3-5 times that of current pledges, despite many of these not having committed a plan yet[118]. The 2030 milestone is thus a race against time and requires significant effort and focus.

Our argument is that such targets can only be reached if the policy environment takes stock of two fundamentals. First, the right focus must be placed on what can be abated now, what we also call "easy to abate" sectors. Five sectors for which technologies already exist and are competitive (power generation, buildings, road mobility, manufacturing and upstream fugitive emissions) represent indeed 60 percent of global emissions[119]. A second fundamental stems from the analysis of natural transformations depicted above. As many of these ultimately bring benefits to consumers, a sound approach to the transition should be to prioritize them over other developments, ensuring an inclusive transition, which will enable faster adoption.

As discussed in chapter 3, **the scenario *"Back to 2050"* sees a reduction of 30 percent of emissions by 2030. By 2030, carbon dioxide emissions drop from around 35,000 million tons to 24,000 million tons**. The contribution of Carbon Capture, Utilization and Storage systems remains limited to 2030, with only 300 million tons abatement, mostly in industry.

A significant shift of focus on the demand side of the energy system

50 percent of the abatement to 2030 stems from transformations on the demand side. While standards on new constructions (buildings, facilities) must take stock of the long-term target of reaching net-zero, the key challenge in this scenario is a major focus on revamping the existing stock of assets, at a faster pace than current. Annual renovation rates must indeed reach around 3 percent in average, with significant savings associated. **The bulk of the effort is also concentrated in affluent economies (OECD countries and China)**.

For buildings, this means 50-60 percent efficiency improvements on the existing stock (respectively for residential and services) and 60-70 percent improvements on new constructions. All new constructions must also embed electric solutions for heating, while renovation must primarily focus on displacing oil and coal heating, and to a lower extent natural gas. Overall, the share of electric heating solutions in buildings reaches 20-25 percent by 2030. Electricity reaches 50 percent of global energy demand in the sector, compared to 35 percent today.

For mobility, a significant acceleration of the turnover to electric vehicles is also projected here, with nearly 20 percent penetration of the road sector by 2030[120]. This is complemented by key measures to mitigate traffic within urban centers and favor modal shifts. 10-15 percent of oil is also displaced across the aviation and shipping sectors, by the recourse to biofuels and hydrogen-based fuels. Globally, the demand for oil drops 20 percent by 2030.

For industry, an acceleration of renovation rates leads to faster adoption of best available technologies and 10-30 percent energy intensity improvements across the different segments (on the stock renovated). New electric heating solutions wherever

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[118] Schneider Electric (2021), The 2030 imperative: a race against time

[119] Climate Watch, managed by the World Resources Institute (2021); Schneider Electric Research

[120] This is a global figure, thus implies higher penetration levels in affluent economies.

competitive further pervade the sector as a solution to displace coal (and oil to a lower extent), while new constructions embed best practices from the start. Biomass also plays a transition role in this scenario. Natural gas demand stays stable by 2030. In sectors that can easily be electrified, natural gas is partially displaced. In sectors which are not easy to electrify, natural gas emerges as a transition alternative to coal. The share of electricity in final energy demand increases to 25 percent compared to 20 percent today[121] (Figure 29).

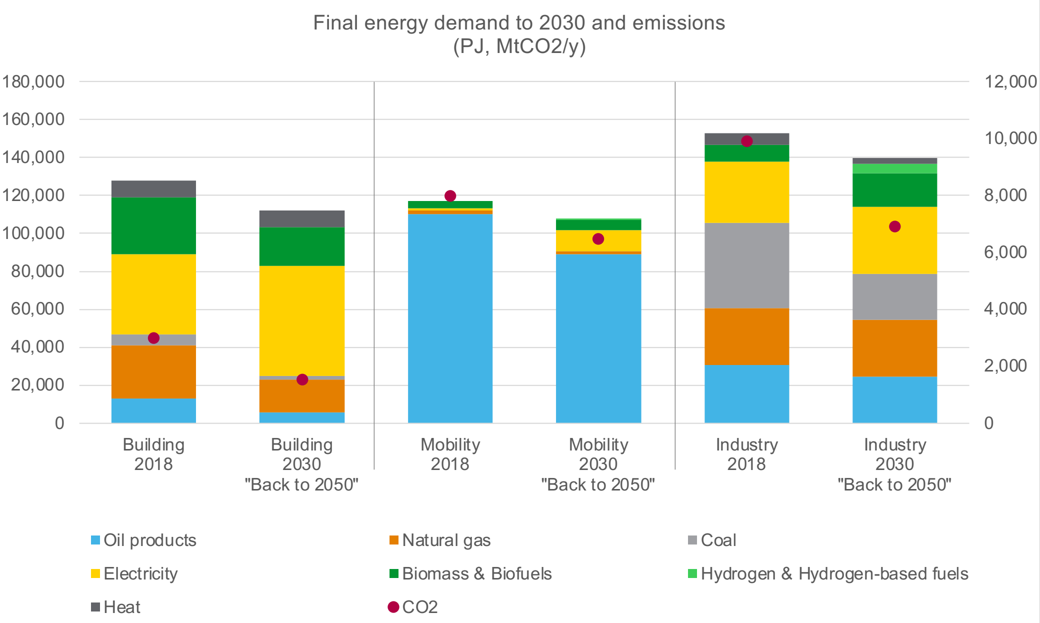

Figure 29 – Final energy demand to 2030

An accelerated transformation of the power system

The decarbonization of supply accounts for the other half of total abatement by 2030 and mainly comes from power generation.

Overall, power generation increases up to around 36,000TWh by 2030, or an increase of around 50 percent (Figure 30). The two main transformations revolve around coal and renewable energies. Coal-fired power generation drops by 40 percent, from natural decommissioning of plants reaching end of life and a significant effort on early retirements. All new capacities deployed (both to fuel new demand and to cope with early retirements) come from zero-carbon resources. Wind and solar generation increase nearly 9-fold to 15,000TWh by 2030. In practice, this means nearly 6 times more wind by 2030, and 15 times more solar than 2018 levels. Hydroelectricity and nuclear provide for the rest.

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[121] Accounting for feedstock as part of energy demand.

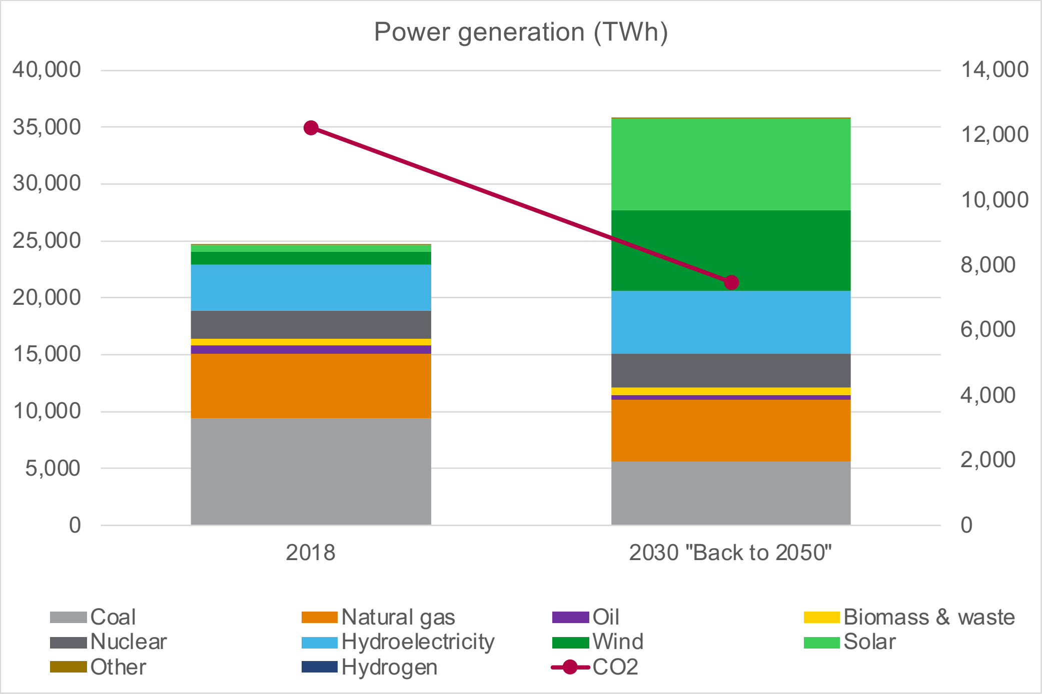

Figure 30 – Power generation in 2030

A major overhaul is required

2030 is only few years away, and the challenge is getting larger every day. The scenario presented here is highly ambitious yet still at reach if a significant policy overhaul materializes in the coming months. **Our key argument is that upcoming policies should take stock of the 2050 end game, that of a fundamentally different energy system, largely driven by transformations in consumption patterns**. Such transformations will prove key not only in the short run, but also in preparing a future-proof energy system to continue the journey post 2030. At the same time, many of these transformations ultimately provide benefits to consumers, a critical factor to generate a positive dynamic of transformation, that of an inclusive transition. In short, **the energy transition can only succeed in time if it is synonymous of modernization and social development**.

Finally, a key question on its feasibility is also that of the power infrastructure, the platform on which all these transformations will build upon. In the short-run, this will mostly remain an issue in affluent economies, as they represent the bulk of the effort to 2030, but the issue will come front and center for new economies in the decade to 2030 as economic development continues. There again, a view to the future of infrastructure should inspire short-run developments.

Chapter 10 – The broader landscape of decarbonization pathways

Scenarios are as good as their assumptions. It is thus critical to compare the scenario *"Back to 2050"* to a variety of existing scenarios and explore key differences across them. This helps better understand the sensitivity of key assumptions in overall decarbonization pathways, hence better inform on key trigger points for a successful decarbonization strategy.

We have selected a set of 4 external scenarios that all have received tremendous attention in the last months: the Net Zero Emissions (NZE) scenario from the International Energy Agency, the Energy Transitions Commission (ETC) pathway toward net zero, the BloombergNEF Green scenario (part of a range of 3 scenarios published in their New Energy Outlook), and the International Institute for Applied Systems Analysis (IIASA) Low Energy Demand (LED) scenario first published in Nature in 2018[122].

A wide range of approaches toward net zero, yet sharing common patterns

All scenarios reach a similar conclusion of a lower energy demand by 2050 compared to current (Figure 31). The LED departs from others with much lower levels, a reduction of nearly 40 percent, compared to other scenarios ranging around 15 percent reduction. The core working hypothesis of the LED was indeed to look at which level of energy demand could indeed be reached by maximizing efficiency measures, including energy efficiency, demand side optimization and electrification. This work suggests that a larger reservoir of efficiency exists, which other scenarios do not necessarily tap into fully.

All scenarios also agree on a significant share of electrification of the energy mix, between 50 percent and 75 percent across them, with the scenario *"Back to 2050"* in the middle at 60 percent. This represents across all of them a significant increase in electricity demand (3-5 times), to the exception of the LED, because of a lower baseline.

The share of fossil fuels is also relatively similar across all scenarios, ranging around 50-70,000 petajoules by 2050, or a reduction of 80 percent from current levels, to the exception of the ETC which sees a sharper reduction to only 22,000 petajoules, a reduction of demand beyond 90 percent.

Outside of these trends which are relatively common, scenarios clearly depart on the use of other fuel sources (besides electricity), notably biomass, hydrogen, hydrogen-based fuels and heat. The ETC and the LED (and to a certain extent the scenario *"Back to 2050"*) show much lower levels of biomass demand than others. The International Energy Agency NZE is notably expecting an increase in biomass demand (mostly modern biomass energy resources[123], as traditional biomass is considered displaced by then in new economies), while others show relatively stable and slightly declining figures. With regard to hydrogen, the LED and the scenario *"Back to 2050"* expect much lower demand for hydrogen than other scenarios, which all consider significantly more demand to 2050. The NZE demand stands at 530 million tons, the ETC ranges between 500 and 800 million tons, and BloombergNEF goes as far as 1,200 million tons, compared to *"Back to 2050"* at 280 million tons. As alluded to in chapter 7, this has essentially to do with expected penetration levels in road transport, power generation and buildings.

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[122] Important to note that there might be slight discrepancies in the scope covered by these different scenarios. After a close look at the data presented in each scenario, we consider however they can be compared as they share similar baseline levels for current final energy demand. BloombergNEF (c) (2021), New Energy Outlook; Energy Transitions Commission (2020), Making Mission Possible; Grubler et al (2018), A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies; © OECD/IEA (2021), Net Zero by 2050

[123] This includes sustainable biomass supply for energy and industry, as well as a variety of biogases and bio feedstocks.

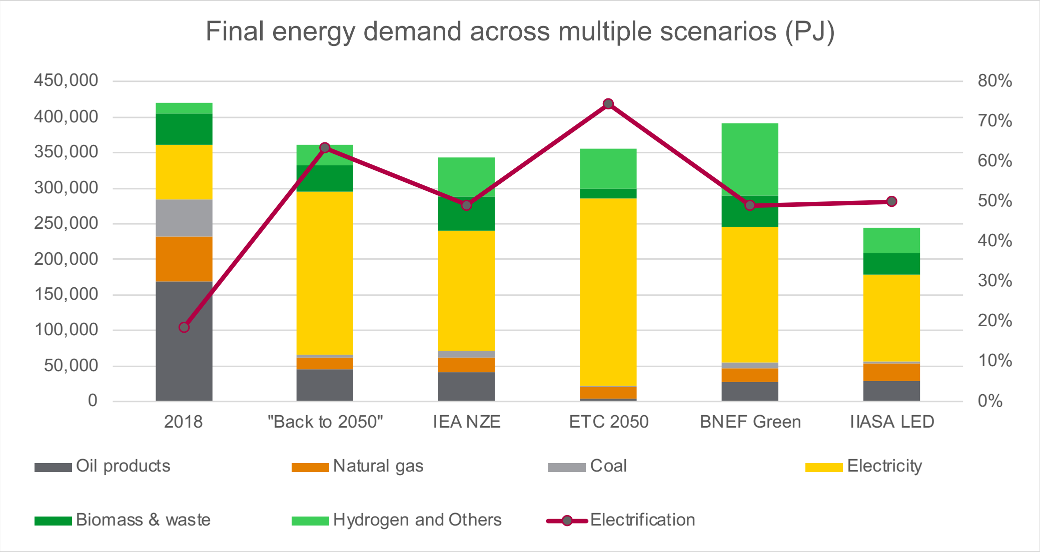

Figure 31 – Final energy demand across multiple scenarios

Final energy demand in buildings is generally considered slightly in decline by 2050 compared to 2018, across all scenarios (Figure 32). Both the NZE and the LED envision a radical reduction of building energy demand (over 30 percent), despite growth in stock, and thus depart from other approaches. This suggests that their assumptions on what is feasible have been maximized.

Final energy demand in mobility follows similar trends than in buildings. While the scenario *“Back to 2050”*, the NZE and the ETC expect a 30 percent reduction in demand from the sector, BloombergNEF and the LED go much further and project a near halving of energy demand by 2050, a radical assumption which builds on massive electrification and significant optimization of activity levels.

Final energy demand in industry and other sectors[124] also shows a wide range of patterns. While the scenario *“Back to 2050”* and the ETC both project a 15 percent reduction of energy demand, the LED scenario suggests a higher potential for savings with 45 percent reduction, while the NZE and the BloombergNEF scenarios see demand slightly growing from current levels by 2050, suggesting they have been more conservative in this case.

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[124] Due to lack of available data on some scenarios, this includes all other final energy demand, including industry, agriculture, transformation industries and non-energy uses, etc.

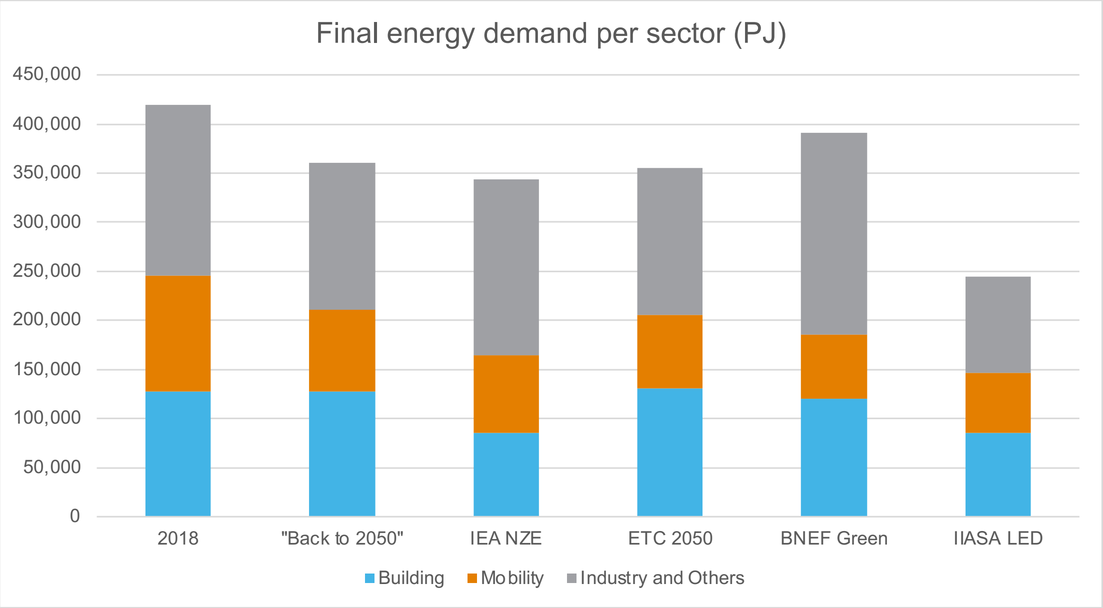

Figure 32 – Final energy demand per sector, across multiple scenarios

As a conclusion, all scenarios converge toward lower energy demand at an aggregated level and a much-increased role for electricity in the energy mix. They however vary in their assumptions across sectors, with +/- 20 percent variations in the building and mobility sector, and up to 40 percent in industry.

This obviously confirms how important it is to clearly outline assumptions taken, particularly on the evolution of activity levels, while reinforcing the role of consumption patterns as a major enabler of the transition toward a low carbon economy. The LED scenario is particularly of interest in this regard as it shows a significant potential for improvements when all opportunities are maximized.

A deeper look by sector shows key disparities across the building and industry sectors

The International Energy Agency has published a major report in 2021, the Net Zero Emissions scenario. This global reference from an institution of such importance in the global conversation deserves a closer look, particularly as the report comes with a breadth of data, which helps requalify and challenge assumptions, what is ultimately important in such exercises.

Buildings

The scenario *"Back to 2050"* departs from the International Energy Agency NZE in few ways (Figure 33). A key difference is on final demand. Our estimate is much higher by 2050, likely due to lower expectations on what can be done from a pure renovation standpoint, the rebound in surface demand, as well as a higher penetration of cooling systems[125]. The rate of electrification is also higher in this scenario, although absolute energy demand from other sources is close. The trends are thus similar. For the stock that is not electrified by 2050, the scenario *"Back to 2050"* assumes a more significant role for heating (district heating, direct heating, etc.), and sees no contribution for hydrogen, likely substituted by more economic resources.

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[125] We have estimated cooling would further penetrate the build environment by 2050, due to increased wealth and climate changes. See annex for details.

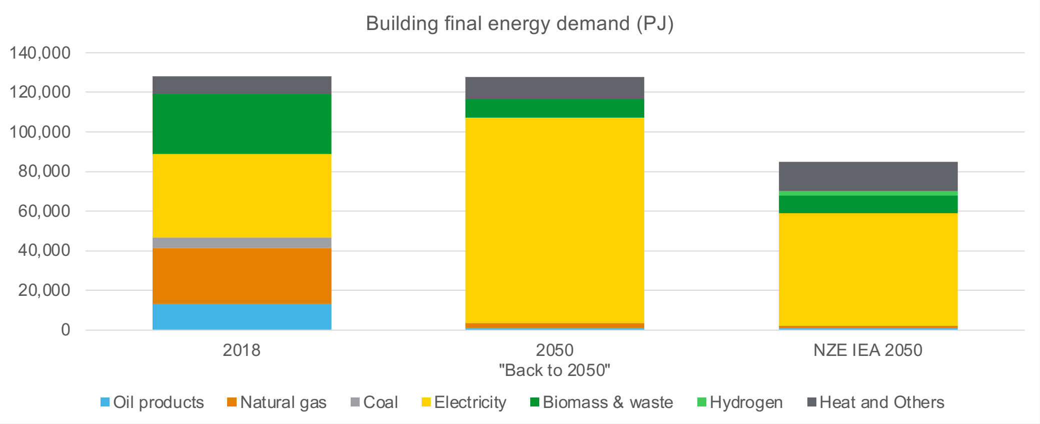

Figure 33 – Building final energy demand and emissions, comparison with the NZE[126]

Mobility

The scenario *"Back to 2050"* compares well with the International Energy Agency NZE (Figure 34). Both scenarios indeed show similar energy demand for the mobility sector. The demand for oil products remains however twice higher in *"Back to 2050"*, likely because of different assumptions on new economies. Our scenario reaches 70 percent of EVs for passenger transport globally by 2050, the remaining share of conventional vehicles essentially being in new economies. The development of hydrogen infrastructures for road freight is also considered less significant in the scenario *"Back to 2050"* than anticipated in the NZE, leading to a lower amount of hydrogen demand in the sector.

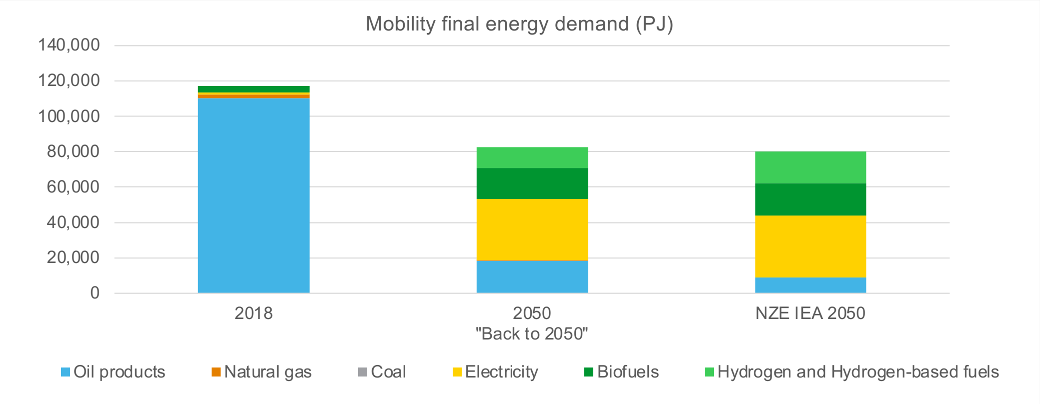

Figure 34 – Mobility final energy demand and emissions, comparison with the NZE

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[126] Carbon dioxide emissions reported in this graph correspond to direct energy-related emissions only.

Industry

The footprint of the scenario *"Back to 2050"* varies significantly from that of the International Energy Agency (NZE) and tells a very different story on the future industrial system (Figure 35). The scenario indeed concludes that final energy demand would be lower than current, a result of key demand evolutions, the development of a sharing economy, and a greater use of recycling. The share of electricity is also much higher in the mix, at 65 percent[127], compared to nearly 50 percent in the NZE. This is due again to a combination of factors: recycling is largely electric[128], distributed manufacturing creates additional demand for electricity, and we assume a more aggressive electrification of certain industries given the economic potential with access to affordable renewable energies[129], notably in chemicals. The NZE scenario continues to rely on fossil fuels, a greater use of biomass and hydrogen as an alternative energy source for industrial heating.

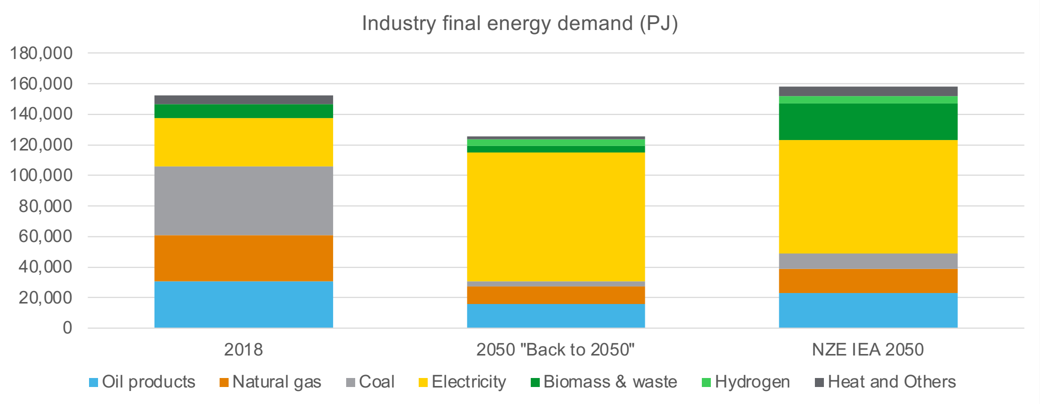

Figure 35 – Industry final energy demand and emissions, comparison with the NZE[130]

In summary, while the International Energy Agency NZE looks more ambitious on the transformation of the building stock than the scenario *"Back to 2050"*, it is however more conservative on the transformation of industry. As suggested earlier, these discrepancies also inform us of the significant potential that exists in both for accelerated transformation, a message which confirms **our initial argument of a necessary focus on the demand-side of the energy system**.

Power

The two forecasts from the scenario *"Back to 2050"* and the NZE are very similar (Figure 36). Power generation reaches above 70,000TWh in both approaches. The power generation mix is also very consistent. The bulk of the increase stems from wind and solar generation, which represent 70 percent of total generation by 2050. Nuclear power and hydroelectricity both double in absolute value, with shares around 7 percent for nuclear and 12 percent for hydroelectricity across both scenarios. The main difference has to do with natural gas. In the scenario *"Back to 2050"*, gas-fired power plants represent 4 percent of global power generation in 2050, while this is (almost) entirely substituted by biomass in the NZE. Despite the intrinsic advantage of using biomass as a power generation resource to generate negative emissions (if combined with carbon, capture, utilization and storage, what is also called BECCS), the scenario *"Back to 2050"* does not expect the industry to scale for such type of

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[127] Accounting for feedstock. See chapter 6.

[128] Notably for steel. For plastics, we assume above 50 percent of recycling to be mechanical (electric), the remaining coming from chemical recycling processes.

[129] See chapter 7 and annex for more details.

[130] Figure 35 includes feedstock as well as energy demand. The figures from the International Energy Agency are limited to the scope of energy resources reviewed in this model.

uses. Another difference in this analysis, though not represented in the graph, is the share of solar coming from distributed generation. As seen in chapter 7, distributed generation accounts for 16,000TWh in *"Back to 2050"* (or nearly 60 percent of total solar power generation), a figure twice higher than that of the NZE (at 7,500TWh).

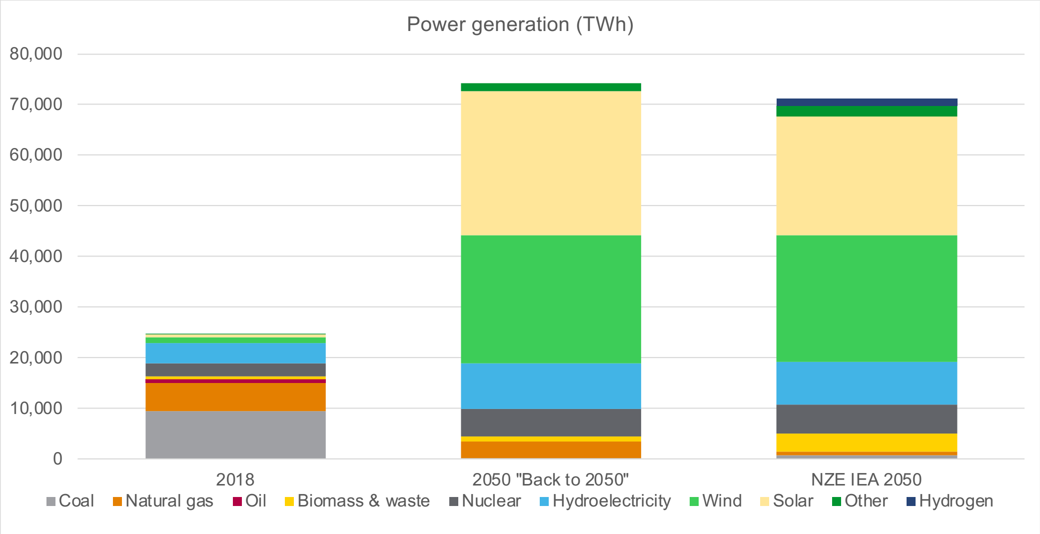

Figure 36 – Power generation, comparison with the NZE

A different approach to bridge the gap to zero

Both scenarios target net-zero emissions by 2050. Their level of residual emissions is however different (Figure 37). The scenario *"Back to 2050"* closes at around 5,500 million tons of carbon dioxide by 2050, while the NZE reaches 7,600 million tons. They are both neutral in carbon thanks to the deployment of carbon capture and negative emission solutions. The development of carbon capture, utilization and storage systems (including on biomass to yield negative emissions) reaches around 3,000 million tons by 2050 in the scenario *"Back to 2050"*, less than half of that of the NZE. On the contrary, the scenario takes greater stock of the potential of negative emissions, notably through the recourse to nature-based solutions (offsets), an assumption that the International Energy Agency has not integrated. Both approaches are equally interesting and shed light on potential arbitrages going forward. Is it ultimately preferable to capture emissions at the source point (and potentially develop a biomass industry at scale to generate negative emissions through direct capture), or to simply offset residual emissions by greater effort on nature-based solutions? What is the cost of each approach to the economy, and what will be the side impacts on biodiversity development? Those are likely to become significant objects of debate in the coming years.

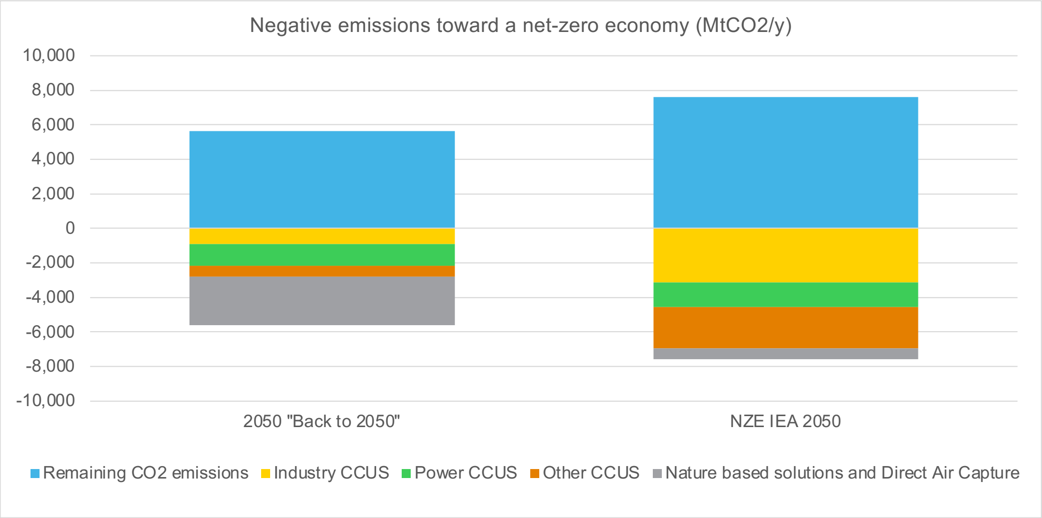

Figure 37 – Negative emissions, comparison with the NZE

Chapter 11 – This is only a beginning, but this is also time to take action

What remains to be looked at and next steps

This report would not be complete without assessing the boundaries and limits of our work. There are several sectors we have indeed voluntarily left out in this review.

The energy (and carbon) footprint of digital technologies was one of those. As the world depicted above grows more digital, the energy demand stemming from the digital infrastructure will inevitably increase. Similarly, water demand is expected to increase by around 50 percent by 2050, and this mainly in water-scarce areas, creating further pressure on energy infrastructure in those regions as water supply becomes increasingly energy intensive. The extent of these increases is however too dependent on a multitude of parameters for a reasonable forecast to be integrated in the above analysis. We estimate however these new "services" to account for a sizeable share of future global energy demand and have provided some reference points in annex. Mining is also likely to grow more energy intensive over time as ore grade quality is on a clear declining course while demand for resources continues to increase[131].

Yet, the main sector we have left out is that of AFOLU (Agriculture, Forestry and Land Use). The sector accounts for around 11GtCO2e/y of greenhouse gas emissions, over 20 percent of total. These are essentially coming from livestock and more importantly land use practices

- Livestock demand is a key question going forward and its development could go in different directions based on evolving diets and appetites from new generations, as well as industrial development of meat substitutes. A reduced demand from natural livestock would not only abate significantly greenhouse gas emissions, it would also free up land for reforestation and natural carbon sinks[132].
- Land use practices will also evolve based on competing interests: a growing need for arable lands in several geographies[133], the potential development of a biomass industry at scale (notably for biofuels), the use of land for harvesting energy resources (utility-scale photovoltaic or wind farms), as well as biodiversity conservation and restoration practices. While natural ecosystems play as a major carbon sink, these other needs could further impact AFOLU greenhouse gas emissions.

30 percent of 78 scenarios from the IPCC find that the sector could in fact become a net carbon sink by 2050, with sequestration levels ranging from a few hundred million tons up to 10,000 million tons. The study from RethinkX suggests a potential on the upper end of this range, achievable by 2035[134]. Oceans could also play a larger role than often thought (they are already the largest carbon sink on Earth).

Additional innovations have also been discarded from this issue. The significant potential of material substitutions stemming from innovations in nano- and bio-technologies could further reshuffle the footprint of primary material industries such as steel, cement and other metals and minerals. This trend goes however beyond the boundaries of this report and requires a more detailed look going forward, due to its potentially massive effect. As well, industrialized additive manufacturing beyond consumer goods (what we considered in this report) could also lead to further impacts

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[131] While forecasts traditionally project a nearly 2-fold increase in resources demand by 2050, our exercise above suggests possible lower demand for metals and fuels. Yet, declining ore grades also mean higher ore extraction (for a given volume of metal or fuel content), hence higher energy demand. United Environmental Program (2019), Global Resource Outlook; Mudd G. (2010), The "Limits to Growth" and 'Finite' Mineral Resources: Re-visiting the Assumptions and Drinking From That Half-Capacity Glass.

[132] See notably the work from Arbib et al. (2021), Rethinking Climate Change

[133] Petit V. (2021), The Future of the Global Order

[134] © IIASA & IAMC (2018-2019), IAMC 1.5°C Scenario Explorer hosted by IIASA; Arbib et al. (2021), Rethinking Climate Change

on upstream value chains, through complete redesigns of machines and assets with lower resource footprints.

In our report, we have also estimated a clear contribution of nuclear technologies to the overall power generation mix. This assumption is based on the promising, yet early stage, developments of new nuclear power generation technologies such as Small Modular Reactors or Micro Modular Reactors. While we could not leave them out of such a report, their development is yet to materialize and prey to many challenges, among which government oversight and overall cost of such installations. We have therefore remained rather conservative and acknowledge more work is needed to further refine this forecast.

Finally, the biggest uncertainty of all has to do with climate adaptation, and the way already visible impacts on climate may trigger new investments in infrastructure to cope with those changes. This may also entail a series of innovations around carbon capture and carbon removal systems, which have not been studied in depth in this issue.

To summarize, there are still numerous areas of research which remain to be investigated. Although promising, this first issue unpacks a whole new array of transformations which could all have a material impact on the future of the energy system, hence global greenhouse gas emissions.

As a final note, this report has essentially provided globally aggregated data on the future of the energy system. Subsequent issues will dwell in more details into regional pathways while further investigating the main uncertainties described above.

Time to take action

There are two main conclusions in this report. The first one is that the natural unfolding of transformations in the way we consume energy (from innovation and behavioral changes) will lead to an economy less carbon intensive. As these changes are largely inevitable, because of the benefits they bring, our first key message is that **a 1.5-degree decarbonization trajectory might be more feasible than we think**.

The second conclusion is that, provided we collectively embrace these changes, and accelerate their unfolding through wise regulatory efforts, a net-zero economy is still achievable by 2050. In short, the energy transition should be conceived as **an “acceleration” of the modernization of our economy**, a “positive investment” rather than a “burden”. What also comes with it is that a well-designed transition would also be synonym of economic and human development. This is because such modernization would also enable greater productivity and wealth, hence motivating change for both consumers and businesses. In other words, **there is a clear pathway to bridge climate change and social progress, and we argue that this is the only option to carry out a change of this magnitude in less than 3 decades**.

For that to happen however, energy transition roadmaps and policies must evolve from a pure “infrastructure-centric” approach to integrate a complementary “consumer-centric” approach. Figure 38 summarizes the key findings of this report and highlights what such a policy shift could look like in practical terms.

The main message is that **modern solutions will solve modern issues and modern policy frameworks must support them**. There is also no time to waste: in the coming decade, a more ambitious policy plan is required to stay on a course consistent with a 1.5-degree trajectory, as 3-5 times more effort is required[135] (on top of current pledges).

Current approaches have so far essentially focused on power generation, mobility electrification (and public charging infrastructure), to some degree the development of grid infrastructure (although mostly to interconnect renewable energy resources), and an emerging focus on developing a hydrogen infrastructure for “hard-to-abate” sectors.

Time to complement these measures with a major focus on the building and industry stock and foster their modernization, or in other words to complement the current policy focus on the infrastructure with that of the consumer. At the heart of this plan lie 3 main priorities

- First, to **disrupt the current inertia of the energy system** by building everything new (buildings, industrial facilities, vehicles) right from the start, and future proof.
- Then, to **repair the existing system** by ambitious renovation programs (across all sectors), progressively bringing the existing stock at the level of the new one.
- Finally, to **build up the twenty-first century energy backbone**, a resilient, more decentralized and digitized grid infrastructure, operating as a platform on which every other change will build upon.

Technologies exist for the most part, and their development will offer strong paybacks and better access to traditional services. **This approach is also a pathway toward a more inclusive (and ultimately more rewarding) transition**.

Another critical outcome of this review is the fundamental disconnect between affluent and new economies. While the former need to accelerate their transformation across all fronts, given they represent the largest share of global emissions today, **a course toward a vibrant net-zero economy must also be charted for new economies**. In this regard, one of the key enablers will be the development of a modern, future-proof (i.e. decarbonized and distributed) power infrastructure, which could in turn enable these economies leapfrog on new solutions.

As a final note, this report is a first glimpse at how innovations will further transform the energy system and how they could contribute to the decarbonization of the global economy by 2050. While we are committed to continue investigating these topics and further refining our findings in the coming years (including specific regional pathways), we hope this work to be a source of inspiration for the research community dedicated all over the world on charting feasible routes toward net-zero.

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[135] Schneider Electric (2021), The 2030 imperative: a race against time

POLICY SHIFT	Traditional Focus	Complementary Focus in a "consumer-centric" transition centered around modernization	Key Wins in 1 year
Reboot Urban Environments	New building standards (key energy performance targets) Large-scale renovation programs (focused on low-efficiency residential buildings, and traditional works on envelopes, windows, etc.) Mandates for EV manufacturing and incentives to switch for consumers Public charging infrastructure development	**Build and Modernize Buildings for the Future** - make digital solutions the baseline standard for efficiency and flexibility, with clear metrics and milestones - boost renovation rates up to 3 percent CAGR for both the residential and commercial stocks - integrate distributed generation and thermal storage (natively in new build) - electrify heating and cooking (no gas boilers in new build, remove fossil fuels in existing: starting with oil and coal) and support development of a vibrant heat pump market - focus adoption of EV private charging, smart EV charging is compulsory within buildings - support further efficiency in appliances (and connectivity for shiftable loads) **Transform Construction** - accelerate digitalization and decarbonization of construction: design, traceability and circularity **Reinvent Mobility within cities** - support deployment of mobility as a service - support autonomous vehicle deployment across specific use cases (new traffic rules) - boost modal shifts within cities (public transportation) **Redesign Urban Infrastructure** - digitize grids: smarter and more flexible operation, down to the meter - grid as a platform: embrace disitributed generation and storage as key energy resources - take stock of opportunities of mixing new construction with existing stock for district optimization	All new build is zero-carbon, by standard Clear ICE Phase Out regulation Smart renovation programs in place (digital, distributed generation, EV, etc.)
Reboot Industrial capabilities	Emerging focus, mainly on hard-to-abate sectors Price on carbon Hydrogen infrastructure	**Build and Modernize Industries for the Future** - boost digitalization of industry (across all segments), with a key focus on CO2 and environment monitoring, energy and resource conservation, and asset lifetime management - boost adoption of Best Available Technologies (and Processes) for both new and existing upgrades - electrify industrial heat (with a key primary focus on removing coal and oil), notably for new build - facilitate adoption of distributed generation (connected renewable farms), and foster development of local storage capabilities (electric, thermal) **Reinvent Industry with Circularity** - drastically accelerate zero-waste to landfill (including scrap) - support traceability and embodied emissions accountability - promote reuse/refurbishing/repurposing schemes - promote design to circularity adoption - drive acceleration of recycling (and collection) targets and mandates **Redesign Infrastructure for Industry and Clusters** - digitize grids: smarter and more flexible operation - grid as a platform: embrace disitributed generation and storage as key energy resources, particularly for industrial clusters - accelerate rollout of grid infrastructure, notably for large industrial setups	All new build is zero-carbon, by standard Smart Renovation mandates in place Circular economy regulation in place Accelerated grid development plan, key focus on clusters
Mobility (outside private EV)	Aviation and shipping decarbonization	**Accelerate modal shifts and new mobility offers** - support shift from air to rail for domestic travels - support development of new logistic flows and systems as well as fleet decarbonization	Roadmap for aviation / shipping
Infrastructure	Grid planning Coal-fired power generation (no new build, phase out existing)	**Create the opportunity for leapfrog in new economies** - support globally an accelerated rollout of grid infrastructure in new economies **Develop a competitive play for electrification** - end all fossil fuels subsidies - facilitate permitting for distributed generation for both urban centers and industries - rebalance taxes across energy sources - redesign retail schemes to create incentives for flexibility (Time of Use, Demand Charges, Grid costs, etc.)	Clear Coal Phase Out regulation Facilitated perimitting and incentives for Distributed Generation New retail and tax schemes for energy resources (fossil fuels vs electricity)
Others	R&D support in new innovative technologies (e.g. batteries, solar energy, etc.) Common language (taxonomy, higher non-financia reporting transparency, green finance)	**Invest in resources** - invest in education of the young generation - promote sufficiency	Common taxonomy

Figure 38 – Policy shift

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The assumptions and models and conclusions presented in the publication represent one possible scenario and are inherently dependent on many factors outside the control of any one company, including but not limited to governmental actions, evolution of climate conditions, geopolitical consideration and shifts in technology.

The scenarios and models are not intended to be projections of forecasts of the future and do not represent Schneider Electric's strategy of business plan.

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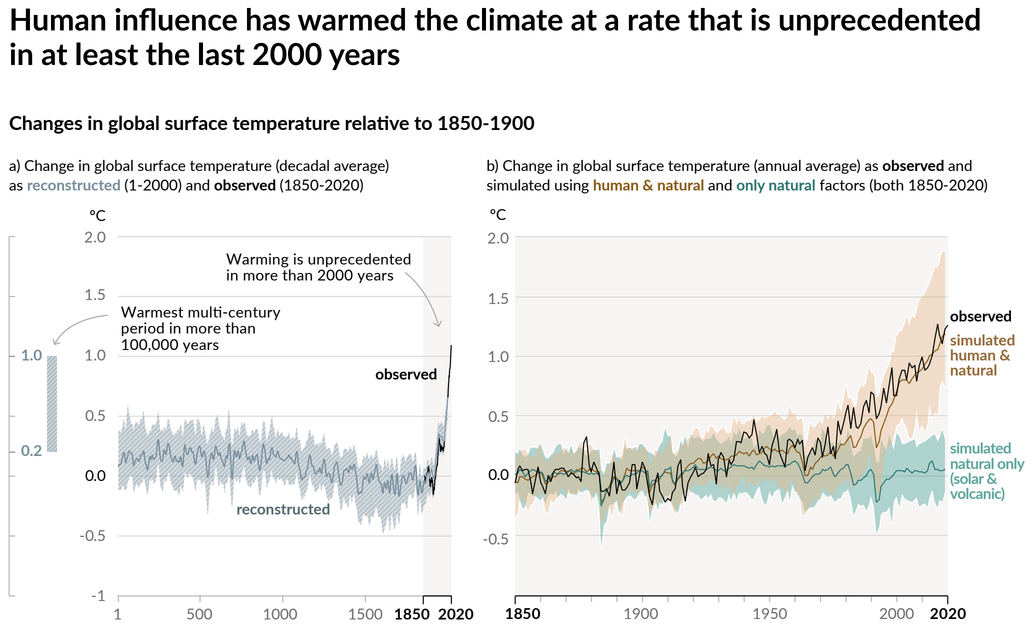
The time window is closing upon us

On August 9, 2021, the Intergovernmental Panel on Climate Change (IPCC) released the highly anticipated contribution from the first working group on the physical science basis on climate change. This report is due to be integrated in the full 6th assessment report (AR6) in 2022, which will also integrate other contributions on climate change impacts and mitigation pathways.

The first working group results of the 6th assessment report (AR6) from the IPCC were released on August 9, 2021[136]. This report has clearly outlined the key role of human influence on global warming (Figure 39).



Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Changes in global surface temperature relative to 1850-1900

a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and **observed** (1850-2020)

b) Change in global surface temperature (annual average) as **observed** and simulated using human & natural and only natural factors (both 1850-2020)

Figure 39 – Human influence on climate change[137]

The development of our modern economy in the last 200 years, which has helped remove billions from an economy of subsistence, has led to major imbalance in the planet's greenhouse gas exchanges, yielding global warming and transformations of our climate.

And this is only a beginning. Consequences will be significant and are already largely inevitable. Further issues from the Assessment Report due in 2022 will shed more light on these. It has also become clear that the further the increase in warming, the more devastating the consequences are likely to be (Figure 40).

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[136] IPCC (2021), Climate Change 2021, the Physical Science Basis

[137] Ibid

Extreme events with different global warming	Present (+1 degree)	Future (+1.5 degree)	Future (+2 degree)	Future (+4 degree)
Decadal extreme temperature event	2.8 times more likely (+1.2 degree hotter)	4.1 times more likely (+1.9 degree hotter)	5.6 times more likely (+2.6 degree hotter)	9.4 times more likely (+5.1 degree hotter)
Half-century extreme temperature event	4.8 times more likely (+1.2 degree hotter)	8.6 times more likely (+2 degree hotter)	13.9 times more likely (+2.7 degree hotter)	39.2 times more likely (+5.3 degree hotter)
Decadal heavy precipitation event	1.3 times more likely (+6.7% wetter)	1.5 times more likely (+10.5% wetter)	1.7 times more likely (+14% wetter)	2.7 times more likely (+30.2% wetter)
Decadal drought	1.7 times more likely (+0.3 sd drier)	2 times more likely (+0.5 sd drier)	2.4 times more likely (+0.6 sd drier)	4.1 times more likely (+1 sd drier)

Figure 40 – Projected changes in extreme events and their intensity[138]

This is why the roots of this climate transformation must now be corrected at rapid pace. In 2018, the IPCC published another publication setting out pathways to limit global warming to 1.5 degrees. This will be further complemented and amended within the upcoming AR6 report[139] (Figure 41).

The outcome is clear. On the one hand, net emissions of carbon dioxide must be zeroed by mid-century, while those of other greenhouse gas emissions must be significantly abated. On the other hand, the pace at which this must happen is extremely rapid. In this regard, 2030 has become a major milestone, which we have explored in another report[140].

At the heart of this issue is energy, which represents around 70-75% of world's greenhouse gas emissions. Another 20% has to do with agriculture, forestry and land use management (AFOLU), the rest stemming from waste and industrial process emissions[141].

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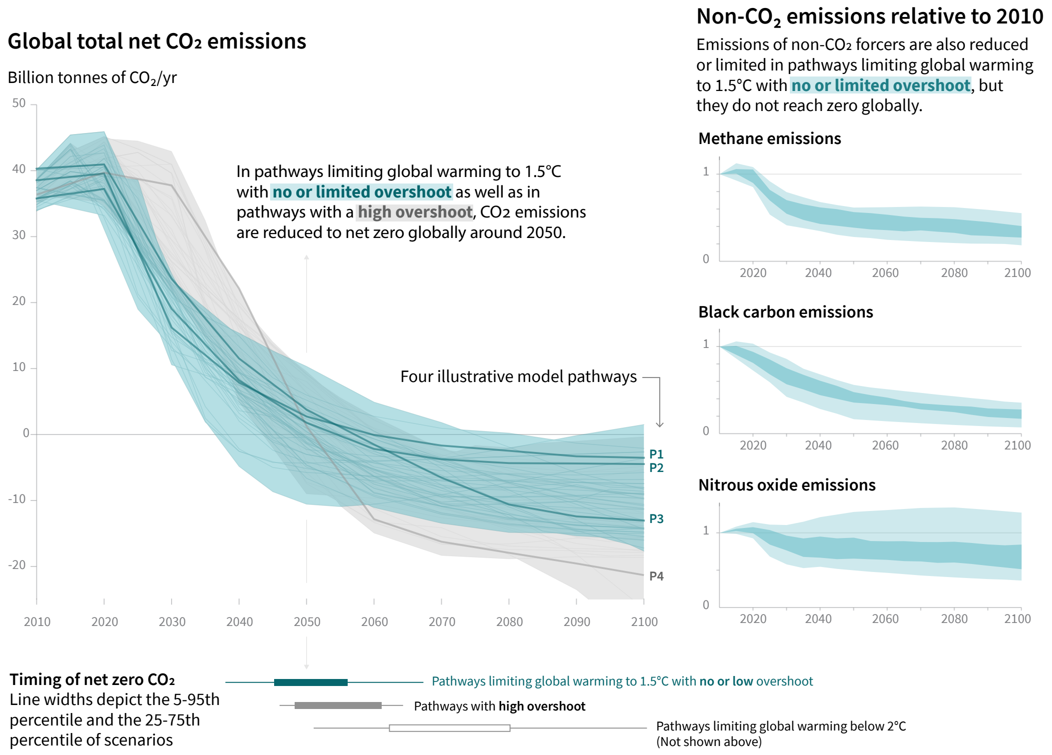
[138] IPCC (2021), Climate Change 2021, the Physical Science Basis

[139] IPCC (2018), Global Warming of 1.5°C

[140] Schneider Electric (2021), The 2030 imperative: a race against time

[141] Schneider Electric Research; Climate Watch, managed by the World Resources Institute (2021)



Global total net CO₂ emissions

Billion tonnes of CO_2/yr

In pathways limiting global warming to 1.5°C with **no or limited overshoot** as well as in pathways with a **high overshoot**, CO₂ emissions are reduced to net zero globally around 2050.

Four illustrative model pathways

Non-CO_2 emissions relative to 2010

Emissions of non-CO₂ forcers are also reduced or limited in pathways limiting global warming to 1.5°C with **no or limited overshoot**, but they do not reach zero globally.

Methane emissions

Black carbon emissions

Nitrous oxide emissions

Timing of net zero CO₂

Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios

Figure 41 – Climate mitigation pathways[142]

Detailed assumptions

Likelihood of deployment of 12 transformations to 2050

Starting from the 12 transformations discussed, we first need to assess the likelihood of their deployment to 2050. The following table, based on the above references mentioned in the body of the report and to the best of our knowledge, provides an indicative perspective of the guidelines we have followed to define assumptions of penetration (Figure 42).

Although we only present in this issue global results, we have also modelled different rates of penetration by region, considering the market maturity, availability of the infrastructure to fuel these innovations, the opportunity to leapfrog, the policies in place, and the age and stock turnover rates across sectors. In the following parts, we go a step further in detailing those assumptions, with a range of assumptions which represent the min/max of penetration rates considered across regions.

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[142] IPCC (2018), Global Warming of 1.5°C

12 Transformations		Benefits fostering adoption		Readiness level	
Mobility	Road transport electrification	Very high	Lower costs of charging Lower costs of maintenance	Very high	ICE parity before 2030 worldwide
Mobility	Transport as a Service Multimodal transport systems	Medium	Heavy infrastructure investments (multimodal systems) TaaS still expensive, even if total cost of ownership attractive	High	Already existing solutions TaaS still lacks reach outside of large metropolitan centers
Mobility	Autonomous Vehicles	Very high	Combined with TaaS, could disrupt costs of mobility	Low	No clear roadmap on Level 5 capabilities But exists for certain specific applications (eg. airport shuttles, etc.)
Mobility	New fuels	Low	Similar or above costs of fuels - policy push mainly	High	Already existing solutions Scale remains a question
Buildings	Distributed Generation and Storage (electric, thermal)	Very high	Lower costs of energy, already demonstrated in certain markets and likely to apply across all within the coming decades Greater resiliency in certain markets poised with low reliability of power systems	High	Already existing at scale Storage is still high capex (for batteries) and lack of proper value chains across regions Complex policy environment
Buildings	Superior Space Conditioning technologies	High	Lower costs of energy, improved comfort	Very high	Already existing at scale Further improvements on local value chains still needed
Buildings	Virtualized living environments	Very high	Real-time connectivity Continuous innovation Digital efficiency solutions bring significant gains at low paybacks	Very high	Already existing at scale Massive innovation ecosystem already set up
Buildings	Construction disruption	Medium	Greater efficiency in construction, lower costs of construction Do not necessarily translate immediately in lower costs of acquisition	Low	Emerging market
Industry	Digital manufacturing Best Available technologies	High	Improved operational reliability ; Improved utilization and return on capital ; Lower costs and dependencies on resources ; Optimized supply chains Greater customer engagement	High	Already widely available, but take time to deploy and taylor to specific needs and constraints. Renovation programs a key target for upgrades
Industry	New industrial processes	Medium	New emerging processes still more expensive Electrification competitive in certain sectors and bring additional benefits. Ultimately a question of access to the renewable energy infrastructure	Low	Pilot stage for most applications
Industry	Circular supply chains	Medium	Lower costs of access to specific services (eg. sharing platforms)	Medium	Platforms for sharing services already exist at scale for many applications True circular loops on supply chains still at emerging stage across most sectors
Industry	Distributed manufacturing	Medium	Greater convenience for manufacturing - still early adoption New 3D-printing designs in manufacturing offer important productivity perspectives	Low	Pilot stage for most applications

Figure 42 – Likelihood of innovations

Key assumptions – buildings

The baseline scenario demand is traditionally based on a demand growth stemming from population evolution, economic growth and natural stock evolution. On top of this approach, we integrate new parameters which all have an impact on the evolution of energy demand. The way we have organized their presentation is similar across all sectors of activity. We first look at evolutions in service demand, including existing services and new patterns of use. Then we assess stock turnover (the rates at which existing systems are substituted with new ones), and differences in performance. Finally, we focus on energy uses, and notably fuel switch and energy efficiency of equipment. We also take different assumptions across our scenarios, the main change being the policy environment which accelerates positive transformations (for climate purposes) and mitigates rebound effects.

For buildings, we notably look at home office, online shopping and new commercial uses, and their associated consequences on the evolution of both the residential stock and commercial stock. On the residential sector, we assume a rebound in stock growth outside cities due to lower costs of acquisition, drop in mobility costs, and less needs from commuting (home office, online shopping). We also integrate new patterns of use, notably around sufficiency from changing behaviors.

We also take assumptions on stock turnover, and levels of performance reached in both new constructions and retrofits.

Finally, we take key assumptions on the penetration of heat pumps and air-conditioning systems in the stock by 2050, to which we also apply expected performance improvements. We also assume appliance energy intensity will be significantly reduced by 2050, following a trend which has already been observed in the last decades. We include as well key assumptions on the electrification of cooking, notably as a substitute to traditional biomass.

Assumptions vary by scenario. While the *”New Normal”* follows natural development trends, the scenario *“Back to 2050”* assumes major policy shifts. In the *”New Normal”*, stock turnover and fuel switch is mainly driven by economics and the convenience of modern technologies. Lower costs of housing also provide a significant rebound in residential demand (compared to baseline), notably in new economies which have not yet fully urbanized. In the scenario *“Back to 2050”*, however, policies accelerate the deployment of modern technologies, with direct incentives, and a focus on accelerating stock turnover. These policies also focus at taming the rebound in residential demand and promote further sufficiency in end-use.

As explained earlier, we provide a range on the assumptions for which we have taken different rates across geographies, without detailing all approaches per region. At a high-level however, we see a more important rebound in residential in new economies than in affluent ones, and lower performance standards and equipment penetration, notably in *“Back to 2050”*.

Residential	Scenario "New Normal"	Scenario "Back to 2050"
Services demand	Evolution of stock from new uses: +13% increase globally vs baseline - housing footprint rebound from construction costs disruption and moves outside city centers: +0-40% impact across regions	Evolution of stock from new uses: +4% increase globally vs baseline - housing footprint rebound from construction costs disruption and moves outside city centers: +0-20% impact across regions
New patterns of use	- Sufficiency adjustments from growingly concerned citizens: -0-10% impact on energy demand for heating/cooling across regions	- Sufficiency adjustments from growingly concerned citizens: -0-15% impact on energy demand for heating/cooling across regions
Stock turnover	Renovations - 1% annual renovation rate in average - -15% energy intensity compared to baseline New build - -20-40% energy intensity compared to baseline across regions (individual) - -30-50% energy intensity compared to baseline across regions (collective)	Renovations - 3% annual renovation rate in average - -35-50% energy intensity compared to baseline across regions New build - -60% energy intensity compared to baseline (individual)
Energy uses	Heat pump penetration - 50-80% penetration in new build across regions, and 20% in existing stock - 18-27% coefficient of performance improvements across regions Air conditioning penetration - 50-90% penetration across regions - 20-50% EER improvement globally Appliances - -30% energy intensity to 2050	Heat pump penetration - 50-80% penetration across all stock (new + renovations) across regions - 18-27% coefficient of performance improvements across regions Air conditioning penetration - 50-90% penetration across regions - 20-50% EER improvement globally Appliances - -30% energy intensity to 2050

Commercial	Scenario "New Normal"	Scenario "Back to 2050"
Services demand	Evolution of stock from new uses: -19% increase globally vs baseline - home office: -30-50% on offices footprint across regions - online shopping: -10% on retail footprint - commercial buildings repurposing and reconfigurations: -5% on retail footprint	Evolution of stock from new uses: -34% increase globally vs baseline - home office: -80% on offices footprint across regions - online shopping: -10% on retail footprint - commercial buildings repurposing and reconfigurations: -5% on retail footprint
New patterns of use		
Stock turnover	Renovations - 1% annual renovation rate in average - -30% energy intensity compared to baseline New build - -30-50% energy intensity compared to baseline across regions	Renovations - 3% annual renovation rate in average - -45-60% energy intensity compared to baseline across regions New build - -70% energy intensity compared to baseline
Energy uses	Heat pump penetration - 50-80% penetration in new build across regions, and 20% in existing stock - 18-27% coefficient of performance improvements across regions Air conditioning penetration - 100% penetration across regions - 20-50% EER improvement globally Appliances - -30% energy intensity to 2050	Heat pump penetration - 50-80% penetration across all stock (new + renovations) - 18-27% coefficient of performance improvements across regions Air conditioning penetration - 100% penetration across regions - 20-50% EER improvement globally Appliances - -30% energy intensity to 2050

Figure 43 – Building assumptions

Key assumptions – mobility

Similarly to buildings, we begin with assessing service demand evolution, on top of the baseline. We take in account various transformations of mobility patterns. Commuting is significantly abated by the rise of home office and online shopping. Lower mobility costs, greater flexibility in work and appetite for social exchanges however yield rebound effects on demand for mobility. Modal shifts also take place, albeit with different patterns of development. Long-haul transportation systems (rail, aviation) are all impacted by changes in policies and behaviors. Carpooling and transport as a service also further increase, the latter being further encouraged by the autonomous vehicle disruption, which reshapes mobility within cities. Electrification of road transport is a clear trend and we take key assumptions on adoption by 2050. We do not consider a key role for hydrogen in road transport by 2050, due to the dominance of battery systems. We expect progress in the field will be such that there will be no room for a competitive hydrogen transport value chain. We believe that, outside of the natural competitiveness of batteries, such trend will be also further accelerated by changing patterns on road logistic systems, transformed by digital technologies and built around key opportunities (and constraints) of more affordable electric powertrains. For aviation and marine, however, we consider at this stage alternative green fuels to dominate, where green hydrogen is likely to be a critical feedstock to produce synthetic green fuels or ammonia (for shipping). This shift is mostly to occur in the scenario *“Back to 2050”*, fueled by stringent policies on decarbonization, rather than by pure economics. The role of direct electrification there is assumed to remain limited, even though several reports have estimated it could play a bigger role than often anticipated.

In the *”New Normal”*, the drop in demand for mobility stemming from less commuting is compensated by a rebound from lower costs of transport (and new urban forms). In the scenario *“Back to 2050”*, however, policies foster adoption of home office, further reducing demand for commute, and provide greater constraints to circulation in cities, mitigating the rebound effect and fostering a greater adoption of public transport, notably in affluent economies. As well, the electrification of road transport is accelerated in scenario *“Back to 2050”*, thanks to a faster ramp up of a comprehensive charging infrastructure across regions[143]. The impact is more limited in new economies than in affluent economies, but a key difference between both scenarios is that we assume in *“Back to 2050”* a significant support from affluent to new economies to accelerate on this development.

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[143] 90 percent of the charging is expected to occur within buildings. BloombergNEF (b) (2021), Electric Vehicle Outlook

Passengers	**Scenario "New Normal"**	**Scenario "Back to 2050"**
Services demand	- Impact of home office, online shopping on commuting: -5% across regions - Rebound effect from decrease in transport costs	- Impact of home office, online shopping on commuting: -15% across regions - Rebound effect from decrease in transport costs mitigated thru policies
New patterns of use	Modal shifts - convergence toward individual vehicles in new economies (share of bus reduces to 10-30% across regions) - rail / aviation: stable compared to baseline (on rail: China falls at 10% total passenger kilometer travelled, India at 20%) Car pooling - +25% in industrialized economies Autonomous vehicles as a service: 30-80% penetration in cities across regions	Modal shifts - convergence toward more buses in cities (30% of passenger kilometer travelled) from policies - rail / aviation: -50% travels from air in OECD countries, compensated by rail Car pooling - +50% in industrialized economies Autonomous vehicles as a service: 30-80% penetration in cities across regions
Stock turnover	100% by 2050	100% by 2050
Energy uses	- EV penetration: 25-75% across geographies - Buses, 2-wheelers: 100% electric	- EV penetration: 50-100% across geographies - Buses, 2-wheelers: 100% electric - Aviation: 100% decarbonization (biofuels, hydrogen, electrification)
Freight	**Scenario "New Normal"**	**Scenario "Back to 2050"**
Services demand	No change compared to baseline	No change compared to baseline
New patterns of use	No change compared to baseline - notably, limited impact from Autonomous Vehicles on demand	No change compared to baseline - notably, limited impact from Autonomous Vehicles on demand
Stock turnover	100% by 2050	100% by 2050
Energy uses	Road freight: electrification 25-75% across geographies	- Road freight: electrification 50-100% across geographies - Aviation: 100% decarbonization (biofuels, hydrogen, electrification) - Marine:100% decarbonization (biofuels, hydrogen, ammonia)

Figure 44 – Mobility assumptions

Key assumptions – industry

Demand for key materials will be considerably impacted by the evolution of other sectors. Evolution in the building and mobility stock, or new construction techniques and circularity measures will impact demand for steel, cement and plastics. The demand for green fuels (notably in aviation and shipping) and changes in processes in several sectors (notably steel[144]) will also impact the demand for hydrogen.

Circularity in manufacturing, notably measures around lifetime extension and the development of a sharing economy will also significantly impact demand for goods in those sectors.

The penetration of distributed manufacturing is also modelled in our scenarios, assuming a partial displacement of traditional consumer goods manufacturing.

As for buildings, we assess stock turnover evolutions. The share of facilities still standing by 2050 will all have undergone several renovation programs by 2050, new facilities will meet new performance standards (and fully deploy by 2050 the potential

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[144] For steel, we have essentially assumed a partial switch from conventional BF-BOF (Blast Furnace – Blast Oxygen Furnace) processes to DRI (Direct Reduction of Iron). There is however an emerging potential for electrowinning technologies which we have not modelled in this issue.

of existing best available technologies), and in part will use different processing techniques. Finally, the rise of recycling facilities will also impact global stock evolution.

From a technology standpoint, we take key assumptions on the savings from digital and best-available-technologies deployment, assuming 100% coverage by 2050. Electrification of processes follows different trends across sectors (and regions), however rising everywhere as the new renewable energy infrastructure comes online.

Assumptions vary as well across scenarios. In the scenario *"Back to 2050"*, policies help foster the rise of a more circular economy, while accelerating adoption of new processes in industry and fuel switch to decarbonized electricity.

Steel	**Scenario "New Normal"**	**Scenario "Back to 2050"**
Services demand	Impact from demand in steel: -3-19% across regions - building stock evolution: see buildings - construction efficiency: -10% demand - mobility stock evolution: see mobility - circularity and distributed manufacturing: -5% impact on steel demand	Impact from demand in steel: -28-35% across regions - building stock evolution: see buildings - construction efficiency: -25% demand - mobility stock evolution: see mobility - circularity and distributed manufacturing: -10% impact on steel demand
New patterns of use	None	None
Stock turnover	Recycling share: 25-67% across regions - current rates in industrialized economies (lifetime in applications 25-50 years) - 25% in new economies Existing plants still in operation: 0-50% across regions New plants online by 2050 - 100% old process in new economies - 50% new processes in industrialized economies (assumed DRI-EAF)	Recycling share: 50-90% across regions - no stock growth in industrialized economies, maximum recycling - 50% in new economies (ambitious policies but continued growth in stock) Existing plants still in operation: 0-30% across regions New plants online by 2050: 50-100% new processes across regions (assumed DRI-EAF)
Energy uses	Energy efficiency - recycling: -80% energy intensity - renovations and new build (digital + best available technologies): -30% energy intensity, across all processes Electrification - defined by the mix in new processes	Energy efficiency - recycling: -80% energy intensity - renovations and new build (digital + best available technologies): -30% energy intensity, across all processes Electrification - defined by the mix in new processes + ambitious renovation policies on existing stock

Cement	**Scenario "New Normal"**	**Scenario "Back to 2050"**
Services demand	- Building stock evolution: -5 to +22% on demand across regions - Construction efficiency (waste management, optimized specifications, modular fabrics): -20% on demand across regions	- Building stock evolution: -8-16% on demand across regions - Construction efficiency (waste management, optimized specifications, modular fabrics): -33% on demand across regions
New patterns of use	None	None
Stock turnover	- Existing plants still in operation: 0-50% across regions - 100% new plants in industrialized economies integrate new processes (low-clinker, etc.)	- Existing plants still in operation: 0-30% across regions - 100% new plants in industrialized economies integrate new processes (low-clinker, etc.), 50% in other regions
Energy uses	Energy efficiency - renovations and new build (digital + best available technologies): -30% energy intensity on current processes - new processes: +10% energy intensity Fuel switch - +5% increase in electrification, 6-22% share across regions	Energy efficiency - renovations and new build (digital + best available technologies): -30% energy intensity on current processes - new processes: +10% energy intensity Fuel switch - 21-33% electrification share across regions - coal use fully displaced globally

Petrochemicals	Scenario "New Normal"	Scenario "Back to 2050"
Services demand	No impact compared to baseline Minor impacts on hydrogen demand from some process changes, notably in steel	Impact on plastic demand from increased building insulation, and more importantly packaging reuse and optimization: -0-13% across regions Significant impact on hydrogen demand from process decarbonization and green fuels (aviation, shipping) Impact of circularity and distributed manufacturing: -5% impact on petrochemical demand (mainly on plastics)
New patterns of use	None	None
Stock turnover	Recycling share: 30% - 60% mechanical, 40% chemical recycling Existing plants still in operation: 0-50% across regions New plants online by 2050, as a result from stock turnover	Recycling share: 30% - 60% mechanical, 40% chemical recycling Existing plants still in operation: 0-50% across regions New plants online by 2050, as a result from stock turnover
Energy uses	Energy efficiency - recycling: -90% energy intensity for mechanical, none for chemical - renovations and new build (digital + best available technologies): -30% energy intensity, across all processes Electrification: 20-85% across regions - doubling of the share of electrification across regions	Energy efficiency - recycling: -90% energy intensity for mechanical, none for chemical - renovations and new build (digital + best available technologies): -30% energy intensity, across all processes Electrification: 85% globally - maximized electrification potential realized

Automotive	Scenario "New Normal"	Scenario "Back to 2050"
Services demand	Impact from mobility demand: -17-44% across regions	Impact from mobility demand: -17-44% across regions
New patterns of use	Negligible impact compared to baseline from further reusing/repurposing measures	Negligible impact compared to baseline from further reusing/repurposing measures
Stock turnover	100% new by 2050	100% new by 2050
Energy uses	Energy efficiency (digital + best available technologies): -10% energy intensity Electrification: 90% by 2050	Energy efficiency (digital + best available technologies): -10% energy intensity Electrification: 100% by 2050

Machinery	Scenario "New Normal"	Scenario "Back to 2050"
Services demand	None	None
New patterns of use	Impact from circularity measures: -15% on machines demand - 50% machines operated as a service - 30% lifetime extension	Impact from circularity measures: -30% on machines demand - 50% machines operated as a service - 30% lifetime extension
Stock turnover	100% new by 2050	100% new by 2050
Energy uses	Energy efficiency (digital + best available technologies + new design and additive manufacturing): -20% energy intensity Electrification: 80% by 2050	Energy efficiency (digital + best available technologies + new design and additive manufacturing): -20% energy intensity Electrification: 100% by 2050

Other Industry	Scenario "New Normal"	Scenario "Back to 2050"
Services demand	None	None
New patterns of use	- impact from circularity measures (sharing economy): -20% on consumer goods - distributed manufacturing (localization of production, decreases in costs): +5% on activity	Impact from circularity measures: - sharing economy + policy regulations to forbid scrap and force reuse: -50-60% on consumer goods across regions Distributed manufacturing (localization of production, decreases in costs): +5% on activity
Stock turnover	100% new by 2050 - 75% traditional processes - 25% distributed manufacturing	100% new by 2050 - 75% traditional processes - 25% distributed manufacturing
Energy uses	Energy efficiency - traditional processes (digital + best available technologies): -10% energy intensity - distributed manufacturing: x1.5 the energy intensity of manufacturing Electrification: 24-80% across regions - doubling of the share of electrification across regions	Energy efficiency - traditional processes (digital + best available technologies): -10% energy intensity - distributed manufacturing: x1.5 the energy intensity of manufacturing Electrification: 95% by 2050

Figure 45 – Industry assumptions

Focus on recycling

We have essentially modelled recycling rates for steel and plastics. Recycling is however expected to accelerate for a variety of other components, notably in different metal groups (copper, aluminum, etc.) and even for concrete and aggregates. As a first approximation, we have estimated these changes to not yield material transformations to energy demand, yet this certainly requires a deeper focus.

For steel, production from scrap EAF (Electric Arc Furnace) accounts today for around 20 percent of total. We estimate this ratio goes up to 40 percent in the *"New Normal"*, and up to 70 percent in *"Back to 2050"*. The latter figure assumes a near saturation of steel demand in affluent economies, enabling 90 percent recycling rates by 2050[145]. Ratios in new economies (which have not reached saturation by 2050) are hence much lower, in the range of 50 percent by 2050, an assumption globally consistent with existing studies[146].

For plastics, we have estimated half of plastics to be collected for recycling and entirely recycled, one third of it through chemical recycling and the other two-thirds by way of mechanical recycling[147].

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145 There are still debates on the ultimate recycling potential of steel. A key question is notably copper contamination, which could prevent its use in many applications (notably automotive). See Allwood J. et al (2017), How Will Copper Contamination Constrain Future Global Steel Recycling?

146 Labbé notably estimates that provided 100 percent of metals can be retrieved (from ambitious policy frameworks), and estimating a 2 percent growth per year in demand, and a 30-40 years lifetime in stock, recycling could support around 50 percent of demand. The lifetime of steel in stock varies across uses (it exceeds 50 years for construction, which corresponds to 50 percent of global demand, but is lower at or below 20 years for machinery and transport equipment). Labbé, J. (2016), Les limites physiques de la contribution du recyclage à l'approvisionnement en métaux.

147 Hundertmark et al (2018), How plastics waste recycling could transform the chemical industry

Focus on distributed manufacturing

Our main assumption on distributed manufacturing is that it pervades first the consumer goods sector and displaces 50 percent of existing processes by 2050. We have not taken assumptions for other sectors, despite very encouraging signs in machinery, transport equipment, and construction. This should be the object of further research.

We also estimate that such adoption drives a rebound in consumer goods demand (we estimate an additional 5 percent on top of the expected growth in activity) because of easier access and lower (possibly perceived) costs.

We also estimate that energy intensity of distributed manufacturing is likely to be higher for this sector than conventional practices, even though material demand will be much lower (with ripple effects on natural resources extraction and refining as a result). Given the lack of literature on the topic, we have arbitrarily assumed energy intensity to be 1.5 times that of current processes, leading to a significant increase in energy demand for the sector.

Our evaluation yields an electricity demand of 7,700TWh in the sector (an additional 2,600TWh compared to baseline levels with no additional energy intensity).

Key assumptions – supply

The supply mix evaluation is a direct output of the POLES-Enerdata model, which results from least cost trajectories for different types of supply technologies and carbon prices (in the scenario *“Back to 2050”*).

Few key assumptions on power generation have also been integrated in the scenario *“Back to 2050”* as we assume zero emissions of the sector by 2050.

- This implies coal and oil-fired power generation to be fully decommissioned, and the remaining gas infrastructure is equipped with Carbon Capture, Utilization and Storage or natural gas is substituted by green gases.
- While most of the power generation is supplied by renewable resources (intrinsically cheaper in Levelized Cost of Electricity – LCOE terms), there remains a share of power generation supplied by nuclear power, stemming from the development (in select geographies) of Small Modular Reactors and Micro Modular Reactors, developments which we consider could unfold by this time.

A specific outlook for distributed generation has also been developed outside of the model. It will be the object of a coming publication by the Schneider Electric Sustainability Research Institute. We therefore describe here the key assumptions built in the model. It is to be noted that the entire model is built on the building sector and does not take into account possible distributed generation resources in industrial facilities.

The following steps are followed to assess over potential

- Assess rooftop surface globally, as a proxy of building surface (current and projected) and types of buildings. These ratios vary between 15 and nearly 100 percent across different building configurations. We have considered them stable over time.

- Assess the suitable roof area for distributed generation, which highly depends on the form of the roof, the density of construction and its location, the orientation and equipment already in place. This suitable roof area depends significantly on building designs[148], and we assume it will continue to evolve upward as penetration of distributed generation becomes more economically sound in the coming decade[149]. While current ratios vary between 10-50 percent in our model for current buildings, we estimate new buildings could go up to 70 percent of suitable roof space, through improved designs.
- Assess the distributed generation potential (per square meter of solar panel). This also varies significantly across regions. We use data from Global Solar Atlas to come up to regional potentials, to which we add a 20 percent downgrading factor, accounting for losses between solar panel outputs and effective electricity available[150].

These assumptions yield a global potential of around 7,500TWh of distributed generation to date, which could increase up to 25,000TWh by 2050, taking into account increase in stock and increase in suitable rooftop surface. These findings are consistent with other studies for both current and projected potentials[151]. 75 percent of this potential is in new constructions (due to the share of new buildings by 2050 and the increased suitability of roofs for solar installations). As well, 80 percent of the potential is in residential settings[152].

The next step of the model is to make assumptions of penetration. We take different assumptions across the two scenarios

- In the scenario ”New Normal”: we assume systematic solar PV development on new buildings begins from 2040 onward (across regions), as economics reach grid parity worldwide (market-driven penetration). We also assume a third of the existing stock is equipped by 2050 globally. This yields a total amount of distributed generation of around 8,000TWh.
- In the scenario *“Back to 2050”*: we assume a more radical approach to decarbonization of the building stock, assuming all new build to be equipped with solar PV from 2025 onward and two-thirds of the existing stock. This yields 16,000TWh of distributed generation by 2050.

Key assumptions – costs of energy across various uses

One of the general claims on the energy transition is that it will lead to higher costs of energy. This is a theme which requires a much deeper look as the actual cost of energy is a complex proxy of several items. We only provide a few insights on this complex issue here. This will be the object of further publications.

Energy costs are traditionally compared from their price point at delivery. A first issue with such comparison is that they include a whole range of taxes which significantly blur the picture. As an example, taxes on electricity are four times those of natural

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[148] Ratios vary between 10-15 percent and 70 percent across regions (the lower case comes from a study from Apur and Egis on downtown Paris, the higher case from a study from Taminau and Byrne on New York). Apur & Egis (2015), Analyse de potentiel solaire. Toitures du Grand Paris; Deng et al (2015), Quantifying a realistic, worldwide wind and solar electricity supply; ©OECD/IEA (2019), Renewables 2019; Taminiau J, Byrne J. (2020), City-scale urban sustainability: Spatiotemporal mapping of distributed solar power for New York City

[149] BloombergNEF (2021), Realizing the Potential of Customer-Sited Solar. It is predicted that distributed generation will reach grid parity across the world in the coming years, pushing for further adoption. As well, paybacks for new constructions are well below 5 years, and on a downward trend, making it largely a “no-brainer” for new constructions.

[150] Global Solar Atlas (2021), Global Solar Atlas, from Solargis, ESMap, World Bank Group

[151] Forecasts range between 8,000TWh and 18,000TWh for current: Deng et al (2015), Quantifying a realistic, worldwide wind and solar electricity supply; ©OECD/IEA (2019), Renewables 2019. For projections, Deng et al (2015) estimate a 2050 potential of 25,000TWh (very consistent with our own), to which needs to be added additional potential from harvesting solar energy from facades (Building-integrated photovoltaics), which accounts for around 15,000TWh additional. Deng et al (2015), Quantifying a realistic, worldwide wind and solar electricity supply

[152] Schneider Electric Research

gas in European households[153]. A second issue is that comparisons often stop at the price at delivery point, not taking into account the cost of useful energy, or the effective energy used for the required service. An emblematic example is the difference in performance of various heating solutions. While traditional gas boilers have efficiencies of around 90 percent, the performance of heat pumps have efficiencies of 300-500 percent (as they use natural renewable energy from the ambient environment). For a similar useful energy, heat pumps thus use 3-5 times less input energy. Another example is that of vehicle powertrains, with electric vehicles around 3 times more efficient than conventional gasoline cars.

To understand energy costs competitiveness across various energy sources, it is thus critical to look at useful energy competitiveness, without tax.

Figure 39 summarizes a high-level perspective on the subject. 1kWh of useful energy is converted into its equivalent final energy demand (accounting for waste in use) for both fossil fuels and electric solutions, across three main sectors: mobility, low-temperature heating (buildings, manufacturing), high-temperature heating (process industries). As electric systems are more efficient, cost parity is defined by the cost of fossil fuels multiplied by the efficiency factor. The cost of fossil fuels and electricity is then assessed, without taxes. Data from the Energy Information Agency in the United States is used for this analysis[154]. The situation obviously significantly differs from one region to another.

A first key conclusion is that, all other things being equal, electric systems are competitive in mobility and low-temperature heating applications (using heat pumps). The situation is more complex in high-temperature heating, although near parity. The rising competitiveness of renewable energies drives deflationary pressure on generation costs which could improve the competitiveness of electrified solutions in the future. Decentralized renewable energy provisions for large industrial sites could also significantly tame overall costs of energy (since no grid costs is included), although it would not supply all of the energy required by those facilities.

A key to the competitiveness of electric solutions will however be the ability to store this highly affordable renewable energy resource at times of plentiful supply. Storage will thus play a fundamental role in overall competitiveness of electric solutions. While a lot of ink has spilled on the costs of stationary electric storage, thermal storage behind the meter also offers a significant prospect (as most of these needs are for heating and/or cooling, outside mobility). Solutions exist already and often come at highly competitive costs, not to say near zero-marginal cost when they are directly integrated into a new facility design (or leveraging existing appliances such as water tanks in buildings)[155].

Although such assessment clearly requires a deeper and more regional and sectorial study, we can safely conclude that the argument that electrification comes at a cost is largely misconstrued. This also does not integrate the growing competitiveness from improved renewable technologies, as well as the likely increase in fossil fuel infrastructure costs as demand is progressively reduced.

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[153] Eurostat (2020), Data For Households

[154] Energy Information Agency (b) (2021), Table 5.3. Average Price of Electricity to Ultimate Customers; Energy Information Agency (c) (2021), Gasoline and Diesel Fuel Update; Energy Information Agency (d) (2021), Natural Gas prices; Schneider Electric Research

[155] See notably Philibert C. (2017), Renewable Energy for Industry; Dorr A., Seba T. (2020), Rethinking Energy 2020–2030

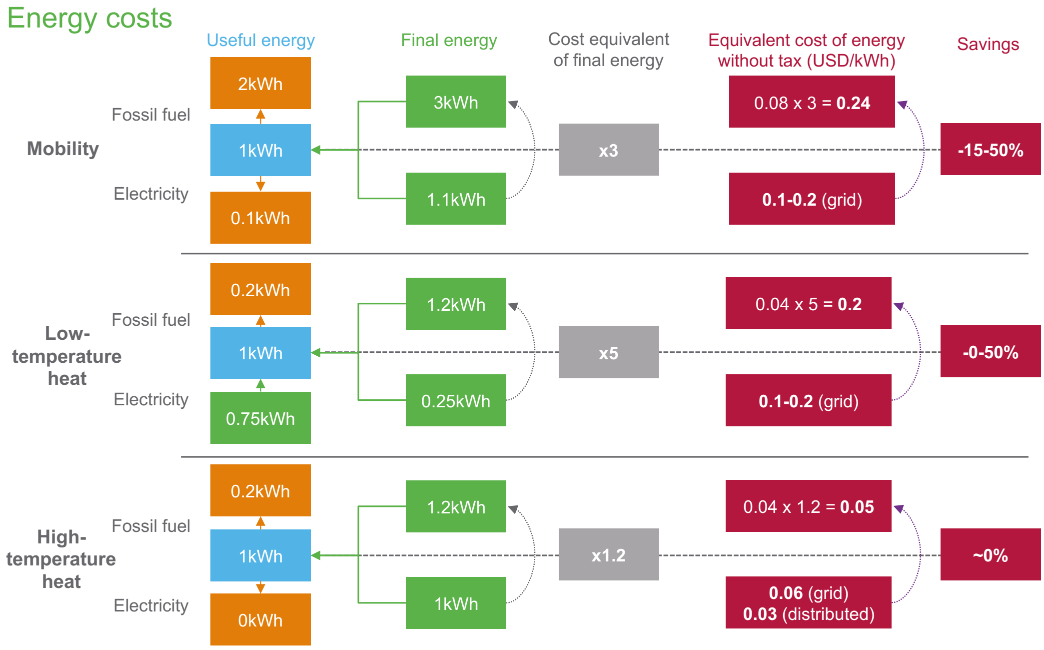

Figure 46 – Energy costs

Key assumptions – water energy demand

Water demand today ranges around 3,900 cubic kilometers per year, and is expected to increase 50 percent by 2050, although forecasts vary significantly[156]. Water energy demand is split across three main processes: supply (and transfer), distribution, and wastewater treatment. Supply takes multiple forms, from surface extraction to ground water pumping and desalination (desalination accounts for less than 1 percent of global water supply). Only 20 percent of wastewater is treated today[157]. Water is mainly used in agriculture (around 70 percent of total needs, directly pumped and used), and then almost equally for energy, industrial and municipal uses (around 10 percent each). The last two involve distribution of water.

Each of these processes shows different energy intensities. Water supply energy intensity ranges between as low as 0.01kWh/m3 up to 3-5kWh/m3 (desalination). Distribution ranges between 0.1-0.5kWh/m3, and wastewater treatment between 0.1-1kWh/m3[158]. Although there is no clear forecast of current water energy demand, it can be modelled at around 800-1,000TWh today, based on global average energy intensities. Our current model yields similar figures as the forecast from the International Energy Agency[159].

Many uncertainties exist around the future energy demand of the water sector to 2050.

- We have based our modelling on a 50 percent growth in demand to 2050. All other things being equal, this yields an increase of around 400-500TWh ofenergy demand.
- We have also assumed that 100 percent of municipal and industrial wastewater would be treated by 2050. This yields an additional 400TWh of energy demand.

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156 Citi (2017), Solutions for the Global Water Crisis; IRENA (2015), Renewable Energy in the Water, Energy and Food Nexus; © OECD/IEA (2016), Water Energy Nexus; Petit V. (b) (2021), The Age of Fire is Over

157 In fact, around 65 percent of municipal wastewater is treated, but this ratio is lower for industrial wastewater, and close to zero for agriculture.

158 OECD/IEA (2016), Water Energy Nexus

159 Ibid

- We have then assumed that a significant share of the growth in water demand would come from desalination. Here the figures vary significantly, from +30TWh (assuming a similar share in total water supply than current) to +4,900TWh (assuming 100 percent of additional demand comes from desalination). Assuming 20 percent of additional demand would yield an additional 1,000TWh of energy demand. A 50 percent share would yield +2,500TWh of energy demand.

This thought experiment is not enough to conclude on a precise forecast, but it already appears clearly that the share of desalination in global water supply will be the defining factor of future energy demand for the sector. Considering increased demand will mainly stem from regions in scarce supply[160], it is reasonable to assume desalination will pick up a larger share of total water supply and hence impact strongly global energy demand in key locations. Overall, this is a new energy use which has so far largely been overlooked. Further research is however required and will be the object of subsequent publications.

Key assumptions – digital technologies energy footprint

The evaluation of the exact impact of digital technologies on energy demand is a complex exercise as there is no agreed taxonomy on what to account for, and significant uncertainties going forward. In 2021, Schneider Electric issued a forecast for energy demand of the ICT sector to 2030, using a bottom-up analysis[161]. The forecast yielded a 50 percent increase of energy demand between 2020 and 2030, from around 2,000TWh to date to 3,200TWh by 2030, a significant increase, yet putting to rest many concerns on uncontrollable and rapid growth in demand.

The study also highlighted key uncertainties, mainly revolving around 2 issues

- How energy demand from manufacturing is accounted for is a key bone of contention across current forecasts, and many uncertainties remain.
- While short-term projections can relatively easily be extrapolated from current trends, projecting the demand of the sector in the medium-term has to account for new IT services (AI, blockchain, autonomous vehicles, etc.) and new IT capabilities (quantum computing, new hardware innovations, new connectivity services, etc.) which are hard to predict.

It is therefore beyond the scope of this report to make a precise forecast of the future footprint of digital technologies on global energy demand by 2050. It appears however clearly that this footprint will grow significantly as the economy continues to leverage digital technologies and could represent a sizeable share of global energy demand by 2050.

As a thought experiment, if the rate of growth in energy demand was to continue as planned (around 5 percent CAGR in our forecast), the 2050 energy demand would reach around 8,000-9,000TWh by 2050.

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[160] Petit V. (2021), The Future of the Global Order

[161] Schneider Electric (e) (2021), Digital Economy and Climate Impact

The POLES-Enerdata Model

POLES-Enerdata is a partial equilibrium simulation model of the world energy sector until 2050, with complete modelling from upstream production to final user demand by sector, and resulting greenhouse gas emissions. POLES is used and jointly developed by Enerdata in collaboration with the European Commission's Joint Research Centre (Seville) and University of Grenoble-CNRS (GAEL laboratory).

The simulation process uses year-by-year dynamic recursive with endogenous international energy prices and lagged adjustments of supply and demand by region, which allows to account for interactions between the main modules: energy supply, energy transformation, and final energy demand.

With a geographical distribution of 54 individual countries including G20 members, and 12 additional regional aggregates making up the world coverage, POLES-Enerdata is suited to analyse long-term energy and climate trends both on a global and on a regional or national level.

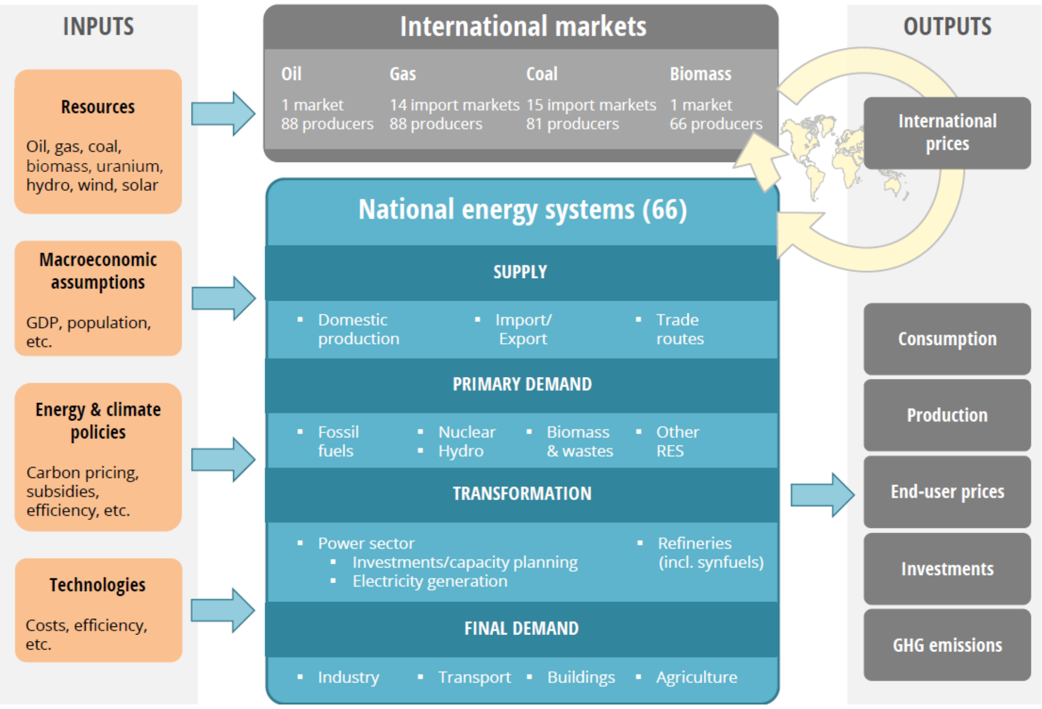

Figure 47 - POLES-Enerdata model structure

Final demand

The model considers 11 different final demand sub-sectors distributed between industry, transport and buildings, using a mix between a more top-down econometric approach and a bottom-up techno-economic assessment to determine the level of energy demand by sector. Energy demand is broken down by specific uses, e.g. space & water heating, cooling or appliances in buildings; freight and passengers in transport; captive electricity, energy use and feedstock in industry. When applicable, a mix of technologies are competing to meet energy uses, this is for instance the case of different type of boilers and heat pumps for heating needs, or different type of vehicles (EVs, PHEVs, ICEs) for road transport.

Energy supply

Supply of major energy sources such as oil, natural gas, coal and biomass is also endogenously considered.

Oil and natural gas supply in particular is well detailed with 88 producing countries covered, and the evolution of reserves is estimated using data available on ultimately recoverable resources. Production and trade flows between countries are modelled accounting for geographic specificities, the particularities trade routes and their potential evolution (e.g. increased role of LNG).

Energy transformation

Electricity and hydrogen demand have to be met within their specific modules which deals with both capacity planning and generation/dispatch.

For power generation, more than 30 technologies are competing to meet capacity requirements among which thermal power plants (including more advanced technologies and CCS), nuclear reactors, hydroelectric plants, wind (onshore and offshore), solar (centralized and distributed). Electricity generation from the resulting capacities are obtained through a merit order approach, accounting for the fatal and intermittent nature of renewable energy sources.

Similarly, 14 different hydrogen production technologies are competing in capacity planning and generation dispatch, including grey, blue and green (electrolysis, solar methane reforming) technologies.

Input data

Historical energy consumption data in POLES-Enerdata are extracted from Enerdata's own international energy databases and are updated on a yearly basis.

The model also uses external macro-economic and demographic assumptions such as GDP and population by country until 2050 from internationally recognised sources[162].

Techno-economic data such as CAPEX and OPEX and performances of power plants, hydrogen plants or other technologies such heat pumps and road transport vehicles are also collected from various sources163 and are updated on a regular basis.

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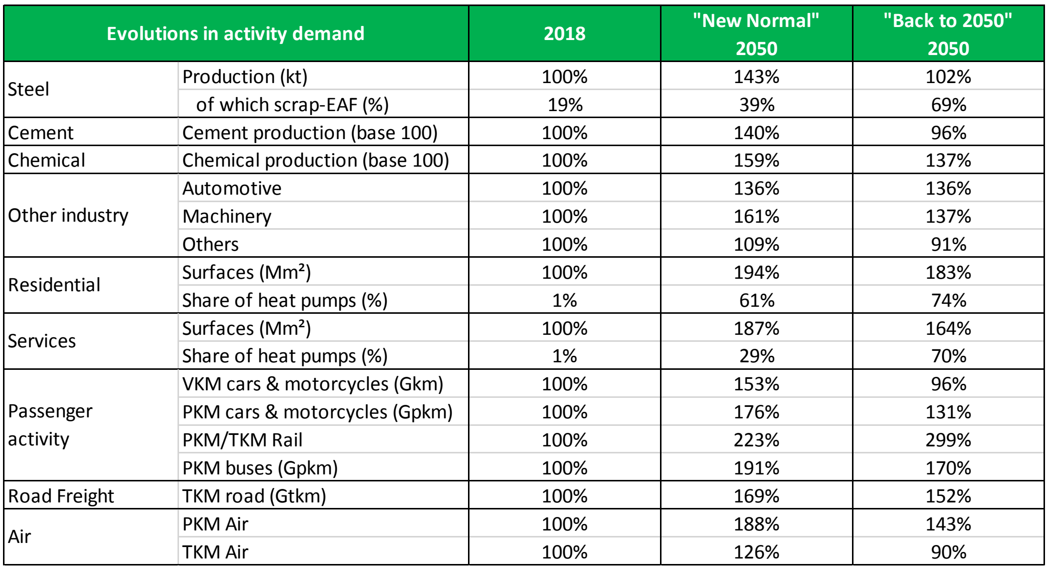
162 IMF, Oxford Economics, United Nations Development Programme (UNDP)

163 © OECD/IEA, ASSET-PRIMES

Detailed results

Based on this set of assumptions, we model the evolution of the energy demand, and then the resulting supply system which will develop to meet those needs. The following tables consolidate all results from the modelling exercise. This is a global view only. Regional forecasts will be detailed in subsequent publications.

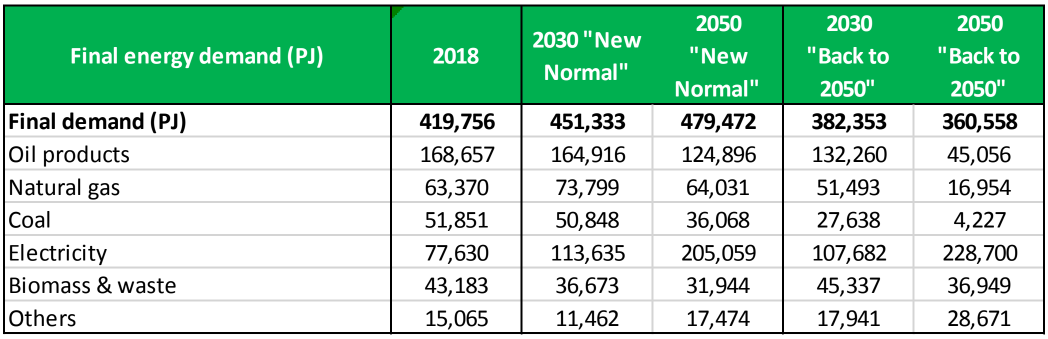
Activity levels



Evolutions in activity demand		2018	"New Normal" 2050	"Back to 2050" 2050
Steel	Production (kt)	100%	143%	102%
	of which scrap-EAF (%)	19%	39%	69%
Cement	Cement production (base 100)	100%	140%	96%
Chemical	Chemical production (base 100)	100%	159%	137%
Other industry	Automotive	100%	136%	136%
	Machinery	100%	161%	137%
	Others	100%	109%	91%
Residential	Surfaces (Mm²)	100%	194%	183%
	Share of heat pumps (%)	1%	61%	74%
Services	Surfaces (Mm²)	100%	187%	164%
	Share of heat pumps (%)	1%	29%	70%
Passenger activity	VKM cars & motorcycles (Gkm)	100%	153%	96%
	PKM cars & motorcycles (Gpkm)	100%	176%	131%
	PKM/TKM Rail	100%	223%	299%
	PKM buses (Gpkm)	100%	191%	170%
Road Freight	TKM road (Gtkm)	100%	169%	152%
Air	PKM Air	100%	188%	143%
	TKM Air	100%	126%	90%

Figure 48 – activity level changes

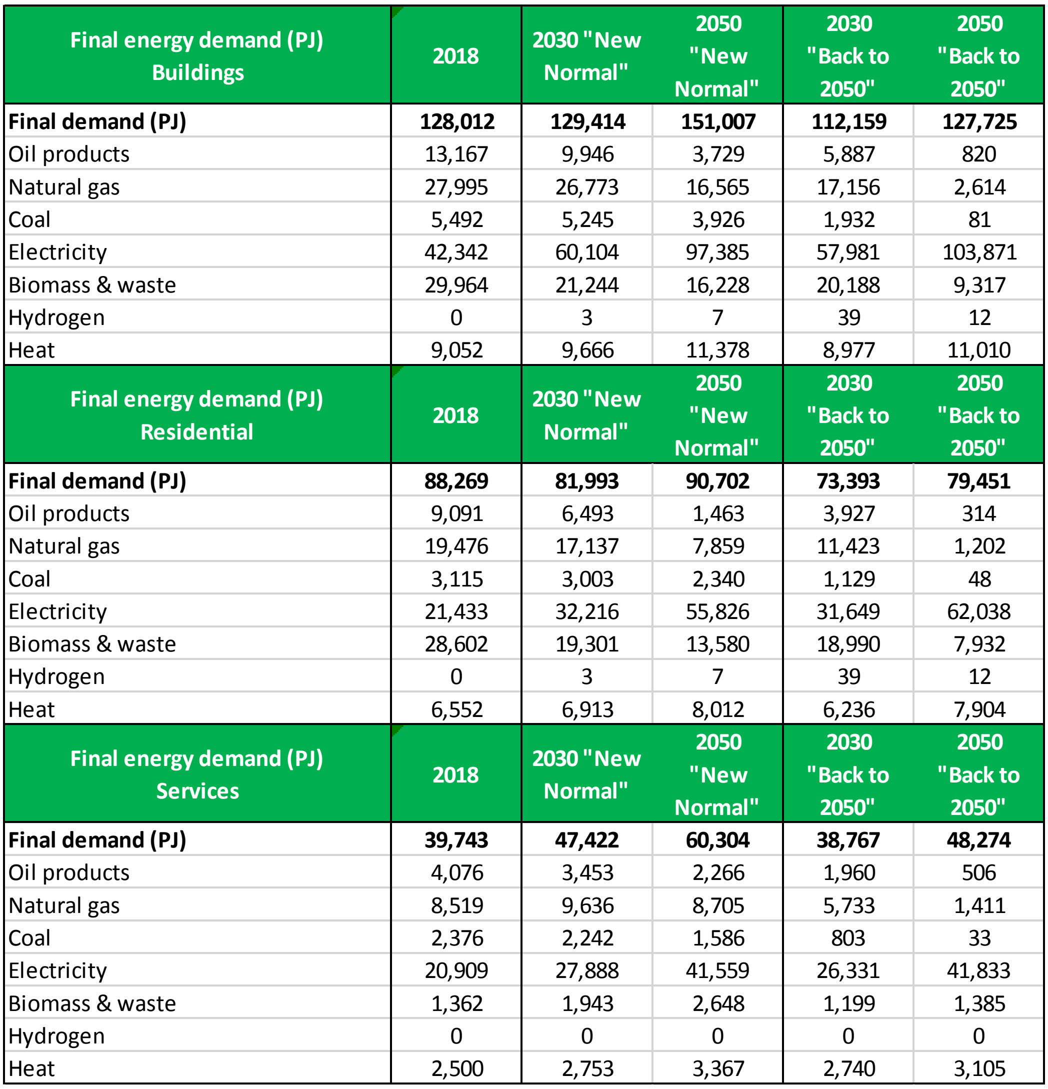
Final energy demand



Final energy demand (PJ)	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**419,756**	**451,333**	**479,472**	**382,353**	**360,558**
Oil products	168,657	164,916	124,896	132,260	45,056
Natural gas	63,370	73,799	64,031	51,493	16,954
Coal	51,851	50,848	36,068	27,638	4,227
Electricity	77,630	113,635	205,059	107,682	228,700
Biomass & waste	43,183	36,673	31,944	45,337	36,949
Others	15,065	11,462	17,474	17,941	28,671

Figure 49 – Final energy demand, global

Final energy demand – Buildings



Final energy demand (PJ) Buildings	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**128,012**	**129,414**	**151,007**	**112,159**	**127,725**
Oil products	13,167	9,946	3,729	5,887	820
Natural gas	27,995	26,773	16,565	17,156	2,614
Coal	5,492	5,245	3,926	1,932	81
Electricity	42,342	60,104	97,385	57,981	103,871
Biomass & waste	29,964	21,244	16,228	20,188	9,317
Hydrogen	0	3	7	39	12
Heat	9,052	9,666	11,378	8,977	11,010

Final energy demand (PJ) Residential	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**88,269**	**81,993**	**90,702**	**73,393**	**79,451**
Oil products	9,091	6,493	1,463	3,927	314
Natural gas	19,476	17,137	7,859	11,423	1,202
Coal	3,115	3,003	2,340	1,129	48
Electricity	21,433	32,216	55,826	31,649	62,038
Biomass & waste	28,602	19,301	13,580	18,990	7,932
Hydrogen	0	3	7	39	12
Heat	6,552	6,913	8,012	6,236	7,904

Final energy demand (PJ) Services	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**39,743**	**47,422**	**60,304**	**38,767**	**48,274**
Oil products	4,076	3,453	2,266	1,960	506
Natural gas	8,519	9,636	8,705	5,733	1,411
Coal	2,376	2,242	1,586	803	33
Electricity	20,909	27,888	41,559	26,331	41,833
Biomass & waste	1,362	1,943	2,648	1,199	1,385
Hydrogen	0	0	0	0	0
Heat	2,500	2,753	3,367	2,740	3,105

Figure 50 – Final energy demand, buildings

Final energy demand – Mobility

Final energy demand (PJ) Mobility	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**117,186**	**129,845**	**127,366**	**107,912**	**82,608**
Oil products	110,255	113,988	89,378	89,126	18,203
Natural gas	2,019	2,387	1,293	1,517	259
Coal	2	2	2	2	2
Electricity	1,087	8,216	29,797	10,954	34,861
Biofuels	3,824	5,064	6,428	5,378	17,615
Hydrogen and Hydrogen-based fuels	0	188	469	936	11,669

Final energy demand (PJ) Road	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**88,896**	**95,384**	**80,115**	**76,446**	**45,056**
Oil products	83,003	82,144	49,125	62,897	15,523
Natural Gas products	2,019	2,387	1,293	1,517	259
Electricity	51	6,651	26,479	8,371	25,298
Biofuels	3,824	4,013	2,749	3,336	1,980
Hydrogen	0	188	469	324	1,995

Final energy demand (PJ) Rail	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**2,296**	**2,832**	**4,544**	**2,955**	**5,853**
Oil products	1,258	1,266	1,224	983	469
Coal	2	2	2	2	2
Electricity	1,037	1,565	3,319	1,971	5,383
Biofuels	0	0	0	0	0
Hydrogen	0	0	0	0	0

Final energy demand (PJ) Air	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**14,228**	**17,270**	**25,460**	**16,271**	**19,177**
Oil products	14,228	16,219	21,781	14,841	959
Electricity	0	0	0	0	2,301
Biofuels	0	1,051	3,678	1,429	14,383
Hydrogen and Hydrogen-based fuels	0	0	0	0	1,534

Final energy demand (PJ) Marine	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**11,766**	**14,359**	**17,248**	**12,241**	**12,522**
Oil products	11,766	14,359	17,248	10,405	1,252
Electricity	0	0	0	612	1,878
Biofuels	0	0	0	612	1,252
Hydrogen-based fuels	0	0	0	612	8,139

Figure 51 – Final energy demand, mobility

Final energy demand – Industry

Final energy demand (PJ) Industry (without feedstock)	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**127,892**	**137,330**	**136,688**	**116,242**	**103,847**
Oil products	12,416	10,536	5,391	8,135	1,014
Natural gas	24,969	30,312	26,141	24,772	7,225
Coal	43,588	39,956	23,225	22,754	1,146
Electricity	31,942	42,378	72,661	35,328	84,190
Biomass & waste	8,964	8,975	5,439	17,263	4,292
Hydrogen	0	897	1,532	5,031	4,117
Heat	6,013	4,274	2,299	2,958	1,863

Final energy demand (PJ) Steel	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**30,338**	**32,722**	**25,914**	**29,198**	**11,173**
Oil products	272	366	163	757	90
Natural gas	2,439	2,800	1,330	3,990	510
Coal	22,053	21,463	11,788	13,069	854
Electricity	4,814	7,034	11,782	5,824	7,099
Biomass & waste	173	487	230	2,810	612
Hydrogen	0	52	85	2,533	1,750
Heat	586	518	536	215	259

Final energy demand (PJ) Minerals	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**18,339**	**20,488**	**19,253**	**16,347**	**15,453**
Oil products	2,210	2,226	1,328	1,827	650
Natural gas	2,732	4,047	4,296	4,729	4,853
Coal	10,286	9,753	7,354	2,875	215
Electricity	2,489	3,042	4,577	2,774	4,990
Biomass & waste	496	1,074	1,091	3,008	1,850
Hydrogen	0	219	484	962	2,090
Heat	127	127	124	173	805

Final energy demand (PJ) Chemicals	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**20,512**	**20,764**	**19,355**	**17,996**	**16,671**
Oil products	2,078	1,840	771	1,223	70
Natural gas	6,600	6,401	3,673	5,051	845
Coal	4,436	3,040	1,584	1,878	37
Electricity	4,776	6,515	11,597	4,942	14,174
Biomass & waste	90	854	539	2,508	641
Hydrogen	0	208	201	493	130
Heat	2,532	1,905	990	1,901	774

Final energy demand (PJ) Other industry	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**58,702**	**63,356**	**72,167**	**52,701**	**60,549**
Oil products	7,856	6,104	3,128	4,329	204
Natural gas	13,198	17,063	16,842	11,002	1,017
Coal	6,813	5,700	2,499	4,932	40
Electricity	19,863	25,787	44,706	21,788	57,927
Biomass & waste	8,205	6,560	3,581	8,938	1,189
Hydrogen	0	418	763	1,043	148
Heat	2,768	1,724	649	669	25

Figure 52 – Final energy demand, industry

Final energy demand - Others

Final energy demand (PJ) Other	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Final demand (PJ)	**46,666**	**54,743**	**64,411**	**46,039**	**46,378**
Oil products	32,819	30,445	26,398	29,112	25,020
Natural gas	8,387	14,326	20,033	8,048	6,856
Coal	2,770	5,645	8,916	2,950	2,999
Electricity	2,258	2,938	5,216	3,420	5,779
Biomass & waste	431	1,390	3,849	2,508	5,725
Hydrogen	0	0	0	0	0
Heat	0	0	0	0	0

Figure 53 – Final energy demand, other

Power generation

Power Generation (TWh)	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Total generation (TWh)	**24,675**	**36,985**	**65,798**	**35,833**	**74,155**
Coal	38%	19%	7%	16%	0%
Natural gas	23%	21%	17%	15%	4%
Oil	3%	1%	1%	1%	0%
Biomass & waste	2%	2%	1%	2%	1%
Nuclear	10%	9%	7%	8%	7%
Renewables	24%	48%	67%	58%	87%
Hydroelectricity	16%	15%	13%	16%	12%
Wind	5%	16%	26%	20%	34%
Solar	2%	17%	28%	23%	38%
Other	0%	0%	0%	0%	2%
Hydrogen	0%	0%	0%	0%	0%

Figure 54 – Power generation

CO2 emissions

Emissions (MtCO2/y)	2018	2030 "New Normal"	2050 "New Normal"	2030 "Back to 2050"	2050 "Back to 2050"
Total	**35,152**	**32,703**	**24,942**	**23,531**	**0**
Total (without compensation)	**35,152**	**32,703**	**25,366**	**23,836**	**5,625**
Industry (incl. non-energy uses)	7,200	7,218	5,244	4,628	1,246
Industry processes	2,716	2,981	2,809	2,278	1,304
Industry CCUS	0	0	-133	-165	-923
Buildings	2,985	2,673	1,557	1,543	210
Transport	7,995	8,291	6,469	6,463	1,320
Power generation	12,240	9,699	8,170	7,473	1,272
Power CCUS	0	0	-232	-70	-1,252
Other transformation	1,636	1,529	1,022	1,293	258
Other CCUS	0	0	-59	-65	-638
Fugitive emissions	381	312	95	158	14
Other negative emissions	0	0	0	-5	-2,811

Figure 55 – carbon dioxide emissions

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