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Sustainability Research Institute

Amrit Kaal

Path to Developed and Decarbonized India

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Amrit Kaal is the 25-year-long lead
up to 100 years of independent India,
which will witness national development
and progress on a global stage.

Introducing the Schneider Electric™ Sustainability Research Institute

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Global awareness for a more inclusive and climate-positive world is at an all-time high. This includes carbon emissions as well as preventing environmental damage and biodiversity loss. Nation states and corporations are increasingly making climate pledges and including sustainability themes in their governance. Yet, progress is nowhere near where it should be. For global society to achieve these goals, more action and speed is needed.

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The mission of the Schneider Electric™ Sustainability Research Institute is to examine the facts, issues, and possibilities, to analyze local contexts, and to understand what businesses, societies and governments can and should do more of. We aim to make sense of current and future trends that affect the energy, business, and behavioral landscape to anticipate challenges and opportunities. Through this lens, we contribute differentiated and actionable insights.

We build our work on regular exchanges with institutional, academic and research experts, collaborating with them on research projects where relevant. Our findings are publicly available online, and our experts regularly speak at forums to share their insights.

Set up in 2020, our team is part of Schneider Electric, the leader in the digital transformation of energy management and automation, whose purpose is to bridge progress and sustainability for all.

In this report, we analyze the possible future energy system evolution of India all the way to 2070. A first important contribution to the global debate is a first-of-its-kind exploration of the energy system all the way to 2070. Second, the key originality of this report is a unique and in-depth exploration of critical transformations in energy services (or practices) and consumption patterns, driven by both technological innovations rapidly spreading across a fast-developing Indian economy as well as ambitious policymaking. Two scenarios are developed. The first one targets current commitments from the Indian government to reach energy independence by 2047 and a net-zero economy by 2070. The second explores what it would take to reach both goals as early as 2047. A critical finding is that such a transition might be more feasible than we think.

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Chief Strategy and Sustainability Officer, Schneider Electric

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About Center for Study of Science, Technology and Policy (CSTEP)

The Center for Study of Science, Technology and Policy (CSTEP) is one of India's leading think tanks, with a mission to enrich policymaking with innovative approaches using science and technology for a sustainable, secure and inclusive society. Their work is in the areas of climate, environment, sustainability, energy, AI for social impact and new materials. CSTEP's research leverages innovative technology-based ideas to solve developmental challenges. Their vision is to be the foremost institution for policy analysis in India.

Enerdata

Enerdata is an independent research company incorporated in 1991, headquartered in Grenoble, France, with a subsidiary in Singapore. The company specializes in the analysis and forecasting of energy and climate issues, at world and country level. Leveraging its globally recognized databases, intelligence systems and models, Enerdata assists companies, investors, and government bodies across the world in designing their policies, strategies, and business plans.

Enerdata's core competencies and expertise

We support you in drawing the energy markets, assessing your options, and making the right decisions, while evaluating their impact on the climate.

Our expertise covers:

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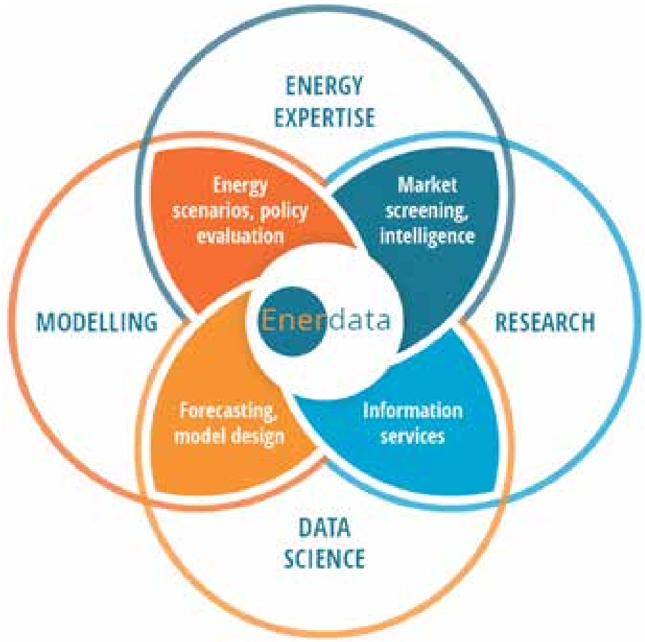
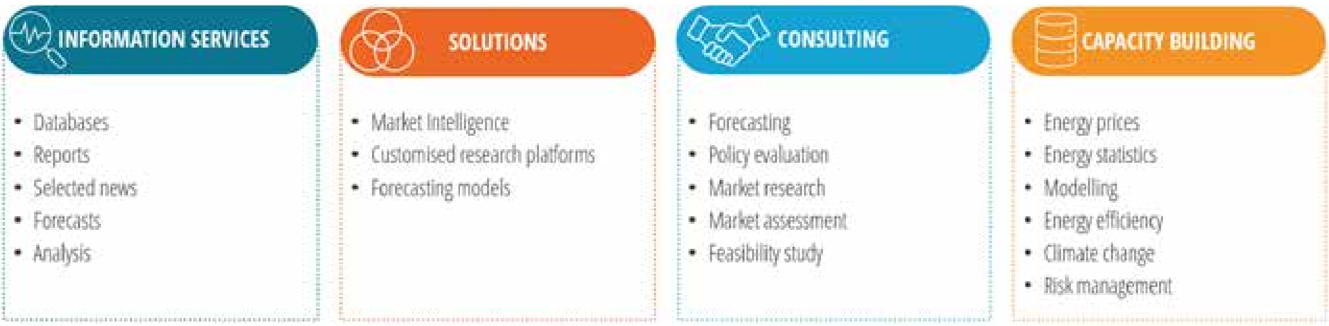
- from industrial, through sector, to end use levels
- full spectrum of the energy market fundamentals and their drivers:
  - Regulatory and policies
  - Supply, imports, and exports
  - Demand and prices
  - Players, assets, and projects





Enerdata's prospective expertise and role in this study

Enerdata has longstanding experience on energy and emissions prospective analysis, both at national and global scale, helping support clients in the definition of strategies, or inform decisions which require exploring possible futures of the energy system. Clients from public and private sectors are trusting the high-quality analyses performed with proprietary models and tools such as POLES-Enerdata[(1)], EnerNEO (national and/or international scopes for both energy demand and supply), and EnerMED (detailed bottom-up analysis of energy demand and policies, formerly known as MedPro). In this study, the role of Enerdata has focused on assumptions and methodology, data and modeling, using the POLES-Enerdata model, as well as project coordination support.

Together, let's accelerate the decarbonization 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.

Executive summary

An original approach on the Energy Transition

Climate change concerns are at an all-time high. In 2022, the Intergovernmental Panel on Climate Change released its 6th Assessment Report, following a previous one in 2014. At the launch of the first part of this report in summer 2021, the United Nations Secretary General Antonio Guterres called it a “Code Red for Humanity”. Science has now made clear that preventing global warming above 1.5 degrees will be essential to mitigate major adverse effects to our way of life. But, to remain within such boundaries requires a complete change of paradigm: greenhouse gas emissions should decline 30-50% by 2030 and be zeroed by mid-century. Progress has remained slow, however. At global level, the carbon intensity of energy use has notably stagnated across most sectors of activity in the last 20 years (except in the power generation sector where it dropped by around 15%). An energy transition of momentous proportions is therefore ahead of us.

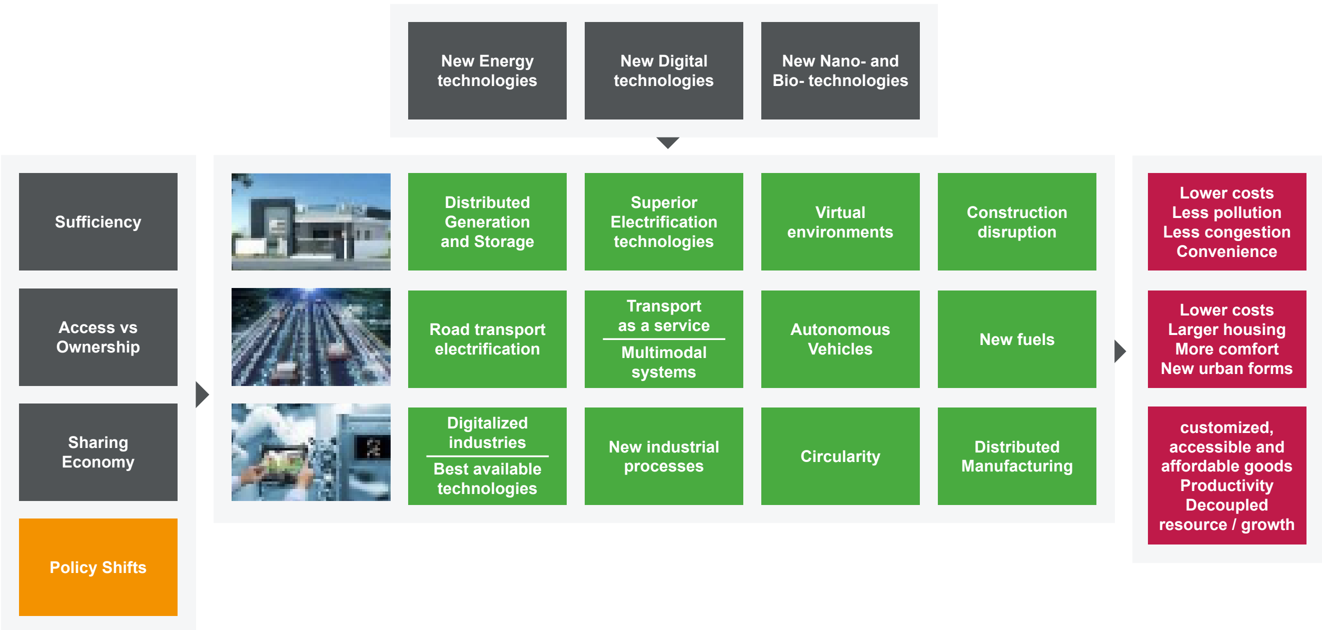
But not all geographies will face such challenge in the same way. A fast-developing economy like India will have, for instance, to **combine both a rapid economic development, in great need of secured and affordable energy, with a necessary transition away from fossil fuels**. The way this will be addressed will to a large extent define the future of the Indian energy system. Moreover, India is on the path to become one of the dominant economies of the 21st century in the coming decades. Its potential for development is mind-blowing. What this means is that the way the Indian energy system will develop will not only impact India, but also affect the entire world. In other words, given the size of the Indian economy, every choice the country makes today will deeply influence the way some of the world’s most pressing challenges are resolved tomorrow, prime of which that of climate change.

The positive side of this argument, however, is that these choices are yet to be made. There is a “window of opportunity”. The purpose of this report is to positively contribute to this discussion. It departs from other and similar analyses in two ways.

First, this report adopts a long view: it explores the evolution of the energy system from 2000 all the way to 2070. Second, this report focuses on energy services (or energy demand). An energy system is indeed more than a system of energy stocks and flows, as often depicted, but rather the complex stratification of a variety of energy services (or uses, or practices) which affect a multitude of socio-technical systems and depend on a variety of environmental, economical, technological, institutional and cultural patterns. These services are not necessarily directly related to energy. They are the product of what we do with energy: the machines and appliances we run, the boilers or furnaces we use for heating, the vehicles we drive, etc. Some of these energy services, while existing today, may be considerably improved (and transformed) by modern technologies. They will also continue to evolve as technology develops. Other energy services may not exist today but could emerge as the result of evolutions in the technological (and economical, institutional and cultural) landscape. The bottom-line of this is that fostering a transition away from the current energy system toward a new one requires a greater focus on such services, both in terms of the impact of their inevitable development, but also in terms of the extent to which they could contribute to reaching a secured, affordable, and net-zero energy system.

In this report, we explore 12 of those in details and model the impact of their development within the future energy system of India.

Figure i – 12 transformations of energy services



Two scenarios for the future of Indian energy

We present 2 scenarios which depict the future energy system of India. *2070 Net Zero* follows the government ambition to reach energy independence by mid-century and a net-zero economy by 2070. In *2047 Net Zero*, we explore the feasibility of reaching both goals by mid-century. Figure ii summarizes most critical socio-economic and energy indicators for each scenario.

Figure ii – Scenarios results, an overview

What to expect in the coming decades	India			EU
	2000	2010	2019	2018
Macroeconomic indicators				
GDP (G$_{2015}$ ppp)	2,725	5,227	9,220	19,950
Population (M)	1,057	1,234	1,366	512
GHG emissions (excluding AFOLU)				
Total greenhouse gas emission ($MtCO_2e/y$) on scope covered	1,191	2,060	2,799	
Final energy demand				
Final energy demand (PJ)	13,473	20,794	28,369	60,004
Share of coal or biomass in final energy demand	57%	55%	46%	11%
Share of electricity (%)	12%	15%	16%	
GDP / Cap ($GDP/cap)	2,579	4,235	6,747	38,965
Energy / Cap (GJ/cap)	13	17	21	85
Energy / $GDP (kJ/$GDP)	4,945	3,978	3,077	2,180
Power generation				
Power generation (TWh)	619	1,133	1,654	4,080
Share of Solar (%)	0%	0%	3%	4%
Out of which share of Distributed Solar (%)	0%	0%	0%	
Industry				
Share of coal or biomass in final energy demand	65%	73%	69%	19%
Share of electricity (%)	16%	17%	19%	
Steel				
Steel production / Cap (kg /cap)	25	56	81	313
Energy Intensity (GJ / ton, including scrap)	28	27	30	
Share of scrap steel in total production	4%	6%	4%	
Non-metallic minerals				
Cement production / Cap (kg/cap)	93	173	271	352
Energy Intensity nonmetallic minerals (MJ/ton)	5,545	3,439	2,343	
Other industry				
Manufacturing production (2019 = base 100)	23	58	100	
Buildings				
Residential				
Square meters / Cap (sqm/cap)	8	9	11	41
Energy Intensity (MJ/m^2)	743	696	499	540
Residential energy demand / Cap (GJ/cap)	6	6	6	
Appliances energy demand / Cap (MJ/cap)	334	517	637	
Cooling energy demand / Cap (MJ/cap)	16	58	202	
Share of coal or biomass in final energy demand	85%	80%	67%	20%
Share of electricity (%)	6%	10%	15%	
Services				
Square meters / Cap (sqm/cap)	1	1	2	17
Energy Intensity (MJ/m^2)	494	754	790	900
Services energy demand / Cap (MJ/cap)	601	1,082	1,341	
Appliances energy demand / Cap (MJ/cap)	207	485	355	
Cooling energy demand / Cap (MJ/cap)	53	132	161	
Share of coal or biomass in final energy demand	54%	37%	39%	2%
Share of electricity (%)	43%	57%	38%	
Mobility				
Total road pkm / Cap (pkm/cap)	1,676	2,263	3,058	11,039
Cars and Motorcycles pkm / Cap (pkm/cap)	133	385	916	9,254
Transport energy demand / Cap (MJ/cap)	1,358	2,353	3,463	
Road Transport energy demand / Cap (MJ/cap)	1,126	1,973	2,960	
Share of electricity in Road Transport (%)	0%	0%	0%	

What to expect in the coming decades	2070 Net Zero – India					2047 Net Zero – India				
	2030	2040	2047	2060	2070	2030	2040	2047	2060	2070
Macroeconomic indicators										
GDP ($G\$_{2015}$ ppp)	17264	28235	36813	51665	60177	17264	28235	36813	51665	60177
Population (M)	1504	1593	1629	1670	1701	1504	1593	1629	1670	1701
GHG emissions (excluding AFOLU)										
Total greenhouse gas emission ($MtCO_2e$/y) on scope covered	3,023	2,723	1,789	522	-52	2,623	1,346	59	-479	-799
Final energy demand										
Final energy demand (PJ)	38,455	49,026	57,682	61,041	60,217	35,615	40,680	45,207	48,859	50,734
Share of coal or biomass in final energy demand	37%	32%	28%	19%	13%	39%	28%	20%	12%	9%
Share of electricity (%)	27%	39%	50%	61%	70%	32%	53%	67%	77%	81%
GDP / Cap ($GDP/cap)	11,482	17,728	22,597	30,943	35,383	11,482	17,728	22,597	30,943	35,383
Energy / Cap (GJ/cap)	26	31	35	37	35	24	26	28	29	30
Energy / $GDP (kJ/$GDP)	2,227	1,736	1,567	1,181	1,001	2,063	1,441	1,228	946	843
Power generation										
Power generation (TWh)	3,661	6,588	9,877	12,870	14,415	3,927	7,406	10,385	12,905	13,998
Share of Solar (%)	32%	41%	45%	43%	45%	31%	41%	46%	44%	47%
Out of which share of Distributed Solar (%)	11%	19%	19%	23%	23%	11%	19%	26%	29%	35%
Industry										
Share of coal or biomass in final energy demand	64%	60%	53%	35%	21%	60%	39%	26%	11%	6%
Share of electricity (%)	24%	30%	37%	53%	68%	30%	51%	63%	76%	81%
Steel										
Steel production / Cap (kg /cap)	112	174	203	230	204	117	149	156	187	178
Energy Intensity (GJ / ton, including scrap)	25	21	20	18	16	22	19	18	14	13
Share of scrap steel in total production	13%	15%	19%	25%	33%	13%	18%	26%	35%	42%
Non-metallic minerals										
Cement production / Cap (kg/cap)	400	535	538	525	501	366	413	415	427	424
Energy Intensity nonmetallic minerals (MJ/ton)	2,260	2,043	1,834	1,823	1,843	2,394	2,023	1,828	1,831	1,879
Other industry										
Manufacturing production (2019 = base 100)	152	205	232	246	240	148	183	188	206	208
Buildings										
Residential										
Square meters / Cap (sqm/cap)	19	24	28	33	34	19	24	29	33	34
Energy Intensity (MJ/m^2)	327	283	312	272	252	298	232	238	208	201
Residential energy demand / Cap (GJ/cap)	6	7	9	9	9	6	6	7	7	7
Appliances energy demand / Cap (MJ/cap)	901	1,010	1,048	1,045	975	864	982	1,029	1,034	983
Cooling energy demand / Cap (MJ/cap)	1,211	2,558	4,697	5,369	5,455	1,023	1,852	3,595	3,835	4,164
Share of coal or biomass in final energy demand	33%	16%	8%	4%	2%	44%	32%	18%	10%	7%
Share of electricity (%)	37%	57%	71%	79%	83%	41%	63%	80%	88%	91%
Services										
Square meters / Cap (sqm/cap)	3	5	6	8	8	3	5	6	8	8
Energy Intensity (MJ/m^2)	738	673	628	544	479	672	594	555	487	443
Services energy demand / Cap (MJ/cap)	2,140	3,125	3,981	4,253	4,027	1,950	2,757	3,523	3,808	3,726
Appliances energy demand / Cap (MJ/cap)	594	807	944	1,115	1,121	564	776	919	1,099	1,134
Cooling energy demand / Cap (MJ/cap)	510	1,211	1,957	2,137	1,974	466	1,064	1,742	1,939	1,880
Share of coal or biomass in final energy demand	20%	9%	4%	2%	2%	19%	7%	4%	4%	4%
Share of electricity (%)	54%	68%	77%	82%	84%	60%	76%	85%	91%	93%
Mobility										
Total road pkm / Cap (pkm/cap)	3,578	5,174	6,649	8,595	9,716	3,559	5,025	6,313	8,522	9,540
Cars and Motorcycles pkm / Cap (pkm/cap)	1,301	2,353	3,652	4,579	4,904	1,188	1,806	2,379	2,787	3,110
Transport energy demand / Cap (MJ/cap)	4,122	4,937	5,597	6,380	7,221	3,835	3,771	3,872	4,726	5,702
Road Transport energy demand / Cap (MJ/cap)	3,442	3,801	3,999	4,031	4,188	3,209	2,710	2,343	2,289	2,522
Share of electricity in Road Transport (%)	3%	15%	31%	51%	62%	3%	29%	55%	84%	93%

A number of findings emerge from this exercise

- The economy of India will increase 4 times by mid-century and 6 times to 2070. Activity levels, notably mobility services, or building floor area, will converge toward mature economies' ones by that time.
- By mid-century, final energy demand will double, and electricity demand will increase 6 times, up to 10,000TWh. The share of electricity in final energy demand could reach by then 50-65% of total. Solar energy would represent around half of total power generation.
- The share of oil and natural gas in total energy supply will drop from around 30% today to 6-13% across both scenarios.
- As surprising as these figures may seem, they actually reflect inevitable evolutions of the energy system. The rise of air conditioning and appliances in buildings, for instance, will significantly push electricity consumption upward. In mobility, the advent of electric vehicles will also lead to rising demand for electricity. In industry, the rapid development and modernization of the manufacturing footprint will also yield rising electrification levels. In fact, these evolutions reflect a new form of development, one that builds on 21st century technologies, now available at scale, a complete change of paradigm compared to what was observed in the last decades.
- 60% of that increase in electricity demand will come from buildings. Yet, about 35-40% of that demand could be provided by distributed generation (representing as a result 20-25% of total power generation), a major enabler and facilitator of electrification and development.
- Hydrogen will also play a role with 15-20Mton/y of green production by mid-century, mainly concentrated around steel manufacturing, alternative fuels production for aviation and shipping, and power generation.
- India's emissions are likely to peak by the 2030s as a result, the pace at which this materializes depending on the scenario selected. In both scenarios, however, the volume of negative emissions to be deployed will be roughly equivalent, at around 1,100-1,300MtCO_2e/y, although with different dynamics over time.

A new pathway for developing a decarbonized India

What this analysis suggests is thus a new paradigm of development for India, which, instead of building on technologies from the 20th century, faces the opportunity to build its fast-growing development over technologies from the 21st century. The outcome is more competitive development, but also greater energy independence and a more sustainable energy system. In other words, the way that the Indian economy will develop in the coming decades is very unlikely to resemble that of mature economies, which face the different challenge of decommissioning their mature infrastructure and moving away from unsustainable consumption patterns. While traditional approaches to scenario planning implicitly assume a continuation of current trends, our modeling work suggests, on the contrary, a completely different development path, enabled by the advent of modern technologies in the first two decades of this century.

This finding is important, because it suggests that India potentially seats at the forefront of a 21st century energy transition, which, only a few decades ago, was deemed impossible. Given the size of the nation, the choices that the government of India will make in the coming years will thus also, to a large extent, define whether global issues are ultimately resolved, or not. Achieving such a feat may be more feasible than we think.

List of tables and figures

Why this report

In 2021 and 2022, the Intergovernmental Panel on Climate Change (IPCC) released the first outcomes of its 6th Assessment Report on climate change. This report, which basically compiles the state of global knowledge on climate change, followed a previous assessment published in 2014[(1)] (5th assessment report). Not surprisingly, the science has made considerable progress in this time window, leading to an even clearer picture of the extent of climate change and the now unequivocal role of anthropogenic forcing, as well as the increased dramatic effects of global warming on climate and biodiversity. As the results of the first working group were published in summer 2021, the United Nations Secretary General Antonio Guterres called the report a "Code Red for Humanity". It has become growingly clear that preventing global warming above 1.5 degrees is essential to mitigate major adverse effects to our way of life, and that even a two degrees trajectory cannot be anymore set as a target, given the critical uncertainties on the actual effects on climate.

This report was followed by COP27, in Sharm El-Sheikh, where global leaders of the world reunited to discuss and commit further efforts to accelerate the decarbonization of the economy. Unfortunately, it is now widely acknowledged that, despite progress on some fronts (notably on loss and damage), this COP has fallen short on the urgency of change voiced by many scientists around the world. In his closing remarks, the COP26 president Alok Sharma declared:

"Emissions peaking before 2025, as the science tells us is necessary. Not in this text. Clear follow-through on the phase down of coal. Not in this text. A clear commitment to phase out all fossil fuels. Not in this text. And the energy text, weakened, in the final minutes. Friends, I said in Glasgow that the pulse of 1.5 degrees was weak. Unfortunately, it remains on life support."[(2)]

To remain within a global warming of 1.5 degrees by end of century would require a transition which has no equivalent in history. Emissions should decline by 30-50% by 2030, followed by a rapid decline to zero (net) emissions by mid-century. Yet, these have in fact increased by an average 1% per year in the last decade, a slowdown, however, from the first decade of the century[(3)] (around 3% per year). In 2022, they are still expected to grow by around 1%[(4)]. Despite a clear agenda and shared sense of urgency, the decarbonization of the economy has thus far appeared to be an irreducible ambition.

Carbon dioxide (CO_2) represents around 75% of these emissions, the rest is associated with methane (15%) from processes, livestock and land use, and other greenhouse gases (mainly from industrial processes). The bulk of CO_2 emissions has to do with energy (around 80-85%), with a 45-55% split between supply-related emissions and demand-related ones[(5)]. The decarbonization of the economy is thus primarily an energy-related topic, and the object of this report[(6)].

Moreover, while the carbon intensity per unit of GDP has dropped globally by 40% since 2000, the actual carbon intensity of energy use has in fact stagnated across most sectors of activity, except in the power generation sector where it dropped by around 15% over the same period. This pattern of change is also visible across most geographies[(7)]. This finding is critical because it shows that, outside of the decarbonization of the power system which is well under way (albeit too slow), the transition has effectively not started for more than half of the scope of emissions covered. **A renewed focus on the way energy is finally used (energy demand) is thus a major priority**.

This issue takes another dimension when considering fast-developing economies like India. The role of energy in economic development does not need to be further demonstrated. While it has been traditionally neglected by neo-classical economics[(8)], it is now proven that energy, because it is essential across all sectors of the economy and non-substitutable, acts as a multiplier of economic growth and productivity[(9)]. **How then to combine rapid economic development, in great need of a secured and affordable source of energy, with a necessary transition away from fossil fuels?** This is a key question for most countries around the world, and for India more specifically.

The purpose of this report is to positively contribute to this discussion, by addressing specifically this gap, i.e., the need to bridge rapid economic development while transitioning toward a zero-carbon energy system. While we recognize this issue has already been addressed in some form by several institutions, we argue that this report brings new and complementary insights to this fundamental question. It indeed departs from other contributions by focusing specifically on the demand-side of the energy system, or how future energy practices are likely to (and could be incentivized to) be reshaped toward more sustainable models of consumption that would enable both growth and sustainability at the same time. What appears to be today an irreducible issue may simply have to do with the boundaries we set to research on decarbonization. We argue in this report that such a transition is more feasible than we think.

(1) IPCC, 2014, 2021, 2022.
(2) UK COP26, 2022.
(3) Based on data from ©OECD/IEA, 2017, 2021.
(4) ©OECD/IEA, 2022.
(5) Climate Watch, 2021.
(6) Our scope of review in this paper includes energy-related and industrial process-related emissions. It excludes emissions from AFOLU (Agriculture, Forestry and Land Use).
(7) See annex for more details.
(8) Jefferson, 2014.
(9) Ayres, 2001; Ayres and Warr, 2005.

2 The starting point: massive potential for accelerated development

The last 20 years

We first analyze the development of key economic and energy indicators from 2000 to 2018 in India, how they compare to world averages, and for a subset of them, to a mature economy like the European Union[11(1)]. This helps to understand:

- what has been the pace of development over a rather long period of time.
- what are the gaps with global averages and standards of a mature economy.

Figure 1 summarizes these key indicators.

At a macro level, in the last 20 years:

- GDP was multiplied by three with a population growth of only 30%, what translated into over a doubling of GDP per capita. GDP per capita is however still 1/6th of that of an economy like the European Union, and almost a 1/3rd of global average. There is thus still huge room for economic growth in India.
- The final energy demand per capita has also strongly increased (by around 40%), but is still nearly three times lower than the global average, and 4 times lower than the European Union. A key challenge for India is thus the actual growth of energy demand, which requires to be both rapid, resilient and sustainable. In fact, nearly half of that energy demand continues to stem form direct consumption of coal and biomass. This ratio is double to the global average, and compares to only 10% in the European Union. While it has slightly improved over the last 20 years (nearly 60% in 2000), there is still much room to cover.
- The energy intensity per unit of GDP is also a good indication of the modernization level of a given economy. It has strongly improved over the last 20 years in India and is now on par with the global average. Yet, it remains 50% higher than that of the European Union.

In Buildings

- Rather than looking at total square meters of surface, it is best to analyze the surface per capita. Despite progress in the last 20 years, it is clear that India is up for a massive construction phase. Residential surface per capita (10 square meters per capita) is today 2.5 times lower than global average and four times lower than in the European Union. In the service sector, it is two times lower than global, but eight times lower than in the European Union. When considering the size of the Indian population, it is clear that India will be one of the hotbeds of the construction industry in the coming decades.
- The energy intensity per square meter shows a decline from very high levels in 2000 (notably in residential) toward levels closer to global averages today. This has notably to do with the significant share of traditional biomass in energy consumption which has declined over the period (2/3rd today, 85% in 2000). Biomass is indeed a very inefficient source of energy for lighting and cooking. When this gets substituted by modern forms of energy, overall intensity per square meters tends to decrease. On this front, much more remains up for grabs, however. In the European Union, less than 20% of the residential footprint is served with "renewable" energy, most of it being supplied in modern form already (hence not traditional biomass).
- In addition, the larger penetration of appliances (and cooling) in the residential (and service) stock globally (and in the European Union in particular) suggests an even greater gap in building energy performance. Both appliance and cooling energy demand per capita are typically 2 times lower in residential (and three times lower in service buildings) than global average, and although we do not have the figures for the European Union, they likely dwarf those of India. To sum up, India's building stock is faced with a modernization of its energy source (away from traditional biomass), what leads to an optimization of energy intensity, alongside a growth in penetration of air conditioning and appliances, what drives an increase of modern forms of energy demand (electricity). These two trends have clearly emerged since 2000 and are likely to continue and accelerate in the coming decades.

In Mobility

- We focus here only on passenger-kilometers per capita (pkm per capita). Once again, the analysis of the last 20 years shows a very significant increase of pkm for cars and 2- and 3-wheelers in India, from a low 133pkm per capita to 6-7 times more in 2019. This is however still 5 times lower than global average and 12 times lower than in Europe, shedding light on the possible road ahead.
- What is important to realize is that, back in 2000, rail and buses dominated transport. This is now less true than it used to be, with all three modes of transport almost on par (at an aggregated level). In the rest of the world, cars and 2- and 3-wheelers dominate pkm. The question of how this will evolve in the future is fundamental, given the size of the population and the rate of urbanization anticipated in India for the coming decades. Will India follow in such footsteps or adopt a different mobility paradigm?

In Industry

- At an aggregated industry level, industry energy demand per capita has doubled over the last 20 years, but remains much lower than the global average and/or the European Union. There is thus still a strong potential for industrialization in India. The share of coal (and biomass) has also stagnated at around 70% of total, versus a global average of 40% and 20% in the European Union. Industry modernization and decarbonization will thus be a pivotal priority in India in the coming decades.
- The steel production per capita in India, despite nearly increasing four times, remains three times lower than global average and four times lower than in Europe. Given the central role of steel production in construction and transport, this suggests a huge uptake in the coming decades. The finding is similar for cement, although differences with global levels are less obvious. Worth to note, however, that India's population is still set to grow, urbanization is also set to increase and modernization of households is yet to happen, suggesting a much higher level of demand per capita in the coming decades than what can be observed in mature economies which have already stabilized.

(1) BPIE, 2011; CSTEP, 2021; Enerdata research; Cembureau, 2020; Eurofer, 2022; European Commission, n.d.; European Environment Agency, 2012; Government of India, MOSPI, 2022; © OECD/IEA, 2021, 2021b; SDSN and FEMM, 2020; United Nations Population Division, 2022.

- The energy intensity of steel manufacturing is 50% higher than average levels, suggesting a strong potential for improvement in the coming decades, notably in new (more efficient) capacities to be developed as demand picks up. We see an opposite situation for cement where energy intensity has reached levels close to Best Available Technologies (BAT), far below global averages and what can be observed in mature economies still relying on aged installations.

To conclude

- India has witnessed a considerable economic development for the last 20 years and is en route to become one of the dominant economies of the 21st century. The potential for development is mind-blowing. If all economic indicators were to match current European levels for instance, the economy would be 6 times larger, the production of steel 4 times bigger, the residential stock 4 times more important, and the kilometers traveled per car (and likely the number of cars) 10 times longer. Two key questions emerge.
  - Will India effectively reach these levels, or will it invent a different future?
  - How much time will this transformation take?
- Such evolutions will obviously define the future of the energy infrastructure in India. Yet, at the same time, a key topic for the country is its over-reliance on age-old forms of energy such as coal and traditional biomass. While coal dominates in power generation and industry, traditional biomass continues to hold a major share of demand in the building arena, notably in rural residential. While the transition toward modern forms of energy has started in buildings, this is not yet the case in industry. One key thing to understand, however, is that the future of India's energy system (and building, industry and transport stocks) is yet largely to be written, given the major build out plan ahead.

We will review this in greater details in the subsequent parts. Yet, and this is the interest of this report, decisions that are taken now may have a defining impact on the future course of India's economic and sustainable development going forward.

Figure 1 – Activity evolution over the last 20 years

What has happened in the last 20 years	India			World	EU	
	2000	2010	2018	2018	2018	Breakeven decade
Macroeconomic indicators						
GDP (G$$_{2015}$ ppp)	2,725	5,227	8,865	129,865	19,950	2030
Population (M)	1,057	1,234	1,353	7,643	512	
Final energy demand						
GDP / Cap ($GDP/cap)	2,579	4,235	6,554	16,992	38,965	2070
Energy / Cap (GJ/cap)	13	17	20	55	85	> 2070
Energy / $GDP (kJ/$GDP)	4,945	3,978	3,101	3,232	2,180	2030
Share of coal or biomass in final energy demand	57%	55%	45%	23%	11%	> 2070
Industry						
Industry energy demand / Cap (MJ/cap)	3,429	5,510	7,594	16,734	27,005	> 2070
Share of steel and minerals energy demand vs total of industry (%)	36%	38%	41%	38%		
Share of coal or biomass in final energy demand	65%	73%	69%	41%	19%	> 2070
Steel						
Steel production / Cap (kg /cap)	25	56	81	238	313	2070
Energy Intensity (GJ / ton, including scrap)	28	27	30	17		
Non-metallic minerals						
Cement production / Cap (kg /cap)	93	173	275	399	352	2020
Energy Intensity nonmetallic minerals (MJ/ton)	5,545	3,439	2,363	4,519		
Buildings						
Residential						
Square meters / Cap (sqm/cap)	8	9	11	24	41	> 2070
Energy Intensity (MJ/m^2)	743	696	501	483	540	
Residential energy demand / Cap (GJ/cap)	6	6	5	12		
Appliances energy demand / Cap (MJ/cap)	334	517	743	1,925		
Cooling energy demand / Cap (MJ/cap)	16	58	187	315		
Share of coal or biomass in final energy demand	85%	80%	67%	36%	20%	2030
Services						
Square meters / Cap (sqm/cap)	1	1	2	5	17	> 2070
Energy Intensity (MJ/m^2)	494	754	778	965	900	
Services energy demand / Cap (MJ/cap)	601	1,082	1,303	5,200		
Appliances energy demand / Cap (MJ/cap)	207	485	668	1,885		
Cooling energy demand / Cap (MJ/cap)	53	132	167	515		
Share of coal or biomass in final energy demand	54%	37%	27%	9%	2%	> 2070

What has happened in the last 20 years	India			World	EU	
	2000	2010	2018	2018	2018	Breakeven decade
Mobility						
Total road pkm / Cap (pkm/cap)	1,676	2,263	2,964	5,229	11,039	2070
Cars and Motorcycles pkm / Cap (pkm/cap)	133	385	841	3,532	9,254	> 2070
Transport energy demand / Cap (MJ/cap)	1,358	2,353	3,385	15,333		
Road Transport energy demand / Cap (MJ/cap)	1,126	1,973	2,879	11,632		

The next decades

How all this is thus likely to evolve? India is set to become one of the major economies of the world by mid-century, following on the trends identified in the past 20 years, and with a population set to rise to around 1,700 million individuals by 2070[(1)] (versus 1,400 million today).

- GDP and GDP per capita will strongly increase. India should become one of the largest construction markets of the world, driven by significant urbanization and a progressive catch up of surface per capita toward wealthy (saturation) levels. At the same time, with increased economic development will come rising demand for appliances and services, that will also bolster industrial development. Mobility is also set to continue to increase rapidly to converge progressively toward saturation levels, with a share of private transportation that should rise in the mix.
- All this will have a significant impact on energy demand, complemented by a rapid move away from traditional forms of energy (biomass notably, but also coal) toward modern forms (e.g., electricity). This increase will be tamed in part by improved performance of all these new assets relative to existing ones (new facilities with greater energy intensity, new buildings with greater energy performance, etc.).

Those are the main trends to watch going forward. The question is the extent of their development (and the pace at which they materialize), but also the technology choices that will be adopted, and which will influence the future energy system. In short, the key question is that of the shape of the massive build out of the economy of India in the coming decades, a critical question for circa 20% of the world population and global sustainable development goals.

This is what makes the exploration of the future of the Indian energy system such a valuable exercise. In fact, the extent and the shape of the future success of India will at large define that of global sustainable development goals, and notably climate change mitigation. Core to this will be the build out of the energy system, and whether this buildout will be synonym of rapid economic development, and sustainable development: for India, but also as a result for the rest of the world.

Post-COP26, India submitted its updated Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in August 2022, with the following additions[(2)]:

- To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation, including through a mass movement for 'LIFE'– 'Lifestyle for Environment' as a key to combating climate change.
- To reduce emissions intensity of its GDP by 45% by 2030, from 2005 level.
- To achieve 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, with the help of transfer of technology and low-cost international finance including from Green Climate Fund (GCF).

This update to India's existing NDC is a step forward towards the country's long-term goal of reaching net-zero by 2070.

Besides the above objectives, on India's 75th Independence Day (2021), the Prime Minister announced a goal to transform the country into an energy-independent nation by 2047, a year that also marks 100 years of independence for the country[(3)]. Currently, India depends on imports for meeting 35-40% of its primary energy needs. In particular, it is dependent on imports to meet the demand for crude oil, natural gas and coal. These together comprise more than 35% of India's import basket[(4)]. India's journey towards energy independence and its decarbonization drive go hand in hand and shall give rise to sustainable growth initiatives which will be a significant economic opportunity as well.

Hence, when it comes to long-term goals in the coming decades, the Indian government has set two critical targets.

- By 2047, the government has an ambition to reach energy independence.
- By 2070, the government has committed to reach net zero emissions.

(1) United Nations Population Division, 2022.
(2) Ministry of Environment, Forest and Climate Change of India, 2022.
(3) Mishra, 2021.
(4) Ernst & Young, 2023.

3 Toward sustainable economic development and new energy services

Why a focus on energy services?

The traditional paradigm in energy research is to study energy as a system, made of physical (resources) and financial stocks and flows[1]. To a large extent, our current fossil-based energy system is about moving resources from one place to another. Yet, and as is covered at length in the study of socio-technical transitions, or rare energy studies, understanding the development of energy systems and their subsequent transitions requires studying energy in relation to the services it provides to society[2]. This suggests that **the energy system is more than a system** (of stocks and flows), but the complex stratification (or backbone) of a variety of energy services in a multitude of socio-technical systems, within a variety of geographies with different environmental, economical, technological, institutional and cultural patterns. Energy fuels services, and innovation in delivering those services is not only the product of new energy resources and infrastructure, but also of adjacent technological and business model advancements. After all, we were not sending emails 30 years ago! Ultimately, these innovations may substitute an existing service, providing enhanced experience or easier access to it (e.g., at lower cost), but also provide new services that do not exist yet. These innovations may also be incremental, or radical[3]. And as these unfold, they inevitably impact energy demand in ways that are often hard to envision at first. Vaclav Smil[4] argues that

“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.”

Following this thread, studying energy system evolutions from the standpoint of stocks and flows only would prevent from apprehending the actual mechanics at play. Energy systems are bound to evolve from the development of new or improved existing services, this is inevitable. Thus, fostering a transition away from the current energy “system” requires primarily acting on such services to transform the demand for energy toward a new form of supply, a critical topic when considering the modern imperative to rapidly mitigate (and ultimately zero) energy-related emissions.

Going a step further, studying future energy services implies key challenges to be resolved. One is that of time boundaries which conflict across actors, a particularly important issue when it comes to energy infrastructure and how past choices may “lock-in” societal change[5] (what is often referred to as path dependency). Another issue revolves around the multi-dimensional aspects of energy system changes. Since energy system evolutions apply across multiple socio-technical systems, they are often associated to “deep transitions”[6]. Finally, a last issue has to do with the proper balance between phasing in a new system while phasing out the existing one, what often proves to be an erratic process.

In this report we present two scenarios for the future of India’s energy system. Where we depart from other analyses is that we emphasize and detail the evolution of energy services (or practices, or uses, i.e., the demand side of the energy system). Through this exploration, we attempt to bring a new contribution to the decarbonization debate in India, one that shed lights on possibly overlooked mechanisms of change, all this in a country which will be at the heart of the fulfillment of all global sustainable development goals in the 21st century.

Exploring future energy services

In 2050, we will live in a different world

This report builds on a previous exercise – **“Back to 2050, 1.5 is more feasible than we think”** – developed in 2021[7]. While the original exercise was global only and with a time boundary to 2050, the scope of this work is solely focused on the development of India’s energy system, with a time boundary extended to 2070. We reproduce here briefly the approach we took in this initial exercise, and which continues to guide this effort.

Two transformations will contribute to evolve existing energy services toward new forms of similar services, or toward new services not invented yet. The first one stems for technological development, or innovation. 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, nano- and bio-technologies, and new energy technologies (notably solar, but also wind, new forms of energy storage, etc.). These new developments come together as they are also dependent on one another. The rise of new nano- and bio-technologies would have proven impossible without the development of digital technologies, and that of new energy technologies will largely rely on advancements on nano- and bio-technologies, but also on the capabilities of digital controls. What these technologies also share in common is that they are

(1) Araujo, 2014; Jefferson, 2014; Truffer et al., 2012.
(2) Edomah et al., 2017; Geels, 2010; Geels, 2021; Geels and Schot, 2007; Grubler et al., 2018; Köhler et al., 2019; Li et al., 2015; Loorbach and van Raak, 2006; Petit, 2021; Rotmans et al., 2001; Schot and Geels, 2018; Sovacool and Hess, 2013; Sovacool, 2014.
(3) Wilson and Tyfield, 2018.
(4) Smil, 2017, p.426.
(5) Eising et al., 2014; Hoppmann et al., 2014; Papachristos, 2014; Yücel, 2010.
(6) Markard and Hoffmann, 2016; Schot, 2016.
(7) Schneider Electric, 2021.

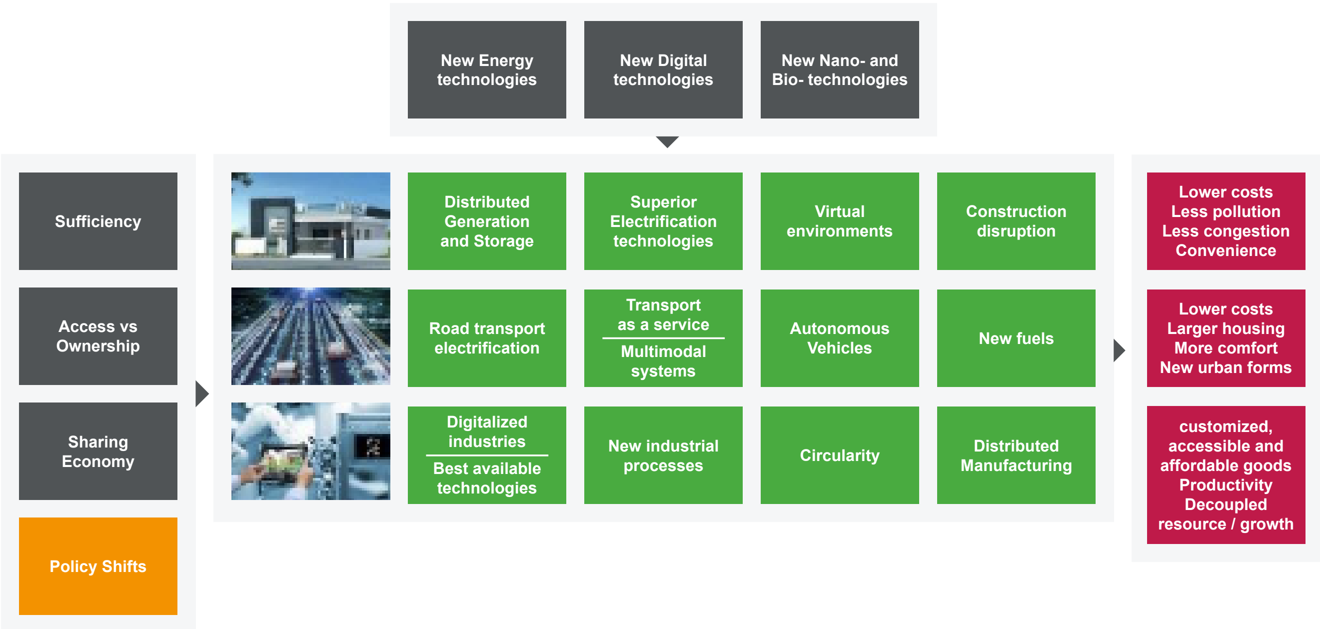
all infinitely scalable (mass manufacturing of "simple" products[1]), highly distributed (close to consumption centers, and possibly channeled through traditional distribution networks), and more importantly come with increasing rates of return (the more the technology develops, the lower the prices[2]). The advent of these 3 technology domains with characteristics so different from the existing system in place also suggests **a major opportunity for innovation toward new ways of delivering existing services and the emergence of entirely new services, in short a profound, or "radical", transition**, what could also be coined as the emergence of a new "dominant design[3]."

The second key transformation is that of the natural (but important) generational shift in the making. The growth in population in India from 2000 to 2050 will represent 20% of the increase in global population by then[4]. In other words, the generation in charge by 2050 will to a large extent be of Indian origin (Africa and the rest of Asia representing the bulk of the rest). And as these generations (generation Z, alpha, beta, etc.) come to responsibility, they will also influence and transform global and regional policymaking as well as the foundations of our socio-economic landscapes. While research on generation Z is well documented, that of the following generations is only emerging. What we can retain, however, is that **future generations may be more entrepreneurial, individualistic, as well as more committed to resolving global issues** than those that have preceded them[5]. And these traits will necessarily heavily play out in reshaping consumer behaviors, innovation, and policy contexts.

The combination of a new innovation toolbox and different generational appetites will lead to transformations of energy services. The breadth of such changes all the way to 2070 (and their networking effects) is probably impossible to capture exhaustively, notably when accounting for possible exogenous factors that might alter their course. In fact, this is a problem that is not only complex, but also complicated, and possibly irreducible[6]. Therefore, such an exercise must be considered as a first-level exploration of the "possible". While some of the transformations detailed below may also be clear to everyone, the extent and pace of their unfolding may also be prey for question, hence a necessary exploration of the "plausible".

After careful exploration, we finally selected 12 key transformations that we have decided to focus on[7] **(Figure 2)**.

Figure 2 – 12 transformations of energy services



Taken altogether, these transformations paint a new narrative of what the future could look like.

(1) Solar panels are a good example, but the now well-known platform effect and multiplier effect of zero-marginal costs in the Internet world is also an obvious case.
(2) When an installed solar panel reaches end of life, it is replaced with a new one with enhanced properties. In short, the energy harvesting potential is increased, in stark contrast with fossil fuels, which fields naturally deplete at a 3-4% annual rate.
(3) Petit, 2021; Suarez et al., 2015.
(4) United Nations Population Division, 2022.
(5) Schneider Electric, 2022.
(6) Andersson et al., 2014.
(7) For more information on the selection process, see Schneider Electric, 2022.

In Buildings

A major development in buildings will be the inevitable **digitalization of our living environments,** at least in cities. This trend will trigger a whole range of new activities, which for part of them, have already begun to emerge: home office, online shopping, etc. This transformation will primarily concern a fraction yet growing share of the Indian population but will also ripple through all sectors and redefine 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(1). A significant potential exists. 15% of materials is wasted in construction, over specification typically drives 20-30% extra materials supply, and advanced construction designs and modular approaches could offer even larger benefits(2). This could have significant impacts on the various industries which supply construction with materials(3) (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 and a critical opportunity for India's booming industry in the coming decades.

Such evolutions could yield **unanticipated evolutions on urbanization,** and the emergence of new urban forms, less concentrated and more distributed (more affordable housing provides the opportunity for greater space, while many of daily commute and mobility needs could be significantly optimized).

Then comes the inevitable rise of **distributed generation** (and storage). A recent study from BloombergNEF(4) showed how such solutions will become (when they are not already) economically attractive in every region of the world within the coming decade, making their deployment largely inevitable. The potential in India is momentous. 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, EV batteries, etc.), and, needless to say, growingly actionable by an emerging digital infrastructure (which can also help optimize energy consumption in real time(5)). This will also lead way to major transformations on grid operations as a result.

Such provisions of near-zero marginal cost energy would also trigger **further transformations of the energy demand within buildings, toward further electrification** (notably for space conditioning, but also cooking).

In Mobility

Electrification of mobility (EV) will become a reality sooner than often anticipated. BloombergNEF(6) 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, EVs are by nature less expensive since there are 100 times fewer parts in electric powertrains, and electric motors enjoy yields 3-4 times those of gasoline cars(7). Over time, they will thus be less costly to purchase, less costly to run, and less costly to maintain. Technology progress also suggests that EVs' driving range may even exceed that of traditional cars within a few years(8). This could prove particularly relevant in India which has yet to build its stock, although the concurrent ramp up of the electrical infrastructure, particularly outside cities, will prove key in such development.

A second transformation is on its way, that of **transport as a service**. Beyond existing public services, 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. Many cities have also the ambition to limit the number of private means of transport, in an attempt to resolve congestion and pollution issues, a major issue in fast-growing Indian cities. Transport as a service, alongside multi-modal transport systems, would make it possible. In addition, autonomous vehicles could add significant value to this development. Several sources have notably estimated that **autonomous transport as a service** could reduce costs of mobility 5-10 times(9). Sources differ on the timing, but it always happens before 2040(10). Moreover, it may be less dependent on technology development than on proper traffic rules that would minimize interactions between (highly unpredictable) human driving and (highly predictable) machine driving. Such transformations could however also lead to rebound effects in total demand for mobility services, at least in cities.

Other mobility patterns (aviation, shipping) will follow a different journey. Sufficiency(11) could yield a reduction in travels. This is particularly noticeable for business purposes. At the same time however, economic and wealth development, but also less physical interactions from remote connectivity and greater flexibility at 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 fuel developments. These are likely to come as a result of major policy shifts and innovation.

(1) Cilia, 2019 ; McKinsey, 2017.
(2) Lovins, 2021; Material Economics, 2018.
(3) Not accounting for further innovation on materials themselves.
(4) BloombergNEF, 2021.
(5) Schneider Electric, 2021b.
(6) BloombergNEF, 2019.
(7) Seba, 2014.
(8) Bloch et al., 2019.
(9) Arbib & Seba, 2017; Keeney, 2017.
(10) Hamblen, 2020; Hyatt, 2021; Litman, 2021; Metz, 2021.
(11) Sufficiency is a change of behavior toward more frugality in use. It can be driven by technology or by self-adjustments and cultural evolutions.

In Industry

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[1]. A quantitative study from 2016 has shown that – in the case of the automotive sector, one of the most automated sectors 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[2]. They will also be crucial in accelerating adoption of Best Available Technologies (BAT). Multiple studies and practical examples have shown the potential to significantly optimize energy and resource demand[3]. Benefits could range between 10-20% across sectors and industries, with cutting-edge technology developments helping to lift these savings to 35% 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**. As the industrial footprint of India continues to develop, a key opportunity to champion these new approaches is thus up for grabs, as witnessed in the cement industry in the last 20 years, with India's cement industry being one of the most efficient in the world.

Beyond better performance, industrial processes are also likely to evolve, driven notably by the race toward decarbonization and associated innovation. Direct reduction of iron, low-clinker cement, new mining techniques, or alternative materials and synthetic or bio-chemicals are all on the agenda[4]. These transformations will 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% across most sectors[5]. Often, the electrification of industrial processes is found to bring additional benefits in terms of operational flexibility and final product quality[6]. Electrification of industrial processes is thus largely inevitable, a natural development with a growingly affordable and plentiful electricity resource.

Then, additive manufacturing could also emerge in the coming decades as a new paradigm for industry. It 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 (spare parts manufacturing, specific machine designs, construction and mass market for consumer goods). 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[7] (low quantities, highly customizable), give rise to more **distributed manufacturing** settings, and possibly lead to unanticipated rebound effects.

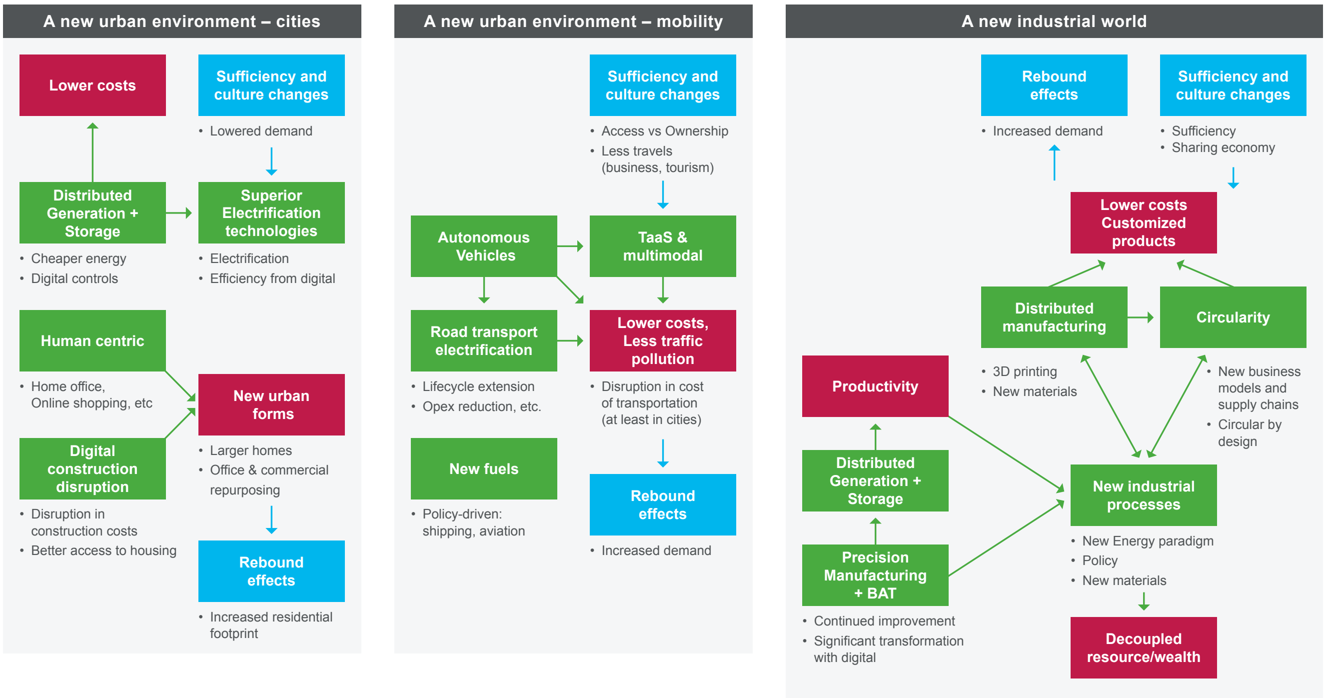
Finally, **circularity will also kick in** and could play a more significant role than often projected. Beyond climate change and environment degradation, resource dependencies could be pivotal in reassessing how to best use and re-use (or recycle) resources available, especially in a context of rapid demand growth. This could be further enabled by new digital technologies, supply chains traceability, better product designs and new service-oriented business models. Some studies have demonstrated that there is economic value to adopt circular approaches, and that ultimately it will increase productivity and differentiation[8]. The industrial system will also be impacted by network effects from buildings and mobility demand evolutions (e.g., less raw materials in construction due to disruption of the industry, in part compensated by rebound effects; less materials in automotive due to mobility footprint evolution, etc.). These effects might actually prove crucial to mitigate the inherent availability issues associated with rapid economic development (lagging supply).

(1) Immelt, 2016; McKinsey, 2017b.
(2) Roland Berger, 2016.
(3) Allwood et al., 2013; Gutowski et al., 2013; Schneider Electric, 2019; © OECD/IEA, 2017b; Petit, 2017.
(4) Philibert, 2017.
(5) Beyond Zero Emissions, 2018; Madeddu et al., 2020.
(6) Agora Energiewende & AFRY management consulting, 2021.
(7) AMFG, 2020; Flaudi & Van Sice, 2020; Gebler et al., 2015; Goodrich, 2013; Gonzales, 2021; Groot, 2018; Jezard, 2018; Reichental, 2020; Schwaar, 2021; Warren, 2018.
(8) Ellen Mac Arthur Foundation (2013, 2014); Lacy et al., 2020.

To sum up

Figure 3 complements this view, describing, at a high-level, how this new narrative unfolds across different sectors of activity.

Figure 3 – A new narrative



Two scenarios toward 2070

A set of scenarios

There is, however, significant uncertainty in the pace at and extent to which such transformations in energy services may unfold. We have therefore developed two scenarios to explore this, while also taking stock of commitments from the government of India. By nature, these scenarios are thus back-casted, their true originality lies in the actual contribution (positive or negative) of energy service evolutions within the overall frame of change set by the government of India.

Figure 4 – Two scenarios

Scenario	Description
2070 Net Zero Scenario	This scenario takes stock of current commitments from the Government of India, notably • Energy independence by 2047 • Net Zero emissions by 2070 It also explores the evolution of the energy mix by modeling specifically the evolution of energy services described above considering no specific policy is implemented toward their rapid unfolding.
2047 Net Zero Scenario	This scenario leverages further the evolutions of energy services to accelerate the transition toward a more sustainable economy. It assumes that ambitious policy changes are implemented to foster their unfolding and looks at reaching both energy independence and Net Zero emissions by 2047.

Modeling of the scenarios

We use Enerdata POLES model to run these two scenarios. POLES is a partial equilibrium model, with global coverage, for long-term energy and GHG emissions projections up to 2070.

As many models, available assumptions on demand offer already a breadth of possibilities, yet not enough detailed to integrate the sophisticated changes to the structure of economic activities we have identified above. A specific "demand module" was thus developed, which evaluates exogenously the evolution of key parameter trends and re-inject them into the core POLES model. Some are actually direct inputs already available in POLES already. Others are not available and thus represent "targeted values" that are ultimately reached in the model's results thru extensive calibration. Some inputs have actually material impacts on others, and these "networking" effects are also taken into account. A detailed description of the demand module is available in annex.

Key assumptions

We provide an overview of key assumptions taken in this report for the two scenarios identified. More details are provided in annex.

In Buildings

Four main transformations are looked at: Distributed Generation and Storage; Superior Space Conditioning and Technologies; Virtual Environments; Construction Disruption.

Distributed Generation
As rooftop PV becomes economically viable across most building types, its level of production increases significantly. By 2047, rooftop PV generates between 1,850-2,700TWh across both scenarios. It is higher in *2047 Net Zero* due to more ambitious deployment policies. By 2070, this figure reaches 3,300-5,000TWh[1].

Superior Electrification technologies
We take key assumptions regarding cooking electrification and air conditioning penetration within both residential and service buildings.

- For cooking: in the *2070 Net Zero* scenarios, electrification of cooking increases steadily up to 30% by 2047 and 50% by 2070 across all building types. In the *2047 Net Zero* scenario, penetration is accelerated by favorable policies, and reaches 65% by 2047 and 80% by 2070.
- For air conditioning: 100% of the service buildings stock is equipped with air conditioning by 2047 in both scenarios. In residential, we differentiate between urban residential (80% by 2047, 90% by 2070) and rural residential (30% by 2047, 80% by 2070).

We also take assumptions on appliances' efficiency and assume different rates of progress over time and for air conditioning versus other appliances. Typically, air conditioning becomes 30-50% more efficient by 2070, while other appliances are 40% more efficient by 2070 (this also include the positive effect of device convergence[2]).

Virtual environments
First, digital technologies bring additional benefits to energy demand thru better controls within premises. This, combined with policies on building performance, helps to drive energy intensity down across the building stock.

- In *2070 Net Zero*, we only assume a growing penetration of digital technologies in the stock, with energy intensity improvements ranging between 15-25% depending on the building type. In *2047 Net Zero*, we assume this is complemented by additional renovation efforts, in part driven by policies, i.e., higher renovation rates (above 1.5%) and renovations that also include passive efficiency measures (up to 40-50% energy intensity improvements).

Second, the virtualization of our environments leads to changes in the evolution of the building stock.

- The development of new working practices (e.g., home office) has an impact on the development of office buildings. We forecast a demand for office buildings 30-50% lower across both scenarios (versus a scenario without its impact taken in account).
- Similarly, online shopping impacts the development of commercial outlets. We forecast a 10-20% reduction compared to not accounting for such development.

Construction disruption
New construction standards, driven by policies and improved construction techniques, yield a significant improvement of energy intensity of new build.

- New construction standards bring energy intensity down by 40-50% by 2047 across both scenarios (compared to today's levels) for residential (50-65% for service buildings). These levels converge by 2070 to around 50% for residential (and 60-70% for service buildings).
- As a result, the energy intensity of residential drops from 500MJ/m^2/y today to 250-300MJ/m^2/y by 2047 and 200-250MJ/m^2/y by 2070.
- For service buildings, energy intensity drops from 800MJ/m^2/y to 550-630MJ/m^2/y by 2047 and 450-500MJ/m^2/y by 2070.

We take no assumption on a possible rebound effect on residential surfaces as a result of this disruption.

In Mobility

4 main transformations are looked at: Road transport electrification; Transport as a service and multimodal systems; Autonomous vehicles; New fuels.

Road transport electrification
We look at the development of EVs across the stock.
- Private cars' share of EVs reaches 65-80% of the stock by 2047 and 85-100% by 2070 across both scenarios. These figures include battery EVs, plug-in hybrid and 2- and 3-wheelers (the latter being 100% electrified by 2047).
- Trucking follows a similar trajectory as the dominant design converges toward battery electric vehicles. 50-70% of trucks are electrified by 2047 across both scenarios.

(1) A dedicated section on the methodology of evaluation is available in annex.
(2) Grubler et al., 2018.

Transport as a service, multimodal systems, and autonomous vehicles
First, the development of home office yields a reduction of mobility services for commuting. Second, the development of new modes of shared mobility, notably rail, has a significant impact on passenger-kilometers traveled within cities. While total passenger-kilometers traveled range around 11,000-12,000pkm by 2047 (and 18,000pkm by 2070), that of private car transportation fundamentally differs across scenarios. In *2070 Net Zero*, private cars account for 5,500pkm by 2047 (10 times current levels), a figure to compare to 3,500pkm in *2047 Net Zero*. In the latter, a clear switch toward rail is observed, the result of ambitious infrastructure development.

Rail also prevails (across both scenarios) over buses, which fall toward 500pkm by 2047, a third of their current levels. Air travels also significantly increase, albeit to a lower extent in Net Zero 2047. Levels of air travels are also impacted by a greater recourse to rail for medium-distance travels.

Finally, the impact of new logistic systems and the rise of distributed manufacturing yields a 5-10% reduction of freight within cities by 2047 (versus a scenario without its effect taken in account).

New fuels
Rail is entirely electrified across India by 2040 across both scenarios. In aviation, alternative fuels to kerosene (biofuels, synthetic fuels), driven by policy, reach 40-90% by 2047 across both scenarios (and 80-90% by 2070). Similarly in shipping, alternative fuels displace fossil fuels by 20-80% by 2047 (and 80%-90% in both scenarios for 2070) across both scenarios, mainly a result of the policy context.

In Industry

We look at 4 main transformations: Digitalized industries and best available technologies; New industrial processes; Circularity; Distributed manufacturing.

Digitalized industries and best available technologies
We take key assumptions on the evolution of energy intensity of existing processes versus baseline evolution.

- Steel: energy intensity drops to around 18-20GJ/ton by 2047 (all the way to 13-15GJ/ton by 2070). This is in large part due to the increase in scrap steel use. The energy intensity of virgin production drops from 31GJ/ton today to around 23GJ/ton by 2047 and 21GJ/ton by 2070.
- Nonmetallic minerals: energy intensity drops to around 1.8GJ/ton by 2047, compared to 2.3GJ/ton today.
- Automotive: the rise of EVs leads to an actual increase of energy intensity of manufacturing of 20% in the early years of development, progressively brought back down to current levels (for ICEs) by 2060.
- Machinery: better processing yields an improvement of 10-15% by 2047 and up to 20% by 2070 versus today's levels.

New industrial processes
At the same time, processes continue to evolve.
- In steel, we take key assumptions on the penetration of Hydrogen-DRI processes. We consider the share of this process to reach by mid-century around 50% of new installations in *2070 Net Zero* and almost 100% in *2047 Net Zero*.
- In cement, processes progressively electrify, up to 5-15% of footprint by 2050, and 25-33% by 2070[(1)].
- The chemical industry also harnesses its potential of electrification. In 2047, this reaches 40% of demand in *2070 Net Zero*, and 80% in *2047 Net Zero*. The figure then converges above 85% by 2070[(2)] (excluding feedstock).
- Other industries (automotive, machinery, other capital and consumer goods, paper, textiles, food industry, etc.) electrify also rapidly, up to 50-80% by 2047 and 90-100% by 2070[(3)].

Circularity
The steel and cement industries are significantly impacted by the evolution of the building and automotive footprints as well as improvement in construction techniques and material substitution.

- The demand for steel grows only up to 250-350Mton/y by 2047 (compared to around 100Mton/y today), and stabilizes around 300-350Mton/y by 2070. As a result, the share of recycled content for steel reaches 20-25% by 2047 and 33-40% by 2070.
- The demand for cement grows to 680-880Mton/y by 2050, and stabilizes around 750-850Mton/y by 2070 (compared to today's level of 370Mton/y). These are also much lower figures than often mentioned in other scenarios and mainly stem from our assumptions on construction and building footprint optimization.

The chemical industry demand grows two times by 2047 and 2.5 times by 2070 (compared to today's levels). This is, however, slightly lower a growth than other anticipations, as packaging substitution and increased recycling, stemming from policy, help limit this rise. Recycling increases notably, and mechanical recycling represents 60% of total by 2047 across both scenarios.

The automotive industry is essentially impacted by the evolution of mobility services (as seen above). By 2047, production volumes increase around 3.5-4.5 times across both scenarios. By 2070, the further development of new urban mobility services is more visible in the *2047 Net Zero* scenario, where demand falls back to two times current levels. In the *2070 Net Zero* scenario, demand stabilizes at 5 times current levels.

The machinery industry is also impacted by the growing development of machine as a service business models (MaaS), which translates into a reduction of 10-15% of demand compared to baseline evaluations. By 2047, production doubles across scenarios, a figure which then stabilizes.

By 2047, demand for consumer goods roughly doubles in *2070 Net Zero*. In contrast, the development of a vibrant sharing economy yields a forecast 20% lower in *2047 Net Zero*.

Distributed manufacturing
Last, the demand for consumer goods is impacted by the rise of distributed manufacturing (in commons, or at home). This translates into an increase in demand of around 10% (around 5% of total "other" goods) by 2050. Distributed manufacturing captures around 20% of the consumer goods market, but also comes with an increased energy intensity of around 50%.

(1) Convergence toward maximum levels as identified today. Madeddu et al., 2020.
(2) Ibid.
(3) Ibid.

4 A major transition in the making

In this part, we focus on aggregated data for the whole of the Indian economy, all the way to 2070.

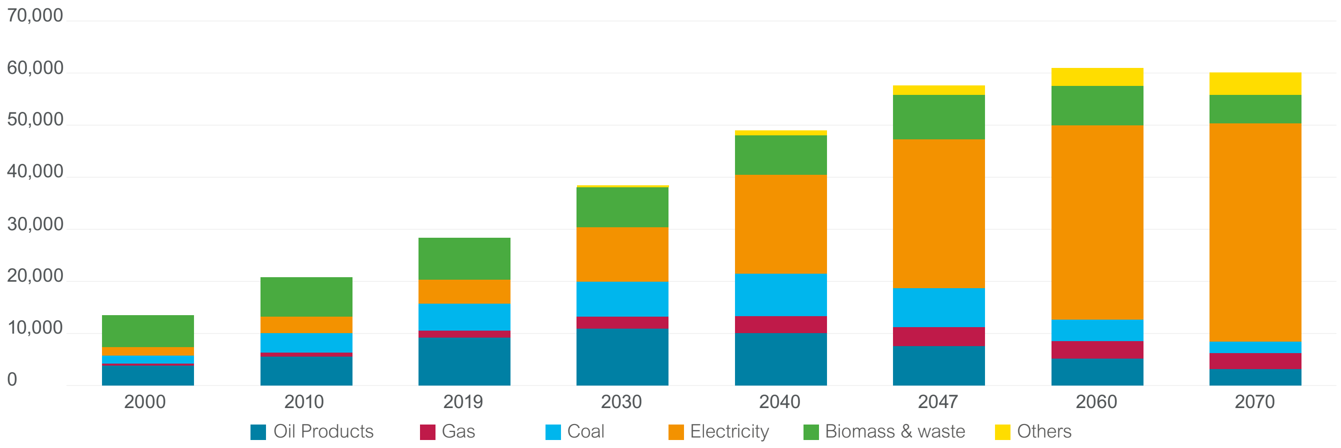
Finding 1: a significant opportunity to build out a sustainable economy

Figure 5 provides a long-term view of the evolution of final energy demand from 2000 to 2070, across both *2070 Net Zero* and *2047 Net Zero* scenarios.

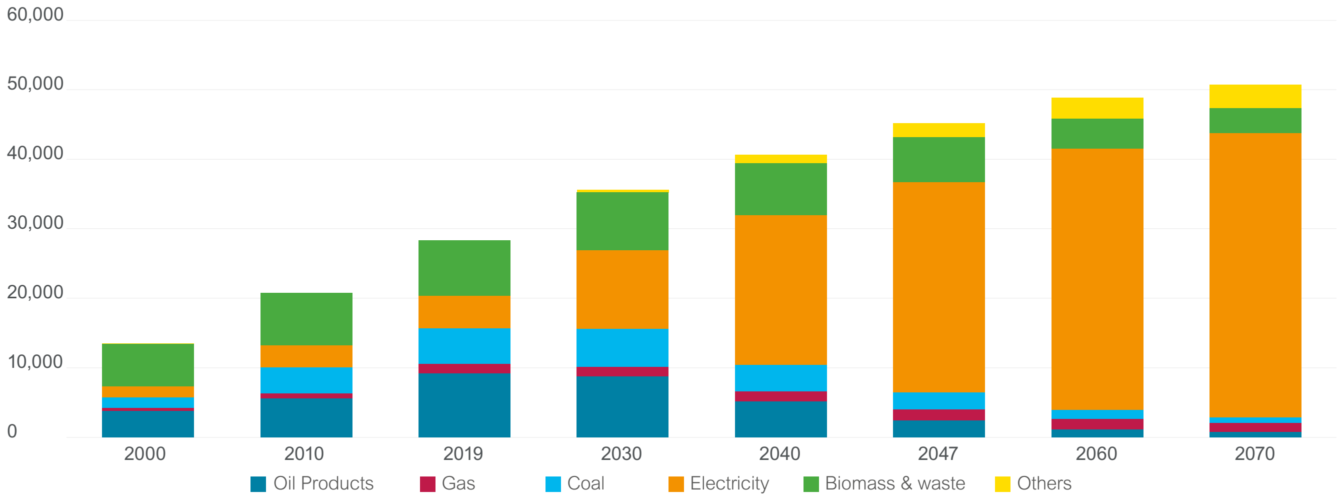
- Final energy demand continues to increase significantly, at least until 2060, doubling from current level at around 30,000PJ/y (with a slightly lower growth in the *2047 Net Zero* scenario).
- Volumes of fossil fuels(1) keep increasing until the 2030s and then begin to decline (during the 2030s for the *2047 Net Zero*, and the 2040s for the *2070 Net Zero*). Energy demand for coal increases by over 50% to 2040 in the *2070 Net Zero* scenario, due to a persistent strategy of energy independence combined with rapid economic growth. In the *2047 Net Zero* scenario, coal demand peaks in the early 2030s.
- Biomass demand peaks before mid-century in *2070 Net Zero* and in the early 2030s for *2047 Net Zero*. Sustained demand until 2070 is due to a progressive switch from traditional biomass to modern forms of bioenergy.
- Electricity rises very significantly across both scenarios and is a key outcome of this exercise. By 2047, electricity represents 50% of final energy in the *2070 Net Zero* scenario, and 2/3rd in the *2047 Net Zero* scenario. We will see in later chapters where and why this demand materializes. At a high-level, however, this rise reflects the ambitious policies from the government of India which target both energy independence and a net-zero economy.

Figure 5 – Final energy demand

Final energy demand per source (PJ) – 2070 Net Zero



Final energy demand per source (PJ) – 2047 Net Zero



(1) In final energy demand, gas accounts for natural gas, as well as other forms of gas, such as biogas. Hydrogen is accounted for in "Others".

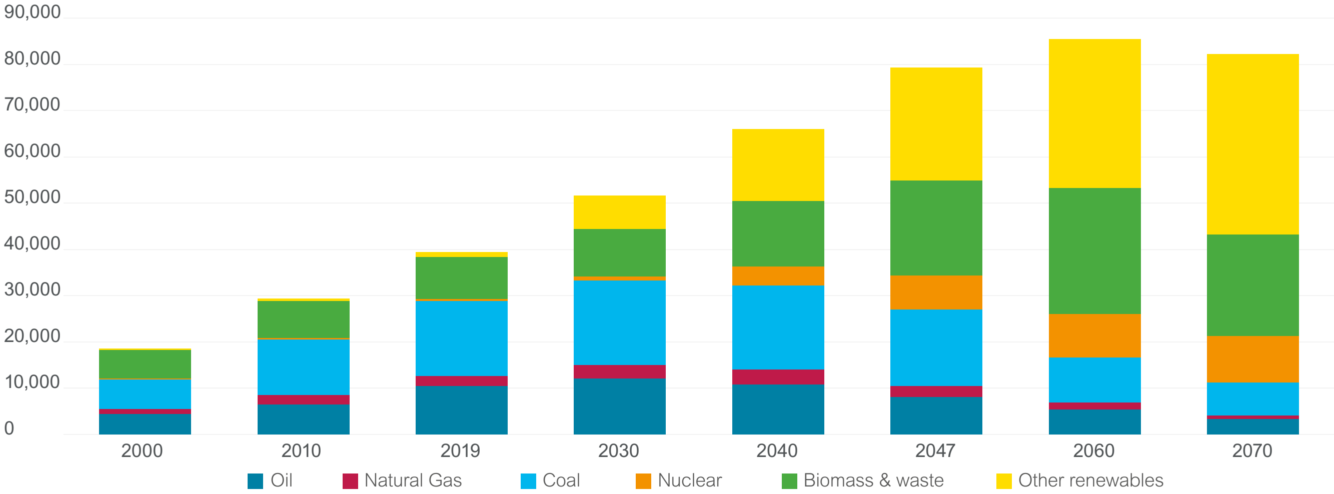
Finding 2: closing toward complete energy independence

Figure 6 shows gross inland consumption, or primary energy demand of India. Naturally, the country progressively substitutes its dependence on fossil fuels to renewable energies, including biomass and waste. Coal continues to represent a major resource in the energy mix until mid-century at least. In *2070 Net Zero*, the demand for oil and natural gas in 2047 is slightly lower than today's in 2047. While there exist some resources in India, these levels overshoot the government's target of full energy independence by then. This is particularly an issue for oil, which continues to be needed in mobility (see subsequent section). As a share of total primary energy demand, however, oil and natural gas only represent 13% of total, compared to over 30% today. In *2047 Net Zero*, this share falls down to 6%, and nearly full energy independence is reached.

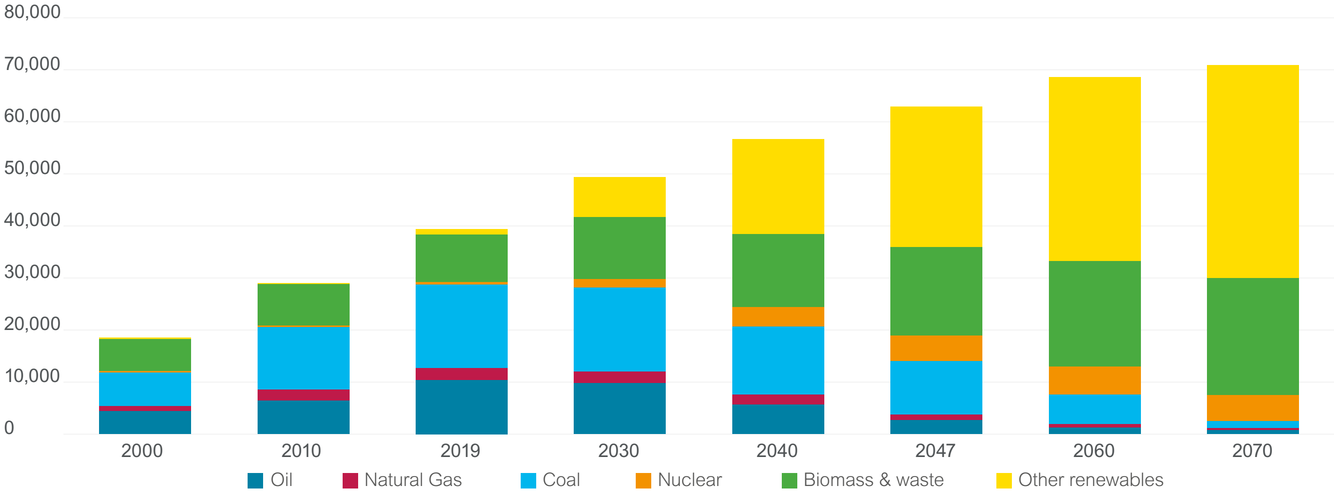
This suggests that both energy independence and net-zero emissions ambitions go hand in hand, and that a strong course toward zeroing emissions by mid-century could in fact accelerate the switch away from fossil fuels in a sustainable manner.

Figure 6 – Primary energy demand

Gross inland consumption (PJ) – 2070 Net Zero



Gross inland consumption (PJ) – 2047 Net Zero



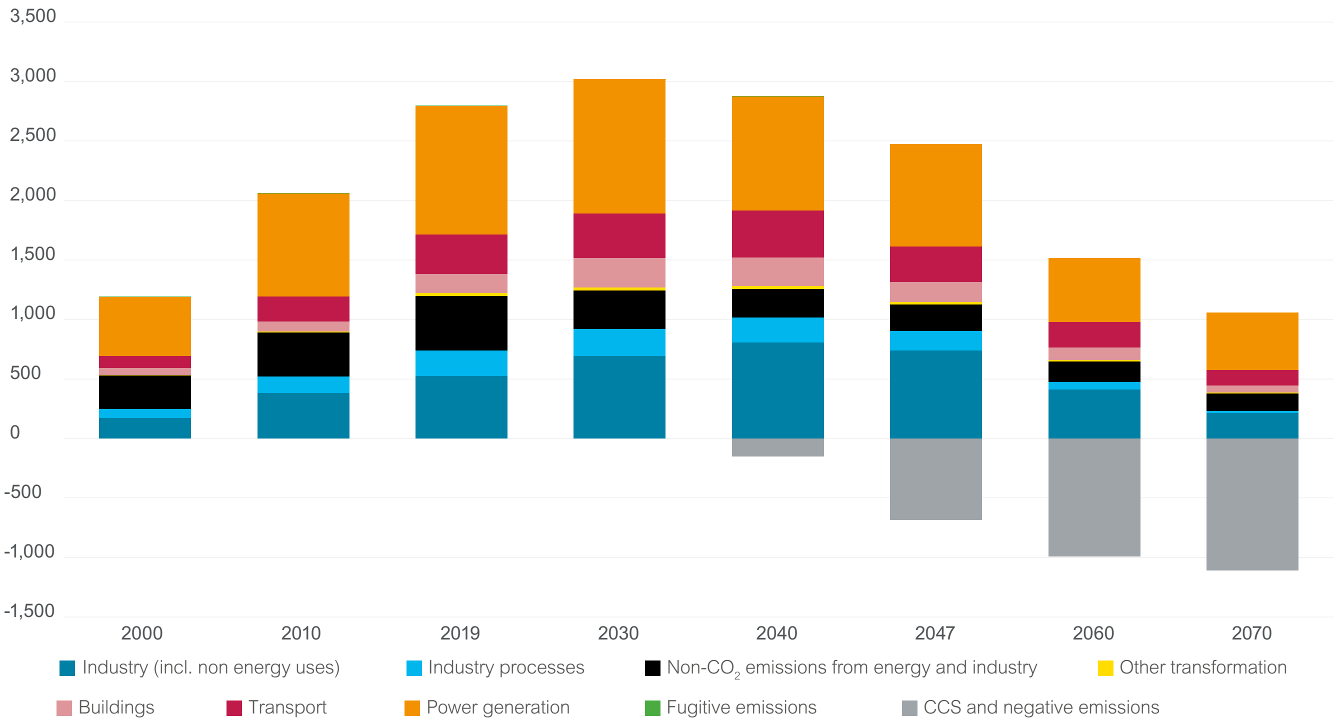
Finding 3: a peak in emissions in the 2030s

Figure 7 provides a detailed view of carbon emissions by sector all the way to 2070. These figures include CO_2 emissions from energy and industrial processes and non-CO_2 emissions from energy use. Agriculture, Forestry and Land Use (AFOLU) is excluded. 2019 baseline is around 2,800MtCO_2e/y.

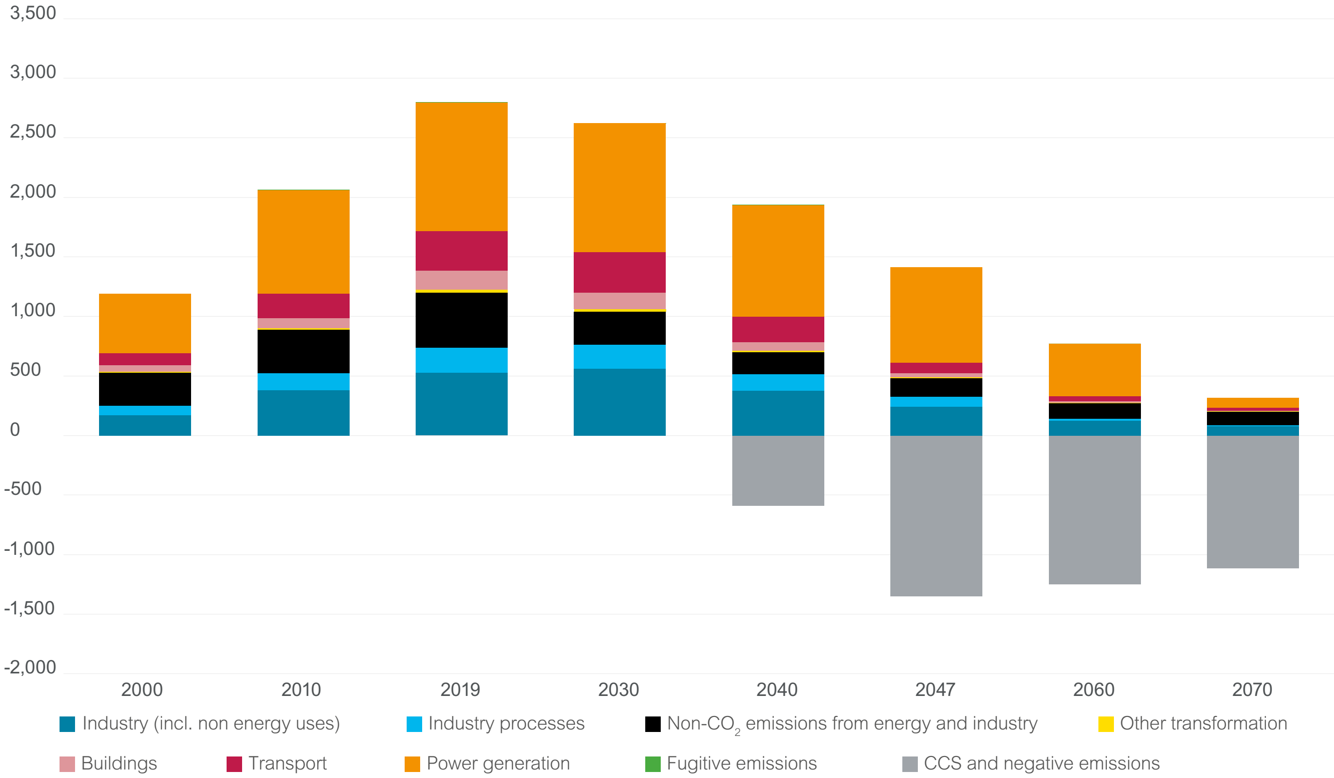
- Emissions peak in the 2030s in the *2070 Net Zero* scenario, but have reached their peak in 2030 for the *2047 Net Zero* scenario
- There are only minor differences across both scenarios on mobility-related emissions. This is because the increase in demand is mitigated by the switch toward EVs, compensating on emissions.
- Non-CO_2 emissions are also better handled, notably waste management, across both scenarios.
- The heart of the challenge revolves around industry and buildings, on the one hand, and power generation, on the other hand.
  - For industry and buildings, emissions are defined by two key patterns
    - A continued reliance on fossil fuels in the mid-term: existing installed base, use of coal as a local and resilient resource, switch from traditional biomass to liquefied petroleum gas (LPG) in rural areas. *2047 Net Zero* is more aggressive in switching away from those end-uses than *2070 Net Zero*.
    - The actual carbon intensity of power generation, in a context where electrification accelerates rapidly.
  - For power generation, new investments in coal generation continue for some time. The share of coal-fired generation is on a clear decline course post-2047, mainly as existing assets reach end of life. There are new investments in coal beforehand, however, and this is in part due to the significant rise in electricity demand, with a supply chain for renewable energies that takes time to ramp up (notably relevant in *2070 Net Zero*). Nuclear also plays a role and increases by 10-15 times current levels by 2047, yet this is not enough to compensate the need for alternative options (see chapter on electricity).
- Residual emissions range around 2,400MtCO_2e/y in *2070 Net Zero*, and slightly over 1,400MtCO_2e/y in *2047 Net Zero*. These emissions are compensated by Carbon Capture and Storage (CCS) and Nature-Based solutions (NBS) in both scenarios, and notably in *2047 Net Zero*, to reach carbon neutrality by mid-century. These solutions only begin to emerge in the late 2030s, however.

Figure 7 – CO_2 emissions

CO_2 emissions – 2070 Net Zero



CO_2 emissions – 2047 Net Zero



5 Multiple and simultaneous transitions

In this part, we deep dive in the transitions that materialize across different sectors of economic activity.

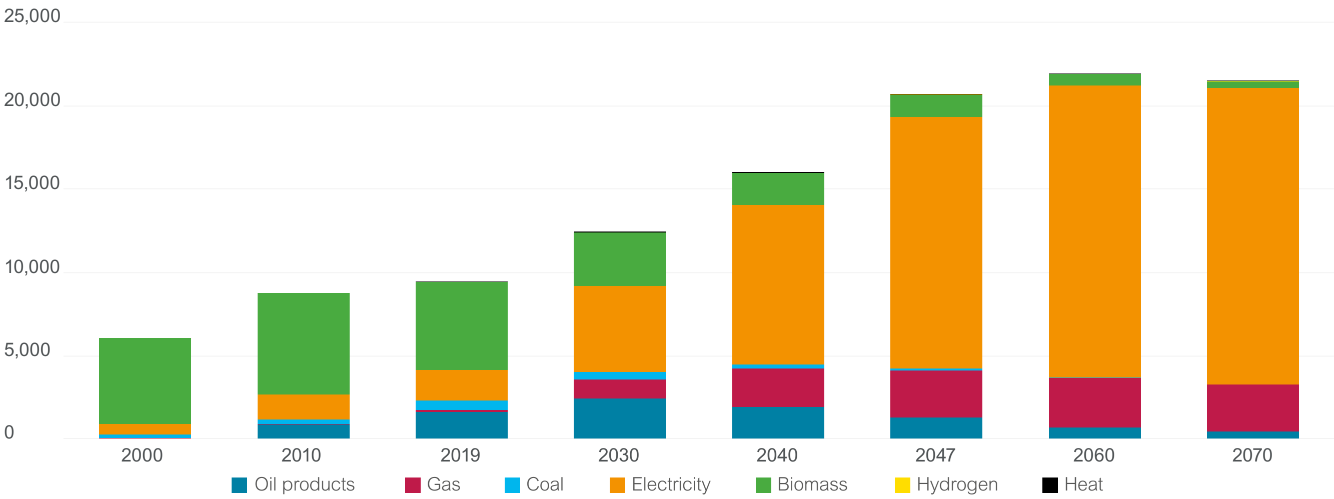
Finding 4: in buildings, new energy services drive a historical transition

Figures 8 and 9 provide a perspective on the evolution of energy demand in buildings. Overall energy demand increases around two-fold by mid-century and stabilizes.

- The residential stock increases 3-fold by 2047 and 4-fold by 2070. The service stock increases 4-fold by 2047 and nearly 7-fold by 2070, across both scenarios.
- Due to more ambitious policies on new constructions, the final level of energy demand in buildings is around 10% lower in *2047 Net Zero* than in *2070 Net Zero*. Renovation policies have limited impact given the significant increase in the stock. New construction policies play a critical role, however.
- A major transition away from traditional biomass materializes. In *2047 Net Zero*, this demand is in part substituted by modern forms of bioenergy, what does not occur in *2070 Net Zero*. In the latter, a greater recourse to gas takes place, notably in urban areas. This is in part natural gas, but also biogas generated from waste.
- Another substitute to biomass is LPG (mentioned above), which however plays only a transition role, before a convergence toward electricity.
- Overall electrification is the key driver of change. Demand for electricity rises 6-8 times by 2047, and over 8-10 times by 2070.

Figure 8 – Building energy demand

Building energy demand per source (PJ) – 2070 Net Zero



Building energy demand per source (PJ) – 2047 Net Zero

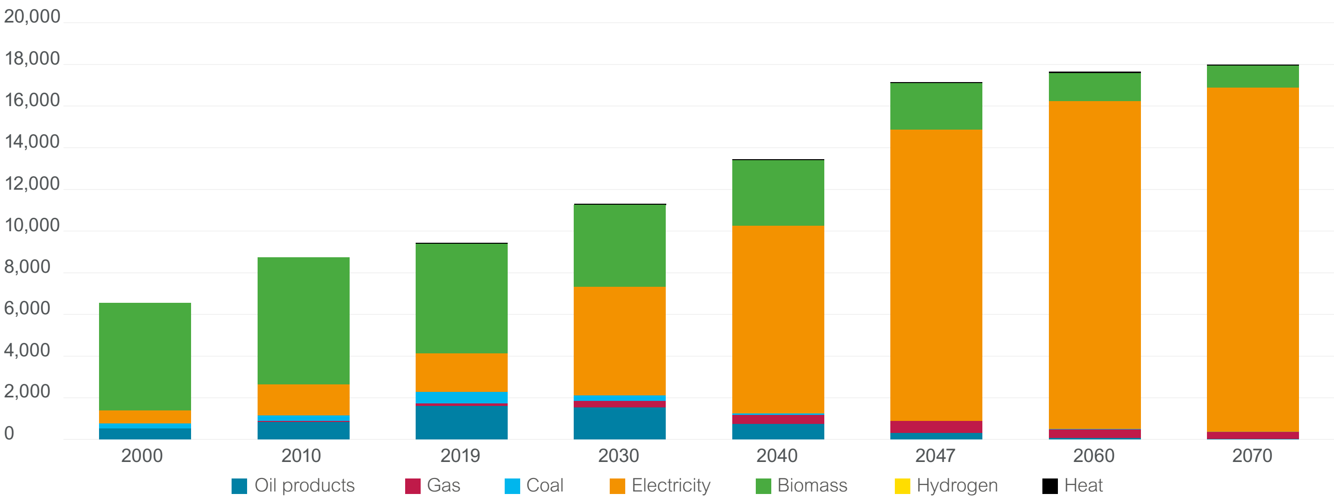
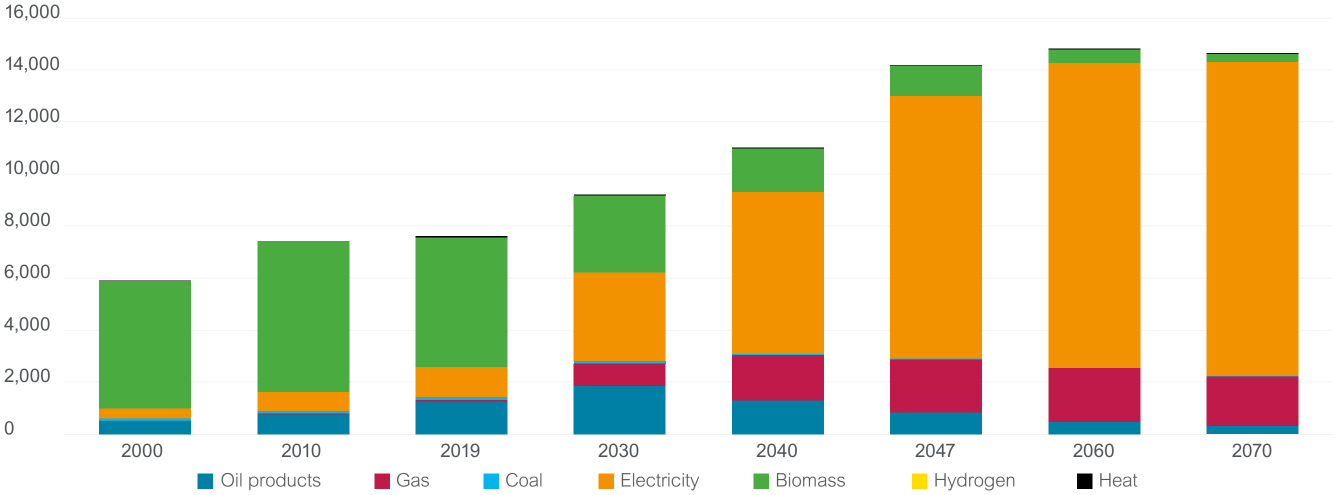


Figure 9 – Building energy demand, per segment

Residential energy demand per source (PJ) – 2070 Net Zero



Residential energy demand per source (PJ) – 2047 Net Zero

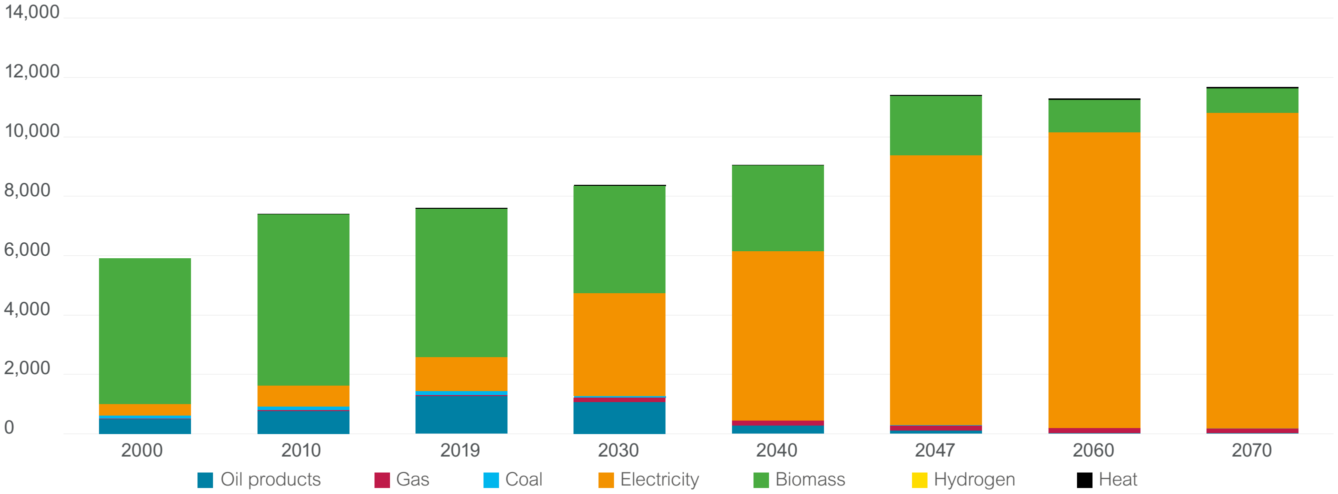
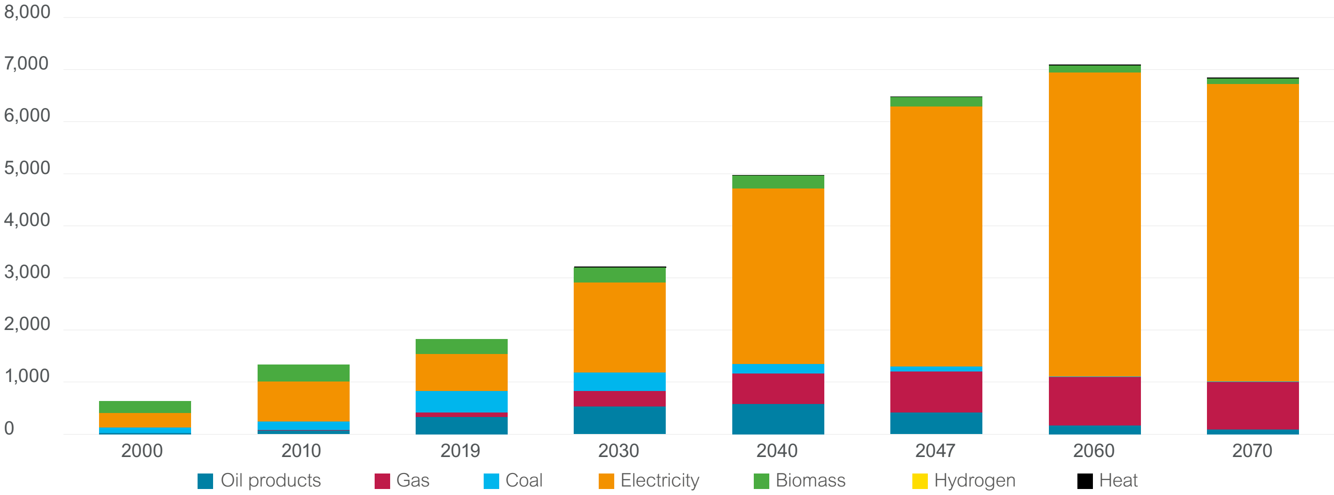


Figure 9 – Building energy demand, per segment (continued)

Service energy demand per source (PJ) – 2070 Net Zero



Service energy demand per source (PJ) – 2047 Net Zero

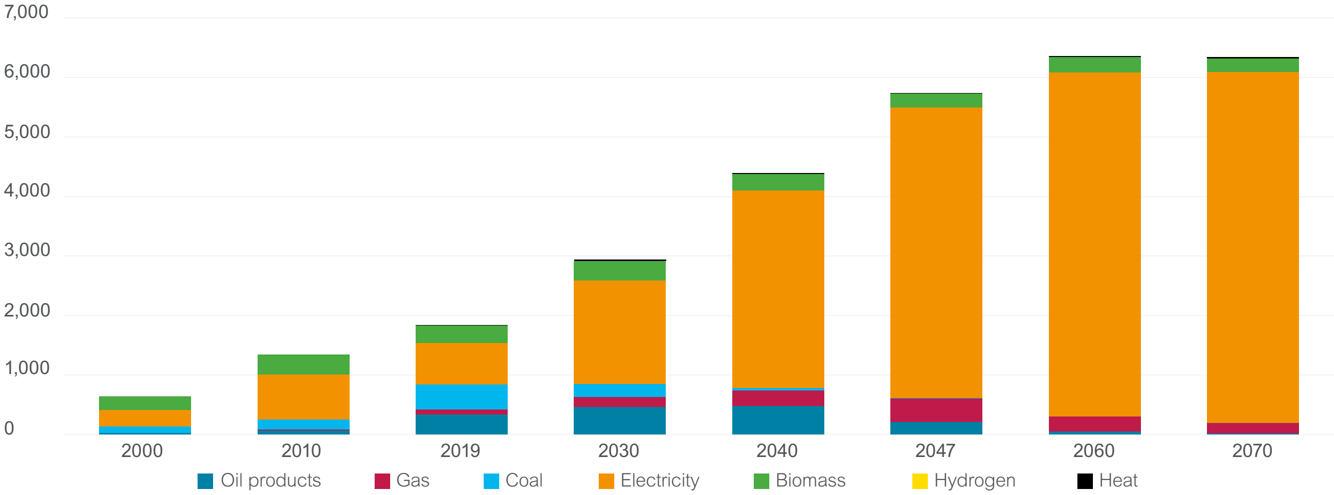


Figure 10 provides a more granular perspective of why electrification is so massive in buildings, with a focus on residential.

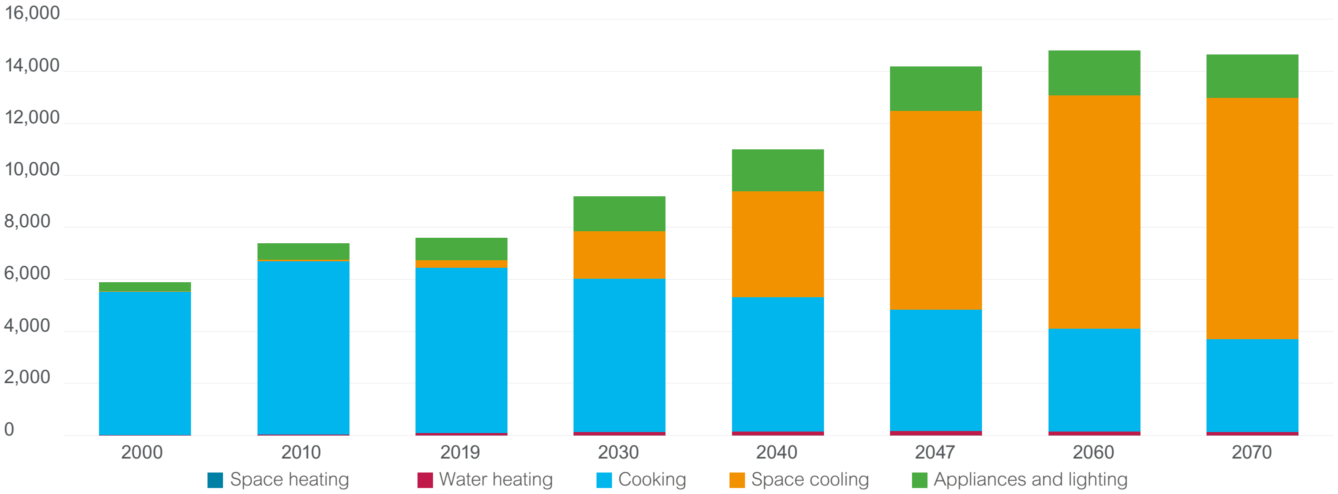
- The bulk of energy demand today comes from cooking. Since it is done with traditional biomass, it is also highly inefficient from an energy standpoint. The switch to modern forms of energy, notably electricity, yields significant optimization with total energy demand for cooking dropping as a result by around 30% by 2047 and 50% by 2070.
- Residential energy demand continues to grow rapidly, however. This is due to new energy services, notably air conditioning (cooling) and the accelerated penetration of appliances within the residential stock. While both benefit from significant efficiency gains over time, the magnitude of the deployment leads to a significant increase in energy demand. Better insulated constructions in the *2047 Net Zero* scenario help mitigate this increase to some extent (for air conditioning).

In service buildings, this pattern is even more visible. The bulk of the increase in energy demand stems from air conditioning and appliances penetration (Figure 11).

In other words, new energy services (not only energy transition policies) drive the uptake of electricity demand in buildings.

Figure 10 – Residential energy demand, per use

Residential energy demand per service (PJ) – 2070 Net Zero



Residential energy demand per service (PJ) – 2047 Net Zero

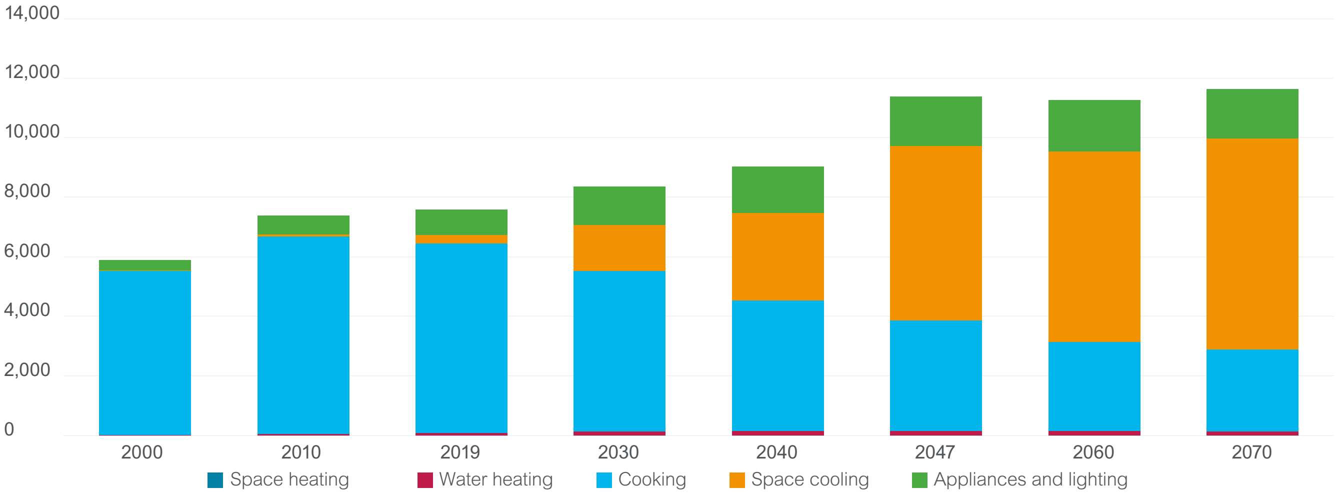
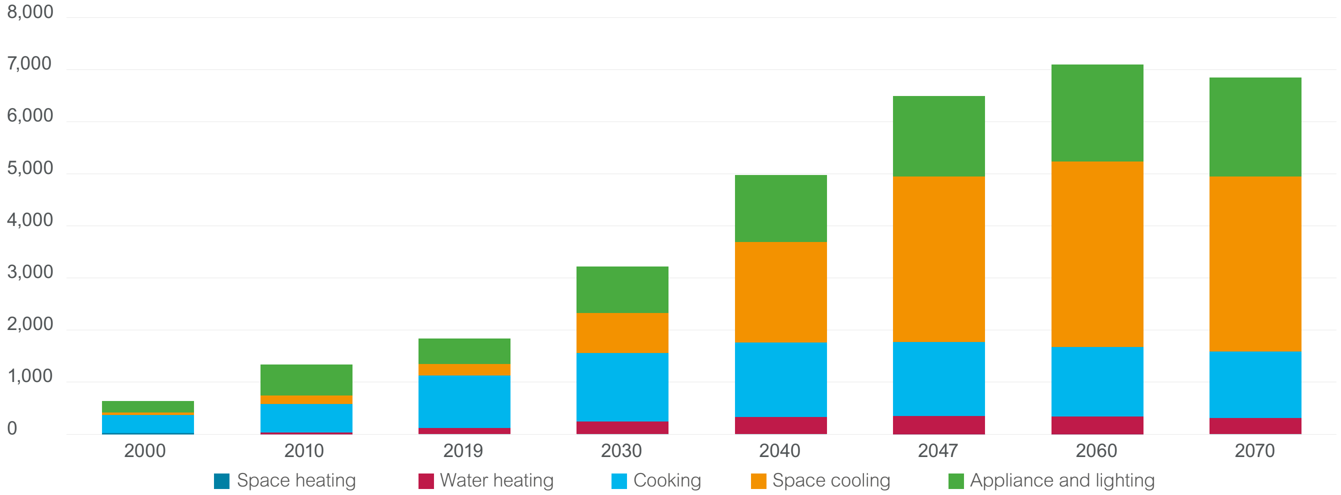
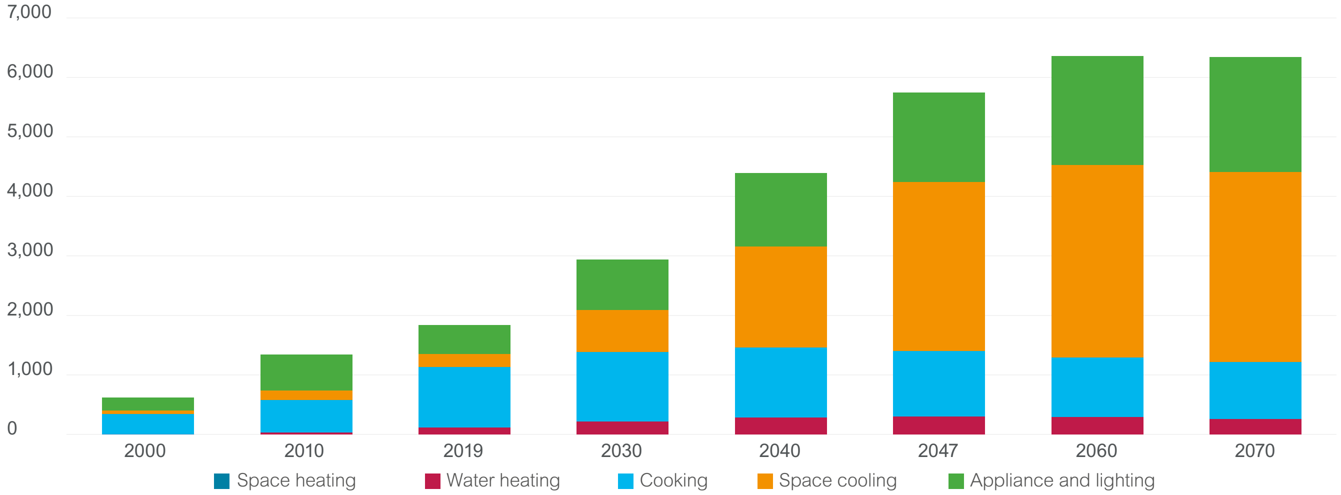


Figure 11 – Service energy demand, per use

Service energy demand per service (PJ) – 2070 Net Zero



Service energy demand per service (PJ) – 2047 Net Zero



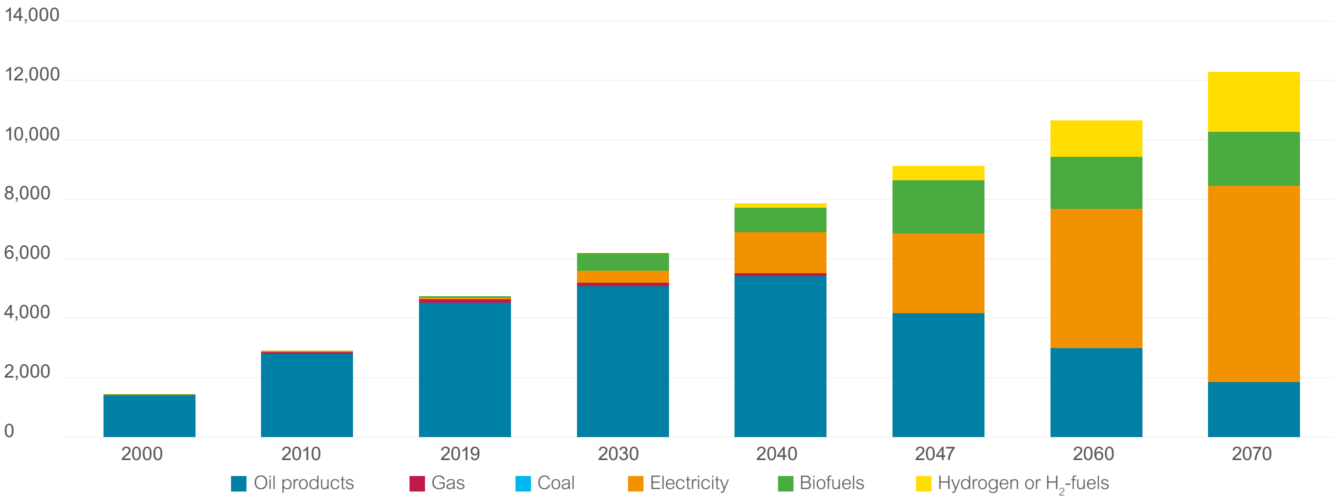
Finding 5: the opportunity to reinvent urban mobility

Mobility is impacted by the combination of a significant rise of demand for new mobility services (e.g., private means of transportation) on the one hand, and sustainable practices development (rail development, mobility as a service, etc.) and fuel switch, notably electrification, on the other hand. This transformation is accelerated by urbanization, and the opportunity to develop a new urban mobility system which does not build on historic experiences from other geographies.

- In terms of energy demand, the two scenarios show different possible futures for mobility, however, depending on the weight of each of the trends described above (Figure 12). Final energy demand doubles in *2070 Net Zero*, but increases "only" by 2/3rd in *2047 Net Zero*.
- This is further explained in Figure 13, where an increase in rail transport mitigates the rise in private road transport. By 2070, a greater recourse to rail is visible across all scenarios (as both reach net zero emissions by or earlier to that date), but the earlier uptake in *2047 Net Zero* helps reduce overall energy demand by around 2,000PJ/y.
- The system also electrifies significantly (Figure 12). In *2070 Net Zero*, 30% of total energy demand is provided by electricity in 2047, a figure that reaches nearly 50% in *2047 Net Zero*. Biofuels and hydrogen-based fuels complement this switch, notably for aviation and shipping. Oil represents only 50% of total energy demand in 2047 in the *2070 Net Zero* scenario, and 20% in the *2047 Net Zero* scenario.
- By 2047, 65% of private vehicles are EVs (this includes motorcycles and plug-in hybrid) in *2070 Net Zero*, and 80% in *2047 Net Zero*. These figures correspond to a rapid rise of EV sales in the booming Indian market: in *2070 Net Zero*, 25% of sales are EVs by 2030, and 80% by 2047. In *2047 Net Zero*, a similar figure is reached in 2030, but this skyrockets to 90% by 2040, and virtually 100% by 2047.

Figure 12 – Mobility energy demand

Mobility energy demand per source (PJ) – 2070 Net Zero



Mobility energy demand per source (PJ) – 2047 Net Zero

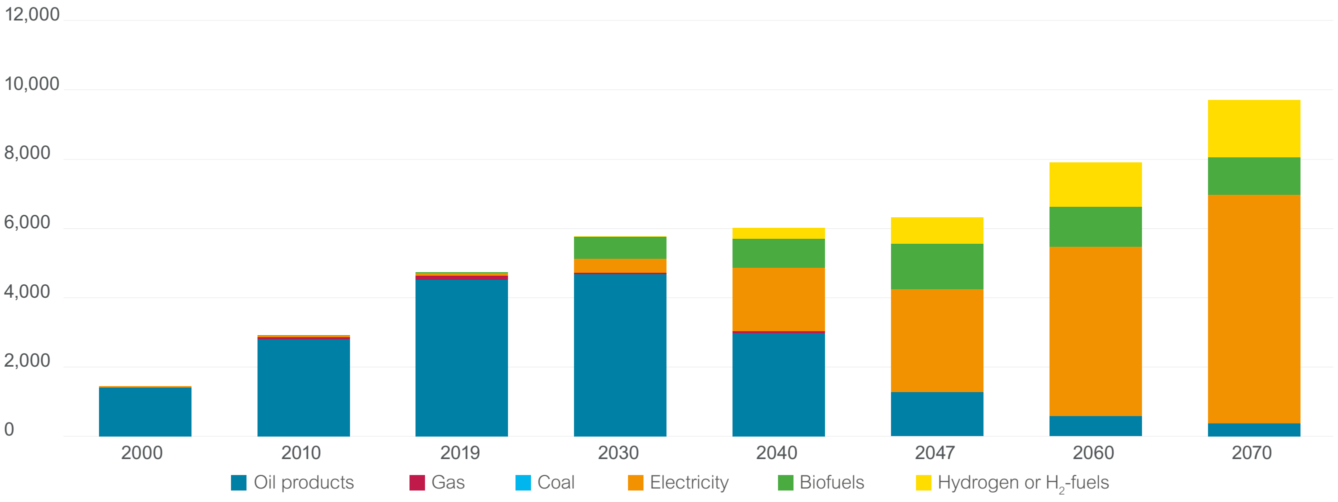
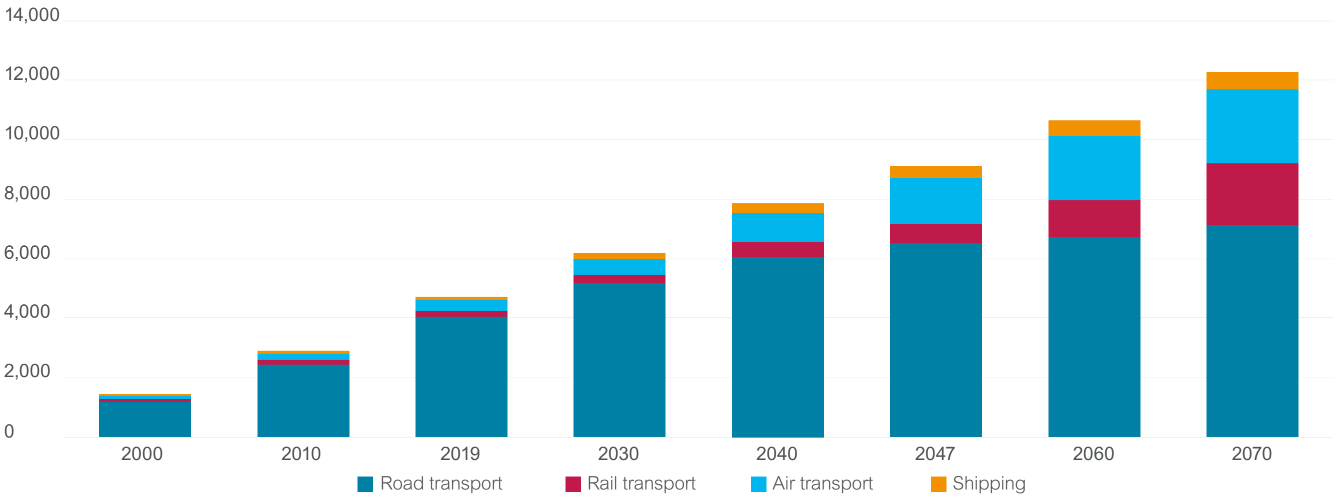
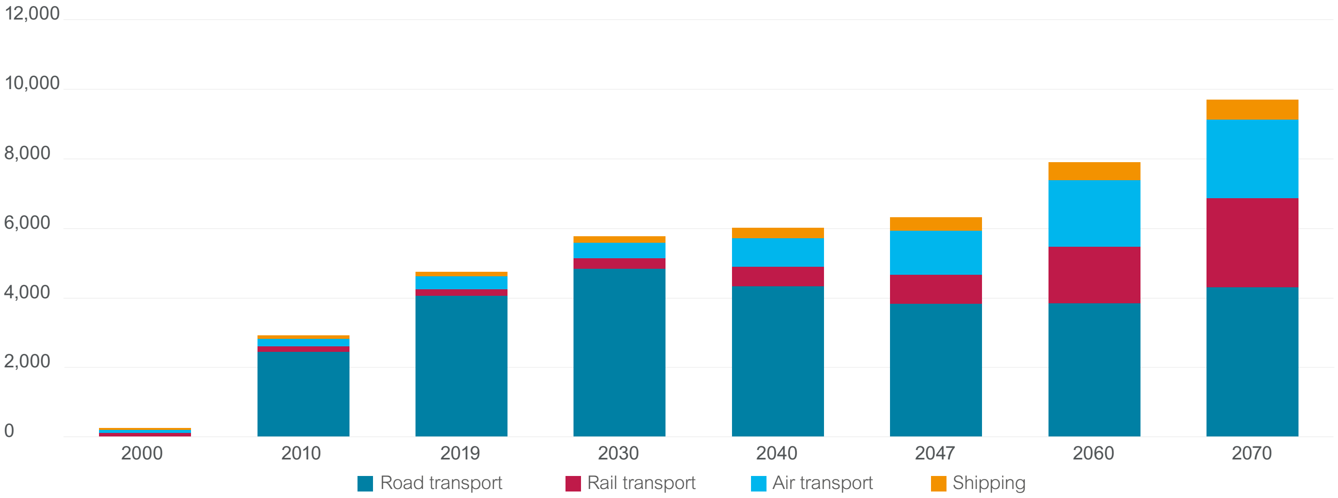


Figure 13 – Mobility energy demand, per service

Mobility energy demand per service (PJ) – 2070 Net Zero



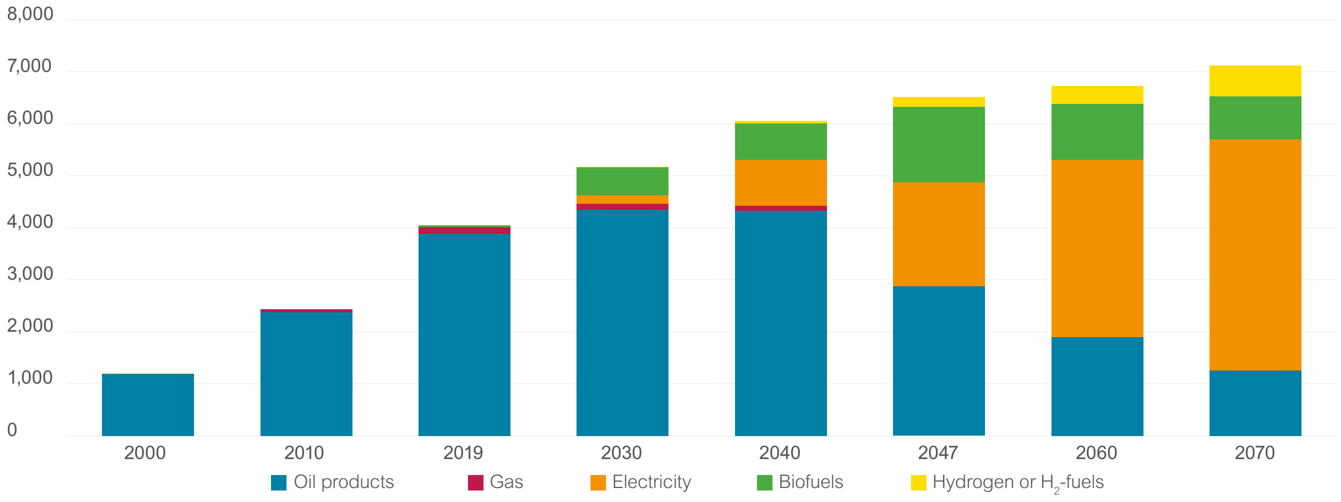
Mobility energy demand per service (PJ) – 2047 Net Zero



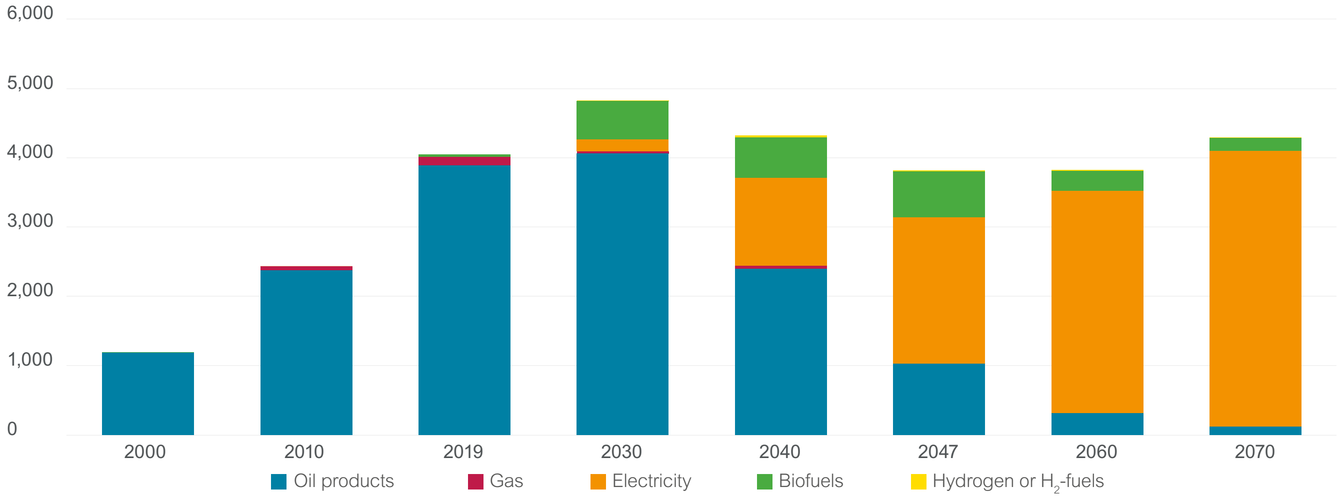
Although road mobility is dominated by electrification, biofuels play a complementary, yet transitionary role, across both scenarios (Figure 14). Electrification applies not only to light-duty vehicles, but to heavy-duty trucking as well. Hydrogen fuel cell vehicles (FCEVs) play a minor role in road transport, given the emergence of a clear dominant battery-based design in the automotive sector, and the complex and highly costly prospect of developing a reliable hydrogen distribution infrastructure across the country. Rather, for trucking, logistics adapt to the new dominant design, while batteries continue to progress significantly.

Figure 14 – Road Mobility energy demand

Road mobility energy demand (PJ) – 2070 Net Zero



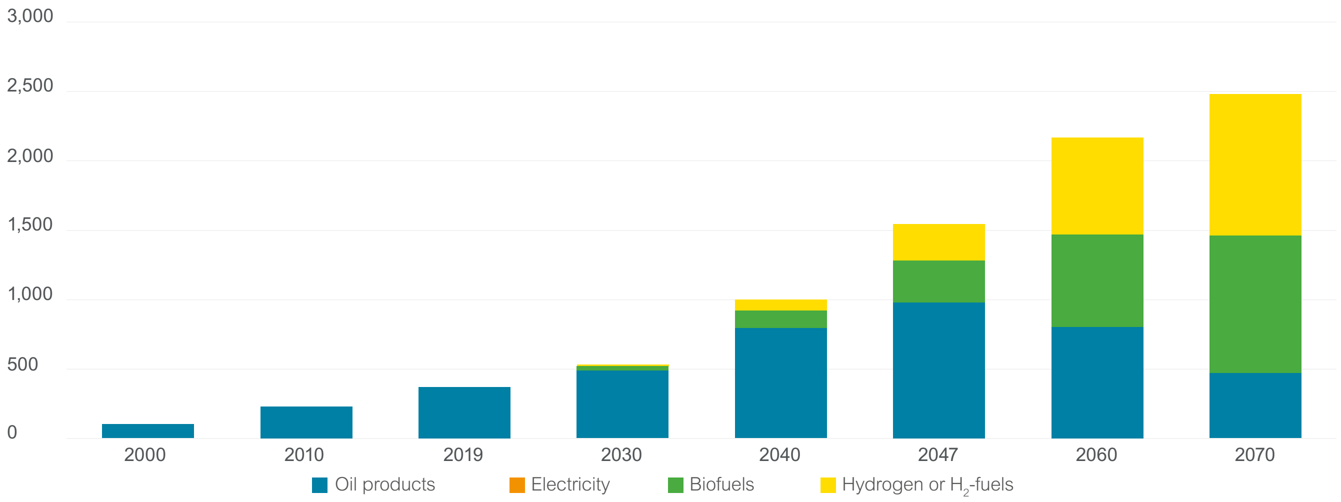
Road mobility energy demand (PJ) – 2047 Net Zero



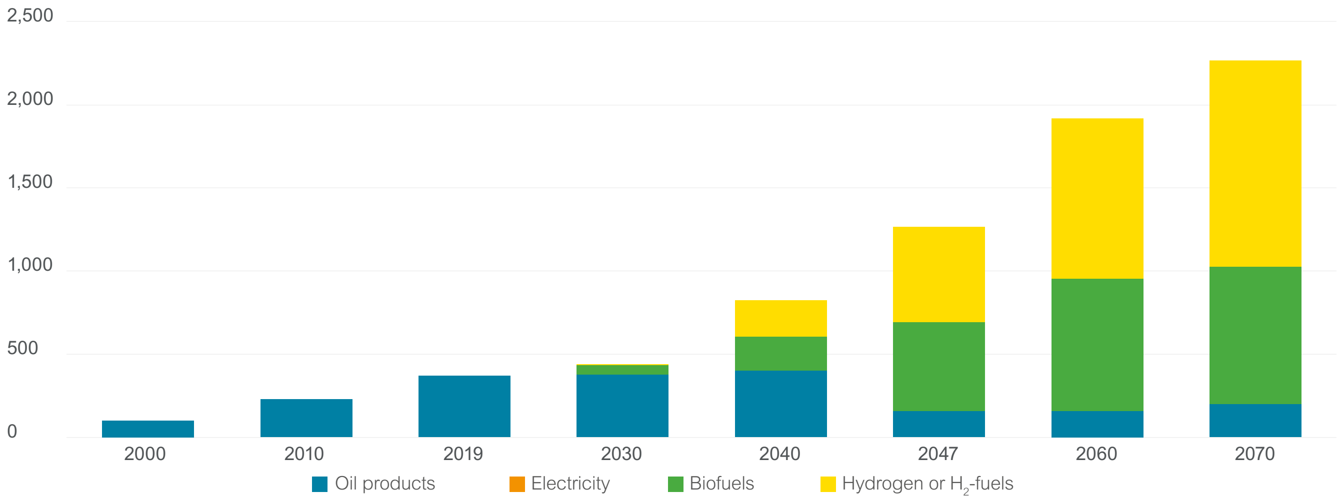
The situation differs significantly in harder to abate sectors such as air or maritime mobility. Figure 15 provides a view for air mobility. Electrification there plays only a minor role, if any. Oil continues to dominate the energy demand of the sector until 2047 in *2070 Net Zero*. Alternative fuels emerge progressively as a mean to decarbonize the industry: these include biofuels and hydrogen-based fuels (e.g., synthetic kerosene for air travels, or ammonia for shipping), which are "manufactured" in petrochemical facilities. While the switch occurs post-2047 in *2070 Net Zero*, it accelerates from the mid-2030s in *2047 Net Zero*.

Figure 15 – Air Mobility energy demand

Air mobility energy demand (PJ) – 2070 Net Zero



Air mobility energy demand (PJ) – 2047 Net Zero



Finding 6: global manufacturing independence and leadership

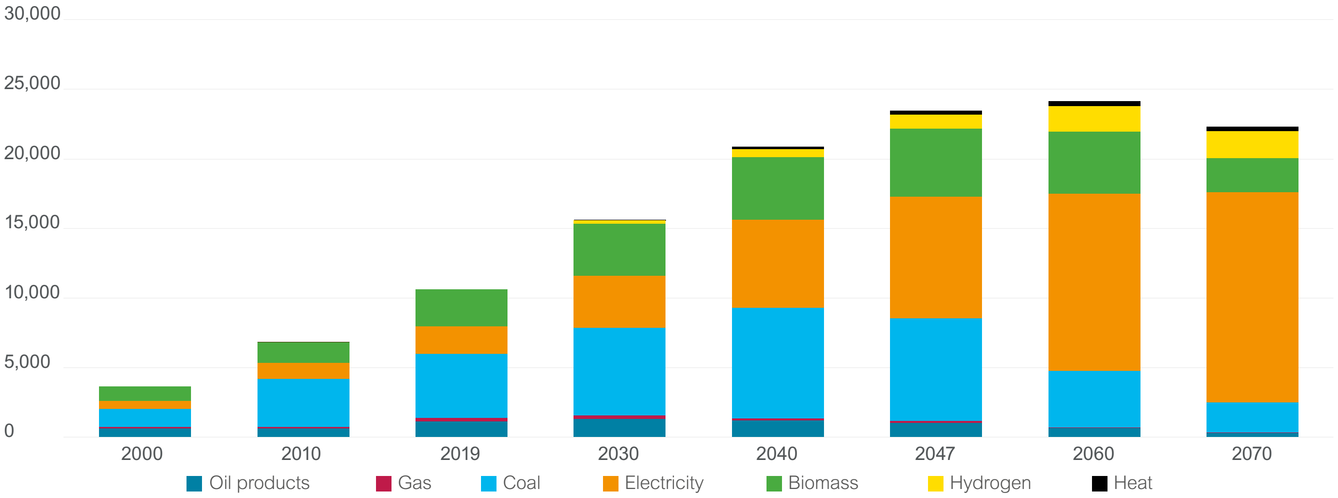
The landscape of industrial demand also significantly evolves in the course of the coming decades. Overall energy demand increases by 1.5-2 times by mid-century, before stabilizing. This comes as the result of a massive industrialization of the Indian economy by mid-century[1] (Figure 16).

Even more striking is the rapid electrification of the industrial energy system. By 2047, electricity accounts for around 35-60% of final energy demand in the sector, a massive transformation compared to today's 20%. An important difference across both scenarios is the reliance on coal which is more prolonged in the *2070 Net Zero* scenario (energy independence), while the race toward net-zero emissions by mid-century in the *2047 Net Zero* scenario accelerates the phasing out of coal in industry, post-2030.

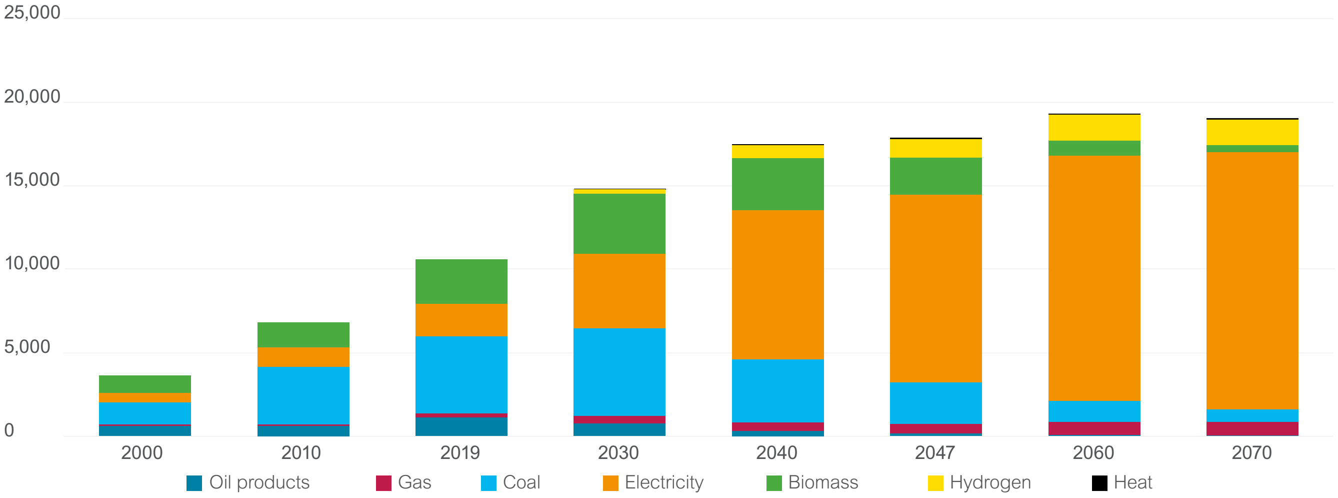
Figure 17 helps understand better these dynamics. While traditionally a lot of focus is placed on steel, nonmetallic minerals and chemical activities, the bulk of energy demand growth by 2047 (and 2070) stems from the significant rise of manufacturing activities. In fact, the energy demand for the former sectors (e.g., hard to abate) grows 1.5-2 times by mid-century, while that of manufacturing grows 2-2.5 times (with a higher baseline). The increase in energy demand from manufacturing represents 65-75% of total energy demand increase by mid-century.

Figure 16 – Industry energy demand

Industry energy demand per source (PJ) – 2070 Net Zero



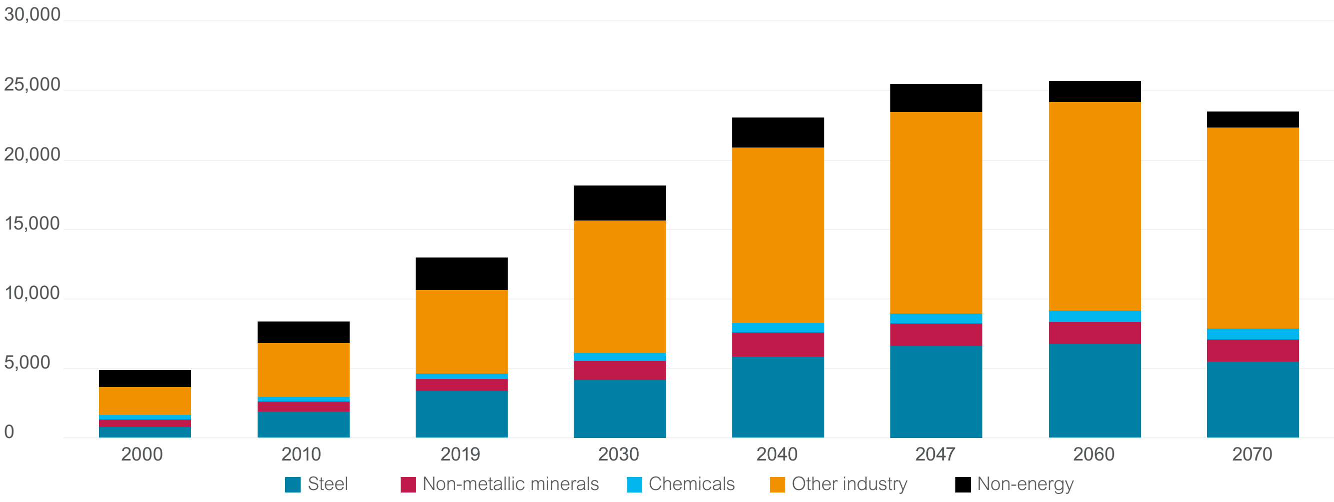
Industry energy demand per source (PJ) – 2047 Net Zero



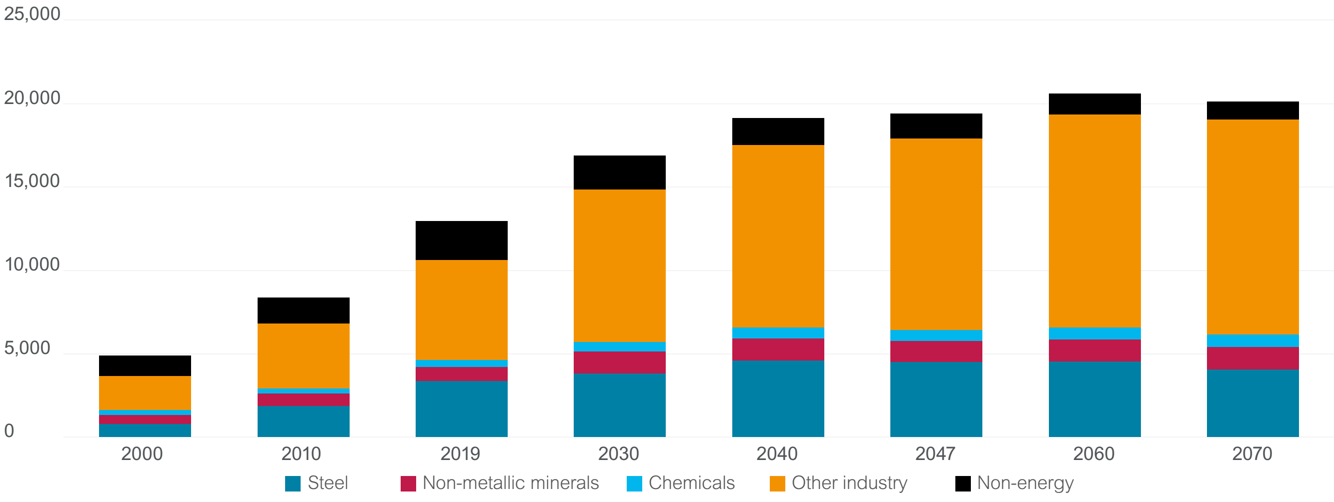
(1) In this chapter, we focus only on energy demand. Feedstock is not included.

Figure 17 – Industry energy demand, per service

Industry energy demand per service (PJ) – 2070 Net Zero



Industry energy demand per service (PJ) – 2047 Net Zero

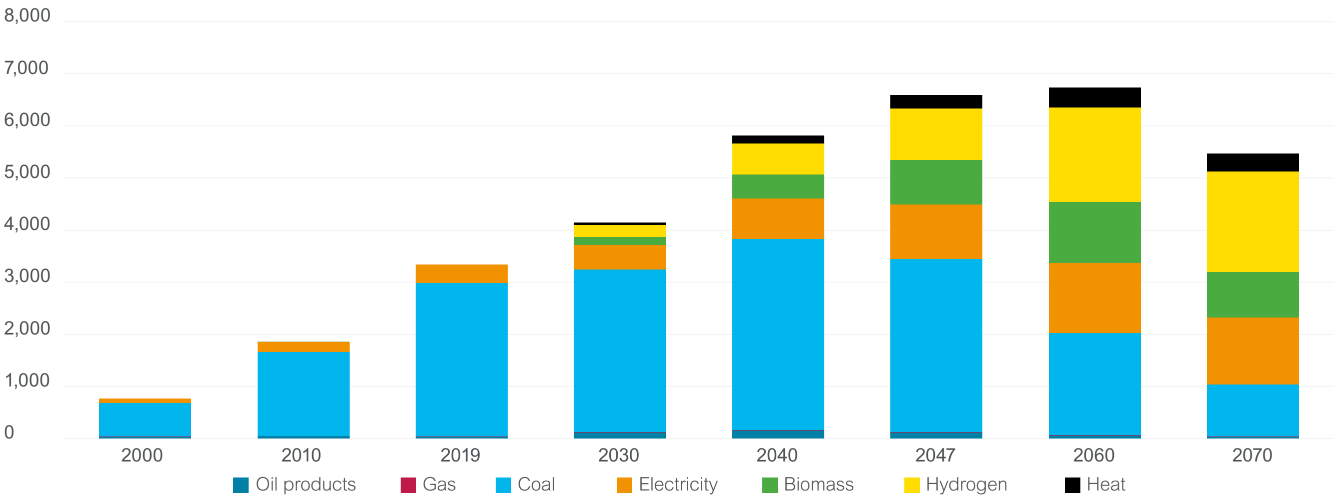


Yet, transitions are contrasted across different sectors. In steel for instance (Figure 18), overall energy demand forecasts vary significantly across both scenarios.

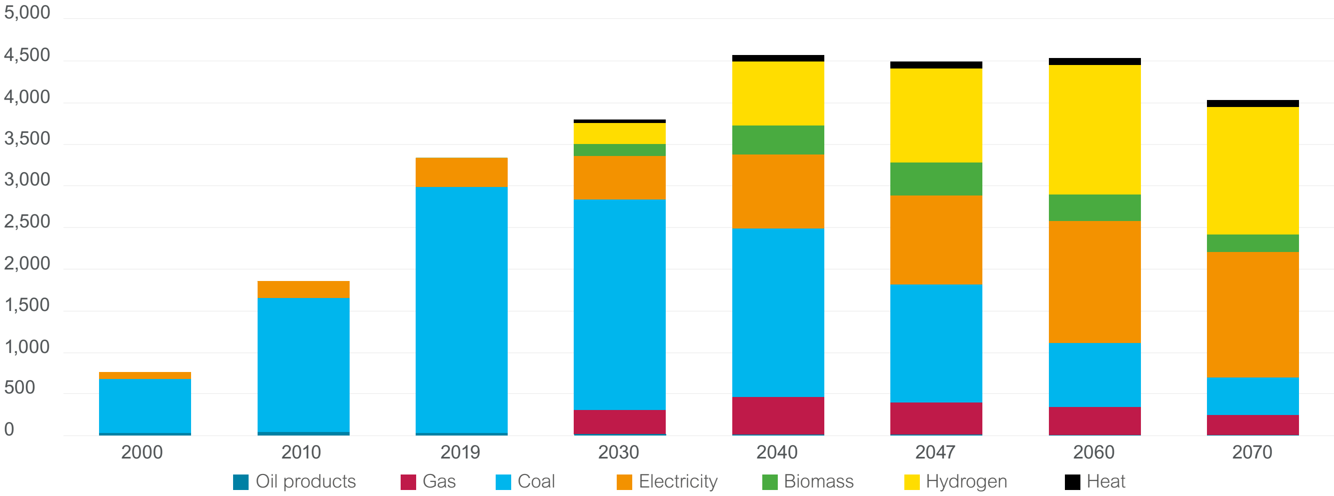
- Similarly to what is observed for the whole of industry, energy demand increases 30-100% across both scenarios. In the *2047 Net Zero* scenario, the growth in demand for steel is lower due to a combination of factors, prime of which being more rapid improvements in construction techniques and a lower demand for private cars (see mobility chapter).
- Due to a lower demand, the share of scrap steel that can easily be reintroduced in the economy is higher and grows faster in this scenario (25% in 2047 vs 19% in *2070 Net Zero*, hence the share of electrification (electric arc furnace) is higher as well.
- Coal demand stabilizes in *2070 Net Zero* by mid-century, but decreases by nearly a factor of two in *2047 Net Zero*. New demand for steel is mainly served, across both scenarios, by some level of biomass (as a transition fuel) and more importantly by hydrogen (i.e., hydrogen-DRI processes).

Figure 18 – Steel industry energy demand

Steel industry energy demand (PJ) – 2070 Net Zero



Steel industry energy demand (PJ) – 2047 Net Zero

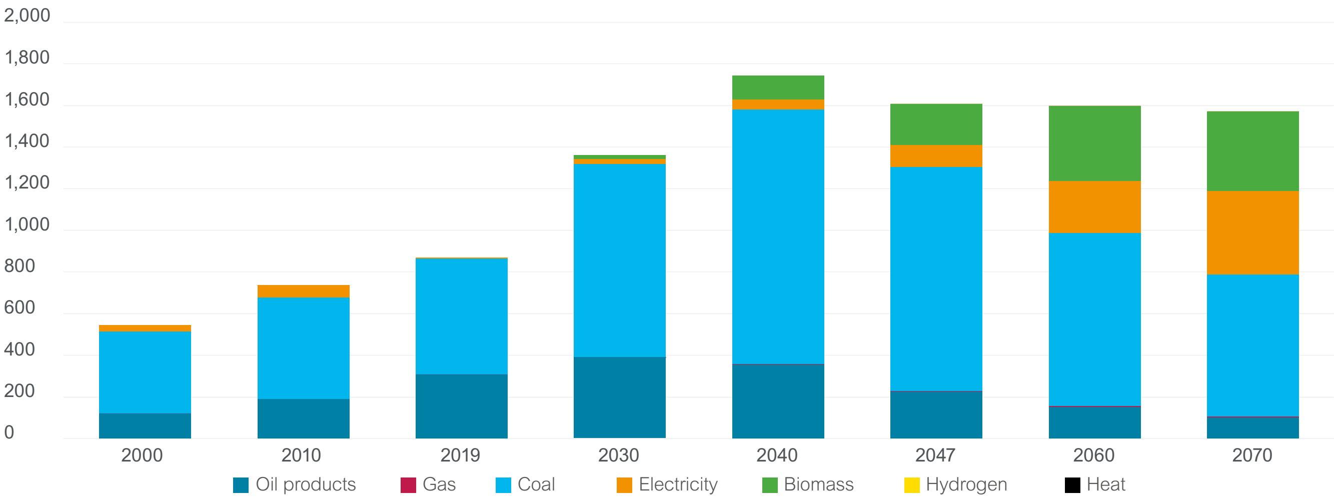


A similar effect on final energy demand is observed in the nonmetallic minerals industry, with a growth that stabilizes by as early as 2040 in the *2070 Net Zero* scenario, and 2030 in the *2047 Net Zero* scenario (Figure 19). This has mainly to do with the emergence of new construction techniques that disrupt traditionally anticipated demand for cement.

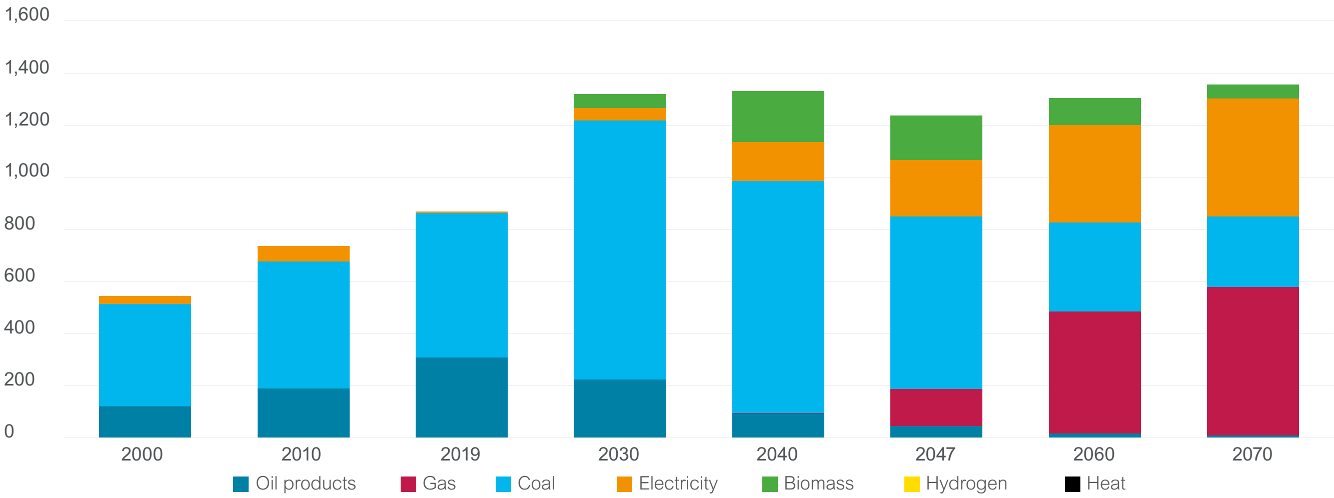
- As this industry is notably hard to abate, coal continues to prevail late in the century. In 2047, coal still represents 55-65% of energy demand.
- Alternatives emerge across both scenarios, however, notably a further electrification of the industry to its maximal theoretical limits[1], and biomass. In the *2047 Net Zero* scenario, gas also emerges by mid-century as an important way to decarbonize and phase out coal more rapidly[2].

Figure 19 – Nonmetallic minerals industry energy demand

Minerals industry energy demand (PJ) – 2070 Net Zero



Minerals industry energy demand (PJ) – 2047 Net Zero



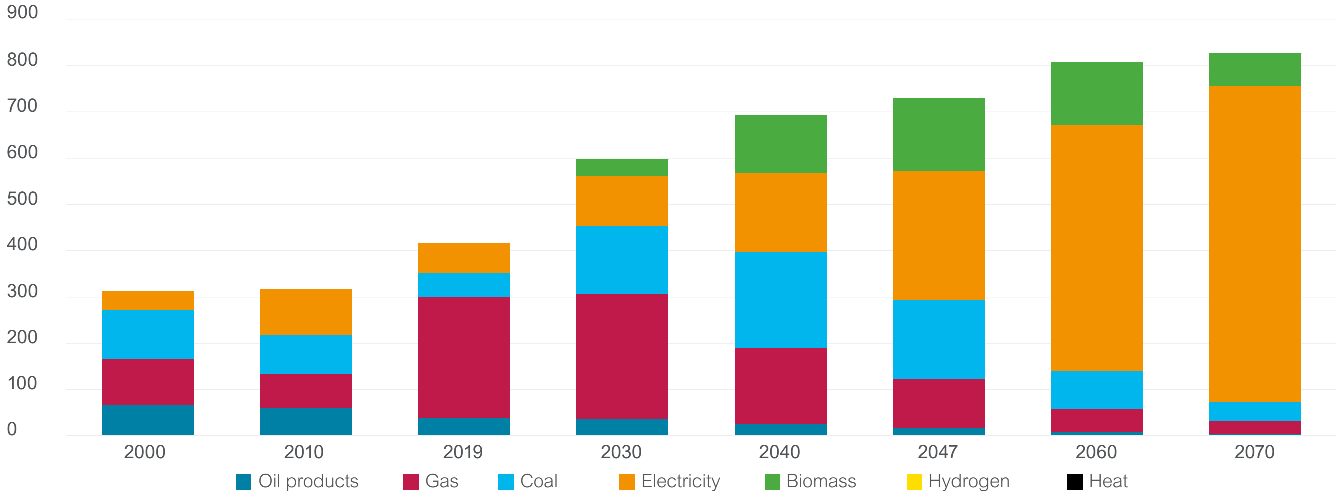
(1) Madeddu et al., 2020.
(2) Natural gas, or other options such as biogas for instance.

The chemical industry follows similar patterns as well, but the main aspect of its evolution is the significant electrification of its footprint (Figure 20).

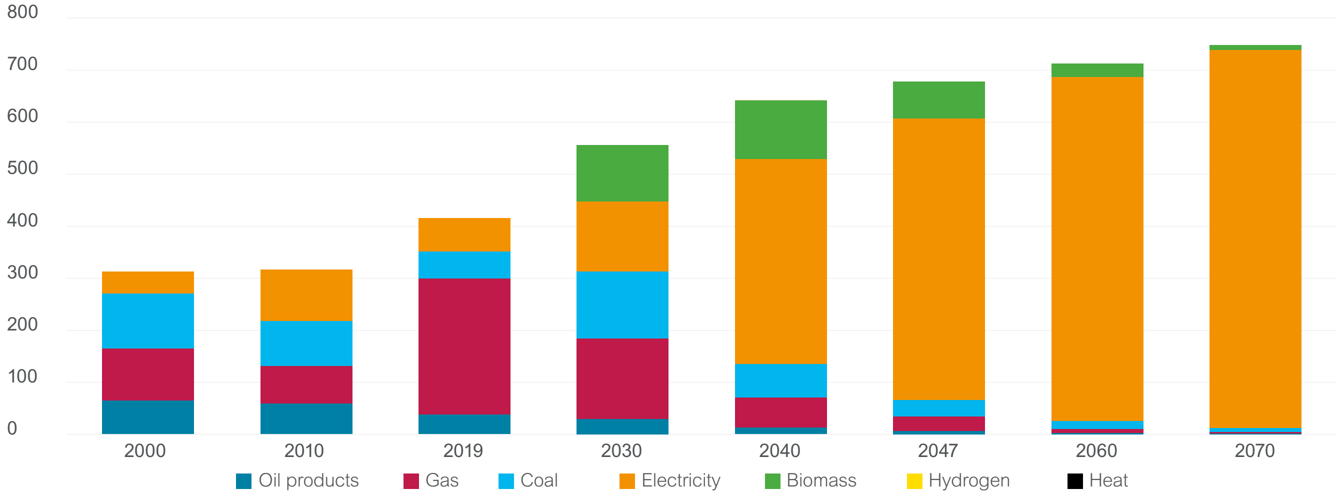
- In the *2070 Net Zero* scenario, this electrification mainly concerns new units put in operation (new demand, or substitutions of decommissioned factories), with a share of electricity reaching 40% of final energy demand by mid-century.
- In the *2047 Net Zero* scenario, electrification grows more rapidly, thru the rapid adoption of electric technologies for all sub-processes that can easily be electrified (e.g., steam) in existing facilities, alongside new units, pushing the share of electricity up to 80% of final energy demand by mid-century.

Figure 20 – Chemicals industry energy demand

Chemicals industry energy demand (PJ) – 2070 Net Zero



Chemicals industry energy demand (PJ) – 2047 Net Zero

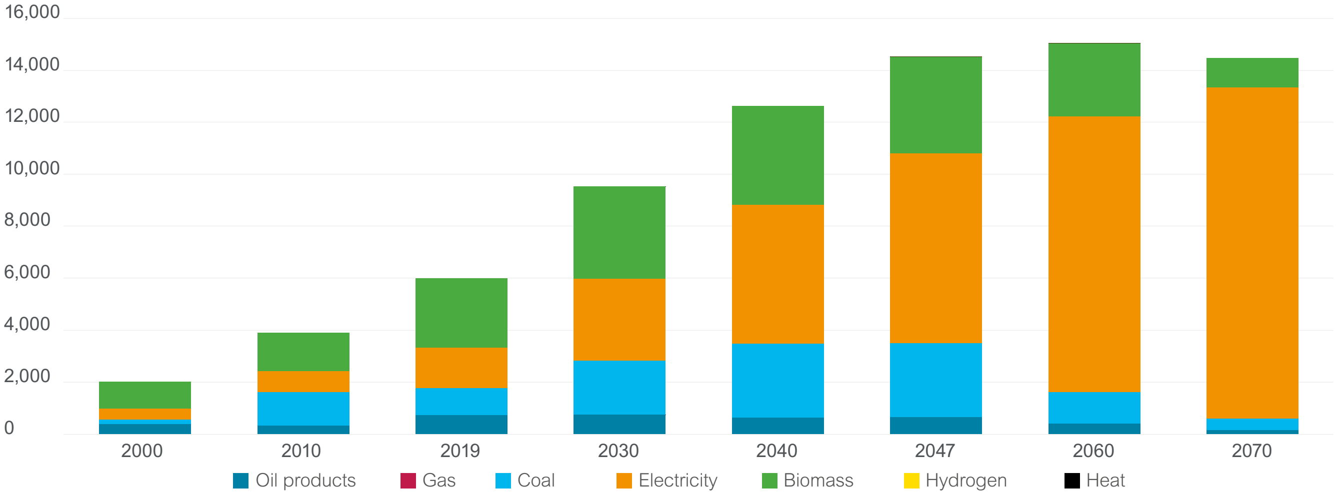


The rise of manufacturing influences dramatically the evolution of final energy demand in industry, with a 2-2.5 times increase in energy demand by mid-century (Figure 21).

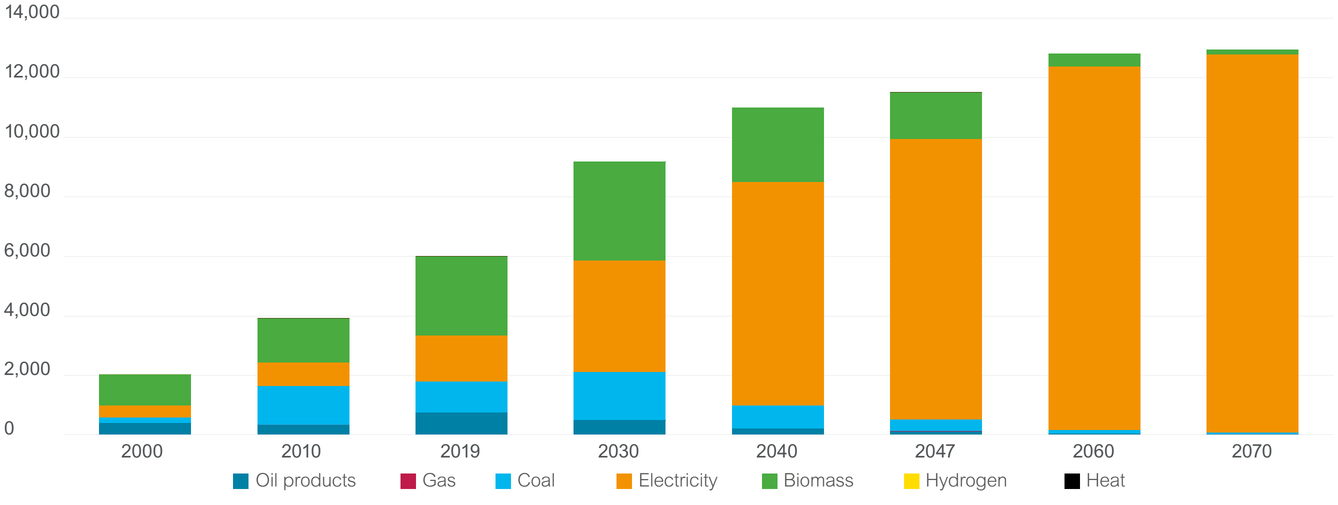
- In *2070 Net Zero*, traditional resources (notably coal) continue to be used (energy independence) and are not displaced before 2047. Electricity also significantly increases as most of new manufacturing facilities can easily be electrified, as discussed above.
- In *2047 Net Zero*, electrification grows even more rapidly, on the back of ambitious decarbonization policies that aim at decarbonizing the sector by mid-century, including the modernization of current facilities.

Figure 21 – Other industry energy demand

Other industry energy demand (PJ) – 2070 Net Zero



Other industry energy demand (PJ) – 2047 Net Zero



6 A new energy system

In this part, we finally explore the evolution of the supply side of the energy system, which follows that of energy demand.

Finding 7: all-electric India

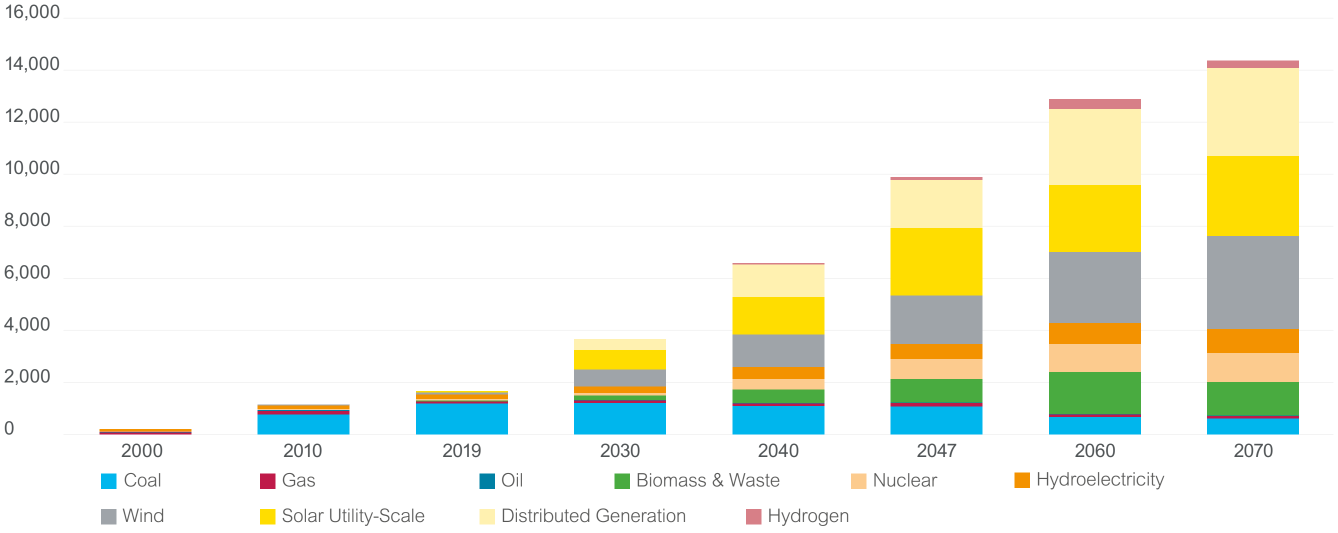
A major finding of the previous analysis on energy demand is that the rapid industrialization and development of the Indian economy leads, across all sectors, to a significant rise of electricity demand. Arguably, the ability of the infrastructure to ramp up at the required pace will define to which extent the economy of India can develop at this pace. This is thus a major question for the coming decades.

- Power generation increases from 1,700TWh/y today up to around 10,000TWh/y by 2047, or 6 times (Figure 22).
- With such a level of increase, all resources need to be put to use. Our scenarios suggest, as a result, that existing installations (coal notably) continue to run long in the century, and begin decommissioning when reaching end of life, post-2047. Coal-fired power generation notably increases slightly to 2030, when it reaches its peak. This has obviously a critical impact on carbon emissions.
- Yet, for the most part, new capacities come from other technologies.
    - Nuclear energy increases by 10-15 times by mid-century, what has, however, only a minor contribution to the overall power system mix. This is notably due to long commissioning times and high upfront costs, which prevent a more rapid increase in the mix.
    - Hence, the bulk of the increase is met by renewable energies, with wind and solar representing the majority of additions. Taken together, they represent 75% of the growth by 2047.
    - Wind accounts for a little over 20-25% of total growth, while solar represents 50% of total growth, or around 4,500TWh by then.
- To put these figures in perspective, the amount of solar generation to be brought online in the coming 3 decades thus represents nearly 3 times current levels of power generation, a massive undertaking. Such development obviously comes with critical questions on supply chain development and land area suitable for such installations.
    - Our modeling suggests however that a significant share of this new generation capacity could be of distributed form (i.e., on rooftops of buildings, parking lots, commercial centers, etc.).
    - Harnessing the massive potential for such solutions in India could contribute 40-60% of the total demand for solar PV generation, or 1,800-2,700TWh by mid-century, and represent by then 20-25% of total electricity generation.
    - This would further rise to 2070, and represent 25-35% of total power generation by then, a major change of paradigm for the electricity system in India[1].

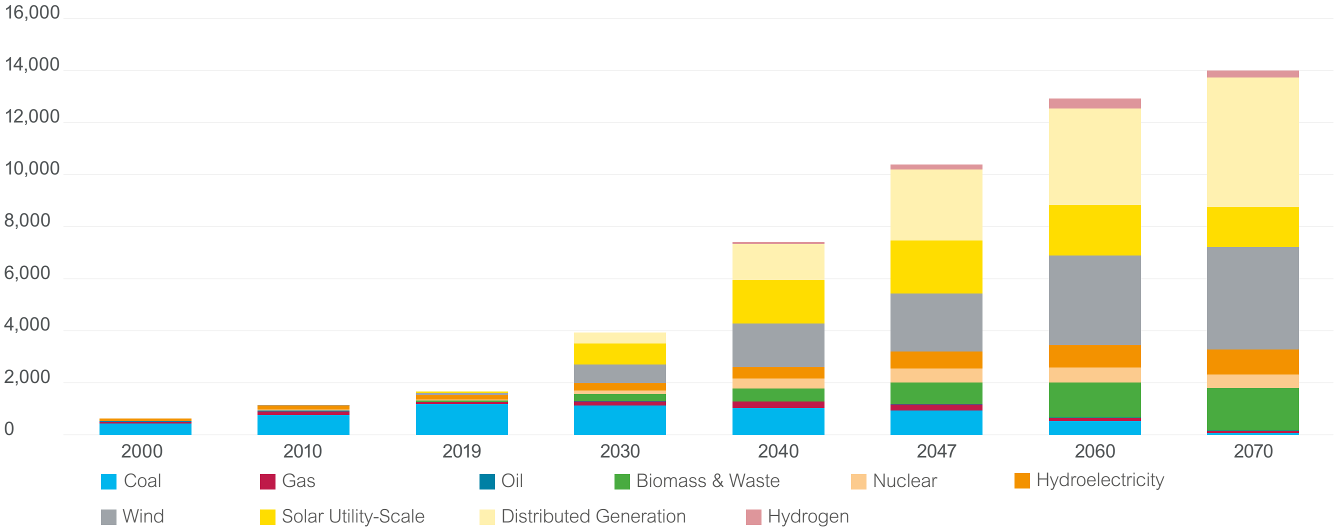
(1) More details available in annex.

Figure 22 – Power generation

Electricity generation (TWh) – 2070 Net Zero



Electricity generation (TWh) – 2047 Net Zero



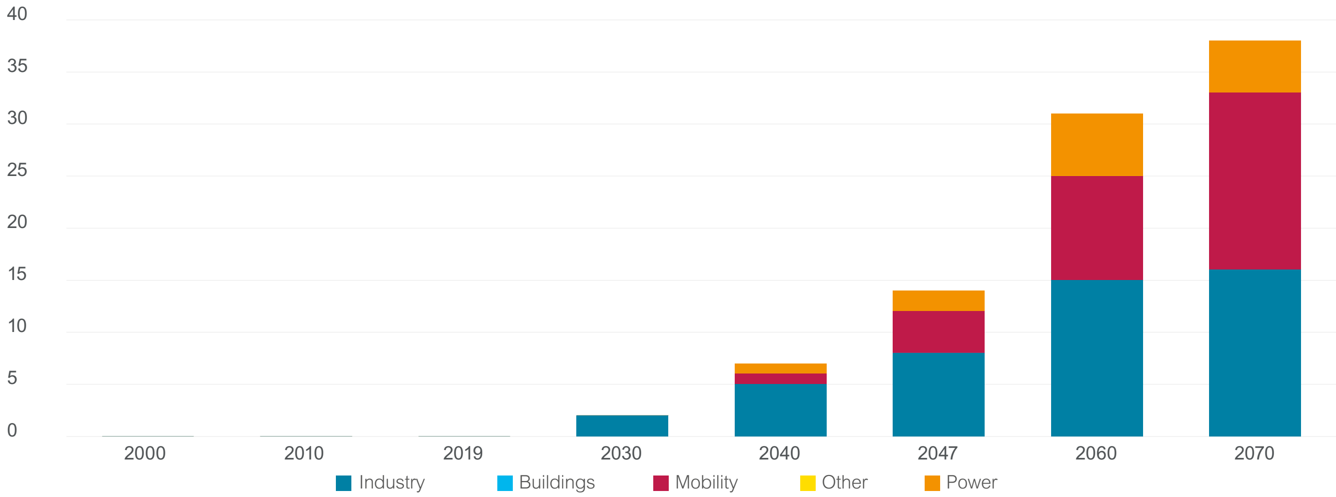
Finding 8: focused hydrogen demand

Hydrogen will play a critical role as well in the overall decarbonization agenda of India. Figure 23 projects additional demand for hydrogen in end-use sectors and power generation.

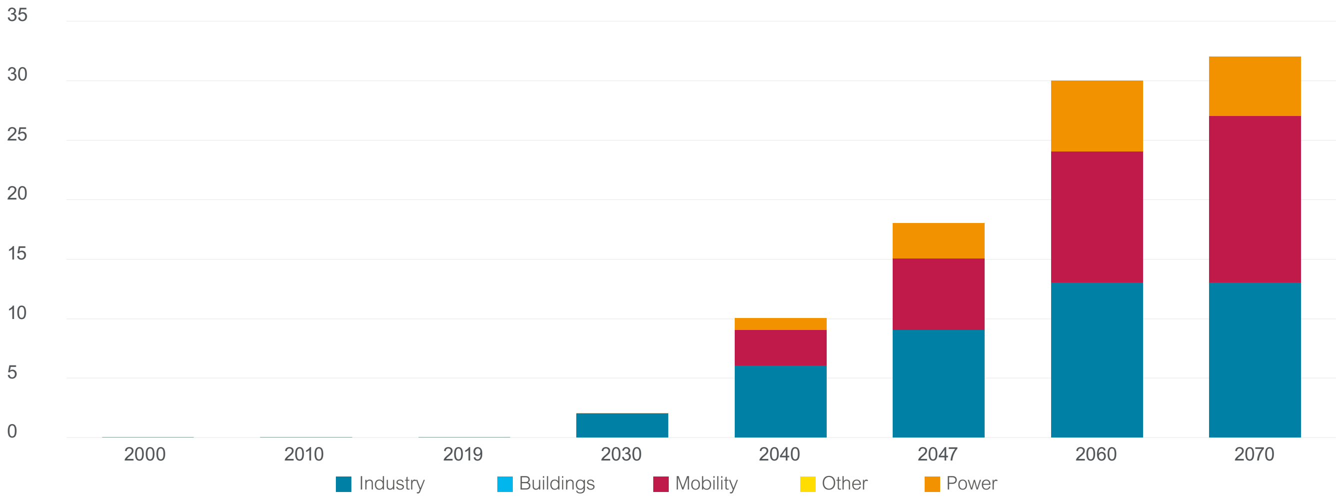
- Overall, this additional demand increases to 15-20Mton/y by mid-century, all the way up to 30-35Mton/y by 2070.
- This additional demand is concentrated in 3 key sectors
  - Industry represents the bulk of the demand in the early phase (post-2030), while mobility and power generation pick up post-2040.
  - In industry, the demand for hydrogen essentially revolves around new capacities of steel production, which are for the most part based on direct reduction of iron ore.
  - In mobility, the demand for hydrogen essentially comes from alternative hydrogen-based fuels growingly used in aviation and shipping (e.g., e-kerosene, ammonia, etc.).
  - While the demand for hydrogen in power generation is significant, the actual contribution to the overall electricity mix is however modest (Figure 21). This reflects both the role of hydrogen-based gas turbines as a balancing option for intermittent renewable energies (a utility-scale storage solution), as well as the very low efficiency levels of power-to-gas-to-power conversions.
- What this analysis suggests is also a specific form of development for the hydrogen infrastructure. In these scenarios, most of hydrogen is being produced in (dedicated) petrochemical facilities, where it is either converted into other fuels or transported to non-distant infrastructure such as steel and power generation facilities, where it could be stored. In fact, the production of hydrogen could also directly happen at (or close to) those sites where it is intended to be used.

Figure 23 – Hydrogen demand

Additional hydrogen demand (Mt/y) – 2070 Net Zero



Additional hydrogen demand (Mt/y) – 2047 Net Zero

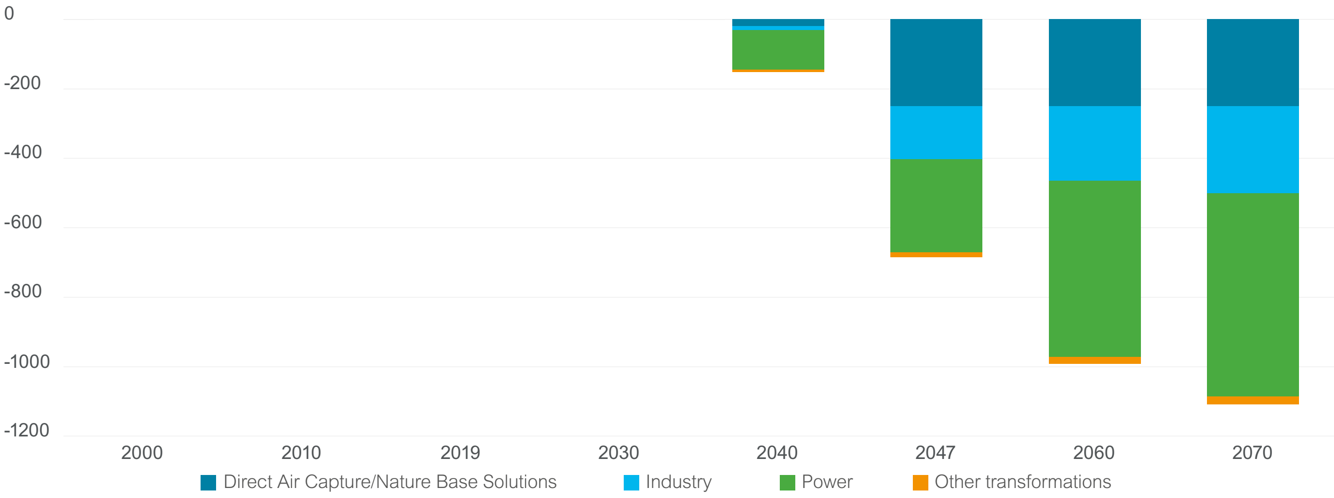


Finding 9: faster decarbonization limits the need for negative emissions in the future

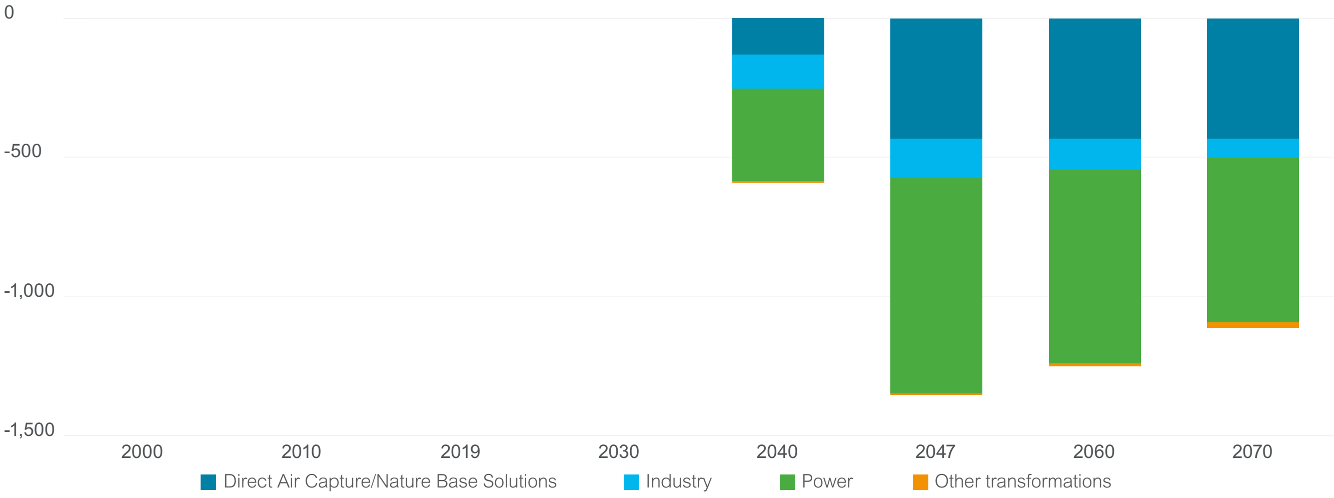
Despite all these transformations, emissions will continue to be high late in the century (Figure 7). In both our scenarios, there is thus a need to develop a strategy around negative emissions. These negative emissions will need to range between 700-1,300MtCO_2e/y by mid-century. The bulk of these negative emissions will apply on existing power generation (coal), with the remaining share on industry (mainly cement). To meet net zero targets by 2070, the volume of negative emissions should increase to 1,100MtCO_2e/y in *2070 Net Zero*. It would stabilize in *2047 Net Zero* at around the same level (Figure 24).

Figure 24 – Negative emissions

Negative emissions – 2070 Net Zero



Negative emissions – 2047 Net Zero



7 What to take away

Nine findings on the future of India's energy system

This exploration provides a number of interesting findings that may contribute to the global discussion on the future of India's energy system. We summarize them here.

1. India faces a major opportunity to build a thriving, resilient, and sustainable economy

By mid-century, final energy demand will double. Most of new infrastructure, facilities, and buildings will be erected in the coming decades. This represents a major opportunity for India to build a system which takes stock of the significant technology advancements of the last decades, and bypass late 20th century options. This is important for at least two reasons:

- A modern infrastructure will provide economic benefits long in the future, whereas an economy that relies on fossil fuels will necessarily face the inevitable instabilities on world's fossil resources from the global decarbonization effort.
- The lifetime of infrastructure spans several decades. In the race to decarbonize the entire economy by 2070, the economic investment needed post-2047 would thus be of momentous proportions if not scheduled ahead and integrated already in today's developments.

The difference between our two scenarios mainly revolves around the pace of such unfolding. In the *2070 Net Zero* scenario, existing infrastructure is decommissioned at end of life (by mid-century), whereas in the *2047 Net Zero* scenario, such decommissioning happens earlier.

2. Energy independence and decarbonization come together

Our modeling work suggests that a single focus on energy independence by 2047 does not actually suffice to meet this goal. Decarbonization of the economy (as presented in our *2047 Net Zero* scenario) contributes to a further acceleration of the phasing out of fossil fuels (notably oil and natural gas) from the economy.

3. India's emissions to peak in the 2030s

Across both scenarios presented, emissions of India peak during the 2030s. In the *2070 Net Zero* scenario, this peak occurs in the late 2030s. In the *2047 Net Zero* scenario, more ambitious on this front, emissions peak by 2030. Though ambitious, we confirm the latter objective is more feasible than what we may think.

4. Living environments will undergo profound changes that will significantly impact the energy system

Energy demand in buildings will double by mid-century. This is, in part, due to the three times increase in building stock. Yet, more importantly, this is also related to the massive rise of new energy services within buildings. While the bulk of energy demand today revolves around cooking, the share of this service will decline significantly by mid-century, thanks to traditional biomass substitution to modern forms of energy. More importantly, however, the bulk of the growth will come from the rapid penetration of new services – cooling, and appliances – which will stem from rapid economic development. As these new services are by nature provided by electricity, the rise of electricity demand will be significant.

5. Radical choices on urban mobility ahead

As India's economy develops and urbanization accelerates, so will its need for mobility services. The question, however, will be the form that these services will take. Our two scenarios suggest different possible futures: one that builds on the classical pattern of individual mobility, a major issue for rapidly growing cities; and an alternative one that favors public transportation, as-a-service mobility models and connected lifestyles, increasingly efficient as they leverage modern technologies (e.g., digital). Unsurprisingly, the latter significantly mitigates the rise in energy demand while accelerating the switch away from fossil fuels.

6. The heart of industrial development and decarbonization will revolve around manufacturing

While a key focus in decarbonization studies often revolves around hard to abate sectors such as steel, cement and petrochemicals, a key finding of this study is that the bulk of industrial energy demand growth will come from manufacturing activities (easier to abate sectors). This is, in part, related to our assumptions that both the construction and automotive industries are poised to see significant changes going forward (thanks to new technologies), mitigating the overall demand for steel and cement to lower levels than often anticipated. The key question then will be the form that such industrial development will take. There is a significant opportunity to build a modern industrial footprint that leverages most recent technologies. The difference between our two scenarios, as for other sectors, revolves around the accelerated modernization of existing facilities, or simply focusing on building out a new footprint over time.

7. The major opportunity and challenge of electrifying India

In both scenarios, power generation increases six times by mid-century, what constitutes a massive undertaking. This is a similar increase than the one observed in China between 2000 and 2019[(1)]. Around 55% of this electricity demand will come from buildings, 30% from industry, 10% from mobility and 5% from other sectors. If we consider that the bulk of mobility-related electricity demand will in fact materialize within buildings (EV charging), then buildings account overall for 2/3rd of the total increase.

Concurrent to this, a massive opportunity exists for more distributed generation. Our modeling suggests that distributed generation could represent 20-25% of total electricity demand by 2047 (a conservative estimate with regard to the overall potential[(2)]), a major enabler of such transformation.

More broadly, the power generation mix will need to evolve. While current capacities (notably coal) will not be decommissioned given the pressure on infrastructure, the bulk of new capacities deployed will come from renewable. Solar energy could notably represent 50% of total increase in electricity generation by mid-century.

(1) ©OECD/IEA, 2017 and ©OECD/IEA, 2021.
(2) See annex for more details.

8. Hydrogen will play a key role in decarbonization post-2040, in very specific sectors

Hydrogen demand will increase to 15-20Mton/y by 2047 and 30-35Mton/y by 2070. This supply will, for the most part, be used in steel production facilities, in power generation for balancing purposes, and used to manufacture e-fuels (e.g., synthetic kerosene, ammonia) for aviation and shipping. Our model thus suggests a relatively concentrated role for hydrogen use, centered around key infrastructure and facilities, with production close to consumption centers, in “industrial clusters”.

9. Decarbonizing the Indian economy will require to rely on negative emissions

The pace of decarbonization of the Indian economy will necessarily lead to the development of negative emissions options, notably for power generation (coal) and industry (cement). The effort will be higher in the *2047 Net Zero* scenario by mid-century to reach carbon neutrality, while it is delayed in the *2070 Net Zero* scenario. An interesting finding, however, is that the level of effort overall is relatively similar across both scenarios ultimately. The challenge of decarbonizing more rapidly thus does not entail massive additional costs in the *2047 Net Zero*, particularly as residual emissions decrease more rapidly.

A modern, resilient and sustainable economy

Figure 25 expands on Figure 1 presented earlier and provides a view on the evolution of the Indian economy (as it relates to energy), from 2000 to 2070, and how this compares to today’s European economy, selected as an example.

GDP per capita converges progressively toward European levels, as should be expected. Similarly, building floor area and mobility services per capita also converge, an indication of the significant rise in wealth of the Indian people.
We however observe a fundamental (relative) decoupling between economic and social indicators on the one hand and energy indicators on the other hand. This is due to two major effects

- The adoption of most recent technologies in the course of industrial and infrastructure development in India, which enables to reach optimized energy intensity levels, often twice lower than current ones in Europe. In this regard, electrification, particularly distributed generation, plays a fundamental role.
- The adoption of modern forms of consumption (e.g., mobility as a service), enabled by modern technologies (e.g., digital), which transform the economy of India away from the current paradigm that prevails in mature economies, thereby limiting the subsequent rise in energy demand.

The key conclusion here is that it is very unlikely that the Indian economy, as it develops throughout the 21st century, resembles that of mature economies which face the different challenge of decommissioning their mature infrastructure and changing their currently highly unsustainable consumption patterns.

Figure 25 – What to expect in the coming decade

What to expect in the coming decades	India			EU
	2000	2010	2019	2018
Macroeconomic indicators				
GDP (G$$_{2015}$ ppp)	2,725	5,227	9,220	19,950
Population (M)	1,057	1,234	1,366	512
Final energy demand				
GDP / Cap ($GDP/cap)	2,579	4,235	6,747	38,965
Energy / Cap (GJ/cap)	13	17	21	85
Energy / $GDP (kJ/$GDP)	4,945	3,978	3,077	2,180
Share of coal or biomass in final energy demand	57%	55%	46%	11%
Industry				
Industry energy demand / Cap (MJ/cap)	3,429	5,510	7,758	27,005
Share of steel and minerals energy demand vs total of industry (%)	36%	38%	40%	
Share of coal or biomass in final energy demand	65%	73%	69%	19%
Steel				
Steel production / Cap (kg /cap)	25	56	81	313
Energy Intensity (GJ / ton, including scrap)	28	27	30	
Non-metallic minerals				
Cement production / Cap (kg/cap)	93	173	271	352
Energy Intensity nonmetallic minerals (MJ/ton)	5,545	3,439	2,343	
Buildings Residential				
Square meters / Cap (sqm/cap)	8	9	11	41
Energy Intensity (MJ/m^2)	743	696	499	540
Residential energy demand / Cap (GJ/cap)	6	6	6	
Appliances energy demand / Cap (MJ/cap)	334	517	637	
Cooling energy demand / Cap (MJ/cap)	16	58	202	
Share of coal or biomass in final energy demand	85%	80%	67%	20%
Services				
Square meters / Cap (sqm/cap)	1	1	2	17
Energy Intensity (MJ/m^2)	494	754	790	900
Services energy demand / Cap (MJ/cap)	601	1,082	1,341	
Appliances energy demand / Cap (MJ/cap)	207	485	355	
Cooling energy demand / Cap (MJ/cap)	53	132	161	
Share of coal or biomass in final energy demand	54%	37%	39%	2%
Mobility				
Total road pkm / Cap (pkm/cap)	1,676	2,263	3,058	11,039
Cars and Motorcycles pkm / Cap (pkm/cap)	133	385	916	9,254
Transport energy demand / Cap (MJ/cap)	1,358	2,353	3,463	
Road Transport energy demand / Cap (MJ/cap)	1,126	1,973	2,960	

What to expect in the coming decades	2070 Net Zero					2047 Net Zero				
	2030	2040	2047	2060	2070	2030	2040	2047	2060	2070
Macroeconomic indicators										
GDP (G$$_{2015}$ ppp)	17264	28235	36813	51665	60177	17264	28235	36813	51665	60177
Population (M)	1504	1593	1629	1670	1701	1504	1593	1629	1670	1701
Final energy demand										
GDP / Cap ($GDP/cap)	11,482	17,728	22,597	30,943	35,383	11,482	17,728	22,597	30,943	35,383
Energy / Cap (GJ/cap)	26	31	35	37	35	24	26	28	29	30
Energy / $GDP (kJ/$GDP)	2,227	1,736	1,567	1,181	1,001	2,063	1,441	1,228	946	843
Share of coal or biomass in final energy demand	37%	32%	28%	19%	13%	39%	28%	20%	12%	9%
Industry										
Industry energy demand / Cap (MJ/cap)	10,393	13,103	14,392	14,471	13,130	9,866	10,997	10,984	11,586	11,202
Share of steel and minerals energy demand vs total of industry (%)	35%	36%	35%	34%	32%	34%	34%	32%	30%	28%
Share of coal or biomass in final energy demand	64%	60%	53%	35%	21%	60%	39%	26%	11%	6%
Steel										
Steel production / Cap (kg /cap)	112	174	203	230	204	117	149	156	187	178
Energy Intensity (GJ / ton, including scrap)	25	21	20	18	16	22	19	18	14	13
Non-metallic minerals										
Cement production / Cap (kg/cap)	400	535	538	525	501	366	413	415	427	424
Energy Intensity nonmetallic minerals (MJ/ton)	2,260	2,043	1,834	1,823	1,843	2,394	2,023	1,828	1,831	1,879
Buildings Residential										
Square meters / Cap (sqm/cap)	19	24	28	33	34	19	24	29	33	34
Energy Intensity (MJ/m^2)	327	283	312	272	252	298	232	238	208	201
Residential energy demand / Cap (GJ/cap)	6	7	9	9	9	6	6	7	7	7
Appliances energy demand / Cap (MJ/cap)	901	1,010	1,048	1,045	975	864	982	1,029	1,034	983
Cooling energy demand / Cap (MJ/cap)	1,211	2,558	4,697	5,369	5,455	1,023	1,852	3,595	3,835	4,164
Share of coal or biomass in final energy demand	33%	16%	8%	4%	2%	44%	32%	18%	10%	7%
Services										
Square meters / Cap (sqm/cap)	3	5	6	8	8	3	5	6	8	8
Energy Intensity (MJ/m^2)	738	673	628	544	479	672	594	555	487	443
Services energy demand / Cap (MJ/cap)	2,140	3,125	3,981	4,253	4,027	1,950	2,757	3,523	3,808	3,726
Appliances energy demand / Cap (MJ/cap)	594	807	944	1,115	1,121	564	776	919	1,099	1,134
Cooling energy demand / Cap (MJ/cap)	510	1,211	1,957	2,137	1,974	466	1,064	1,742	1,939	1,880
Share of coal or biomass in final energy demand	20%	9%	4%	2%	2%	19%	7%	4%	4%	4%
Mobility										
Total road pkm / Cap (pkm/cap)	3,578	5,174	6,649	8,595	9,716	3,559	5,025	6,313	8,522	9,540
Cars and Motorcycles pkm / Cap (pkm/cap)	1,301	2,353	3,652	4,579	4,904	1,188	1,806	2,379	2,787	3,110
Transport energy demand / Cap (MJ/cap)	4,122	4,937	5,597	6,380	7,221	3,835	3,771	3,872	4,726	5,702
Road Transport energy demand / Cap (MJ/cap)	3,442	3,801	3,999	4,031	4,188	3,209	2,710	2,343	2,289	2,522

What was left unattended, and what should be discussed further

Scenarios are thought experiments, not predictions. They are built to test assumptions and analyze their impact on aggregated systems, such as energy. This exercise does not depart from others in this regard. What our scenarios have tested, and what hopefully constitutes a meaningful contribution to the debate, are key consumption pattern changes stemming from the rapid deployment of new technologies in the rapidly growing Indian economy. Naturally, such type of exercise thus come with its lot of uncertainties, and we summarize in this chapter some of the key assumptions that could be challenged in further exercises.

We identify five main avenues for further research.

1. A deeper focus is needed on the construction industry

A key finding of this report is the systemic role of the construction industry in the overall energy transition. Despite consuming a fraction of final energy by itself, the construction industry uses significant shares of materials of all sorts (cement, steel, metals, plastics, etc.). Its development is also directly related to economic development, as urbanization and wealth are both powerful drivers of construction activities.

In our scenarios, we also took key assumptions in terms of the evolution of the building stock, on top of traditional economic activity indicators (e.g., population, GDP). We notably assessed the impact of more connected lifestyles on the development of the stock (e.g., home office, online shopping and entertainment, etc.). These assumptions mostly impact service buildings, and we assumed no impact on the residential stock at this stage[(1)] (e.g., rebound effects).

We have assumed as well a significant improvement of construction techniques in the coming decades, powered by new technologies. While there is a lot of evidence on such unfolding[(2)], the construction industry remains a heavily-regulated and fragmented sector of a multitude of small and medium enterprises (SMEs). The extent and the pace of such change could thus be questioned and further researched. This is all the more critical as this has a significant impact on the overall evolution of the demand for steel and cement, and at large defines the future evolution of these sectors (even though, for steel, the evolution of the automotive industry and mobility needs also play a non-negligible role).

2. More research on specific consumption pattern evolutions could bring new insights

The evolution of final energy demand in India stems from major consumption pattern changes. Yet, some show more impact than others. We retain here three for which further research could complement our analysis.

- Air conditioning: as discussed in the buildings chapter, air conditioning penetration is a key game changer for India's energy system. The extent and the pace of its development are thus highly prey for question. We have differentiated our forecasts between rural and urban areas, but overall assumed a progressive penetration of air conditioning across the stock. Our estimates could possibly be challenged, both upward and downward. As well, we have taken key assumptions in terms of efficiency gains over time (differentiated between the two scenarios), and those could be further discussed, particularly over time given the magnitude of the market evolution, hence opportunity for innovation.
- Our modeling has favored alternative modes of transportation to individual car use, in both scenarios, taking stock of key issues associated with rapid urbanization as well as technology development. We have also assumed specific rates of penetration of EVs within the stock. Such an evolution could however vary, depending, for instance, on a rush toward individual car ownership and/or a stronger reliance on secondhand markets for cars, which could delay the switch to EVs by a decade or more.
- Industrial manufacturing, as discussed, plays a major role in the way industrial energy demand shapes up. We have not provided extended datasets for this sector (outside of some specific considerations on automotive and machinery), and this could be the object of further publications. Notably, the size of the automotive sector is highly dependent on the demand for private mobility services, and our scenarios tend to forecast a milder growth than often anticipated. As well, we have taken key assumptions in terms of circularity development for consumer goods, and these assumptions could also be further challenged, both upward (more circularity than modeled) and downward (less than modeled). All these assumptions may have a significant impact on the overall evolution of demand for manufacturing, hence energy.

3. What role for biomass in the future energy system?

Our modeling suggests a doubling of biomass and waste supply (primary energy) by mid-century. Biomass demand for final energy uses actually stabilizes by mid-century, and is in fact combined with a progressive substitution of traditional biomass for cooking to alternative forms of energy. However, supply to power generation increases significantly at the same time in our scenarios. This level of growth implies that a new sustainable biomass and waste industry would scale up. Such an implicit assumption, despite a clear outcome of our model, could be revisited, particularly in light of critical dependability issues, arbitrages between agriculture and bioenergy production, and the effects of climate change on agricultural yields.

We have also not reviewed in detail the agriculture sector, and excluded forestry and land management, despite their significant value in today's Indian economy. These could be the object of further research.

(1) This could be challenged in further research.
(2) Schneider Electric, 2021.

4. More research is needed on the role for and the type of negative emissions

Clearly, negative emissions appear to be mandatory across both scenarios to reach a net-zero economy by 2047 or 2070. They do not significantly vary in volume terms by 2070. The ramp up of negative emissions solutions is expected to materialize in the late 2030s and ramp up all the way to 2070. A key question will be the pace at which these come online. The type of negative emissions employed is also highly dependent on where emissions continue to exist in the energy system. Our model works like this: once emissions are reduced, CCS is deployed on remaining facilities to reach acceptable emission levels, and other nature-based solutions (NBS) or technologies such as Direct Air Capture (DAC) are further implemented. The approach could be different, privileging for instance NBS as way forward (and possibly faster). This would require however to analyze more specifically what potential exists in India, an avenue of research which strongly echoes that of (3) on biomass.

5. We are far from having seen it all

As explained in the introduction, such a prospective effort on new technologies and how they can reshape energy demand cannot be considered exhaustive. More research is thus needed to further refine the landscape of innovations, and their potential for unfolding. Notably, there are few elements that we have voluntarily left unattended at this stage, around specific decarbonization technologies in hard to abate industrial sectors, and that could play a more critical role going forward. These include alternative process technologies in steel (e.g., electro-winning), cement (e.g., low-clinker), and chemicals (e.g., new material designs, leading to material substitutions across a vast array of industries). As well, we have not considered how the combination of access to a plentiful electricity resource alongside new forms of energy storage (e.g., high temperature heat storage) could transform existing industrial facilities. In a sector like cement, for instance, relying on such an infrastructure could, in theory, help remove fossil fuel consumption entirely. Such developments being however at prototype stage (low Technology Readiness Level – TRL), they were not integrated in our analysis at this stage[1].

The coming decade

In the last 20 years, the Indian economy has significantly evolved and its development massively accelerated. The road ahead remains fascinating, however, and the next decades will see India reaching among the largest and most modern economies of the world.

Given its size, the choices that India makes today will also profoundly influence the shape of some of the world's most pressing challenges, particularly that of climate change. The positive side of this argument is that these choices are yet to be made. The development prospects ahead are such that they represent a one-in-a-century opportunity to build an entirely new pathway to economic wealth, one that breaks away with the 20th century paradigm of dependence on fossil fuels.

Consider this: by 2030, across both scenarios presented in this report:

- Electricity demand would double.
- 15 billion square meters would be added to the stock.
- Air conditioning penetration would triple in residential.
- Passenger-kilometers traveled by cars would triple, and double by rail.
- 25% of sales could be EVs by this time.
- Industrial output would increase 1.5 times (steel, non-metallic minerals, manufacturing).
- And peak emissions could be in sight.

The key finding of this report is that achieving such a feat is probably more feasible than we may think. Carefully targeted policies on key leverage points within the economy could substantially accelerate all agendas at hand: economic development, energy independence, and decarbonization. In this regard, the 2047 milestone set by the government of India represents a realistic timeline, as well as a highly symbolic milestone. Yet, a lot needs to happen within the coming decade. In 2022, India climbed to the 5th place in terms of global GDP, and will "overtake China as the most populated country of the world" in 2023[2].

(1) Such innovations could also significantly challenge, among other things, the emerging role of gas toward mid-century in certain sectors, such as building and cement, for instance. They could also challenge the need for hydrogen as a balancing solution for the power system, at least in part.

(2) Hindustan Times, 2022 Murthy, 2023.

8 Annex

Evolution of carbon intensity over the last 20 years globally

We retrieved the data on final energy demand per key sector, electricity generation and carbon emissions (per sector) from 2000 to 2019, which we combined for selected regions of the world in order to provide a perspective of the evolution of carbon intensity of the global energy system[(1)]. Figure 26-28 shows these evolutions. In a nutshell

- Emissions have strongly increased from 2000 to 2010 (around 3% per year) and then slowed down (around 1% per year). The dynamics of growth in energy demand follow a similar pattern (and in fact GDP as well).
- The carbon intensity has declined for power generation across all geographies. Yet, it has stagnated at global level for final energy demand, and has even increased in India and the United States, a sign of limited transition on the demand side.

Figure 26 – Evolution of final energy demand

		Energy (TWh/y)							
Country		Industry	Mobility	Building	Power Total	Power Industry	Power Mobility	Power Building	Total
US	2000	2,768	6,838	2,989	3,501	1,140	0	2,349	**17,980**
	2010	3,556	6,924	2,777	3,792	830	6	2,917	**17,715**
	2019	3,266	7,405	2,868	3,834	754	14	2,992	**18,585**
EU	2000	2,547	3,454	3,582	2,524	1,058	70	1,361	**13,724**
	2010	3,082	3,190	3,401	2,513	928	56	1,481	**12,743**
	2019	2,904	3,309	2,822	2,487	938	59	1,437	**12,092**
China	2000	2,838	1,047	3,373	1,070	698	12	302	**9,199**
	2010	11,309	2,253	3,409	3,493	2,366	65	920	**21,158**
	2019	11,986	3,632	3,767	6,568	3,923	166	2,189	**26,837**
India	2000	802	361	1,710	372	163	12	128	**3,663**
	2010	1,866	740	2,165	718	320	13	258	**5,688**
	2019	2,423	1,202	2,024	1,325	547	19	530	**7,447**
Africa	2000	488	593	2,617	361	174	12	174	**4,292**
	2010	908	1,008	3,035	542	238	5	281	**5,662**
	2019	849	1,378	3,769	663	261	6	372	**6,919**
World	**2000**	**16,340**	**22,551**	**21,737**	**12,700**	**5,373**	**221**	**6,769**	**81,864**
	2010	**33,361**	**27,945**	**23,139**	**17,917**	**7,445**	**306**	**9,611**	**106,251**
	2019	**34,500**	**33,167**	**23,778**	**22,889**	**9,556**	**417**	**12,000**	**120,251**

Figure 27 – Evolution of CO_2 emissions

		CO_2 emissions ($MtCO_2/y$)							
Country		Industry	Mobility	Building	Power Total	Power Industry	Power Mobility	Power Building	Total
US	2000	500	1,682	511	2,433	792	0	1,633	**5,602**
	2010	561	1,680	545	2,329	510	4	1,792	**5,418**
	2019	545	1,757	551	1,682	331	6	1,313	**4,826**
EU	2000	509	889	556	1,379	578	38	744	**3,758**
	2010	566	794	549	1,154	426	26	680	**3,236**
	2019	528	814	425	811	306	19	468	**2,744**
China	2000	998	258	407	1,449	945	16	410	**3,127**
	2010	3,858	575	479	3,486	2,361	65	919	**8,766**
	2019	4,100	910	499	5,242	3,131	132	1,747	**11,198**
India	2000	226	95	103	459	201	14	158	**890**
	2010	511	193	135	785	350	15	282	**1,683**
	2019	742	308	158	1,172	484	17	469	**2,475**
Africa	2000	127	149	67	299	145	10	145	**659**
	2010	220	260	79	419	184	4	217	**1,109**
	2019	260	355	117	501	197	4	281	**1,370**
World	**2000**	**4,359**	**5,589**	**2,516**	**9,243**	**3,911**	**161**	**4,926**	**23,013**
	2010	**8,191**	**7,010**	**2,891**	**12,380**	**5,144**	**211**	**6,641**	**32,345**
	2019	**8,876**	**8,211**	**2,941**	**13,933**	**5,817**	**254**	**7,305**	**35,966**

(1) ©OECD/IEA, 2017, 2021.

Figure 28 – Evolution of carbon intensity

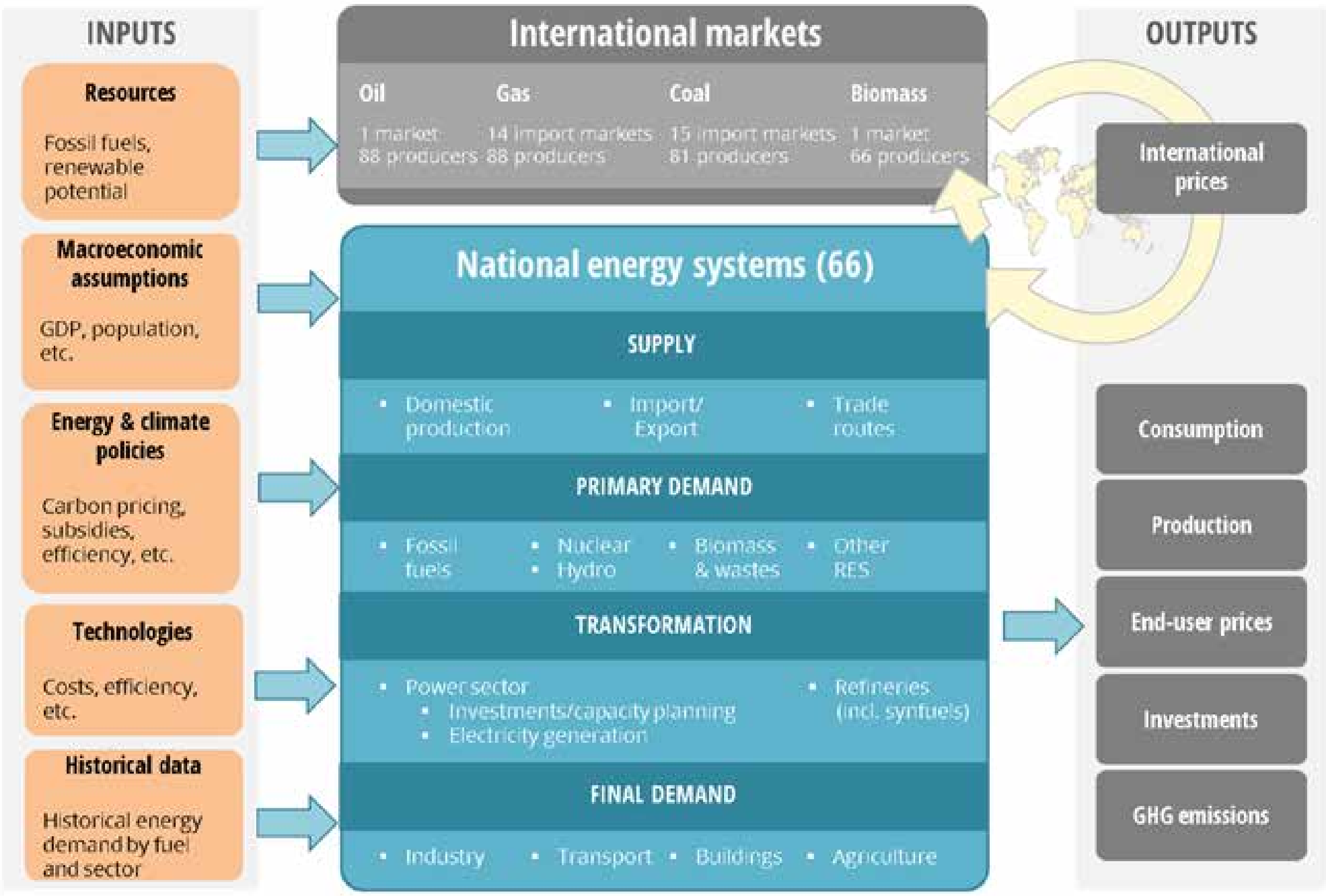
		gCO₂/kWh							
Country		Industry	Mobility	Building	Power Total	Power Industry	Power Mobility	Power Building	Total
US	2000	181	246	171	695	695		695	**312**
	2010	158	243	196	614	614	614	614	**306**
	2019	167	237	192	439	439	439	439	**260**
EU	2000	200	257	155	546	546	546	546	**274**
	2010	184	249	161	459	459	459	459	**254**
	2019	182	246	151	326	326	326	326	**227**
China	2000	352	246	121	1,354	1,354	1,354	1,354	**340**
	2010	341	255	141	998	998	998	998	**414**
	2019	342	250	132	798	798	798	798	**417**
India	2000	281	263	60	1,233	1,233	1,233	1,233	**243**
	2010	274	261	62	1,093	1,093	1,093	1,093	**296**
	2019	306	256	78	884	884	884	884	**332**
Africa	2000	260	251	25	829	829	829	829	**154**
	2010	242	258	26	773	773	773	773	**196**
	2019	306	258	31	756	756	756	756	**198**
World	**2000**	**267**	**248**	**116**	**728**	**728**	**728**	**728**	**281**
	2010	**246**	**251**	**125**	**691**	**691**	**691**	**691**	**304**
	2019	**257**	**248**	**124**	**609**	**609**	**609**	**609**	**299**

POLES model and "demand module"

We use Enerdata POLES model to run the scenarios. POLES is a partial equilibrium model, with global coverage, for long-term energy and GHG emissions projections up to 2070 (Figure 29).

- The time horizon is 2070 with an annual resolution.
- The model uses a recursive simulation: all variables are calculated for year t before calculating year t+1. Results from year t impact the calculations in year t+1.
- The modeling of energy demand is a mix of econometric and techno-economic parameters; A more detailed bottom-up approach is used for electricity supply.
- The model is simulated using the Vensim software, a simulation software developed by Ventana systems.

Figure 29 – POLES model overview



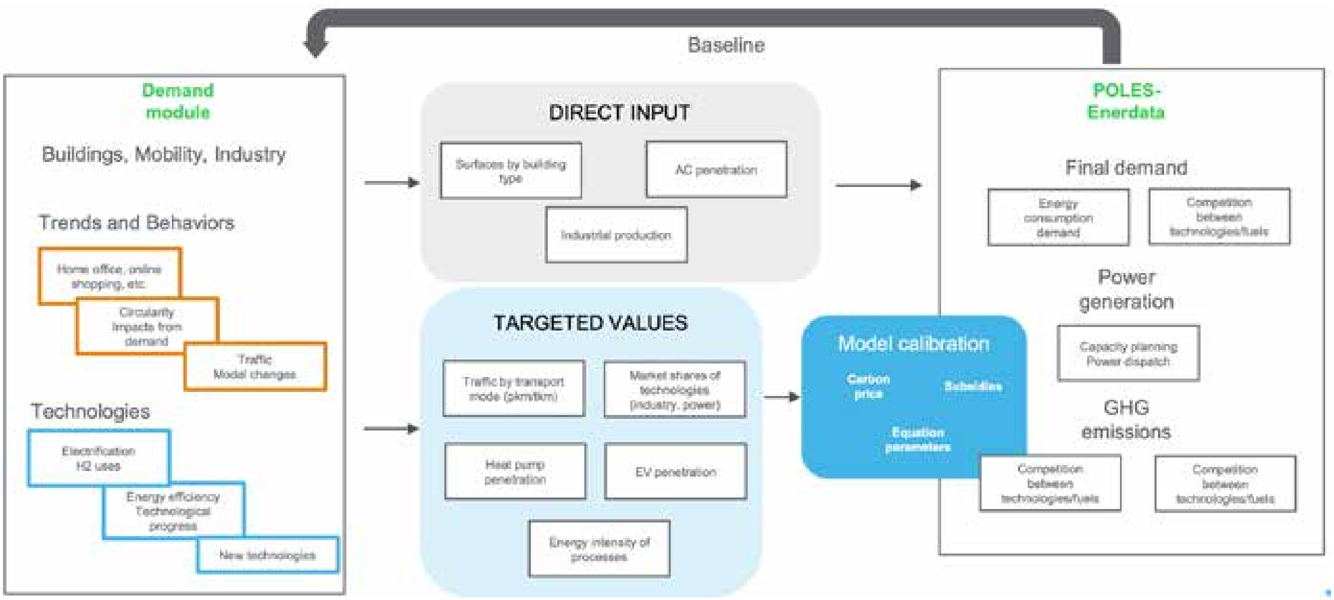
Demand module

As many models, available assumptions on demand offer already a breadth of possibilities, but we added a specific "demand module" to further integrate sophisticated changes to the structure of certain economic activities that current models cannot easily reproduce (Figure 30).

The "demand module" evaluates exogenously the evolution of key parameter trends and reinject them into the core POLES model.

- Some are actually direct inputs already available in POLES.
- Others are not available and thus represent "targeted values" that are ultimately reached in the model's final results thru extensive calibration, leveraging parameters such as carbon prices, subsidies or specific equation parameters.

Figure 30 – POLES model stylized demand module description



Demand module description – Buildings
We have 4 main transformations that we look at: Distributed Generation and Storage; Superior Space Conditioning and Technologies; Virtual Environments; Construction Disruption (Figure 31).

Distributed Generation
This is dealt outside of the model. We leverage a different study from the Schneider Electric™ Sustainability Research Institute on the potential of distributed generation per region[1], assessing suitable roof space across the building stock, and project assumptions on rates of penetration all the way to 2050, considering different rates of economic improvements. In this report, we have also extrapolated these trends to 2070.

Superior Electrification technologies
We look specifically at the rate of penetration of various pieces of equipment, notably heating and cooling systems, but also electric cooking systems (we consider the rate of penetration of other appliances is defined by economic development). Heat pumps could benefit from a policy push, while being naturally driven by increasingly affordable electricity from distributed generation. Air conditioning systems could penetrate the building stock faster than GDP growth suggests (notably given externalities such as climate change). We also include in the model the possible impact of sufficiency, which can have an impact on overall energy demand in buildings, at least in certain geographies.

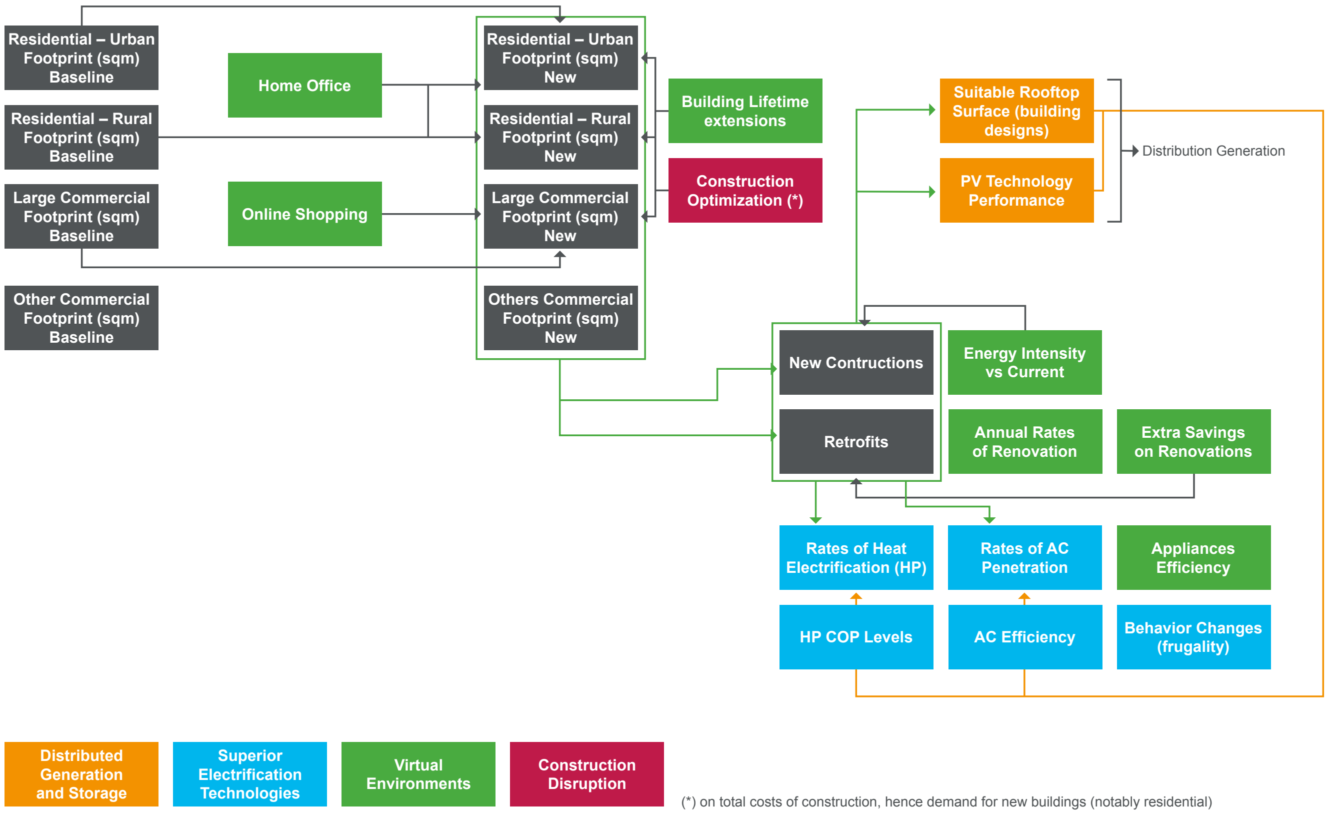
Virtual environments
The growing digitalization of living environments will have three types of impact

- First, we take key assumptions on home office and online shopping penetration and how these could affect the supply of stock across different building types (notably residential, offices and retail centers). This would also have an indirect impact on building lifetime extension and repurposing, further affecting stock evolution.
- Second, digital technologies can provide an important contribution to the optimization of energy intensity of buildings. Therefore, we revisit typical assumptions on building energy intensity optimization (alongside policy-driven renovation programs) to include their impact on energy intensity evolution.
- Third, appliances efficiency will also continue to improve, and in fact, device convergence could also yield extra efficiency gains in this area. We take key assumptions in this regard.

Construction disruption
The significant and positive disruption on the construction sector (driven by digital technologies), enables major productivity gains, notably in the form of designing-out raw materials at a significant scale (steel, cement), while optimizing execution and reducing waste to minimum levels. Doing so, costs of construction decline. It results from this that access to housing becomes more affordable, driving a rebound in residential building demand which, further amplified by lesser needs for commute from digitalization, trends toward new urban forms. Specific assumptions are also taken on the building envelope performance as a result of new construction standards.

(1) Schneider Electric, 2022.

Figure 31 – Demand module, Buildings



(*) on total costs of construction, hence demand for new buildings (notably residential)

Demand module description – Mobility
4 main transformations are looked at: Road transport electrification; Transport as a service and multimodal systems; Autonomous vehicles; New fuels (Figure 32).

Road transport electrification
We look at rates of electrification of private and freight transport for cars, trucks and rail. While the model leverages factors such as GDP and technology learning curves, we also integrate dynamics of consumer adoption. We also integrate in our evaluation the impact of one technology becoming the dominant design rapidly in one sector (e.g., EVs) and its possible networking effect on adjacent services (e.g., further pervading in trucking). The rate of penetration of electric systems in rail is mostly the result of a policy-driven environment.

Transport as a service, multimodal systems, and autonomous vehicles
We look first at passenger kilometers (pkm). In addition to natural rates of growth stemming from wealth and population increase, we also consider the networking effects observed in buildings (home office, etc.), those of a growingly affordable mobility service (with autonomous vehicles), an improvement in terms of multimodal transportation systems, as well as possibly changing appetites in terms of travel (e.g., new travel habits for tourism, carpooling, etc.). We apply a similar approach to freight and tons-kilometers (tkm). What we notably look at is the impact of retail business transformation (online shopping), circularity (e.g., sharing economy), and the rise of distributed manufacturing (local production and consumption of goods) on logistic systems.

Second, we look at vehicle-kilometers (vkm), which also account for the number of vehicles on the road (this does not apply to inland waterways and rail). There, we explore how new technologies and more importantly new consumer behaviors (lesser reliance on a car, unwillingness to own a vehicle, etc.) may further affect projected stocks of vehicles on the road.

New fuels
Last, we consider alternative options in road transport (fuel cells, biofuels) and in aviation and marine transport (fuel cells, biofuels, synthetic fuels). While this is largely driven by the model, its learning curves, and our exogenous assumptions on policies, we also crosscheck biofuels penetration in light of sustainable supply, and revisit fuel cells deployment in light of infrastructure needs, and truly plausible emergence alongside a much larger and fully integrated EV supply chain.

Figure 32 – Demand module, Mobility

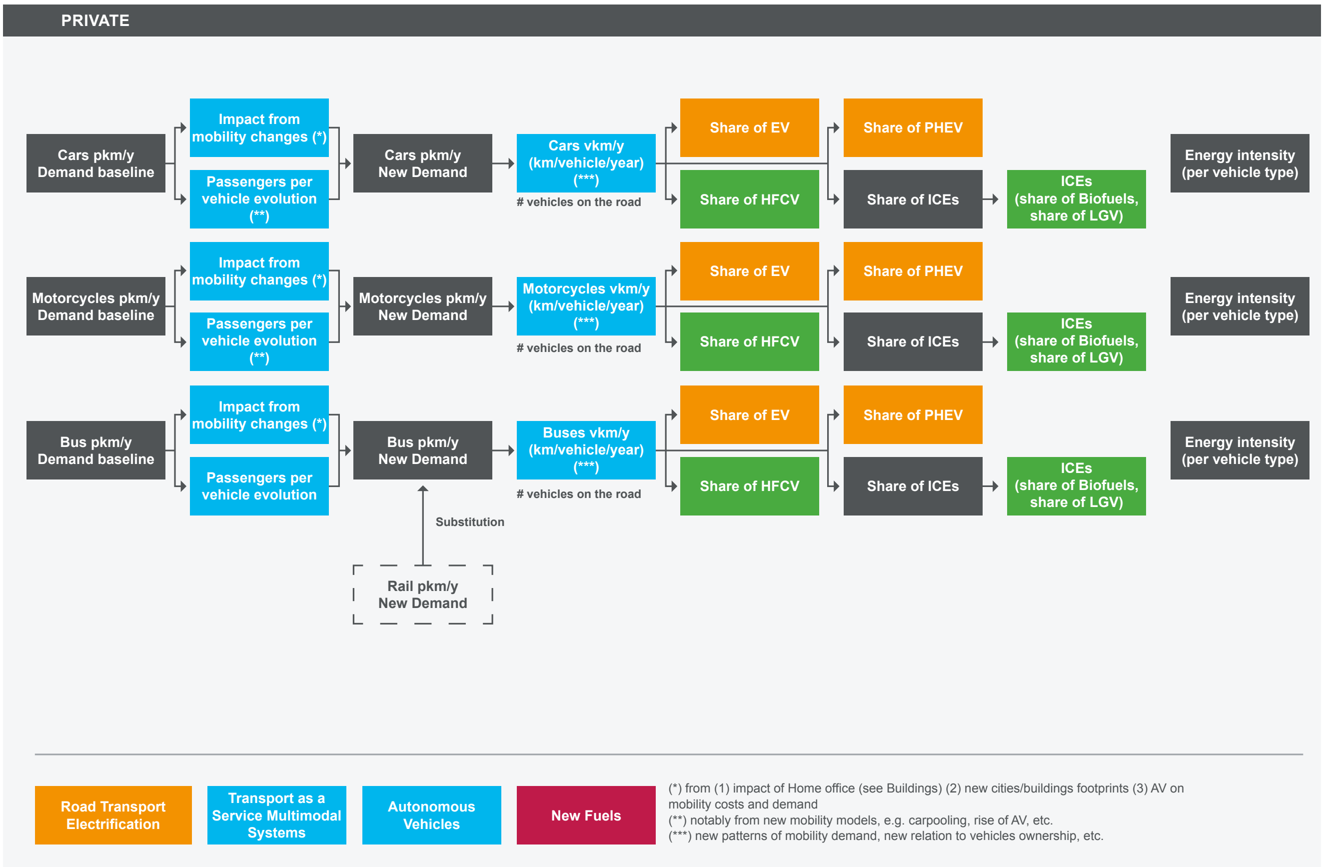
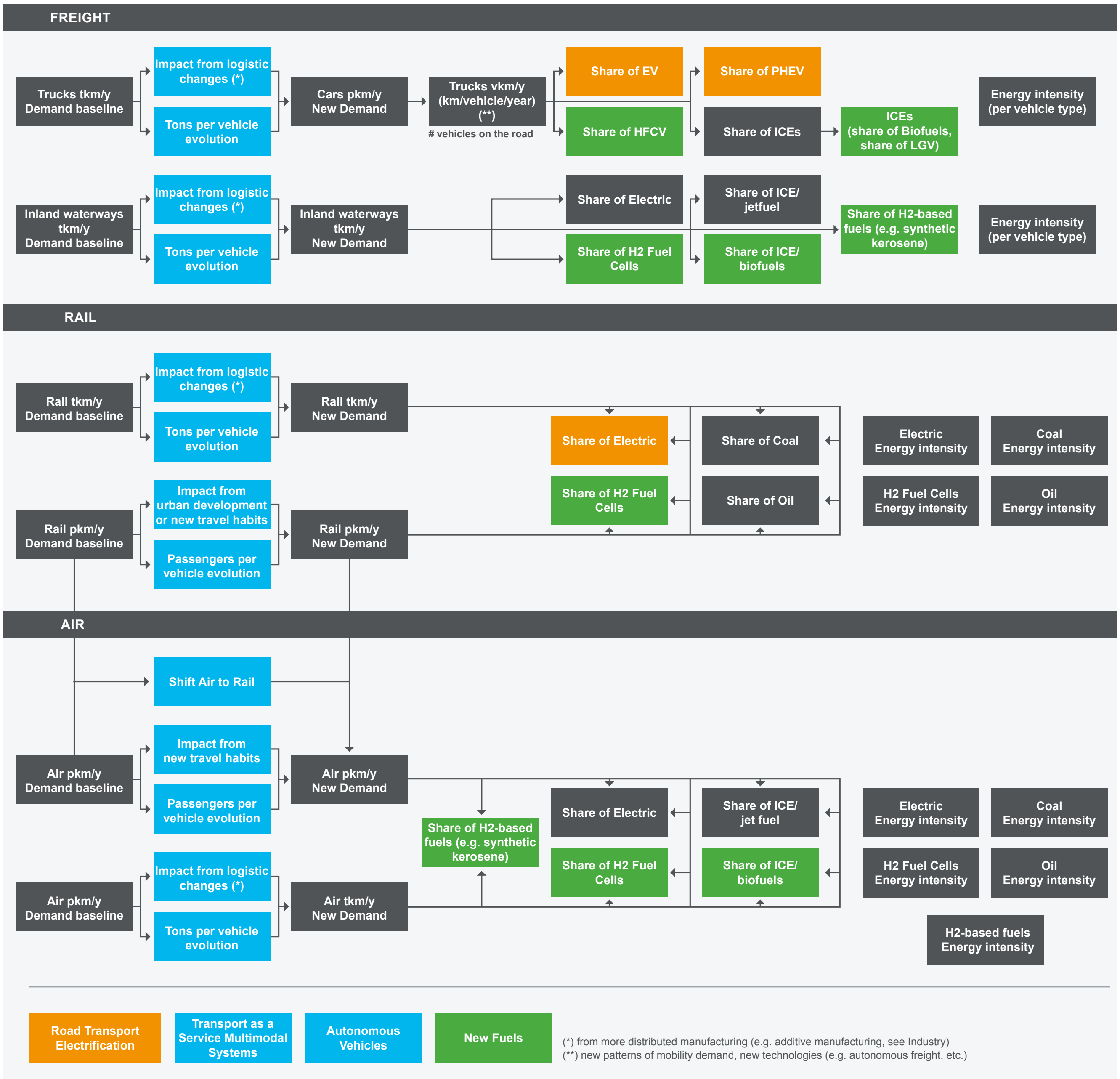


Figure 32 – Demand module, Mobility (continued)



Demand module description – Industry

We look at 4 main transformations: Digitalized industries and best available technologies; New industrial processes; Circularity; Distributed manufacturing (Figure 33).

Digitalized industries and best available technologies
This is mainly covered in the model thru key estimates of further improvements in energy (and carbon) intensity of key industrial processes. We further focus on those by assessing, in ambitious scenarios, to which extent technology disruptions (notably stemming from digital technologies) could further accelerate the convergence toward best levels, but also further improve those closer to thermodynamical limits.

New industrial processes
This mainly concerns processes for steel, cement and chemicals. Beyond policy-driven initiatives, we refine the rate of penetration of alternative processes over time. This has to do, on the one hand, with the actual growth in demand for products (hence subsequent rates of stock turnover, see Circularity), and on the other hand, with the level of technology development. While covered in the model, we carefully calibrate those rates of penetration, considering further technology progress is likely (while penetration may be limited with slow stock turnovers). For steel, we essentially look at H-DRI (Hydrogen Direct Reduction of Iron). For cement, we look at penetration of prefabricated systems in construction, as well as new cement “recipes” (evolutions of clinker-to-cement ratios that can lead to lower carbon intensities). For chemicals, we essentially focus on plastics and the rate of penetration of recycling (both mechanical and chemical).

Circularity
First, we need to account for the multitude of effects stemming from other sectors transformations, namely the building’s footprint evolution, the construction disruption (and its impact on steel and cement demand), and the evolution of mobility services (more or less vehicles, hence different sizing of the automotive industry, thus second order impacts on steel and chemicals – e.g., plastics – demand).

Then, we also consider the possible development of a sharing economy, essentially focused on specific consumer goods, combined with possible cultural evolutions (sufficiency) in certain geographies. These are complemented with the development of second-hand markets across manufacturing sectors, with second-order effects on the demand for steel and chemicals.

Finally, material substitution in cement, and the evolution of policies around packaging (around 40-50% of the demand for plastics) all have an effect on virgin production forecasts.

Combined, these effects on demand also influence the maximum achievable rate of recycling, hence ultimate technology distribution across the steel and chemicals industries.

Distributed manufacturing
Finally, we explore how additive manufacturing makes it way thru a variety of manufacturing sectors (automotive, machinery and consumer goods), and the impact of their relative energy intensity (vs conventional production systems) on overall energy demand.

Figure 33 – Demand module, Industry

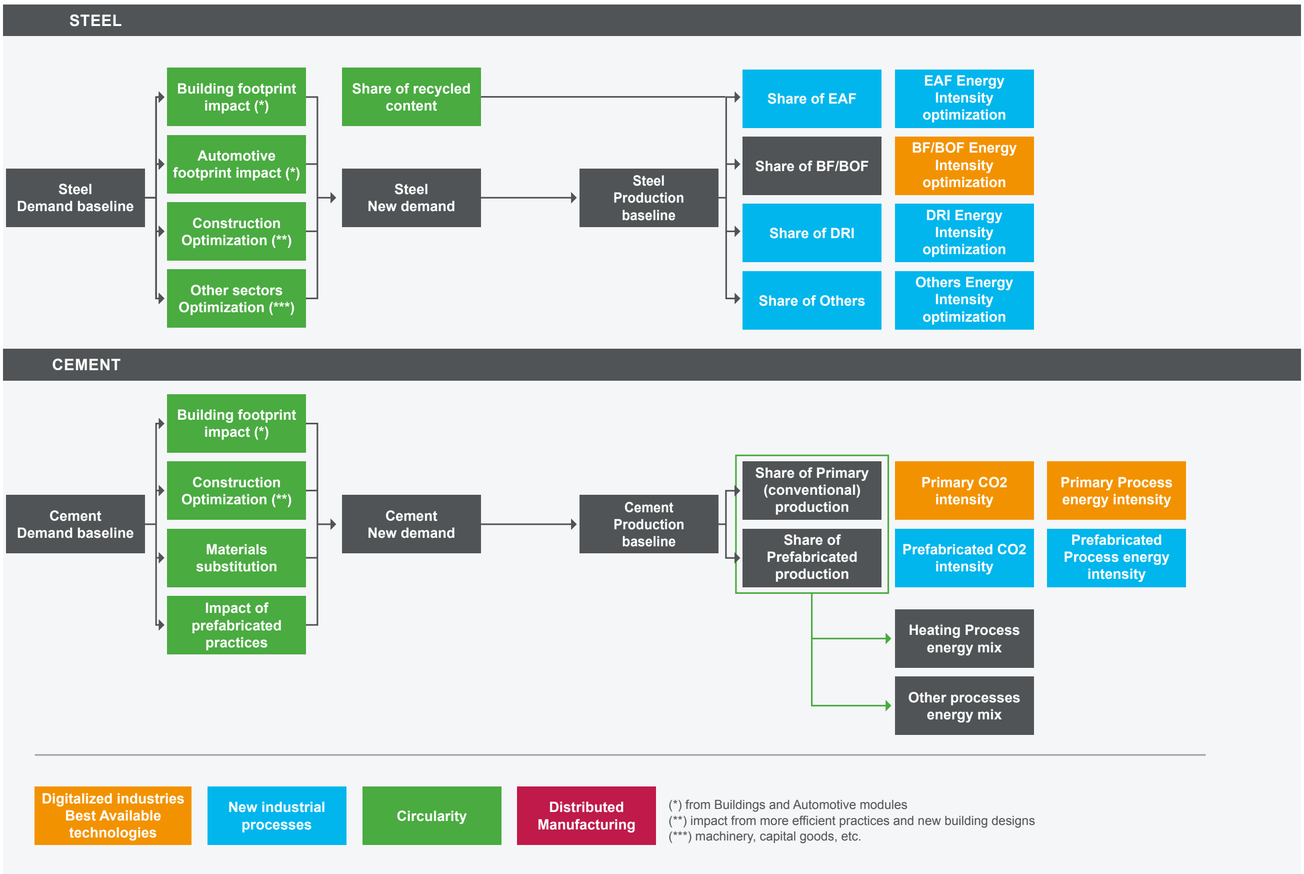
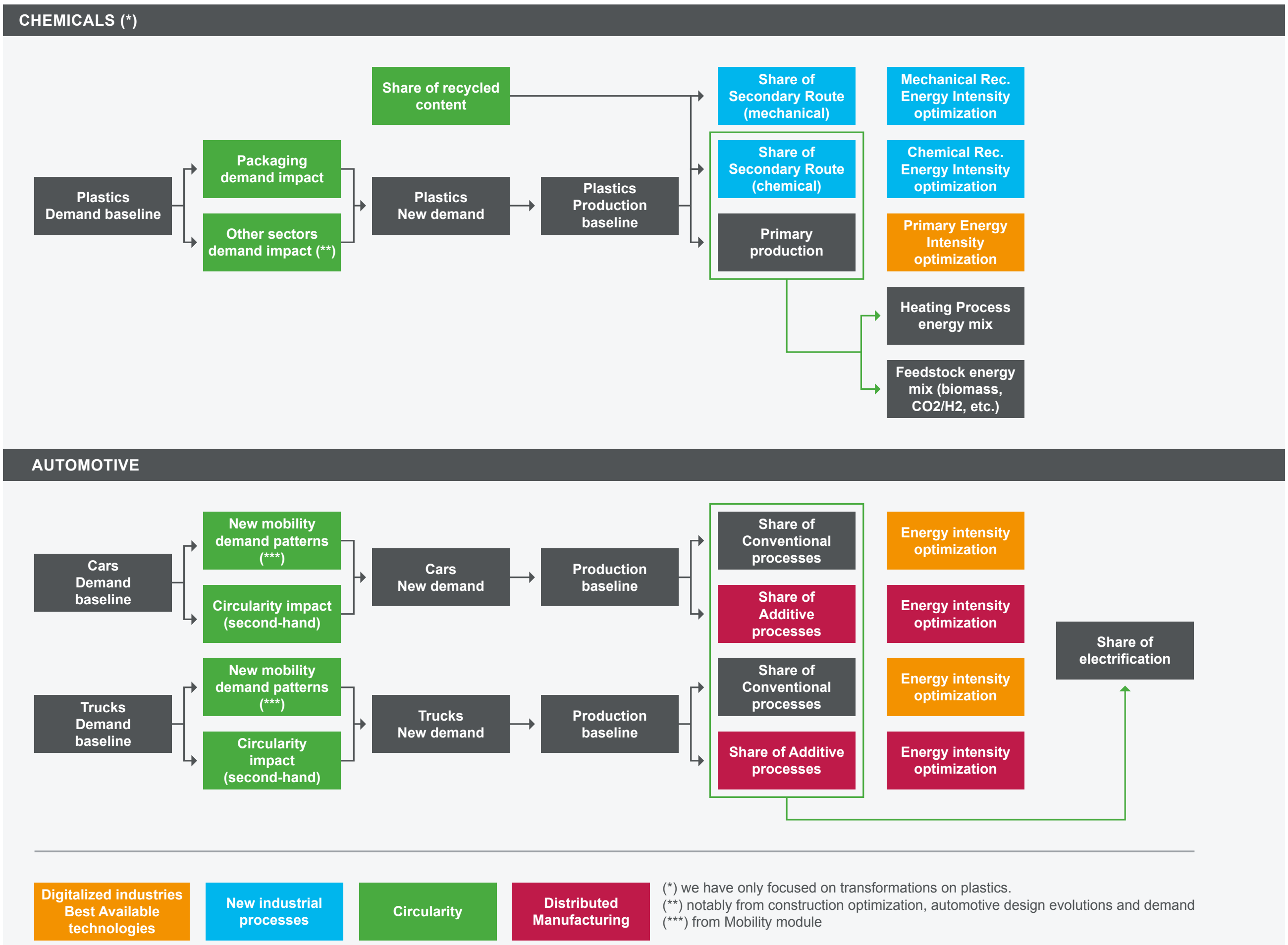
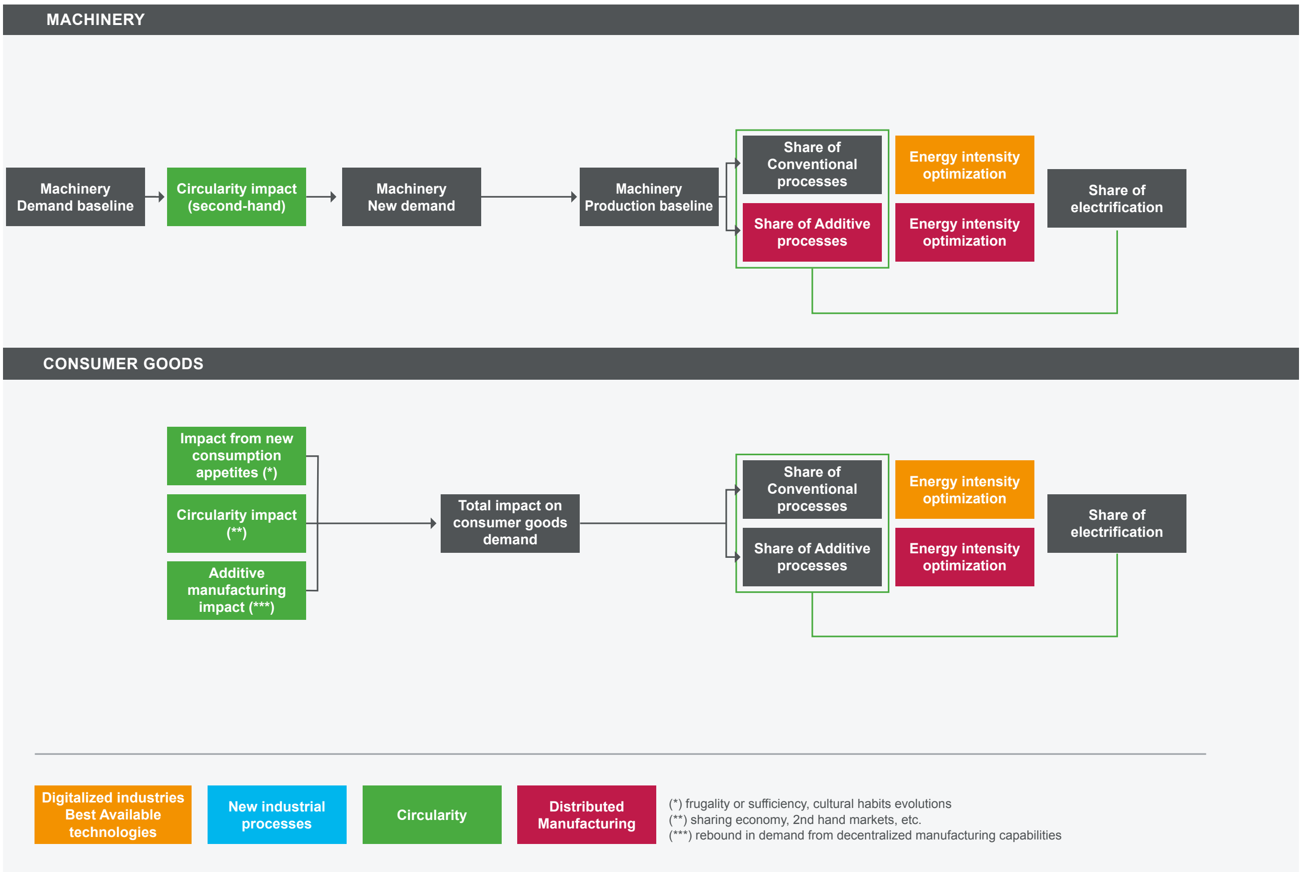


Figure 33 – Demand module, Industry (continued)



(*) we have only focused on transformations on plastics.
(**) notably from construction optimization, automotive design evolutions and demand
(***) from Mobility module

Figure 33 – Demand module, Industry (continued)



Demand module – key parameters

Figure 34 summarizes the key assumptions made, and whether they are of "Direct" or "Targeted" nature in the model. Also described below which parameters these assumptions apply to (direct impact), as well as how these contribute to the setting of other assumptions (networking effect, indirect impact).

Figure 34 – Direct and Indirect assumptions in the demand module

Sector	Transformation	Assumption	Direct impact	Networking effect (indirect impact)	Direct/Targeted
Buildings	Distributed Generation	Suitable Roof Space	PV Generation	Space conditioning (HP, AC)	Outside model
	Distributed Generation	PV technology	PV Generation	Space conditioning (HP, AC)	Outside model
	Space conditioning	HPs: penetration, COP	HP penetration		Direct
	Space conditioning	Acs: penetration, COP	AC penetration		Direct
	Space conditioning	Sufficiency	Energy intensity of build		Targeted
	Virtual environments	Home office	Building footprint	Mobility, Industry	Direct
	Virtual environments	Online shopping	Building footprint	Mobility, Industry	Direct
	Virtual environments	Building lifetime extension	Building footprint	Industry	Direct
	Virtual environments	Energy intensity development	Energy intensity of build		Targeted
	Virtual environments	Energy savings in renovations	Energy intensity of build		Targeted
	Virtual environments	Rates of renovation	Building footprint		Direct
	Construction disruption	Cost optimization	Building footprint	Mobility, Industry	Direct
Mobility	Road electrification	EV/PHEV penetration	Distribution share		Targeted
	MaaS, Multimod., Avs	Impact from Buildings	pkm		Targeted
	MaaS, Multimod., Avs	MaaS, Multimodal systems, AV	pkm		Targeted
	MaaS, Multimod., Avs	Modal shifts (e.g., bus/rail/air)	pkm		Targeted
	MaaS, Multimod., Avs	Mobility models, culture	vkm	Industry	Targeted
	MaaS, Multimod., Avs	Impact from Industry (logistics)	tkm		Targeted
	MaaS, Multimod., Avs	Technology dev (tons per vehicle)	tkm		Targeted
	MaaS, Multimod., Avs	Technology dev (AV)	vkm		Targeted
	New fuels	ICEs, HFCV, Biofuels, Synfuels	Distribution share		Targeted
Industry	Digital, BAT	Energy intensity development	Energy intensity of build		Targeted
	Digital, BAT	Carbon intensity development	Carbon intensity of build		Targeted
	New Ind. processes	Impact from recycling potential	Production steel, cement, chemicals		Direct
	New Ind. processes	Share of new processes	Production steel, cement, chemicals		Direct
	Circularity	Impact from Buildings	Production steel, cement	Recycling potential	Direct
	Circularity	Impact from Mobility	Production steel, automotive	Recycling potential	Direct
	Circularity	Material substitution	Production cement	Recycling potential	Direct
	Circularity	Prefabricated practices	Production cement	Recycling potential	Direct
	Circularity	Packaging demand	Production chemicals	Recycling potential	Direct
	Circularity	Second-hand markets	Production cons. goods, machinery, auto	Production steel, chemicals	Direct
	Circularity	Consumer behaviors (sufficiency)	Production consumer goods	Production steel, chemicals	Direct
	Circularity	Circularity models (sharing)	Production consumer goods	Production steel, chemicals	Direct
	Circularity	Impact from other Industries	Production steel, chemicals		Direct
	Dist. Manufacturing	Share of additive manufacturing	Production cons. goods, machinery, auto	Production steel, chemicals, Logistics	Direct
	Dist. Manufacturing	Energy intensity of add. manuf.	Energy intensity of build		Targeted

Key assumptions in scenarios

The following figures describe the key assumptions taken in terms of activity change, energy intensity improvements, renovation rates, etc. considered in the two scenarios of this report. To establish those assumptions, we begin by generating a business as usual – BAU scenario which simply projects the continuation of current trends, based on typical energy intensity improvements, rates of construction, population growth and GDP evolution. Then, the demand module inputs force specific "target" values at key points in time to take into account the exogenous evolutions already described and not accounted for in the model. The model then reaches a new equilibrium and recomputes all data accordingly.

Key assumptions

We take the following assumptions on activity levels (Figures 35-38).

Figure 35 – macroeconomic indicators

What to expect in the coming decades	India			EU
	2000	2010	2019	2018
Macroeconomic indicators				
GDP ($G\$_{2015}$ ppp)	2,725	5,227	9,220	19,950
Population (M)	1,057	1,234	1,366	512

What to expect in the coming decades	*2070 Net Zero* – India					*2047 Net Zero* – India				
	2030	2040	2047	2060	2070	2030	2040	2047	2060	2070
Macroeconomic indicators										
GDP ($G\$_{2015}$ ppp)	17264	28235	36813	51665	60177	17264	28235	36813	51665	60177
Population (M)	1504	1593	1629	1670	1701	1504	1593	1629	1670	1701

Figure 36 – Assumptions in Buildings

Activity levels

			2070 Net Zero			
Residential Buildings	2019	2030	2040	2047	2060	2070
Energy intensity (MJ/m²)	499	327	283	312	272	252
Stock evolution (Mm²)	15,219	28,124	38,940	45,521	54,503	58,011
of which urban	5,736	13,798	22,906	28,223	35,427	38,287
of which rural	9,483	14,326	16,034	17,298	19,076	19,724
Annual renovation rates (%)	na	0.6%	0.7%	0.7%	0.6%	0.5%
Energy intensity of renovated buildings (base=100)	na	85	85	85	85	85
Energy intensity of new buildings (vs existing, base=100)	80	77	65	61	54	51
AC penetration rate (%)	6%	19%	34%	61%	73%	87%
of which urban	0%	34%	51%	80%	85%	90%
of which rural	0%	5%	10%	30%	50%	80%
Electric cooking penetration rate (%)	0%	10%	21%	30%	42%	50%
AC efficiency gains (%, vs today)	na	0%	13%	25%	28%	30%
Appliance efficiency gains (%, vs today)	na	0%	15%	30%	35%	40%

			2070 Net Zero			
Service Buildings	2019	2030	2040	2047	2060	2070
Energy intensity (MJ/m²)	790	738	673	628	544	479
Stock evolution (Mm²)	2,319	4,362	7,391	10,333	13,062	14,291
Annual renovation rates (%)	na	0.5%	0.6%	0.6%	0.5%	0.5%
Energy intensity of renovated buildings (base=100)	na	75	75	75	75	75
Energy intensity of new buildings (vs existing, base=100)	70	69	69	53	46	43
AC penetration rate (%)	50%	60%	80%	100%	100%	100%
Electric cooking penetration rate (%)	0%	10%	18%	30%	43%	49%
AC efficiency gains (%, vs today)	na	0%	13%	25%	28%	30%
Appliance efficiency gains (%, vs today)	na	0%	15%	30%	35%	40%

Figure 36 – Assumptions in Buildings continued

Activity levels

	2047 Net Zero					
Residential Buildings	2019	2030	2040	2047	2060	2070
Energy intensity (MJ/m²)	499	298	232	238	208	201
Stock evolution (Mm²)	15,219	28,124	38,940	47,810	54,324	57,820
of which urban	5,736	13,798	22,906	29,642	35,310	38,161
of which rural	9,483	14,326	16,034	18,168	19,013	19,659
Annual renovation rates (%)	na	1.7%	1.6%	1.4%	1.2%	1.0%
Energy intensity of renovated buildings (base=100)	na	60	60	60	60	60
Energy intensity of new buildings (vs existing, base=100)	80	66	47	44	43	44
AC penetration rate (%)	6%	19%	34%	61%	73%	87%
of which urban	0%	34%	51%	80%	85%	90%
of which rural	0%	5%	10%	30%	50%	80%
Electric cooking penetration rate (%)	0%	26%	49%	65%	80%	83%
AC efficiency gains (%, vs today)	na	0%	15%	30%	40%	50%
Appliance efficiency gains (%, vs today)	na	0%	15%	30%	35%	40%

	2047 Net Zero					
Service Buildings	2019	2030	2040	2047	2060	2070
Energy intensity (MJ/m²)	790	672	594	555	487	443
Stock evolution (Mm²)	2,319	4,362	7,391	10,333	13,062	14,291
Annual renovation rates (%)	na	1.4%	1.7%	1.5%	1.2%	1.1%
Energy intensity of renovated buildings (base=100)	na	50	50	50	50	50
Energy intensity of new buildings (vs existing, base=100)	70	66	45	36	32	30
AC penetration rate (%)	50%	60%	80%	100%	100%	100%
Electric cooking penetration rate (%)	0%	29%	48%	65%	81%	86%
AC efficiency gains (%, vs today)	na	0%	15%	30%	40%	50%
Appliance efficiency gains (%, vs today)	na	0%	15%	30%	35%	40%

Figure 37 – Assumptions in Mobility

Mobility	2070 Net Zero 2019	2030	2040	2047	2060	2070
Total passenger kilometers (pkm)	4,172	5,711	8,956	11,998	16,160	18,682
PKM cars	589	1,512	3,330	5,561	7,352	8,098
Passengers per car	1.4	1.4	1.5	1.5	1.6	1.7
PKM motorcycles	473	445	418	389	293	243
PKM rail	1,263	2,351	3,831	4,419	6,371	7,775
PKM bus	1,664	1,072	662	463	335	409
PKM air	182	331	715	1,166	1,808	2,158
Total tons kilometers (freight, tkm)	3,554	6,340	9,021	11,476	18,557	28,855
TKM road	2,797	4,956	6,539	7,741	10,508	13,552
TKM rail	757	1,384	2,482	3,734	8,050	15,303
Share of EVs (Battery + Plug-in Hybrid) in stock (light duty)	0%	18%	46%	65%	81%	88%
Share of EVs (Battery + Plug-in Hybrid) in sales (light duty)	0%	25%	69%	82%	90%	93%
Share of EVs (Battery + Plug-in Hybrid) in stock (heavy duty)	0%	11%	32%	53%	68%	75%
Energy intensity Internal Combustion Engines (base = 100)	100	86	85	84	83	82
Energy intensity BEV (light-duty, base = 100)	100	92	92	92	92	92
Energy intensity BEV (heavy-duty, base = 100)	100	89	87	87	85	83
Energy intensity Rail (base = 100)	100	82	83	83	81	81
Share of alternative fuels and electricity in Air (%)	0%	8%	21%	37%	63%	81%
Share of alternative fuels and electricity in Shipping (%)	0%	3%	10%	21%	44%	81%

Mobility	2047 Net Zero 2019	2030	2040	2047	2060	2070
Total passenger kilometers (pkm)	4,172	5,654	8,670	11,342	15,870	18,139
PKM cars	589	1,378	2,546	3,650	4,485	5,132
Passengers per car	1.4	1.5	1.8	2.1	2.1	2.1
PKM motorcycles	473	409	330	225	169	157
PKM rail	1,263	2,493	4,460	5,913	8,825	9,971
PKM bus	1,664	1,072	667	495	750	966
PKM air	182	302	667	1,058	1,641	1,914
Total tons kilometers (freight, tkm)	3,554	6,340	9,345	11,955	19,331	28,779
TKM road	2,797	4,956	6,622	7,496	9,231	11,024
TKM rail	757	1,384	2,722	4,459	10,100	17,755
Share of EVs (Battery + Plug-in Hybrid) in stock (light duty)	0%	20%	65%	83%	95%	98%
Share of EVs (Battery + Plug-in Hybrid) in sales (light duty)	0%	28%	93%	100%	100%	100%
Share of EVs (Battery + Plug-in Hybrid) in stock (heavy duty)	0%	13%	50%	74%	92%	97%
Energy intensity Internal Combustion Engines (base = 100)	100	86	84	84	84	84
Energy intensity BEV (light-duty, base = 100)	100	92	92	92	92	92
Energy intensity BEV (heavy-duty, base = 100)	100	87	85	85	84	83
Energy intensity Rail (base = 100)	100	88	83	75	65	58
Share of alternative fuels and electricity in Air (%)	0%	14%	52%	88%	92%	91%
Share of alternative fuels and electricity in Shipping (%)	0%	7%	42%	79%	81%	91%

Figure 38 – Assumptions in Industry

Industry	2070 Net Zero					
	2019	2030	2040	2047	2060	2070
Steel production (Mtons/year)	111	169	277	331	384	347
of which scrap (%)	4%	13%	15%	19%	25%	33%
Steel energy intensity (MJ/ton)	29,919	24,586	21,020	19,918	17,541	15,763
of which virgin production (MJ/ton)	31,162	27,652	24,152	23,823	22,266	21,688
Steel electrification (%)	11%	11%	13%	16%	20%	24%
Cement production (Mtons/year)	371	602	852	877	876	852
Non-metallic minerals energy intensity (MJ/ton)	2,343	2,260	2,043	1,834	1,823	1,843
Nonmetallic minerals electrification (%)	1%	2%	3%	7%	16%	25%
Chemicals production (base=100)	100	154	200	222	252	257
Chemicals energy intensity (base=100)	100	93	83	79	77	78
Chemicals electrification (%)	16%	18%	25%	38%	66%	83%
Other industry production (base=100)	100	152	205	232	246	240
of which automotive	100	261	299	461	541	531
of which machinery	100	147	203	233	237	216
Other industry energy intensity	100	105	103	105	102	101
of which automotive	100	121	116	106	99	93
of which machinery	100	101	94	92	85	79
Other industry electrification (%)	26%	33%	42%	50%	71%	88%

Industry	2047 Net Zero					
	2019	2030	2040	2047	2060	2070
Steel production (Mtons/year)	111	176	237	254	313	302
of which scrap (%)	4%	13%	18%	26%	35%	42%
Steel energy intensity (MJ/ton)	29,919	21,598	19,286	17,637	14,472	13,317
of which virgin production (MJ/ton)	31,162	24,230	22,826	22,537	20,288	20,328
Steel electrification (%)	11%	14%	20%	24%	32%	38%
Cement production (Mtons/year)	371	551	657	676	712	721
Non-metallic minerals energy intensity (MJ/ton)	2,343	2,394	2,023	1,828	1,831	1,879
Nonmetallic minerals electrification (%)	1%	4%	11%	18%	29%	33%
Chemicals production (base=100)	100	149	193	216	231	240
Chemicals energy intensity (base=100)	100	90	80	76	74	75
Chemicals electrification (%)	16%	24%	61%	80%	93%	97%
Other industry production (base=100)	100	148	183	188	206	208
of which automotive	100	229	286	349	278	201
of which machinery	100	152	184	196	214	220
Other industry energy intensity	100	104	100	102	104	104
of which automotive	100	120	113	104	101	96
of which machinery	100	100	92	85	82	81
Other industry electrification (%)	26%	41%	68%	82%	96%	98%

Distributed Generation

We leverage here a previous report[1] from Schneider Electric which projected the potential of distributed generation globally. In this report, the estimated potential for distributed generation for India ranged at around 700TWh per year today, growing to 4,400TWh by 2050, thru the combination of increased building stock, rooftop PV panel technology improvements, and enhanced architectural designs which favored the deployment of PV over building rooftops.

The model developed is highly dependent on

- the type of building (individual household, residential building, flat or vertical retail centers, etc.) which constrains the rooftop surface (as a share of total floor space).
- the suitable rooftop surface effectively available for deployment of PV panels (no equipment installed, no shaded areas, etc.).

For India, the simulation translated into a suitable PV surface ratio (over total floor space) of around 5-10% in cities up to 30% for rural households today. This ratio increased by 2050 to 15% for city households, 30% for service buildings and up to around 40% for rural individual households, thanks to favorable architectural designs.

We reuse these estimates which we extrapolate to 2070. The increase in potential post-2050 is mainly derived from the increase in stock. We assume no further technology improvements (a conservative estimate), and no further increase in suitable rooftop surface (by 2050, it is considered architectural designs will already have evolved to optimize PV deployment).

Finally, we assume specific rates of penetration across the two scenarios of this report to estimate a production of distributed generation, by year, from today to 2070. By 2050, we reach 1,900-2,700TWh across both scenarios, and 3,300-5,000TWh by 2070 (Figure 39).

(1) Schneider Electric, 2022.

Figure 39 – Distributed Generation

Distributed Generation Forecast	2070 Net Zero 2019	2030	2040	2047	2060	2070
PV forecast	6	419	1,243	1,856	2,906	3,364
Rates of penetration						
Urban residential	na	10%	20%	30%	30%	30%
Rural residential	na	30%	50%	50%	70%	70%
Services	na	10%	30%	50%	50%	50%

Distributed Generation Forecast	2047 Net Zero 2019	2030	2040	2047	2060	2070
PV forecast	6	419	1,399	2,714	3,696	4,960
Rates of penetration						
Urban residential	na	10%	30%	50%	60%	70%
Rural residential	na	30%	50%	70%	70%	80%
Services	na	10%	40%	60%	70%	80%

Detailed simulation results

Detailed tables of our simulation are available in figures 40-47.

Figure 40 – Primary and Final energy demand

2070 Net Zero: Energy and Emissions Balance In Petajoules

India	2000	2010	2019	2030	2040	2047	2060	2070
Primary balance								
Gross inland consumption								
Oil	4394	6428	10385	12070	10803	8081	5392	3246
Natural gas	1021	2058	2251	2918	3173	2331	1470	783
Coal	6428	12009	16123	18246	18153	16565	9765	7230
Nuclear	193	314	466	884	4164	7372	9399	10019
Biomass & waste	6199	7950	9082	10242	14130	20477	27206	21890
Other renewables	286	576	1052	7286	15557	24495	32211	39071
Final demand								
Total	**13473**	**20794**	**28369**	**38455**	**49026**	**57682**	**61041**	**60217**
Oil products	3752	5551	9199	10862	10008	7571	5113	3090
Gas	442	757	1337	2340	3303	3604	3445	3134
Coal	1544	3750	5145	6731	8163	7519	4083	2162
Electricity	1551	3130	4658	10487	19033	28615	37324	42001
Biomass & waste	6182	7593	7982	7666	7576	8578	7602	5476
Others	2	13	48	369	943	1794	3474	4353

2047 Net Zero: Energy and Emissions Balance In Petajoules

India	2000	2010	2019	2030	2040	2047	2060	2070
Primary balance								
Gross inland consumption								
Oil	4394	6429	10385	9744	5624	2646	1201	749
Natural gas	1021	2060	2251	2215	1990	1091	675	394
Coal	6428	12024	16123	16232	12971	10273	5679	1296
Nuclear	193	315	466	1624	3828	4948	5416	5045
Biomass & waste	6199	7951	9082	11840	13929	16911	20191	22479
Other renewables	286	577	1052	7765	18302	27066	35426	40918
Final demand								
Total	**13473**	**20794**	**28369**	**35615**	**40680**	**45207**	**48859**	**50734**
Oil products	3752	5551	9199	8722	5132	2405	1150	721
Gas	442	757	1337	1375	1492	1554	1501	1334
Coal	1544	3750	5145	5539	3812	2518	1242	764
Electricity	1551	3130	4658	11277	21480	30216	37612	40927
Biomass & waste	6182	7593	7982	8330	7558	6494	4382	3648
Others	2	13	48	372	1204	2022	2972	3341

Figure 41 – Industry energy demand

	2070 Net Zero: Energy and Emissions Balance In Petajoules							
India	2000	2010	2019	2030	2040	2047	2060	2070
Industry								
Final demand	**3623**	**6800**	**10600**	**15627**	**20869**	**23445**	**24162**	**22331**
Oil products	589	603	1095	1272	1158	997	613	278
Gas	101	74	263	273	172	116	61	36
Coal	1324	3481	4602	6281	7932	7408	4068	2159
Electricity	570	1152	1969	3748	6343	8737	12735	15119
Biomass	1039	1490	2669	3765	4511	4929	4488	2460
Hydrogen	0	0	0	231	593	997	1817	1924
Heat	0	1	3	56	160	262	381	356
Steel sector								
Final demand	**756**	**1852**	**3332**	**4143**	**5817**	**6598**	**6732**	**5473**
Oil products	28	39	24	115	150	111	55	26
Gas	1	1	1	1	2	4	5	2
Coal	648	1611	2956	3123	3672	3330	1959	1002
Electricity	80	201	351	474	779	1047	1347	1292
Biomass	0	0	0	145	464	849	1170	874
Hydrogen	0	0	0	231	593	997	1817	1924
Heat	0	0	0	53	157	259	379	353
Fuel mix – other processes								
Oil products	4%	2%	1%	3%	3%	2%	1%	1%
Gas	0%	0%	0%	0%	0%	0%	0%	0%
Coal	86%	87%	89%	77%	65%	52%	31%	20%
Electricity	10%	10%	10%	10%	11%	13%	16%	17%
Biomass	0%	0%	0%	4%	8%	13%	18%	17%
Hydrogen	0%	0%	0%	6%	10%	16%	29%	38%
Heat	0%	0%	0%	1%	3%	4%	6%	7%
Non-metallic minerals								
Final demand	**542**	**735**	**868**	**1360**	**1741**	**1607**	**1598**	**1571**
Oil products	119	188	307	389	354	225	151	100
Gas	0	0	0	1	2	2	3	4
Coal	392	488	555	926	1223	1074	831	682
Electricity	32	59	6	24	47	106	249	400
Biomass	0	0	0	20	115	199	362	384
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Chemicals								
Final demand	**313**	**317**	**415**	**596**	**691**	**727**	**805**	**826**
Oil products	64	58	37	34	24	16	7	3
Gas	100	73	262	270	165	105	49	28
Coal	106	86	51	148	206	170	82	41
Electricity	42	99	65	109	172	279	532	683
Biomass	0	0	0	35	124	158	136	70
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Other industry								
Final demand	**2012**	**3897**	**5985**	**9529**	**12621**	**14513**	**15027**	**14462**
Oil products	378	317	726	733	630	645	398	149
Gas	0	0	0	1	3	5	4	2
Coal	179	1296	1041	2085	2832	2833	1195	434
Electricity	416	793	1547	3142	5345	7305	10608	12744
Biomass	1039	1490	2669	3565	3807	3722	2820	1131
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	1	3	3	3	3	3	3

Figure 41 – Industry energy demand continued

	2047 Net Zero: Energy and Emissions Balance In Petajoules							
India	2000	2010	2019	2030	2040	2047	2060	2070
Industry								
Final demand	**3623**	**6800**	**10600**	**14836**	**17514**	**17894**	**19345**	**19051**
Oil products	589	603	1095	741	304	150	45	18
Gas	101	74	263	451	509	557	810	817
Coal	1324	3481	4602	5260	3756	2499	1240	763
Electricity	570	1152	1969	4461	8947	11274	14724	15411
Biomass	1039	1490	2669	3632	3151	2202	885	427
Hydrogen	0	0	0	247	765	1124	1552	1533
Heat	0	1	3	45	83	88	88	81
Steel sector								
Final demand	**756**	**1852**	**3332**	**3792**	**4565**	**4488**	**4530**	**4024**
Oil products	28	39	24	14	10	6	3	2
Gas	1	1	1	294	449	389	335	244
Coal	648	1611	2956	2526	2023	1413	773	446
Electricity	80	201	351	518	893	1072	1463	1510
Biomass	0	0	0	150	346	398	318	209
Hydrogen	0	0	0	247	765	1124	1552	1533
Heat	0	0	0	42	81	85	86	79
Fuel mix – other processes								
Oil products	4%	2%	1%	0%	0%	0%	0%	0%
Gas	0%	0%	0%	8%	10%	9%	8%	7%
Coal	86%	87%	89%	68%	46%	33%	19%	13%
Electricity	10%	10%	10%	12%	17%	20%	26%	29%
Biomass	0%	0%	0%	4%	8%	9%	8%	6%
Hydrogen	0%	0%	0%	7%	17%	26%	38%	43%
Heat	0%	0%	0%	1%	2%	2%	2%	2%
Non-metallic minerals								
Final demand	**542**	**735**	**868**	**1318**	**1329**	**1236**	**1304**	**1355**
Oil products	119	188	307	222	92	44	15	7
Gas	0	0	0	0	1	141	468	570
Coal	392	488	555	995	892	663	343	271
Electricity	32	59	6	49	150	218	373	454
Biomass	0	0	0	53	195	170	105	54
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Chemicals								
Final demand	**313**	**317**	**415**	**556**	**642**	**676**	**711**	**746**
Oil products	64	58	37	29	12	6	2	1
Gas	100	73	262	154	58	27	7	3
Coal	106	86	51	129	64	32	16	7
Electricity	42	99	65	135	394	541	661	727
Biomass	0	0	0	108	113	71	25	9
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Other industry								
Final demand	**2012**	**3897**	**5985**	**9170**	**10978**	**11494**	**12800**	**12926**
Oil products	378	317	726	476	190	93	26	9
Gas	0	0	0	2	1	1	0	0
Coal	179	1296	1041	1610	777	391	108	39
Electricity	416	793	1547	3759	7510	9443	12226	12721
Biomass	1039	1490	2669	3321	2497	1563	437	154
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	1	3	3	2	2	2	2

Figure 42 – Building energy demand, residential

	2070 Net Zero: Energy and Emissions Balance In Petajoules							
India	2000	2010	2019	2030	2040	2047	2060	2070
Buildings								
Total demand	**6527**	**8731**	**9433**	**12419**	**15977**	**20674**	**21914**	**21489**
Oil products	507	826	1585	2378	1877	1244	637	395
Gas	12	48	129	1159	2316	2832	2989	2835
Coal	220	269	543	449	231	111	15	3
Electricity	646	1475	1854	5151	9592	15105	17559	17804
Biomass	5141	6101	5277	3223	1920	1338	663	398
Hydrogen	0	0	0	1	2	2	3	3
Heat	1	12	45	58	41	43	51	55
Residential								
Total demand	**5892**	**7395**	**7601**	**9201**	**11001**	**14188**	**14813**	**14640**
Oil products	488	759	1254	1850	1294	831	468	307
Gas	12	31	50	857	1736	2040	2063	1919
Coal	110	108	122	97	50	24	3	1
Electricity	372	713	1149	3418	6217	10104	11720	12081
Biomass	4909	5774	4987	2940	1676	1161	525	296
Hydrogen	0	0	0	1	2	2	3	3
Heat	1	10	39	38	27	29	34	37
Space heating	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil products	0	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0
Of which heat pumps	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Water heating	**8**	**35**	**80**	**130**	**152**	**157**	**146**	**134**
Oil products	0	0	0	0	0	0	0	0
Gas	7	25	41	87	111	106	82	66
Coal	0	0	0	0	0	0	0	0
Electricity	0	0	0	2	7	9	14	16
Of which heat pumps	0	0	0	2	5	8	11	13
Biomass	0	0	0	2	7	12	16	15
Hydrogen	0	0	0	0	0	0	0	0
Heat	1	10	39	38	27	29	34	37
Cooking	**5514**	**6650**	**6375**	**5896**	**5165**	**4672**	**3959**	**3571**
Oil products	488	759	1254	1850	1294	831	468	307
Gas	5	6	9	770	1625	1934	1981	1853
Coal	110	108	122	97	50	24	3	1
Electricity	3	3	3	240	528	735	998	1130
Biomass	4909	5774	4987	2938	1669	1148	509	281
Hydrogen	0	0	0	0	1	2	3	3
Heat	0	0	0	0	0	0	0	0
Space cooling	**17**	**72**	**277**	**1821**	**4074**	**7651**	**8964**	**9277**
Appliances and lighting	**353**	**638**	**870**	**1354**	**1609**	**1708**	**1744**	**1658**

Figure 42 – Building energy demand, residential continued

2047 Net Zero: Energy and Emissions Balance In Petajoules

India	2000	2010	2019	2030	2040	2047	2060	2070
Buildings								
Total demand	**6527**	**8731**	**9433**	**11303**	**13435**	**17135**	**17631**	**17983**
Oil products	507	826	1585	1513	729	300	61	20
Gas	12	48	129	317	437	567	412	334
Coal	220	269	543	279	57	18	2	0
Electricity	646	1475	1854	5207	9010	13967	15734	16515
Biomass	5141	6101	5277	3928	3162	2240	1368	1056
Hydrogen	0	0	0	0	0	0	0	0
Heat	1	12	45	58	41	44	53	58
Residential								
Total demand	**5892**	**7395**	**7601**	**8370**	**9045**	**11396**	**11273**	**11646**
Oil products	488	759	1254	1060	258	96	16	5
Gas	12	31	50	148	176	174	161	159
Coal	110	108	122	60	12	4	0	0
Electricity	372	713	1149	3462	5690	9086	9952	10622
Biomass	4909	5774	4987	3601	2881	2008	1107	820
Hydrogen	0	0	0	0	0	0	0	0
Heat	1	10	39	38	27	29	36	39
Space heating	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil products	0	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0
Of which heat pumps	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Water heating	**8**	**35**	**80**	**123**	**140**	**147**	**137**	**129**
Oil products	0	0	0	0	0	0	0	0
Gas	7	25	41	77	85	81	63	61
Coal	0	0	0	0	0	0	0	0
Electricity	0	0	0	3	8	10	15	16
Of which heat pumps	0	0	0	2	7	8	12	13
Biomass	0	0	0	5	20	26	24	13
Hydrogen	0	0	0	0	0	0	0	0
Heat	1	10	39	38	27	29	36	39
Cooking	**5514**	**6650**	**6375**	**5409**	**4391**	**3716**	**3005**	**2763**
Oil products	488	759	1254	1060	258	96	16	5
Gas	5	6	9	71	91	92	98	98
Coal	110	108	122	60	12	4	0	0
Electricity	3	3	3	621	1168	1542	1807	1853
Biomass	4909	5774	4987	3597	2861	1982	1084	807
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Space cooling	**17**	**72**	**277**	**1538**	**2949**	**5857**	**6404**	**7081**
Appliances and lighting	**353**	**638**	**870**	**1299**	**1564**	**1677**	**1727**	**1671**

Figure 43 – Building energy demand, services

	2070 Net Zero: Energy and Emissions Balance In Petajoules							
India	2000	2010	2019	2030	2040	2047	2060	2070
Buildings								
Total demand								
Oil products	6527	8731	9433	12419	15977	20674	21914	21489
Gas	507	826	1585	2378	1877	1244	637	395
Coal	12	48	129	1159	2316	2832	2989	2835
Electricity	220	269	543	449	231	111	15	3
Biomass	646	1475	1854	5151	9592	15105	17559	17804
Hydrogen	5141	6101	5277	3223	1920	1338	663	398
Heat	0	0	0	1	2	2	3	3
Services								
Total demand	**635**	**1336**	**1832**	**3218**	**4977**	**6486**	**7101**	**6849**
Oil products	20	67	331	528	583	413	168	88
Gas	0	16	79	302	580	792	927	916
Coal	110	161	421	352	181	88	12	2
Electricity	274	762	705	1734	3375	5001	5840	5723
Biomass	231	328	290	283	244	178	138	102
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	2	6	20	14	14	17	18
Space heating	**20**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil products	20	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0
Of which heat pumps	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Water heating	**0**	**29**	**110**	**240**	**324**	**348**	**338**	**307**
Oil products	0	11	25	28	16	9	3	1
Gas	0	16	79	189	272	287	264	224
Coal	0	0	0	0	0	0	0	0
Electricity	0	0	0	3	18	31	47	56
Of which heat pumps	0	0	0	3	15	26	39	47
Biomass	0	0	0	0	3	6	8	8
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	2	6	20	14	14	17	18
Cooking	**341**	**545**	**1017**	**1318**	**1440**	**1413**	**1332**	**1278**
Oil products	0	56	306	500	566	405	166	87
Gas	0	0	0	113	307	504	663	692
Coal	110	161	421	352	181	88	12	2
Electricity	0	0	0	70	144	244	362	403
Biomass	231	328	290	282	241	172	130	94
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Space cooling	**56**	**163**	**220**	**766**	**1928**	**3188**	**3568**	**3358**
Appliances and lighting	**218**	**598**	**485**	**894**	**1285**	**1538**	**1862**	**1906**

Figure 43 – Building energy demand, services continued

2047 Net Zero: Energy and Emissions Balance In Petajoules								
India	2000	2010	2019	2030	2040	2047	2060	2070
Buildings								
Total demand								
Oil products	6527	8731	9433	11303	13435	17135	17631	17983
Gas	507	826	1585	1513	729	300	61	20
Coal	12	48	129	317	437	567	412	334
Electricity	220	269	543	279	57	18	2	0
Biomass	646	1475	1854	5207	9010	13967	15734	16515
Hydrogen	5141	6101	5277	3928	3162	2240	1368	1056
Heat	0	0	0	0	0	0	0	0
Services								
Total demand	**635**	**1336**	**1832**	**2933**	**4390**	**5739**	**6357**	**6338**
Oil products	20	67	331	454	471	204	45	14
Gas	0	16	79	169	261	394	251	176
Coal	110	161	421	219	44	14	2	0
Electricity	274	762	705	1745	3319	4881	5782	5893
Biomass	231	328	290	326	281	232	261	235
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	2	6	19	14	14	17	19
Space heating	**20**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil products	20	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0
Of which heat pumps	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Water heating	**0**	**29**	**110**	**213**	**278**	**302**	**291**	**254**
Oil products	0	11	25	25	12	6	2	1
Gas	0	16	79	157	213	227	199	154
Coal	0	0	0	0	0	0	0	0
Electricity	0	0	0	10	30	40	59	71
Of which heat pumps	0	0	0	8	24	33	48	60
Biomass	0	0	0	2	10	14	14	10
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	2	6	19	14	14	17	19
Cooking	**341**	**545**	**1017**	**1171**	**1181**	**1101**	**995**	**957**
Oil products	0	56	306	429	459	197	43	14
Gas	0	0	0	12	48	166	52	22
Coal	110	161	421	219	44	14	2	0
Electricity	0	0	0	187	358	506	652	695
Biomass	231	328	290	324	271	218	246	226
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Space cooling	**56**	**163**	**220**	**701**	**1695**	**2838**	**3237**	**3198**
Appliances and lighting	**218**	**598**	**485**	**848**	**1236**	**1497**	**1834**	**1929**

Figure 44 – Mobility energy demand

	2070 Net Zero: Energy and Emissions Balance In Petajoules							
India	2000	2010	2019	2030	2040	2047	2060	2070
Transport								
Total demand	**1435**	**2904**	**4732**	**6198**	**7863**	**9117**	**10652**	**12281**
Oil products	1399	2796	4510	5067	5400	4162	2988	1833
Gas	3	57	119	119	102	0	0	0
Coal	0	0	0	0	0	0	0	0
Electricity	30	48	66	407	1389	2698	4691	6607
Biofuels	3	2	37	581	823	1766	1748	1822
Hydrogen or H2-fuels	0	0	0	23	149	492	1225	2019
Road transport								
Total demand	**1190**	**2435**	**4045**	**5176**	**6053**	**6515**	**6731**	**7122**
Oil products	1184	2375	3889	4343	4323	2872	1896	1256
Gas	3	57	119	119	102	0	0	0
Electricity	0	0	0	157	883	2002	3403	4445
Biofuels	3	2	37	547	692	1451	1077	818
Hydrogen or H2-fuels	0	0	0	9	53	190	355	603
Rail transport								
Total demand	**92**	**151**	**188**	**284**	**496**	**665**	**1240**	**2096**
Oil products	63	103	122	36	1	0	0	0
Coal	0	0	0	0	0	0	0	0
Electricity	30	48	66	248	495	664	1240	2096
Biofuels	0	0	0	0	0	0	0	0
Hydrogen or H2-fuels	0	0	0	0	0	0	0	0
Air transport								
Total demand	**100**	**227**	**368**	**528**	**999**	**1542**	**2165**	**2479**
Domestic	30	91	185	266	502	775	1088	1246
International	70	136	183	263	497	767	1077	1233
Fuel mix (%)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil products	100	227	368	486	792	977	801	468
Electricity	0	0	0	0	0	0	0	0
Biofuels	0	0	0	32	126	301	664	991
Hydrogen or H2-fuels	0	0	0	11	82	264	700	1019
Other transport								
Total demand	**52**	**92**	**130**	**209**	**315**	**396**	**517**	**583**
Inland waterways	24	37	64	112	175	225	312	354
Maritime bunkers	28	55	66	98	139	171	205	230
	0	0	0	0	0	0	0	0
Fuel mix (%)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil products	52	92	130	202	284	312	291	108
Electricity	0	0	0	2	11	32	48	66
Biofuels	0	0	0	2	5	14	8	13
Hydrogen or H2-fuels	0	0	0	3	15	38	170	397

Figure 44 – Mobility energy demand continued

2047 Net Zero: Energy and Emissions Balance In Petajoules

India	2000	2010	2019	2030	2040	2047	2060	2070
Transport								
Total demand	**1435**	**2904**	**4732**	**5766**	**6005**	**6307**	**7892**	**9698**
Oil products	1399	2796	4510	4670	2975	1267	571	365
Gas	3	57	119	35	46	0	0	0
Coal	0	0	0	0	0	0	0	0
Electricity	30	48	66	417	1831	2973	4889	6599
Biofuels	3	2	37	620	838	1301	1153	1067
Hydrogen	0	0	0	23	316	766	1278	1668
Road transport								
Total demand	**1190**	**2435**	**4045**	**4825**	**4317**	**3817**	**3822**	**4290**
Oil products	1184	2375	3889	4057	2393	1028	313	116
Gas	3	57	119	35	46	0	0	0
Electricity	0	0	0	166	1265	2110	3209	3981
Biofuels	3	2	37	557	588	660	288	186
Hydrogen	0	0	0	10	24	19	12	7
Rail transport								
Total demand	**92**	**151**	**188**	**302**	**560**	**836**	**1634**	**2559**
Oil products	63	103	122	53	4	3	1	1
Coal	0	0	0	0	0	0	0	0
Electricity	30	48	66	250	556	833	1633	2559
Biofuels	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0	0	0	0
Air transport								
Total demand	**100**	**227**	**368**	**438**	**824**	**1263**	**1916**	**2263**
Domestic	30	91	185	220	414	635	963	1137
International	70	136	183	218	410	628	953	1126
Fuel mix (%)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil products	100	227	368	375	399	155	157	197
Electricity	0	0	0	0	0	0	0	0
Biofuels	0	0	0	57	204	537	794	827
Hydrogen	0	0	0	6	221	571	965	1239
Other transport								
Total demand	**52**	**92**	**130**	**201**	**304**	**391**	**520**	**586**
Inland waterways	24	37	64	111	171	220	302	349
Maritime bunkers	28	55	66	90	134	171	218	237
	0	0	0	0	0	0	0	0
Fuel mix (%)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil products	52	92	130	186	178	81	101	51
Electricity	0	0	0	2	10	30	48	59
Biofuels	0	0	0	6	45	104	70	54
Hydrogen	0	0	0	7	71	176	302	422

Figure 45 – Other sectors' energy demand

				2070 Net Zero: Energy and Emissions Balance In Petajoules				
India	2000	2010	2019	2030	2040	2047	2060	2070
Agriculture								
Total demand	**646**	**812**	**1242**	**1690**	**2138**	**2409**	**2791**	**2977**
Oil products	335	350	466	430	187	0	0	0
Gas	5	7	7	9	8	7	5	4
Coal	0	0	0	0	0	0	0	0
Electricity	305	455	769	1180	1709	2076	2338	2471
Biomass	0	0	0	71	234	326	447	502
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Non-energy uses								
Total demand	**1242**	**1547**	**2362**	**2521**	**2180**	**2035**	**1523**	**1139**
Oil products	921	976	1543	1716	1386	1168	876	585
Gas	321	571	818	780	706	649	390	259
Coal	0	0	0	0	0	0	0	0
Biomass	0	0	0	25	87	219	256	295

				2047 Net Zero: Energy and Emissions Balance In Petajoules				
India	2000	2010	2019	2030	2040	2047	2060	2070
Agriculture								
Total demand	**646**	**812**	**1242**	**1681**	**2112**	**2373**	**2742**	**2922**
Oil products	335	350	466	357	133	0	0	0
Gas	5	7	7	8	7	6	5	3
Coal	0	0	0	0	0	0	0	0
Electricity	305	455	769	1191	1693	2002	2265	2402
Biomass	0	0	0	125	279	365	472	517
Hydrogen	0	0	0	0	0	0	0	0
Heat	0	0	0	0	0	0	0	0
Non-energy uses								
Total demand	**1242**	**1547**	**2362**	**2029**	**1614**	**1498**	**1250**	**1079**
Oil products	921	976	1543	1441	992	688	472	319
Gas	321	571	818	564	493	424	274	179
Coal	0	0	0	0	0	0	0	0
Biomass	0	0	0	25	128	386	504	581

Figure 46 – Power generation

2070 Net Zero: Energy and Emissions Balance In Petajoules

India	2000	2010	2019	2030	2040	2047	2060	2070
Electricity generation								
Total generation (TWh)	**619**	**1133**	**1654**	**3661**	**6588**	**9877**	**12870**	**14415**
Coal	430	765	1178	1201	1077	1058	670	602
Gas	62	132	73	92	110	143	93	103
Oil	24	21	8	23	17	14	9	6
Biomass & waste	1	17	45	176	520	919	1628	1300
Nuclear	19	31	45	83	401	762	1057	1115
Renewables	85	187	355	2260	4916	7798	10659	12238
Hydroelectricity	82	146	185	259	454	568	814	919
Wind	2	23	70	656	1249	1865	2740	3562
Solar Utility-Scale	0	0	49	751	1450	2590	2570	3093
Distributed Generation	0	0	6	419	1243	1856	2906	3364
Other	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	66	99	387	290

2047 Net Zero: Energy and Emissions Balance In Petajoules

India	2000	2010	2019	2030	2040	2047	2060	2070
Electricity generation								
Total generation (TWh)	**619**	**1135**	**1654**	**3927**	**7406**	**10385**	**12905**	**13998**
Coal	430	766	1178	1123	1036	925	535	59
Gas	62	132	73	150	232	240	109	93
Oil	24	21	8	24	17	12	2	1
Biomass & waste	1	17	45	257	495	832	1362	1648
Nuclear	19	31	45	153	369	521	569	502
Renewables	85	187	355	2475	5680	8484	11309	13062
Hydroelectricity	82	147	185	284	453	658	866	970
Wind	2	23	70	700	1675	2231	3437	3931
Solar Utility-Scale	0	0	49	815	1658	2049	1949	1554
Distributed Generation	0	0	6	419	1399	2714	3696	4960
Other	0	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	74	208	387	280

Figure 47 – Emissions

2070 Net Zero: Energy and Emissions Balance In Petajoules

India	2000	2010	2019	2030	2040	2047	2060	2070
GHG emissions Total emissions ($MtCO_2$eq.)								
Total w/o AFOLU	1191	2060	2799	3023	2723	1789	522	-52
CO_2 emissions from Energy Total ($MtCO_2$ eq.)	**835**	**1551**	**2125**	**2471**	**2426**	**2088**	**1277**	**895**
of which coal & lignite	573	1095	1446	1636	1606	1460	864	655
of which gas	42	104	95	137	159	121	78	42
of which oil	220	353	583	698	661	506	335	198
Final consumption	**329**	**669**	**1019**	**1316**	**1440**	**1206**	**725**	**404**
Industry (incl. non-energy uses)	171	380	525	691	806	736	408	214
of which coal & lignite	94	290	358	513	655	615	334	178
of which gas	18	25	45	39	27	15	6	2
of which oil	60	64	121	139	123	105	68	34
Buildings	56	83	160	252	239	169	101	57
of which coal & lignite	21	25	51	43	22	11	1	0
of which gas	1	3	7	57	97	79	58	32
of which oil	35	55	102	152	120	80	41	25
Transport	102	207	334	373	396	302	217	133
of which oil	102	204	327	367	391	302	217	133
of which gas	0	3	7	6	4	0	0	0
	0	0	0	0	0	0	0	0
Power generation	**499**	**866**	**1080**	**1128**	**960**	**859**	**537**	**481**
of which coal & lignite	456	772	1023	1066	912	819	518	469
of which gas	23	68	32	32	30	26	13	8
of which oil	20	25	25	30	18	13	6	4
	0	0	0	0	0	0	0	0
Other transformation	**6**	**12**	**22**	**23**	**25**	**22**	**15**	**10**
of which coal & lignite	2	7	14	14	16	16	11	7
of which gas	0	0	0	0	0	0	0	0
of which oil	3	5	8	9	8	6	4	2
	0	0	0	0	0	0	0	0
Fugitive emissions	**1**	**5**	**4**	**3**	**1**	**1**	**1**	**0**
	0	0	0	0	0	0	0	0
Industry processes	**77**	**141**	**212**	**229**	**210**	**167**	**65**	**16**
Non-CO_2 emissions from energy and industry	**279**	**367**	**462**	**323**	**239**	**219**	**172**	**146**
Fugitive (CH4)	59	94	127	82	50	39	23	18
Waste	145	180	232	170	144	143	122	105
Others	75	94	103	71	46	37	27	23
CCS and negative emissions	**0**	**0**	**0**	**0**	**-152**	**-686**	**-992**	**-1108**
Direct Air Capture/Nature Based Solutions	0	0	0	0	-20	-250	-250	-250
Industry	0	0	0	0	-11	-152	-215	-250
Power	0	0	0	0	-114	-269	-506	-586
Other transformation	0	0	0	0	-7	-14	-21	-22

Figure 47 – Emissions continued

	2047 Net Zero: Energy and Emissions Balance In Petajoules							
India	2000	2010	2019	2030	2040	2047	2060	2070
GHG emissions Total emissions (MtCO$_2$eq.)								
Total w/o AFOLU	1191	2062	2800	2623	1346	59	-479	-799
CO$_2$ emissions from Energy Total (MtCO$_2$ eq.)	**835**	**1553**	**2125**	**2142**	**1614**	**1173**	**628**	**195**
of which coal & lignite	573	1096	1446	1467	1172	933	517	110
of which gas	42	104	95	112	114	91	52	49
of which oil	220	353	583	563	328	149	59	36
Final consumption	**329**	**669**	**1019**	**1037**	**661**	**364**	**178**	**109**
Industry (incl. non-energy uses)	171	380	525	559	376	240	125	78
of which coal & lignite	94	290	358	432	303	200	97	61
of which gas	18	25	45	38	30	16	17	10
of which oil	60	64	121	88	42	24	11	7
Buildings	56	83	160	138	68	32	11	5
of which coal & lignite	21	25	51	26	5	2	0	0
of which gas	1	3	7	15	16	11	7	4
of which oil	35	55	102	97	47	19	4	1
Transport	102	207	334	340	217	92	42	26
of which oil	102	204	327	339	216	92	42	26
of which gas	0	3	7	2	2	0	0	0
	0	0	0	0	0	0	0	0
Power generation	**499**	**868**	**1080**	**1082**	**937**	**799**	**444**	**83**
of which coal & lignite	456	774	1023	997	854	724	415	48
of which gas	23	69	32	54	65	63	28	35
of which oil	20	25	25	31	18	12	2	1
	0	0	0	0	0	0	0	0
Other transformation	**6**	**12**	**22**	**20**	**15**	**10**	**5**	**3**
of which coal & lignite	2	7	14	12	10	8	4	2
of which gas	0	0	0	0	0	0	0	0
of which oil	3	5	8	8	4	2	1	1
	0	0	0	0	0	0	0	0
Fugitive emissions	**1**	**5**	**4**	**3**	**1**	**1**	**0**	**0**
	0	0	0	0	0	0	0	0
Industry processes	**77**	**141**	**212**	**201**	**136**	**84**	**16**	**6**
Non-CO$_2$ emissions from energy and industry	**279**	**367**	**462**	**281**	**186**	**155**	**129**	**114**
Fugitive (CH4)	59	94	127	74	41	30	18	10
Waste	145	180	232	140	106	99	94	90
Others	75	94	103	66	39	27	17	13
CCS and negative emissions	**0**	**0**	**0**	**0**	**-590**	**-1353**	**-1252**	**-1114**
Direct Air Capture/Nature Based Solutions	0	0	0	0	-130	-432	-432	-432
Industry	0	0	0	0	-122	-141	-114	-72
Power	0	0	0	0	-334	-776	-695	-589
Other transformation	0	0	0	0	-4	-5	-11	-21

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