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Sustainable Manufacturing for India's Low-carbon Transition

Four Bets for Hard-to-abate Sectors

Tirtha Biswas, Karthik Ganesan, and Arunabha Ghosh

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About CEEW

The Council on Energy, Environment and Water (CEEW) is one of South Asia's leading not-for-profit policy research institutions. The Council uses data, integrated analysis, and strategic outreach to explain – and change – the use, reuse, and misuse of resources. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public.

In 2019, CEEW once again featured extensively across nine categories in the 2018 *Global Go To Think Tank Index Report*, including being ranked as South Asia's top think tank (15th globally) with an annual operating budget of less than USD 5 million for the sixth year in a row. CEEW has also been ranked as South Asia's top energy and resource policy think tank in these rankings. In 2016, CEEW was ranked 2nd in India, 4th outside Europe and North America, and 20th globally out of 240 think tanks as per the ICCG Climate Think Tank's standardised rankings.

In nine years of operations, The Council has engaged in over 230 research projects, published over 160 peer-reviewed books, policy reports and papers, advised governments around the world nearly 530 times, engaged with industry to encourage investments in clean technologies and improve efficiency in resource use, promoted bilateral and multilateral initiatives between governments on 80 occasions, helped state governments with water and irrigation reforms, and organised nearly 300 seminars and conferences.

The Council's major projects on energy policy include India's largest multidimensional energy access survey (ACCESS); the first independent assessment of India's solar mission; the Clean Energy Access Network (CLEAN) of hundreds of decentralised clean energy firms; the CEEW Centre for Energy Finance; India's green industrial policy; the USD 125 million India-U.S. Joint Clean Energy R&D Centers; developing the strategy for and supporting activities related to the International Solar Alliance; designing the Common Risk Mitigation Mechanism (CRMM); modelling long-term energy scenarios; energy subsidies reform; energy storage technologies; India's 2030 Renewable Energy Roadmap; energy efficiency measures for MSMEs; clean energy subsidies (for the Rio+20 Summit); Energy Horizons; clean energy innovations for rural economies; community energy; scaling up rooftop solar; and renewable energy jobs, finance and skills.

The Council's major projects on climate, environment and resource security include advising and contributing to climate negotiations in Paris (COP-21), especially on the formulating guidelines of the Paris Agreement rule-book; pathways for achieving NDCs and Mid-century Strategy for decarbonisation; assessing global climate risks; heat-health action plans for Indian cities; assessing India's adaptation gap; low-carbon rural development; environmental clearances; modelling HFC emissions; the business case for phasing down HFCs; assessing India's critical minerals; geoengineering governance; climate finance; nuclear power and low-carbon pathways; electric rail transport; monitoring air quality; the business case for energy efficiency and emissions reductions; India's first report on global governance, submitted to the National Security Adviser; foreign policy implications for resource security; India's power sector reforms; zero budget natural farming; resource nexus, and strategic industries and technologies; and the Maharashtra-Guangdong partnership on sustainability.

The Council's major projects on water governance and security include the 584-page *National Water Resources Framework Study* for India's 12th Five Year Plan; irrigation reform for Bihar; *Swachh Bharat*; supporting India's *National Water Mission*; collective action for water security; mapping India's traditional water bodies; modelling water-energy nexus; circular economy of water; participatory irrigation management in South Asia; domestic water conflicts; modelling decision making at the basin-level; rainwater harvesting; and multi-stakeholder initiatives for urban water management.

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Tirtha is a policy analyst, working on the development of sustainable and competitive pathways for Indian industry to support its low-carbon growth aspirations. At The Council, his research revolves around mineral resource security, greenhouse gas emissions, and energy efficiency of the domestic industrial sector in India. He has completed a dual degree from the Indian Institute of Technology (Indian School of Mines), Dhanbad, and holds an undergraduate degree in Mineral Engineering and a Masters in Mineral Resource Management.

"The low-carbon technologies available for the manufacturing sector are now at a similar crossroad already traversed by renewables a decade earlier. This document analyses these technologies with respect to the Indian context and outlines a novel plan to square the impossible trinity (jobs – growth – sustainability) in the sector."

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Karthik is a Research Fellow at CEEW. He has over seven years of experience in analysing energy and macroeconomic policies. His current work is on cost effective power generation options for discoms, understanding environmental impacts of power generation, and the role of energy efficiency in industrial production. He has a B.Tech. and an M.Tech. in Civil Engineering from IIT Madras and a Master's in Public Policy from National University of Singapore.

"If the coming generations have to see further, it must be by standing on a foundation that does not depend on conventionally produced cement, steel and commodities."

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Dr Arunabha Ghosh is a public policy professional, adviser, author, columnist, and institution builder. As the founder-CEO of the Council on Energy, Environment and Water, since 2010, he has led CEEW to the top ranks as one of South Asia's leading policy research institutions (six years in a row); and among the world's 20 best climate think-tanks in 2016. With experience in 44 countries, he previously worked at Princeton, Oxford, UNDP, and WTO. In 2018, the UN Secretary-General nominated him to UN's Committee for Development Policy. He holds a D.Phil. from Oxford and topped Economics from St. Stephen's College, Delhi.

"India's low-carbon development pathway will create potential trade-offs between growth, jobs and sustainability. Pursuing industrial growth while maintaining manufacturing competitiveness will be at the heart of this dilemma. India has an opportunity to place some bets on emerging technologies in the hard-to-abate sectors, which could open new avenues for prosperity."

Image: iStock

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Abbreviations

AMRUT	Atal Mission for Rejuvenation and Urban Transformation
APM	administrative pricing mechanism
ASTM	American Society for Testing and Materials
BAU	business as usual scenario
BEE	Bureau of Energy Efficiency
BF	blast furnace
CBM	coal-bed methane
COTC	crude oil to chemicals
DRI	direct reduced iron
EE	energy efficiency
FAI	The Fertiliser Association of India
GDP	gross domestic product
GHG	greenhouse gas
GRIHA	Green Rating for Integrated Habitat Assessment
GVA	gross value addition
IBEF	India Brand Equity Foundation
IEA	International Energy Agency
LC3	limestone clacined clay cement
LEED	Leadership in Energy and Environmental Design
LNG	liquified natural gas
MTOE	million tonnes of oil equivalent
MW	megawatt
NDC	nationally determined contributions
OCM	oxidative coupling of methane
OPC	ordinary portland cement
PAT	Perform Achieve and Trade scheme
PMAY	Pradhan Mantri Awas Yojna
PSU	public sector undertaking
ROGC	refinery off-gas cracker
SMR	steam methane reforming
ULCOS	ultra-low CO_2 steel making programme
UNIDO	United Nations Industrial Development Organisation
WBCSD	World Business Council for Sustainable Development

Overview

India aims to become a USD 5 trillion economy in the next five years and join the ivy league of top five major economies, namely USA, China, Japan, and Germany. The historical growth of these economies has relied on the manufacturing sector playing a key role in creating jobs, driving innovation, catering to domestic demand and exporting technology overseas. Now, as India embraces a similar transition, the manufacturing sector is faced with an additional challenge – achieving sustainable production and reducing its emissions footprint.

This brief analyses four key sectors of the manufacturing industry: iron and steel, cement, ammonia and chemicals (primarily petrochemicals). These sectors have the highest emissions intensity of production because they rely on a carbon-intensive fuel mix or carbonaceous feedstock or a combination of both. Globally, even if these sectors were to achieve the best-in-class energy efficiency levels within the next 10 years, cumulative emissions from these sectors between 2010 and 2050 would consume about 13 per cent of the global carbon budget required to achieve 2DS by 2100, against approximately 15 per cent in the current BAU scenario. This spells out the serious challenge that the globe faces in decarbonising industrial output. Clearly, energy efficiency and optimising processes will not suffice.

Our analysis reveals that the opportunities to decarbonise the manufacturing sector are aplenty. India's competitiveness in manufacturing iron and steel, cement, ammonia and petrochemicals needs a boost, and shifting to low-carbon technologies provides the opportunity for a large manufacturing economy like India to take the lead. While many of the technologies discussed here are still in their nascent stage, in many cases the underlying processes remain the same. In the case of cement and petrochemicals, we need to fundamentally rethink the materials we use and how we can get them from with the ensuing emissions. For all sectors change in the fuel input is a key component. A review of studies and our own analyses suggests that the use of hydrogen, derived from electrolysis using solar and/or wind (hybrid) power, is likely to become as competitive as conventional fuels. With India and many parts of the global south being blessed with solar resources, this presents an interesting proposition to rekindle the role of industries in driving economic growth.

Sustainability could become a key driver to bet on new technologies that could help India prepare for changing market structures and product and process standards at home and abroad. While jobs in conventional manufacturing are present today, they are at a risk of being lost, either because these will become uncompetitive or their relevance in a world with stricter regulation on emitting carbon will be limited. A different approach is then needed if India is to sustain and increase the pace of job creation that the growing working-age population will impose.

A key outcome of our analysis is also that much effort is needed in R&D and commercialisation of technologies to abate emissions from those manufacturing sectors and processes - like clinker making - which will continue to emit significantly even by mid-century. There are no alternatives in sight today. A concerted global effort to leverage resources across countries will be needed to mainstream new technologies. India must lead the charge if we are to reap the benefits of these new approaches to manufacturing, lest we end up in the historical trap of technology dependence and the resulting apathy to resource efficiency. A big bet on the essential trinity of growth, jobs and sustainability is now needed urgently.

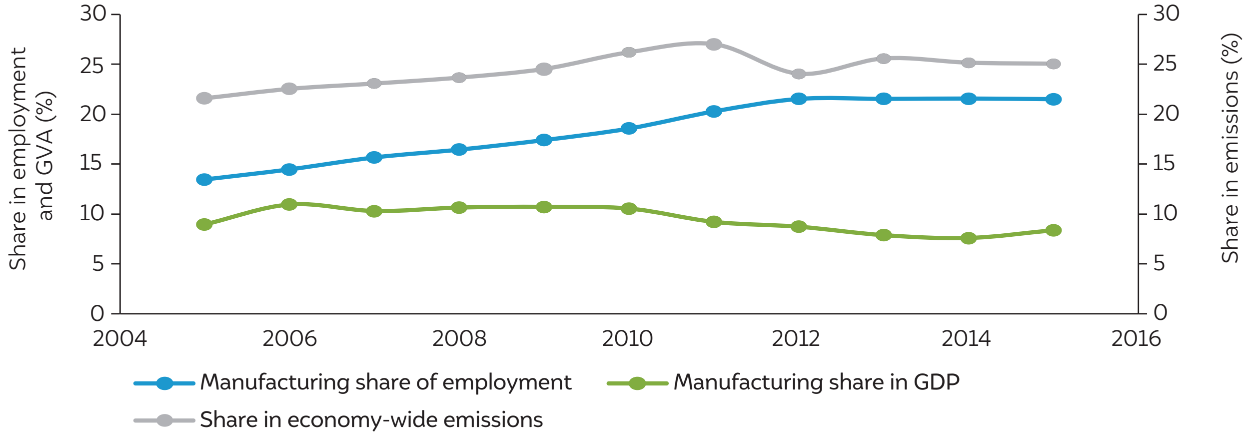
1. Introduction

Industrialisation, or increasing contribution of the manufacturing sector in GDP, plays an important role in the economic growth of a country and represents a phase where incomes, productivity and jobs rise as the economy transitions out of the dependence on agriculture and allied activities. Unlike developed countries, which have gone through this transition, developing countries today are increasingly showing trends of a premature shift to the services sector, with the manufacturing share of GDP, peaking at much lower income levels than those who industrialised early on (UNIDO, 2016). The premature transition is a result of the manufacturing sector's inability to scale up and compete with rapid industrialisation in a handful of countries.

> **Between 1995 and 2015, imports exponentially increased nearly seven-fold, and ate into what could have been a contribution from domestic production**

Indian manufacturing is no exception to this trend that newly industrialising economies have shown. The manufacturing share of GDP in India reached an all-time high of approximately 18 per cent in 1995 and has declined or tended to remain at this level since then (Figure 1). Lack of suitable supporting policies have limited domestic industries from catering to rising

Figure 1: The hitherto impossible trinity of the manufacturing sector (growth – jobs – sustainability)



Source: The World Bank. (2019a). Manufacturing, value added (% of GDP); The World Bank. (2019b). Employment in industry (% of total employment); and authors' analysis

consumer demand, which instead is being met by imports. Between 1995 and 2015, imports exponentially increased nearly seven-fold, and ate into what could have been a contribution from domestic production. In fact, the increase in imports as a share of GDP for India is highest amongst the G20 countries for the last 17 years (The World Bank, 2019d).

Increasing imports, alongside automation and labour migration (to other economic sectors), leads to loss of potential manufacturing jobs. Figure 1 highlights a stagnation of manufacturing jobs since 2012, which is also marked by the period of declining share of the manufacturing sector in GDP. This is a lost opportunity for India, especially when the country has the second largest workforce with a median age of only 27.5 years (Kletzer, 2005). Economists often argue that imports do not necessarily replace or reduce manufacturing jobs, as they are offset by jobs created from rising exports (Rose, 2018). However, this is not the case for India, as the trade deficit for capital goods has been steadily increasing. While we cannot avoid automation as it offers significant productivity gains for industries to retain their competitive edge, additional jobs could be created by scaling up of manufacturing production to meet demand from both domestic and global markets.

> **Over 60 per cent of energy demand is met by coal, and another 20 per cent is met by petroleum fuels**

The manufacturing sector is the second largest contributor to India's emissions contributing about 25 per cent of the total (Gupta, Biswas, Janakiraman, & Ganesan, 2019). Industrial activity is the single largest consumer of delivered energy and, as a result, a large share of emissions as well. The energy mix in industry is dominated by fossil fuels. Over 60 per cent of energy demand is met by coal, and another 20 per cent is met by petroleum fuels. Natural gas has a meagre share of 5 per cent in the energy mix and majority of it is consumed by the petrochemical sector as feedstock. The high reliance on fossil fuels (especially coal) as a primary source of energy has resulted in the higher emissions footprint of the industrial sector. The Government of India has taken several initiatives to decouple emissions from economic growth. The Perform, Achieve and Trade (PAT) scheme aims to improve the overall energy efficiency of large energy-intensive sectors. However, despite achieving the stated energy efficiency target, there has only been a marginal impact on emissions levels. Manufacturing sector emissions (from energy use) increased with higher annual rate when compared to the overall economy-wide emissions. The International Energy Agency's (IEA) New Policies Scenario (NPS) outlook for India's industrial emissions indicates that its share in overall emissions would increase from 25 per cent in 2017 to 35 per cent in 2040 (Biswas, Janakiraman, & Ganesan, 2019).

2. A novel plan towards squaring the impossible trinity

India aims to become a USD 5 trillion economy within the next five years and join the ivy league of top five major economies, along with the United States, China, Japan, and Germany. The historical growth of these economies indicates that the manufacturing sector had a key role in their economic development by significantly contributing to GDP growth and employment (UNIDO, 2016). Now, as India embraces a similar transition, the manufacturing sector is faced with an additional challenge – achieving sustainable production by reducing the emissions footprint.

India is on track to meet its NDC commitments for 2030. Yet, its current ambitions combined with those of the major emitters, are far from aligning with the long-term goal of the Paris Agreement. With the available technology options – and best in class energy efficiency levels – emissions from the manufacturing sector would need to peak well before 2050 if India were to align with the 2 Degrees Celsius temperature increase limit scenario (2DS) by 2100 (Chaturvedi, Nagarkoti, & Chordia, 2018). The emissions peak will come at a cost of decreased industrial output compared to business-as-usual (BAU) growth, resulting in a loss of economic value addition of USD 230 billion and about 19 million jobs in 2050, roughly equivalent to present gross value added (GVA) and jobs contribution from the manufacturing sector (Chaturvedi, Nagarkoti, & Chordia, 2018).

As one of the countries most vulnerable to climate change, it is not only imperative but also in India's self-interest to put in place policies that create incentives for a departure from the decades' old supply and demand approaches we have used to address the needs of the sector. We cannot continue to measure industrial output, prices and overall demand in a manner that is devoid of the impact on the environment. On the supply side, transition needs to happen at scale and not merely in pilot demonstrations.

So, here is the main challenge for India. Can the manufacturing sector remain competitive, increase its contribution to national income and to job creation, even as environmental constraints impose hard choices on the pattern and processes of industrial development? There are economically viable demonstrations that showcase the potential that low-carbon technology offers but there are trade-offs as well, possibly lower profit margins and subdued demand in the short run as industrial structure transforms. So, how can India square a potential impossible trinity between growth, jobs and sustainability?

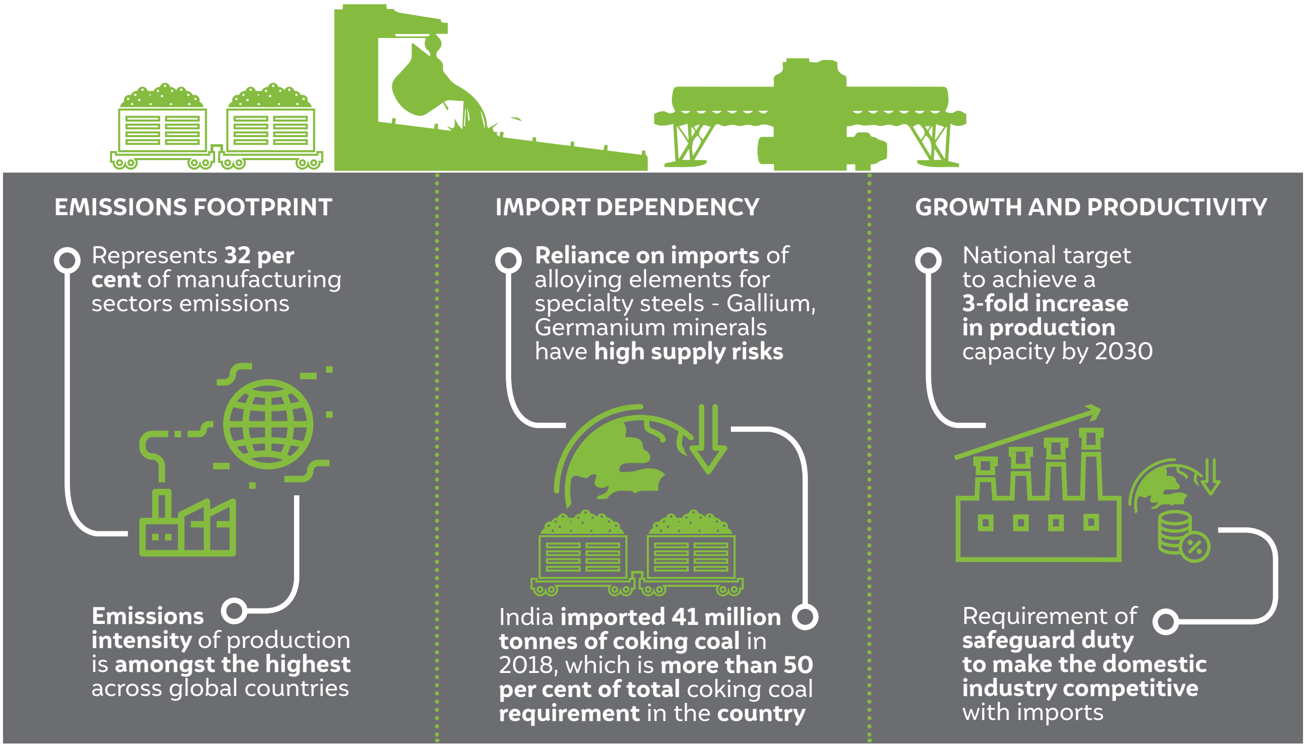
This brief analyses four key sectors of the manufacturing industry: iron and steel, cement, ammonia and chemicals (primarily petrochemicals). These sectors have the highest emissions intensity of production primarily because of reliance on a carbon-intensive fuel mix or carbonaceous feedstock or a combination of both. Till date, majority of the emissions reductions in these sectors have happened through process optimisation with the objective of reducing production costs. As a result, these sectors continue to rely on older production methods with little innovation or adoption of low-carbon technologies.

> **The emissions peak will come at a cost of decreased industrial output compared to business-as-usual growth, resulting in a loss of economic value addition of USD 230 billion and about 19 million jobs in 2050**

> Consider this. Globally, even if these four sectors, iron and steel, cement, ammonia and chemicals (primarily petrochemicals), were to achieve the best feasible technology options energy efficiency levels within the next 10 years, cumulative emissions from these sectors between 2010 and 2050 would consume about 13 per cent of the global carbon budget required to achieve 2DS by 2100, against approximately 15 per cent in the current business-as-usual scenario. This spells out the serious challenge that the globe faces in decarbonising industrial output. Clearly, energy efficiency and optimising processes will not suffice.

Can India make a big bet on the technologies that could transform the key industrial sectors of steel, cement, ammonia and petrochemicals? In India, together these sectors contribute to about 27 per cent of value addition and about 23 per cent of employment, but a whopping 74 per cent of emissions from the manufacturing sector (Gupta, Biswas, Janakiraman, & Ganesan, 2019). They also form the backbone of India's economic growth as they cater to the demand from other downstream sectors and, hence, have a strong growth outlook in the future. The National Steel Policy 2017, for instance, aims to achieve per capita steel consumption of 160 kilogrammes by 2030 by increasing crude steel production capacity from about 130 million tonnes in 2017 to 300 million tonnes by 2030 (Ministry of Steel, 2017). Increasing income levels would also lead to higher per capita consumption of cement and petrochemical products, thus warranting further investments in their production capacities. While the national policies have set a growth target for these sectors, the manufacturing process and, indeed, the demand for some of these products would have to be better understood. This is essential to achieve a sustainable trajectory by simultaneously reducing both import dependency as well as the emissions footprint from manufacturing.

2.1 Iron and steel



Source: Authors' analysis

Iron and steel production is the single largest emitter of greenhouse gas (GHG) emissions contributing to 32 per cent of the total manufacturing sector emissions in India. Driven by the National Steel Policy 2017, the sector is expected to have a three-fold increase in production capacity by 2030.

Although the industry is able to cater to domestic demand, it is struggling to remain competitive in global markets (Financial Express, 2019). India has put in place multiple measures like import duty, anti-dumping duty and a safeguard duty on steel imports to stop them flooding the domestic market. The lack of competitiveness is also evident from the low capacity utilisation of 78 per cent and a small export share of production especially when there is a huge export market. With China and Japan ramping down their production levels in recent years, India got an opportunity to capture a share of the South East Asian market. Between 2016 and 2017, the top two exporters, China and Japan reduced their exports by 32 per cent and 7 per cent, respectively. In the same period, Indian exports grew by 58 per cent pushing the country into the league of top 10 exporters. However, for India to even retain existing share in export markets in future, the domestic industry needs to improve on multiple fronts.

Most of the steel produced today is via integrated steel plants, primarily using the blast furnace (BF) technology. The raw material costs for these industries cut into half the revenue. The lack of domestic high-grade coking coal has forced the industry to increasingly rely on imports, thus impacting their competitiveness (PTI, 2018). In 2018, India imported more than 50 per cent of its coking coal requirement.

However, the future outlook for coal trade is weakening as major producers are shifting their priorities towards a low-carbon economy. Coking coal produced in Australia and the United States represents about 70 per cent of global production. Investors are pushing coal companies in Australia (The Economist, 2019) and in the US (Jamasmie, 2019) to reduce their production levels.

In response to the shortage of high-quality coking coal, a significant share of production of steel (about 33 per cent) shifted towards direct reduced iron (DRI) technology in early 2000s, which uses the (relatively) abundant reserves of low-grade non-coking coal. However, unlike the integrated plants, DRI producers have a higher share of input costs in production, amounting to about 70 per cent of their revenue. Also, the presence of a larger number of small-scale players make the sector highly sensitive to variations in raw material prices. These units leveraged cheap iron ore prices to rapidly scale up, but stagnated after the increase in iron ore prices after 2015.

Technology options for decarbonisation

India's iron and steel sector has the highest emissions footprint per unit of production globally (Figure 2). The average emissions intensity of production of steel in India is around 2 tonnes CO_2 per tonne of crude steel compared to a global average of 1.1 tonnes CO_2 per tonne of crude steel (IEA, 2018).

Developed economies in the European Union, Japan, and Korea have a fair share of production coming from recycling, thus reducing the energy intensity and emissions intensity of the sector (Figure 2). Unfortunately for India, a growing amount of virgin raw materials are to be pumped into the sector to cater to increasing needs. The current practices for recovery do not cater to all the secondary steel requirements that India has.

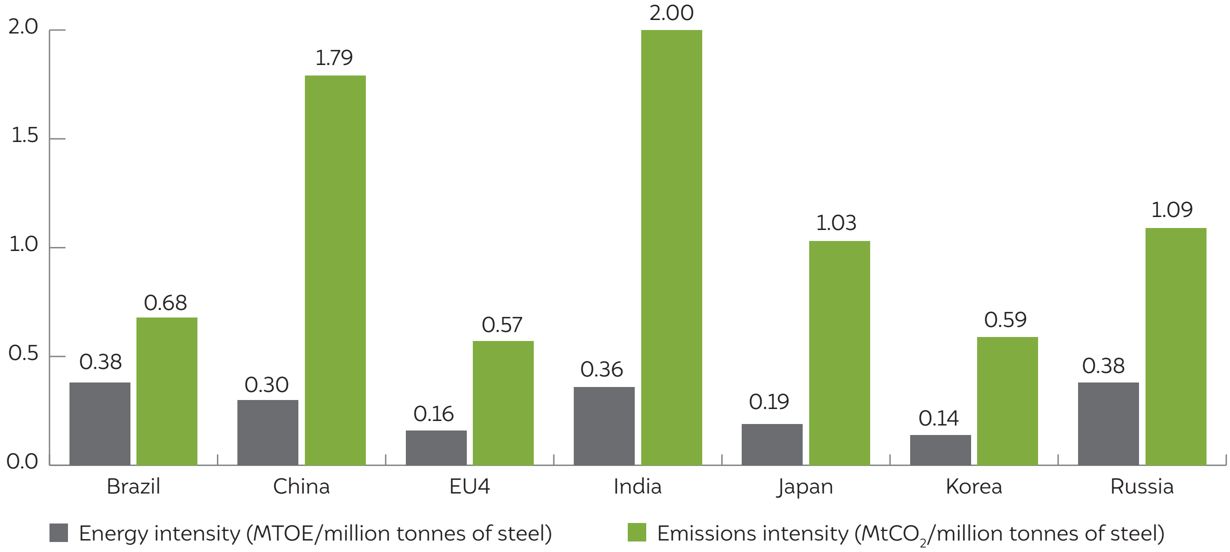
Other leading steel producers like Brazil, Russia and China have similar energy intensity levels, but varying levels of emissions intensity (Figure 2). A closer look at their fuel mix indicates a higher share of low-carbon fuels, namely biomass and natural gas. Brazilian industries have a similar energy intensity of production as compared to India but their emissions intensity is more than 65 per cent lower than their Indian counterparts. Around 42 per cent of the energy mix for the Brazilian industries comes from biomass sources, thus enabling them to achieve a significant reduction in the emissions intensity of production. Arcelor Mittal-owned BioFlorestas grows eucalyptus trees in Brazil to cater to the charcoal demand by the iron and steel industries. With approximately 60 per cent of land as forest area (The World Bank, 2019c), Brazil can balance production needs with sustainability.

Russia, on the other hand, leveraged the abundant supply of natural gas. It has been able to achieve a much lower emissions footprint than India, despite operating the world's most energy-intensive production facilities. The glut of locally available gas has meant that energy efficiency has not been on the radar for Russia. Nevertheless, commercially available natural gas-based technologies, as offered by MIDREX and Tenova HYL, have almost 40 per cent lower emissions intensity when compared to the BF technology.

> **India has the fifth largest reserves of coal-bed methane but is yet to explore its use in the iron and steel industry**

Despite recognising the importance of upgrading both the BF and DRI units to use natural gas, there is no explicit policy push in India for low-carbon steel-making. A value-based market for natural gas is non-existent in India as there is limited supply of domestic gas and many competing demands. The supply is highly subsidised and prioritises power, fertiliser and city-gas requirements, with large industries (other than fertiliser) left in the lurch. This distorts the market and precludes competitive use of gas in the most appropriate end-use application. Further, limited access to pipeline networks has prevented private sector participation and uptake in many parts of the country. It has also put paid to producers of non-conventional gas like coal-bed methane (CBM). India has the fifth largest reserves of CBM but is yet to explore the use of CBM

Figure 2: Compared to other countries, India has high emissions intensity for steel production



Source: IEA. (2018). World Energy Outlook in the iron and steel industry. Shifting the subsidy on gas given to specific manufacturing sectors entirely to end-consumers of products within the priority sectors would remove the existing price distortions and unlock the latent demand of natural gas within the economy. Additional incentives to transition to gas-based processes could emerge from the stricter enforcement of environmental regulations in key industrial sectors (including DRI producers).

Ambitious emissions mitigation commitments and strict enforcement of environmental regulations in Europe have facilitated many R&D partnerships between government and private sector. These partnerships have led to notable innovations towards low-carbon manufacturing of steel. For example, TATA Steel's plant in Ijmuiden, Netherlands has successfully piloted the low-carbon Hlsarna process for manufacturing steel. The plant has demonstrated 50 per cent lower carbon intensity of production when compared to the firm's Indian operation in Jamshedpur. However, implementing the same technology in India would shift the import dependency from coking coal to low-ash non-coking coal. This, then, would directly compete with the power sector, which has shown an increasing appetite for imported coal, despite having a domestic policy that aims to bring down imports to zero.

A technological bet on green steel for India?

The European steel industry has also been a pioneer in demonstrating zero-carbon steel making. Their research has two commercially available technologies, namely Circored process and electrolyser. The Circored process uses natural gas to produce hydrogen, which is then used to reduce iron. Swapping the steam methane reformer (SMR) with an electrolyser, which uses renewable electricity to produce hydrogen, eliminates the emissions in the iron-making process. A joint venture founded by Swedish companies SSAB AB, Luossavaara-Kiirunavaara Aktiebolag (LKAB), and Vattenfall initiated the HYBRIT project with the aim of achieving 100 per cent fossil fuel-free steelmaking by 2035. Their pre-feasibility study indicates that the cost of green hydrogen-based steel making is 20-30 per cent higher than the conventional process (blast furnace – basic oxygen furnace) (HYBRIT, 2019). Voestalpine, an Austrian steel company, in partnership with Siemens and VERBUND, has installed a 6MW electrolyser in their steelmaking plant in Linz (H2Future, 2019).

CEEW's analysis indicates that green hydrogen-based steel production in India would be competitive with the conventional production method with a carbon tax of USD 40 per tonne of CO_2

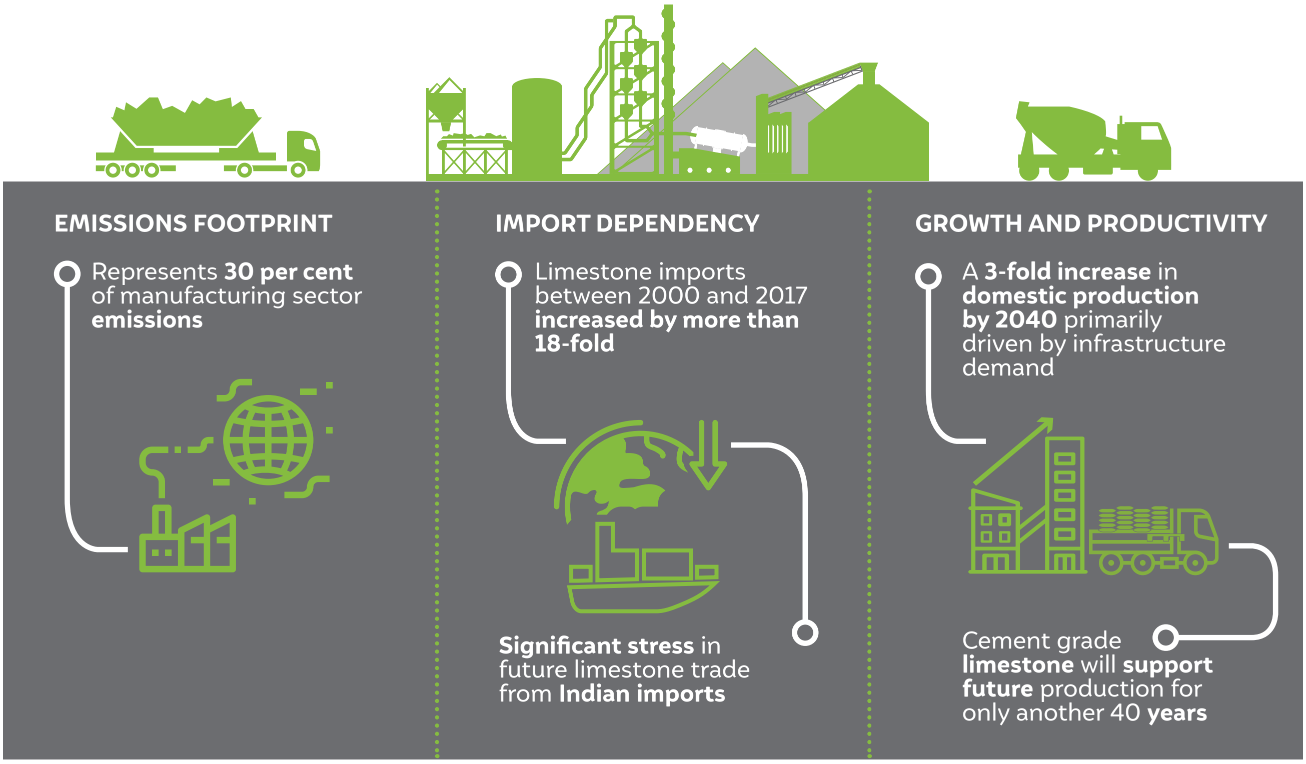
The higher costs of green steel, notwithstanding, policy uncertainty is the major barrier towards reducing the emissions footprint of Indian steel plants. While the availability of low-carbon fuels like natural gas or CBM is not a challenge, the absence of a pricing structure, which does not reflect the true environmental costs, is a barrier to the transition to low-carbon fuels. Our computations suggest that a tax of USD 32 per tonne of CO_2 would bring parity for industrial consumers between the cost of natural gas (imported as LNG) and coal on a delivered energy basis. Such an emissions tax would also increasingly make other zero-carbon energy sources like green hydrogen[1] competitive in the market. CEEW's initial analysis indicates that green hydrogen-based steel production in India would be competitive with the conventional BF production method with a carbon tax of USD 40 per tonne of CO_2.

A swift transition to green hydrogen-based steelmaking is not likely to happen in India. Incremental measures or signals would avoid additional investments being locked into coal-based processes. Preferring the natural gas-to-hydrogen reduced iron production technology, instead of adopting only natural gas reduced iron production technology, would offer higher emissions reduction that could outweigh the efficiency loss from the reforming of natural gas in the former (IETD, n.d.). Choosing the former would also reduce further investment costs required for green hydrogen-based production. This is because it would only require swapping SMR with the electrolyser.

In a carbon constrained global-economy, the green hydrogen-based steel production would support scaling up of production in meeting the strong domestic demand and provide for about 4 million direct manufacturing jobs by 2050. Further, it would create another 1.6 million jobs along the hydrogen supply chain, far replacing the fewer jobs involved only in the import and transport of coking coal.

1 Hydrogen derived from electrolysis of water using renewable energy sources

2.2 Cement production



Source: Authors' analysis

Among the manufacturing processes, cement production is the most emissions intensive of all. As one of the fastest growing economies, infrastructure investment in India has sustained cement demand in India. Robust growth in cement production has made India the second largest producer in the world. The associated emissions contribute to 30 per cent of total manufacturing emissions, second largest after steel manufacturing.

> Robust growth in cement production has made India the second largest producer in the world. The associated emissions contribute to 30 per cent of total manufacturing emissions, second largest after steel manufacturing

The industry is expected to have a strong growth outlook as government increases its budgetary expenditure for the infrastructure sector. The 2019 budget indicates a significant increase in allocation for major initiatives like *Pradhan Mantri Awas Yojana* (PMAY) providing housing for all by 2022, *Atal Mission for Rejuvenation and Urban Transformation* (AMRUT) targeting urban infrastructure improvement across 500 cities, and Urban Mass Rapid Transport System (Moneycontrol, 2019).

Between 2017 and 2040, IEA estimates indicate a three-fold increase in cement production in India (IEA, 2018).

Similar to iron and steel, the cement industry is also grappling with issues of raw material availability. A majority of the limestone reserves in India are unsuitable for use in cement production and, given the current rate of consumption, they can only support the industry for another 40 years (Indian Cement Review, 2018). In order to compensate for the declining quality, cement industries are increasingly using high-quality imported limestone for blending. Between 2000 and 2017, limestone imports increased more than 18-fold.

Technology options for decarbonisation

GHG emissions from cement production are a combination of emissions from combustion of fossil fuels and also the release of CO_2 from the calcination of limestone (calcium carbonate releases CO_2 upon being heated to high temperatures). The cement industry has been a pioneer in pursuing sustainable production practices. Efforts to improve the energy efficiency of the production process began as early as 1970s. With modern cement plants today already operating at their theoretical limits of efficiency, much of today's efforts are directed towards use of alternative fuels and lowering clinker content in the cement.

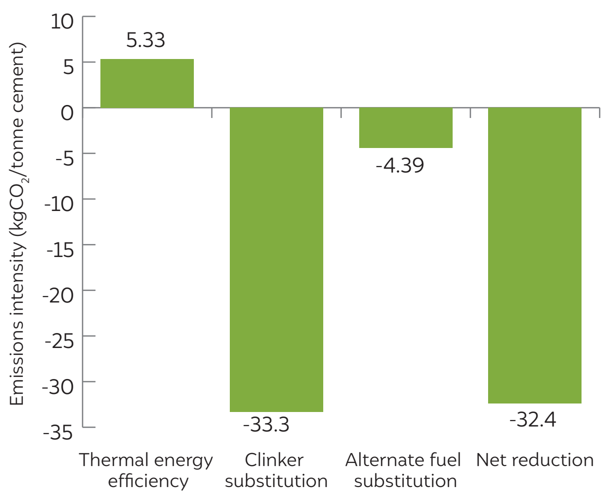
European countries have been able to make significant headway in replacing a large share of fossil fuels with alternative fuels in the clinker production stage. Poland's waste management policy, for instance, imposes a heavy tax on landfills, thus forcing waste management companies to look for alternative sources of waste disposal. Most of the cement plants in the country now have long-term contracts with waste management companies, and have been able to achieve an alternative fuel substitution rate of 60-85 per cent.

In India, the emissions intensity of cement production decreased by 32.4 kg CO_2/tonne of cement (a decrease of only 5 per cent) between 2010 and 2017 (Figure 3). While clinker substitution is responsible for much of the reduction in emissions intensity, use of alternative fuels in the clinker production process has been limited so far.

As of 2017, coal, petroleum coke (petcoke) and alternative fuels catered to 41, 56 and 3 per cent, respectively, of total energy demand by the sector (WBCSD, 2018). Further, the decreasing grade of limestone is forcing industries to use fuels having high calorific value, further limiting the potential of using biomass. The availability of low-cost petcoke has made it the preferable choice for cement production. However, studies also indicate that extensive use of petcoke can potentially increase the emissions intensity of the process (WBCSD, 2018).

For Indian cement plants, more than alternative fuel use, it is the reduction in clinker content in cement that can help address their increasing import dependency

Figure 3: Contribution of different factors to emissions intensity improvement of Indian cement production between 2010 and 2017



Source: WBCSD. (2018). Low Carbon Technology Roadmap for the Indian Cement Sector: Status Review 2018

for high-grade limestone and simultaneously reduce the emissions footprint of the manufacturing process. Between 2010 and 2017, the production share of blended cements has increased from 68 per cent to 73 per cent. However, the average clinker factor of Indian cement still remains at 0.71 when compared to a global average of 0.66. For blended cement, such as Portland Slag Cement having clinker factor as low 40 per cent, production remained at very low levels (10 per cent). Unavailability of granulated blast furnace slags continues to be a major hindrance in scaling up its production.

A technological bet on low-carbon cements?

Other low-carbon alternatives to Ordinary Portland cement (OPC) are already in various stages of R&D, while some are making rapid progress towards commercial availability. In collaboration with École polytechnique fédérale de Lausanne (EPFL), researchers from IIT Delhi, IIT Madras and IIT Bombay are already working on pilot production and testing the strength of a Limestone Calcined Clay Cement (LC3) in India. Results indicate that LC3 can achieve similar strengths compared to Portland cements by replacing as much as 50 per cent of the clinker and use the low-grade limestone abundantly available in the country. Production of the cement still uses similar raw materials, equipment and processes as Portland cement.

Other commercially available natural pozzolans, like geopolymers, could completely replace the use of clinker and potentially do away with the need for limestone. Geopolymer cements are produced by mixing of thermally active materials like flyash, blast furnace slag or volcanic rocks with an activating solution to create a hardened binder, with performance similar to Portland cement. Zeobond's E-crete and Wagner's Earth Friendly Concrete have up to 90 per cent lower emissions intensity of production when compared to the Portland cement (Batten, 2018).

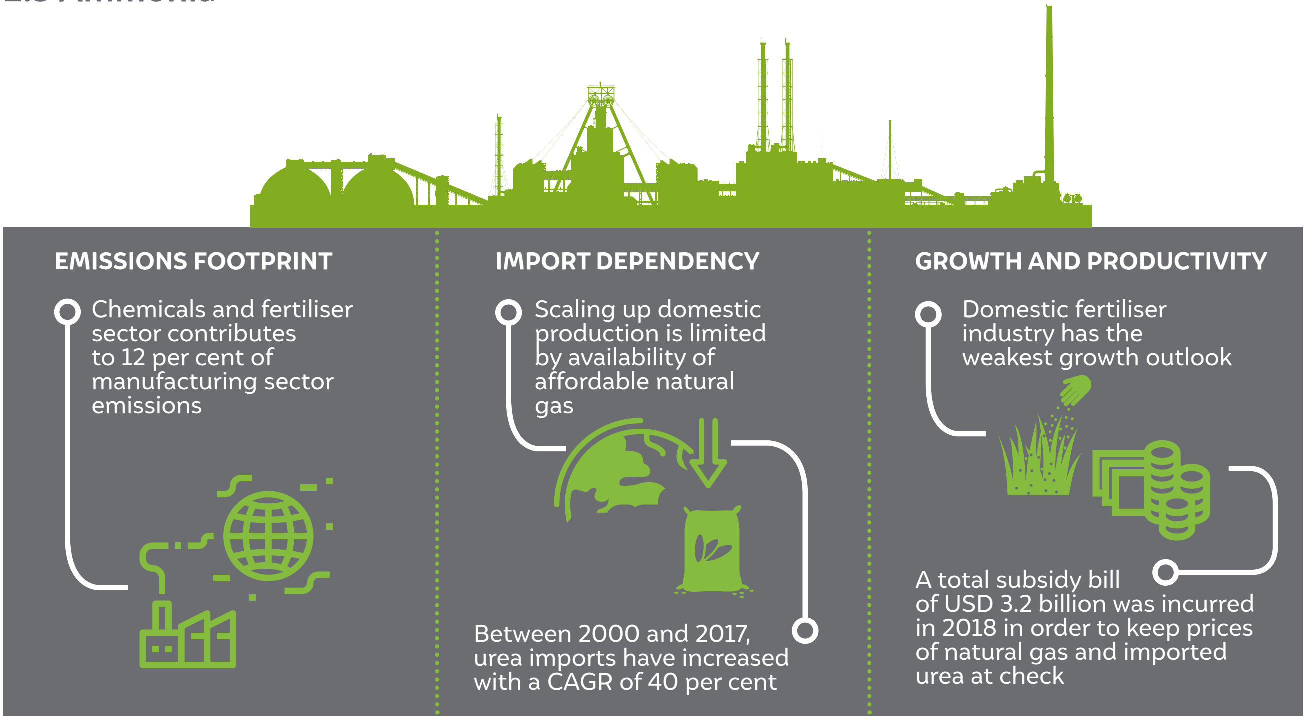
While the transition away from OPC would lead to sustainable production, their adoption is dependent on long-term performance data to promote social acceptance for these alternative materials. Further, performance data would be crucial to develop industry standards. In order to allow more blending of limestone directly (instead of clinkers) into cement in the United States, the American Society for Testing and Materials (ASTM) standard was revised to allow up to 15 per cent blending (Batten, 2018). However, for European countries the blending limit was at 35 per cent as they have been using limestone blended cements for decades (Batten, 2018). In India, the commercialisation of LC3 cements are subject to approval by the Bureau of Indian Standards.

> **Supporting transition of the domestic cement manufacturing to low-carbon cement would ensure that the sector would support 0.54 million jobs in 2050, and zero import dependency on limestone imports**

To increase awareness and social acceptance of alternative cements, government infrastructure and public sector undertakings (PSUs) could be the ideal testing grounds. The University of Queensland was the pioneer in using geopolymer cement to build the Global Change Institute in 2013. Additionally, policy nudge for faster adoption can be created by leveraging the existing building codes and standards and voluntary labelling programmes. Both GRIHA and LEED rating systems offer credit points in using low-carbon cements (CPWD, 2014). Rewarding the voluntary certifications with suitable financial incentivises could potentially accelerate the adoption of these alternatives. The cement industry also supports 600 direct manufacturing jobs for every million tonne of cement manufactured. Supporting the domestic manufacturing to transition towards low-carbon cement would ensure that the sector would support 0.54 million jobs in 2050, and a significantly lower emissions intensity and zero import dependency on limestone imports.

In 2050, the total demand for cement globally is likely to hit 4.4 billion tonnes – a 100 per cent increase from the present capacity. Even assuming a clinker factor of 0.66 is achieved globally, and all of the fuel- related emissions are negated, process emissions from cement alone would amount to 1.6 billion tonnes of CO_2. There will be a need for dedicated carbon sequestration (either on site or from air) to at least ensure that process emissions from cement are abated. There is no development on the horizon on a material that will replace the need for clinkerisation in its entirety.

2.3 Ammonia



Source: Authors' analysis

Ammonia production is the third largest emitter of GHG emissions from the manufacturing sector, after steel and cement. Ammonia is integral towards ensuring national food security as it is primarily used to make urea, an essential fertiliser. India is the world's second largest producer of urea and simultaneously also the largest importer of urea (in 2016) (YARA, 2018). This clearly highlights the inability of the domestic manufacturing industry in scaling up to meet domestic demand. The IEA's NPS scenario also indicates that the domestic fertiliser sector would have the lowest growth rate until 2040 compared to the other manufacturing sectors considered in this brief (IEA, 2018).

Domestic ammonia production has always been marred with challenges from regulatory price controls, energy inefficiencies of production, and import dependency for feedstock and fuel requirements. The oil crisis of 2007-08 forced the industries to switch to domestic natural gas from naphtha as feedstock. While this switch provided significant cost advantages, industries faced supply shortages of cheaper domestic gas.

Further, government interventions to keep the domestic gas prices low has an adverse impact on fertiliser production and also on the exchequer. The price control on urea, to shield the farmers from price shocks, limits the uptake of imported natural gas by fertiliser industries unless government subsidies absorb the incremental price difference with respect to the fixed gas tariff as per the Administrative Pricing Mechanism (APM). The Fertiliser Association of India (FAI) estimates that USD 3.2 billion was spent as an additional subsidy towards use of imported gas in the fertiliser industries in 2018 (BusinessLine, 2018). This amount represented about 10 per cent of total subsidy (food, fuel and fertiliser) budget for the fiscal year (IndiaToday, 2019). Further, subsidies on imported urea also paved the way for imported urea flooding the market. Consequently, urea imports have increased from 0.2 million tonnes in 2000 to 6 million tonnes in 2017.

Technology options for decarbonisation

The conventional ammonia manufacturing process is a mature technology. It was invented in the late 1920s and has undergone considerable improvement in production efficiency. The theoretical energy requirement to produce a tonne of ammonia improved from approximately 19 GigaCalories (GCal) to nearly 6 GCal in recent years (Brown, Innovations in Ammonia, 2018). Baseline data from India's Bureau of Energy Efficiency indicates that the domestic fleet is operating with an average energy efficiency of 7.4 GCal per tonne of ammonia (BEE, 2015). This suggests that there is a possibility of nearly 20 per cent improvement in energy efficiency before the process hits the theoretical limits of efficiency. Beyond that, further reduction in emissions footprint would not be achievable with the existing production process.

Baseline data indicates that domestic industries are operating with an average energy efficiency of 7.4 GCal per tonne of ammonia. This suggests that there is a possibility of nearly 20 per cent improvement before hitting the theoretical limits

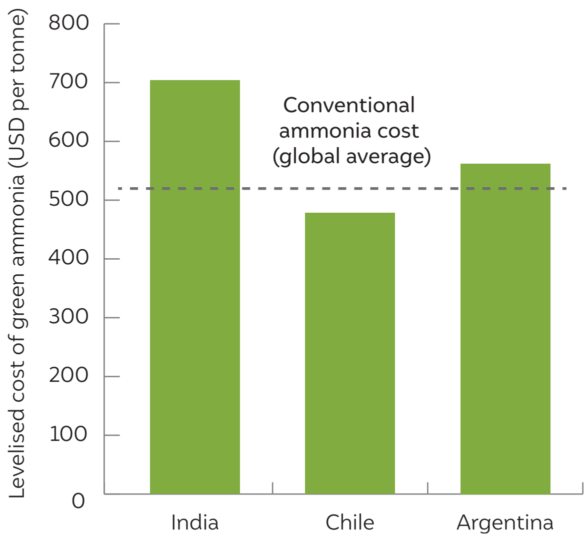
To reduce the import dependency on urea, the government has rolled out initiatives to revive the loss-making industrial units and ensure sustained supplies of feedstock at competitive prices. Using alternative feedstock like syngas from coal and coal bed methane (CBM), instead of natural gas, is one among these efforts. India's first coal gasification project to produce urea is under construction in Odisha while another CBM-based urea manufacturing unit in West Bengal is anticipated to start commercial production by end-2019 (Argusmedia, 2019) (DNAIndia). Although successful trials of these two plants would reduce the sector's dependency on imported gas, the emissions footprint from these processes would be not lower compared to the conventional natural gas-based production.

A technological bet on green ammonia for India?

With an ambitious aim of truly decarbonising the ammonia production process, public-private investments are increasingly being used to support R&D and commercial pilots of green ammonia[2]. Two of the pilot projects are already running in Oxford and Fukushima, while many others are in the pipeline (Brown, 2018a). The aim is to reach zero carbon emissions from the current emissions intensity of 2.1 tonnes of CO_2 per tonne of ammonia produced. The process focuses on generating hydrogen from the electrolysis of water using renewable electricity and further combine with nitrogen captured from the air to produce ammonia. Further, the green ammonia technology is easy to integrate with the existing production process as the electrolyser would only replace the steam methane reformer.

Significant reduction in electrolyser costs (from USD 4.4 million per MW to USD 0.6 million per MW) and cheaper renewable electricity have already incentivised major global economies to develop policy roadmaps for the green hydrogen transition. Countries like Australia, France, Japan, Netherlands, Norway, Singapore and South Korea have announced their national

Figure 4: Levelised cost of green ammonia comparison across India, Chile, and Argentina



Source: Nayak-Luke, R., & Biswas, T. (2018). Techno-economic assessment of ammonia production using green hydrogen (to be published); Armijo, J., & Philibert, C. (2019). Flexible production of green hydrogen and ammonia from variable solar and wind energy. Case study of Chile and Argentina

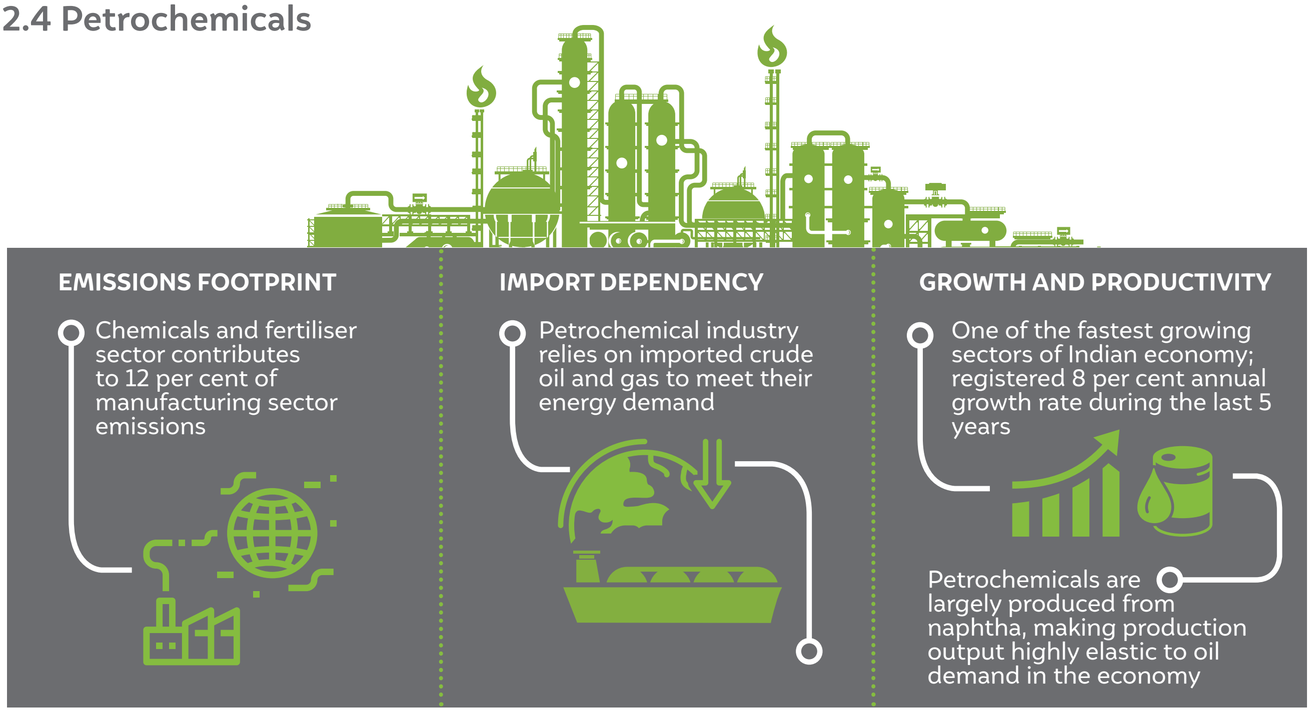
commitments towards transitioning to a hydrogen economy (Schoentgen, 2018).

A joint study by CEEW and IEA estimated the cost of green ammonia in India to be 36 per cent higher than the conventional production by 2030 (Nayak-Luke & Biswas, 2018). However, the study assumed conservative estimates for the capital costs of electrolyser and hydrogen storage, especially when the recent market trends indicate a further decrease in costs with economies of scale. A recent paper by IEA, which assumed more optimistic capex costs, indicated that green ammonia production in Argentina and Chile would reach cost parity with conventional production in the near-term (Armijo & Philibert, 2019).

More importantly for India, a transition to green ammonia production would help the fertiliser industry break away from the vicious cycle of natural gas supply and demand in India while achieving near-zero emissions footprint from production. Further, by 2050 about 200,000 jobs could be created along the hydrogen supply chain replacing the 20,000 jobs involved in the domestic natural gas supply chain.

2 Ammonia produced using hydrogen derived from renewable sources.

2.4 Petrochemicals



Source: Authors' analysis

Within the chemicals sector, the production of petrochemicals – primarily production of ethylene and propylene – is the most emissions intensive process after ammonia. These chemicals are the building blocks for the polymer industry – and we depend on these polymers. Polymers are increasingly being used across all applications in the economy as they provide varied operational benefits over their metal counterparts. Between 2017 and 2040 the IEA estimates a near two-fold increase in ethylene and propylene production. Most of the future production capacity is anticipated to come online in South Asia, especially with India poised to have a strong growth outlook from its current domestic production representing four per cent of global capacity.

Over the last five years, the petrochemicals sector was one of the fastest growing sectors within the Indian manufacturing industry registering an annual growth rate of more than eight per cent (FinancialExpress, 2018). The sector was able to leverage the presence of huge refining capacity to scale up production and meet growing domestic demand. This resulted in a rapid decrease of petrochemical (ethylene, propylene, and butadiene) imports from 39,300 tonnes in 2000 to just 24 tonnes in 2017. India's current per capita consumption of petrochemicals is at 10 kilogrammes compared to the global average of 30 kilogrammes, indicating significant room for further expansion of the domestic manufacturing sector (IBEF, 2018).

However, this growth will come at a considerable cost to the environment as every tonne of petrochemicals production emits roughly around 2 tonnes of CO_2. Most of the emissions arise from the need for thermal energy for the cracking process (about 60 per cent of total energy consumption). Decarbonising the sector will require efforts to change the feedstock and fuel for the existing processes as the steam cracking furnaces today are already operating at their peak efficiencies of 94 per cent (Batten, 2018).

The global landscape of petrochemical production has been rapidly evolving, with countries using a variety of feedstock and production technologies primarily to gain economic advantages. Much of the global production (including in India) today relies on naphtha as the primary feedstock for petrochemicals production as it allows oil refineries to gain additional revenues by converting it into high value-add chemicals, which otherwise would have been sold as fuel. However, with global focus shifting towards electric mobility, industry experts forecast that as demand for transportation fuel in passenger cars tapers down, the petrochemical sector is likely to step in and prop up demand for crude oil. Estimates indicate that the petrochemical feedstock will drive 70 per cent of oil demand until 2035 (Roelofsen, Sharma, Sutorius, & Tryggestad, 2016).

Technology options for decarbonisation

Recent investments by oil companies aim to strengthen links with petrochemical markets and driving more integration with the refineries to increase the share of output of chemicals from each barrel of crude processed. This integration, although driven by economic decisions, will have an indirect impact on improving the efficiency of production from crude oil. In January 2018, Reliance Industries commissioned the world largest Refinery Off-Gas Cracker (ROGC), which uses the refinery gases (and gasified petroleum coke) as feedstock for the petrochemicals production. This also has made it the most energy efficient producer of petrochemicals around the world (The Economic Times, 2019). Similar investments are also seen across a number of plants in Kuwait, Oman and Saudi Arabia (Sadoun, 2018). However, refinery integration would still produce a fair amount of oil products. This would limit the petrochemical throughput unless alternative markets can be developed especially for India, where year-on-year growth for oil product demand is expected to taper down after 2020 (IEA, 2018).

Further, technologies like Crude Oil to Chemicals (COTC) and Oxidative Coupling of Methane (OCM) would completely de-link the petrochemical output from demand of oil products. These technologies aim to merge a refinery and a petrochemical plant into one. The objective has been to increase the output of petrochemicals from a barrel of oil to a range of 40 to 80 per cent from the existing range of 15 to 25 per cent. In June 2018, a joint venture between Siluria technologies and Saudi Aramco (the world's second largest daily producer of oil) was announced to pilot an integration of both the technologies in Aramco's refinery. The project aims to increase the yields of petrochemical up to 72 per cent while achieving a net-negative CO_2 emission per tonne of ethylene produced (Business Wire, 2018).

While these technologies would certainly reduce the emissions footprint, it would still make India import dependent on the feedstock for production of petrochemicals. Often these trade-offs are decided by a country's policy priorities. China commercialised a radically different process to manufacture petrochemicals in order to reduce its import dependency on oil. It was able to leverage their vast resources of coal to produce methanol, which was then used as a feedstock for petrochemicals production. This process, however, has a significant environmental cost. Studies indicate that the coal-to-methanol-based process is five times more emissions intensive when compared to the conventional naphtha-based process (Zhao, et al., 2018).

A technological bet on green methanol to petrochemicals for India?

The methanol route, however, can offer opportunities for India to address both import dependency on crude as well as reduce emissions footprint of production. Methanol can be produced from biomass and has a negligible carbon footprint associated with its production. Typical sources of these biomass include sugarcane, corn and wheat starch, plant dry matter, along with host of vegetable oils (palm, soybean, oilseeds etc.) and could be sourced readily. However, additional challenges like costs associated with harvesting, transportation, the water footprint and, most importantly, impact on global food supply have to be evaluated and addressed.

An alternative green methanol-based production process, on the other hand, provides opportunities to replace natural gas (which is the predominant way it is produced today) with water, and utilise CO_2 emissions from other industrial processes to produce methanol with zero carbon emissions. The technology would involve an electrolyser producing hydrogen using renewable electricity and CO_2 captured from the air to produce syngas, a feedstock for green methanol production. A recent industry joint venture in the Netherlands aims to set up a commercial plant to produce green methanol (The Chemical Engineer, 2019).

> **CEEW and IEA's study indicates that by 2030 the green methanol process would likely have lower cost when compared to both natural gas and coal-based production processes in India**

CEEW and IEA's study indicates that by 2030 the green methanol process would likely have lower cost when compared to both natural gas and coal-based production processes in India. With the petrochemicals sector seeing an increase in demand for more products, shifting towards the green methanol-based production process could provide India with an opportunity to simultaneously reduce the import dependency on oil and the emissions footprint of production.

> We estimate that the green methanol based petrochemical process would also create an additional 160,000 jobs along the hydrogen supply chain, which otherwise would be lost in the conventional production process as both the fuel and feedstock requirement would be met through imports.

3. Accelerating the industrial decarbonisation

Historical trends indicate that the manufacturing sector has been able to achieve significant reductions in its emissions intensity, a result of continued efforts to inch closer to theoretical efficiency limits for their individual processes. But the demand for these core products – steel, cement, ammonia, petrochemicals – will remain robust for a growing economy like India's. Decoupling emissions from economic growth and the production processes for these industries is important. Interventions are needed to substitute existing technologies and processes with their low-carbon counterparts.

As for any new technologies or processes, mainstreaming them into commercial production comes with a lot of initial challenges, especially in terms of costs (business bottom lines), logistical challenges (new production facilities) and social acceptability (what new technologies mean for existing jobs and incomes). It is imperative for domestic policies to address the levers that can catalyse a transition towards sustainable manufacturing.

3.1 R&D and innovation partnerships for mitigation technologies

Lessons can be learnt from the Ultra-Low CO_2 Steelmaking (ULCOS) programme that brought together 48 European companies and 15 European countries for joint public-private R&D investments to reduce the emissions footprint for steel-making. Tata Steel's Hlsarna technology is one of the successful technologies from the programme that is now ready for commercialisation.

India's R&D expenditure as a share of GDP is much lower than the world average. The paltry levels of research spending have limited indigenisation of technologies and the ability of the manufacturing sector to implement process innovations. Mitigation technologies are in various stages of development and require tailored technology partnerships, financing, and governance structures.

These technology stages can be categorised as: technologies needing commercial pilots to scale; technologies needing significant early stage investments to prove commercial viability; and horizon technologies with high mitigation potential but also significant risks (Ghosh, Chaturvedi, & Bhasin, 2019).

Technologies requiring commercial pilots to scale up have the lowest risk compared to the other two (as mentioned above) and could be supported by a venture fund. Further, assistance from philanthropic foundations could aid in specific activities like demonstration pilots, underwriting risks to lower cost of finance for investors etc. This approach could be followed once technologies have matured enough to deploy at commercial scale, such as increasing energy efficiency for ammonia production in India.

The technologies that are at the early stage of development could be supported through R&D partnerships between universities, government research laboratories and commercial enterprises. A public-private financing model could offset a substantial portion of the risks associated with the uncertainties regarding their success. If consortia were formed, members could co-own the resulting intellectual property. Advanced market commitments from governments to procure new products that meet specified parameters would give an added incentive for private investment. Such an approach could be useful in the cement sector if the development and promotion of LC3 cement were to be encouraged or for green methanol use in petrochemicals.

> **Pooling resources across countries for joint R&D to develop green hydrogen would be a more transparent and equitable way forward**

Horizon technologies have significant mitigation potential, but have equally high inherent risks. The risks could directly be associated with technological failures or indirectly from adverse impacts on environmental ecosystems or geopolitical tensions. They would require international cooperation to pool together resources as well as avoid unilateral development or deployment of the technologies leading to unintended consequences. The cost reductions in deriving green hydrogen from renewable energy as a substitute in the steel and ammonia sectors would be a significant challenge and is bound to result in a technological race of sorts. Instead, pooling resources across countries for joint R&D to develop green hydrogen would be a more transparent and equitable way forward.

3.2 Regulatory drivers to enable a clean energy transition

Make clean energy affordable and available

The potential of policy intervention in making clean energy affordable is evident in the case of solar and wind electricity. However, majority of the energy demand in heavy industries is in the form of thermal energy and their cleaner alternatives are yet to become economically competitive.

Private sector participation along the energy supply value chain increases competition leading to continual improvement in the quality of supply and competitive pricing. Natural gas in India is highly regulated starting from production to supply, thereby giving disincentives to private participation along the value chain. Much of the natural gas supply and distribution networks are owned by public sector undertakings (PSUs) and they have shown limited interest to cater to the distributed demand across multiple small-scale manufacturing clusters. The Chinese government's decision to open up the natural gas market led to a significant increase of LNG demand in an economy primarily reliant on coal for its energy needs (CNBC, 2019). By doing away with administrative price controls, non-uniform a taxation at sub-national level, and opening-up for private sector participation in natural gas supply and distribution, India could potentially unlock gas production from non-conventional fields and alternative distribution models offering competitive prices.

Tax environmental externalities

In order to enable a transition to a cleaner energy mix, fuel prices need to reflect the true cost of their environmental impact. The existing taxation system in India is required to be revised such that they penalise polluting fuels and incentivise the cleaner ones, ensuring no adverse impact on the government exchequer and industry competitiveness.

In anticipation of a possible carbon-constrained economy in the future, private companies are considering an internal carbon price (shadow price) to make their investment decisions. Around 1400 companies globally, including 37 in India, are in the process of adopting an internal carbon price (The Economist, 2018). Although market signals indicate an appropriate time to implement a carbon tax, a unilateral move would warrant additional measures to avoid carbon leakage or the shifting of manufacturing to countries having relaxed carbon constraints.

Introduce other non-economic drivers for energy transition

The fact that energy prices today do not reflect the cost of associated environmental degradation and health impacts makes the economic argument for energy transition weak. However, holding industries accountable for their contribution to environmental pollution would incentivise investments in mitigation measures.

> **Much of India's manufacturing capacity is yet to be built and putting in place strict emissions control standards now would ensure the new capacities built are compliant, and at a much lower cost of transition**

Enforcement of emissions standards in India has not been an easy task. While a revised set of emissions standards for coal-based utility scale power producers was notified in late-2015, the standards are yet to be implemented. Unlike the power sector, much of the manufacturing capacity is yet to be built and putting in place strict emissions control standards now would ensure the new capacities built are compliant, and at a much lower cost of transition.

3.3 Creating a domestic market for green products

Consumers have a strong influence on the manufacturing processes and raw materials used. With global heating becoming ever more perceptible and widely accepted as being driven by anthropogenic factors, the consumer appetite and preference for low-carbon products is gradually increasing. And investors are also driving changes in management decisions regarding fuel use, process efficiency or withdrawal from potentially stranded assets. This process can be accelerated further.

> **Providing a financial incentive for the purchase of green products would enable a faster market development especially for products having a social acceptance barrier**

Financial incentives and consumer awareness

Governments across many countries are leveraging this opportunity to create their domestic market for green products. The Korean Ministry of Environment introduced a green card, which provides reward points on purchase of eco-friendly products. Similarly, governments in China and the Republic of China (Taiwan) are increasing consumer awareness through carbon labelling of products.

In India, the Bureau of Energy Efficiency (BEE) has been running a *Star Labelling Programme* to promote consumer awareness towards certain energy efficient appliances. The same could be extended to represent the emissions footprint both from a product's manufacturing as well as its use, recycling and reuse. Further, providing a financial incentive for the purchase of green products would enable a faster market development especially for products having a social acceptance barrier.

Leveraging vendor supply chains

Many large corporates have established tiered-vendor chains and it highlights the opportunity to green the supply chain. Apple's initiative to reduce the carbon footprint of its products has led to complete transition in the aluminium industry. Apple facilitated the development and scale up of a new smelting process that releases oxygen instead of carbon dioxide, thus decarbonising the production process. Similarly, Samsung was also able to make substantial headway in improving the energy efficiency at their global production sites. Supply chains offer scale economies when otherwise small and medium enterprises would find it harder to invest in the technological upgrades needed to shift to a low-carbon, high efficiency path for production processes and for fuel switching.

4. Conclusion

India's NDCs and contribution to the global mitigation effort are predicated to a large extent on the achievement of an aggressive build out of renewable energy sources, mainly solar energy. This is a logical choice for a country where about 55 per cent of the emissions are from power generation and which has more than 300 days of sunshine. However, a single-minded pursuit of one sector and one source of emission must not let other opportunities fall by the wayside. Industrial energy use is a key area of focus given that its share in primary energy will rise to 42 per cent by 2030, even under newly proposed policies. Clearly, the targeting of energy efficiency alone may not be sufficient, if India were to ramp up ambitions, in tandem with the rest of the world, to rein in temperature increase to within 1.5 C by the end of this century.

Our analysis of the four key sectors – steel, cement, fertilisers and petrochemicals – reveals that the opportunities to decarbonise them are aplenty. India's competitiveness in manufacturing some of these products needs a boost and the shift to these technologies provides a window of opportunity to a large manufacturing economy like India to take the lead. While many of the technologies discussed here are still in their nascent stage, in many cases the underlying process remains the same. It is only the fuel input that changes. We find that the use of hydrogen derived from electrolysis, using solar and/or wind (hybrid) power, is likely to become competitive with conventional fuels. With India and many parts of the global south being blessed with solar resources, this presents an interesting proposition to rekindle the role of industries in driving economic growth. Sustainability can become one key driver to bet on new technologies that could help India prepare for changing market structures and product and process standards at home and abroad.

While jobs in conventional manufacturing are present today, they are at a risk of being lost, either because these will become uncompetitive or their relevance in a world with stricter regulation on emitting carbon will be limited. A different approach is then needed if India had to sustain and increase the pace of job creation that the growing working age population will impose.

A key outcome of our analysis is also that much effort is needed in R&D and commercialisation of technologies to abate emissions from sectors or processes (like clinker making), which will continue to emit significantly even by mid-century. There are no alternatives in sight today. A concerted, global effort to leverage resources across countries will be needed to mainstream these new technologies. India must lead the charge if we are to reap the benefits of these new approaches to manufacturing, lest we end up in the historical trap of technology dependence and the resulting apathy to resource efficiency. A big bet on growth, jobs and sustainability is now needed urgently.

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