A macro investigation into the evidence for circular economy initiatives in India:

National policy, key indicators and future implications

by

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Declaration

This thesis is submitted in fulfilment of the requirements for the degree of Master of Research in the Macquarie Graduate School of Management (MGSM), Macquarie University. Except as acknowledged in the references, the material included in the thesis represents the original work and contributions of the author.

I hereby certify that the research described in this dissertation has not been submitted for a higher degree to any other university or institution.

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Abbreviations used in thesis

ADC	Asian Developing Country
B2C	Business-to-Consumer
BEE	Bureau of Energy Efficiency
BF	Blast Furnace
BF-BOF	Blast Furnace and Basic Oxygen Furnace
BRIICS	Brazil, Russia, India, Indonesia, China, South Africa
CAGR	Compounded Annual Growth Rate
CDM	Clean Development Mechanism
CDRI	Cold Direct Reduced Iron
CE	Circular Economy
CEA	Central Electricity Authority
CER	Certified Emission Reduction
CETP	Common Effluent Treatment Plant
COP21	Conference of Parties, Paris 2015
CRM	Cold Rolling Mill
DC	Designated Consumer
DMC	Domestic Material Consumption
DMI	Direct Material Inputs
DMIC	Delhi Mumbai Industrial Corridor
DRI-EAF	Direct Reduced Iron and Electric Arc Furnace
EAF	Electric Arc Furnace
EE	Environmental Economics
EIA	Environmental Impact Assessment
EID	Eco-Industrial Development
EIP	Eco-Industrial Park
EKC	Environmental Kuznets Curve
ELV	End-of-Life Vehicle
EMC	Environmental Management Cell
EPI	Environmental Performance Index
EPR	Extended Producer Responsibility
ETP	Effluent Treatment Plant
FES	Fume Extraction System
FMCG	Fast moving consumer goods
FYP	Five-year plan
GCPC	Gujarat Cleaner Production Centre
GDP	Gross Domestic Product
GSDP	Gross State Domestic Product
GOI	Government of India
GPCB	Gujarat Pollution Control Board
GVA	Gross Value Added
HBI	Hot Briquetted Iron
IE	Industrial Ecology
IEA	International Energy Agency
IGEP	Indo German Environment Partnership

IMF	International Monetary Fund
INDC	Intended Nationally Determined Contribution
IS	Industrial Symbiosis
ISA	International Solar Alliance
ISI	Iron and Steel Industry
Kgoe	Kilograms of oil equivalent
KSCB	Karnataka State Pollution Control Board
LCA	Life Cycle Analysis
MFA	Material Flow Accounting and Analysis
MI	Material Intensity
MII	Make in India
MNRE	Ministry of New and Renewable Energy
MoEFCC	Ministry of Environment, Forest and Climate Change
MP	Material Productivity
MSME	Ministry of Micro, Small and Medium Enterprises
MSW	Municipal Solid Waste
Mtoe	Million tonnes of oil equivalent
NAPCC	National Action Plan for Climate Change
NDRC	National Development and Reform Commission in China
NIE	Naroda Industrial Estate
NMEEE	National Mission for Enhanced Energy Efficiency in Industry
NMIZ	National Manufacturing Industrial Zone
NMSH	National Mission on Sustainable Habitat
NSM	National Solar Mission
OECD	Organisation for Economic Co-operation and Development
PAT	Perform, Achieve and Trade
PCPIR	Petroleum Chemicals and Petrochemical Investment Zones
PPP	Public-Private-Partnership
RDF	Refuse Derived Fuel
REC	Renewable Energy Certificate
SEC	Specific Energy Consumption
SEZ	Special Economic Zones
SFA	Substance Flow Analysis
SME	Small and Medium Enterprise
T&D	Transmission and Distribution
TDS	Total Dissolved Solids
TERI	The Energy and Resources Institute
TPE	Total Primary Energy
TSDF	Treatment, Storage and Disposal Facility
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNIDO	United Nations Industrial Development Organization
WB	World Bank
WEEE	Waste of electrical and electronic equipment
WEF	World Economic Forum

Abstract

The idea that a circular economy (CE) signifies an inevitable transition to a sustainable future, where the often divergent goals of economic growth and ecological conservation harmoniously function in tandem, is gaining prominence in both academia and industry. This study reviews the present policy structure, significant indicators and future outlook of CE underpinnings within the Indian context.

India’s burgeoning economy and rapidly expanding manufacturing pursuits have placed enormous burden on its resource security and already substantial dependence on coal as a source of energy. The nation’s thrust on renewables envisages optimistic prospects of attaining the targeted GDP growth while decoupling the impact on domestic material and energy sources. In the midst of immense international scrutiny and quantified targets for reduction of emissions and energy intensity, this study offers an extensive review of India’s accomplishments in decoupling resource use from economic growth and related policy framework. Evidence of CE implementation is established through the case of a steel manufacturer. While CE presents a national socio-economic growth strategy for China, India is yet to develop a comprehensive CE plan.

The results of the review suggest substantial gaps in current action vis-à-vis targeted long-term ecological goals. This initial examination has facilitated a deeper understanding of the present and future drivers of circular economic action in India, and how these compare with the still-evolving worldwide CE agenda. Caution is critical in assessing the application of alternative economic models to the developing world, since their economic-environmental-social foundations and goals differ from those of the developed world. Future research into field-level data collection and assessment will build upon the present findings and enable a more complete evaluation of India’s path to CE accomplishment.

Chapter 1: Introduction and research background

1.1 Introduction

The global population is expected to reach 9 billion by 2030, with 30% anticipated to comprise the middle-higher income group, marked by an augmented spending capacity (EllenMacArthurFoundation, 2013; WorldEconomicForum, 2014). The consumption of goods and services will undeniably soar, requiring an even more intensive input of raw materials and energy, and producing increased levels of global emissions and waste that ends up in landfill. Fast-moving consumer goods (FMCG) alone account for an annual USD 2.5 trillion worth of waste material and energy release worldwide (EllenMacArthurFoundation, 2013; WorldEconomicForum, 2014). The most likely outcome of the skewed imbalance between economic progress and ecological impact is resource insecurity, unless the economic system makes a strategic shift from the current 'take-make-dispose' wasteful consumption patterns.

The literature illustrates the inextricable connection between economic growth or industrialization, and the increased intensity of its material and energy use. The consequent increase in emissions, pollution, and loss of materials and energy through waste, compounded with an ever higher rate of raw materials extraction, has created a complicated web leading to resource security distress in domestic and international economies (Figure 1). Concerns about increased consumption of virgin resources to support economic progress, and the resulting ecological and social deprivation, have led to sustainability research gaining prominence in environmental science and management studies alike.

Industrial Ecology (IE) research investigates the links between industrial systems and their associated ecological footprint, by suggesting methods for industry to mitigate use of resources by embedding longer material and energy circulation flows within the system, reducing dependence on raw materials and drastically cutting down on waste and emissions (Chertow, 2000; Desrochers, 2002b; Ehrenfeld, 2004; Erkman & Ramaswamy, 2000; Gibbs & Deutz, 2005; Lifset & Graedel, 2002; Lowe & Evans, 1995; Roberts, 2004). One widespread practical solution is a system of networks that exchange materials and by-products between co-located firms, termed Industrial Symbiosis (IS), usually implemented through Eco-Industrial Parks (EIPs) (Chertow, 2000; Ehrenfeld & Gertler, 1997; Gibbs & Deutz, 2005, 2007). Circular Economy (CE) and associated concepts like ‘urban mining’ have in recent times gained prominence as a strategic system to induce renewed use of resources within an economic system, with the objective of upcycling the value derived from waste materials, by-products and energy (EllenMacArthurFoundation, 2012b; Ghisellini, Cialani, & Ulgiati, 2016; Mathews & Tan, 2011; Stahel, 2016; WorldEconomicForum, 2014).

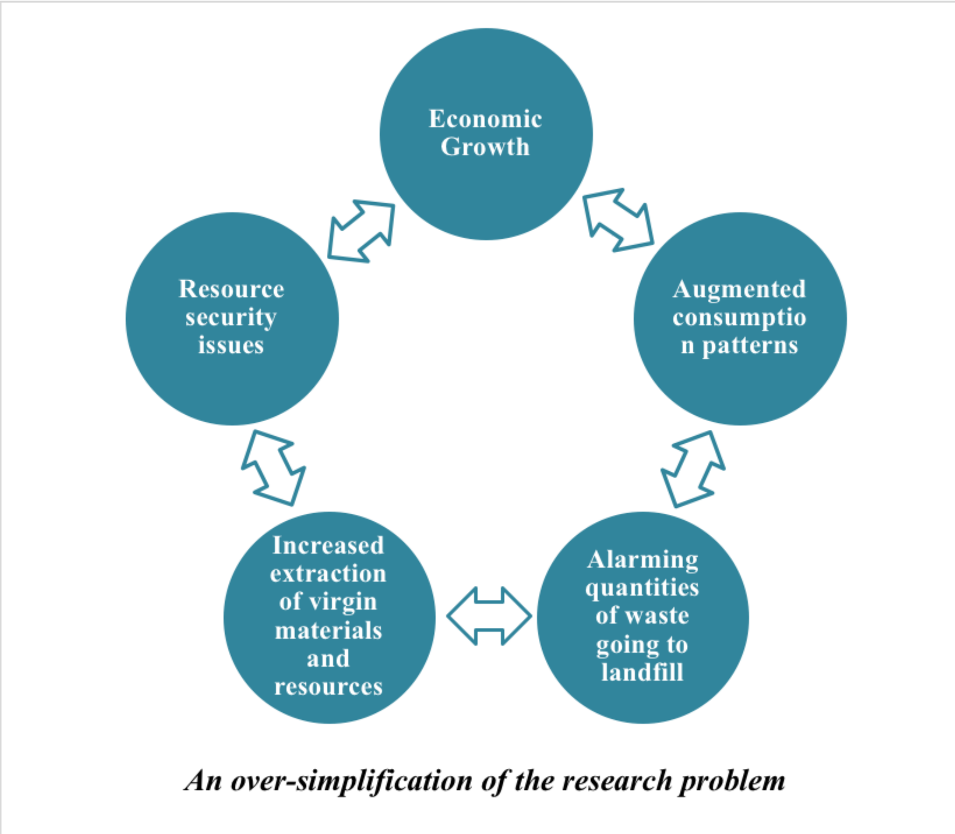

Figure 1. Research problem: the complex interdependencies between economic growth and augmented resource use.

1.2 Decoupling: A critical agenda for the world economy

The idea that resource consumption (both quantity and intensity), economic advancement and environmental degradation should be de-linked is referred to as *decoupling*. Delinking commercial prosperity from ecological degradation, and attaining steady growth within the constraints of available natural resources, is an ongoing conundrum for any nation pursuing a development path. The literature on CE, derived largely from IE and ecological economics, has concentrated primarily on the experiences and evidence of developed nations, focusing on North America, Europe (particularly Germany) and Japan. Amongst developing countries there has also been a focus on Chinese empirical studies and analysis, no doubt due to concrete action being taken by that nation. Yet analytical inquiry into other regions of the developing world, especially India, with its burgeoning manufacturing base, remains limited. Academic investigation of the nation's duality of economic progress and the intensity and impact of its use of resources is lagging. Critical evaluation of India's policy agenda towards resource security, reuse and recycling – factors that suggest a circular economy – is a specific gap in knowledge that this study proposes to address.

Developed regions such as the USA, Europe, Japan and Australia have instituted multiple policies and legal frameworks, aiming to attain CE evolution by introducing fundamental changes in resource recovery methods, industrial recycling, strategic waste management and converting waste to energy, among others (Ghisellini et al., 2016; Sakai et al., 2011). China, which is rapidly expanding its industrial and manufacturing base, has taken the lead in addressing equitable economic and social development by formalizing a CE legal and regulatory agenda through the introduction of the Circular Economy Law in 2009 (Geng & Doberstein, 2008; Mathews & Tan, 2011; Yong, 2007). China's industrial prowess, unrestrained resource consumption, and consequent environmental and human health damage motivated the government to introduce a long-term socio-economic growth agenda centred around the circular economy, with a phase-wise completion of EIPs, among other targets (Su, Heshmati, Geng, & Yu, 2013; Yong, 2007; Zhijun & Nailing, 2007). Strict enforcement, monitoring and measurement, coupled with the country's unique political and socio-economic structure and diverse financial support mechanisms, have seen steady improvement in resource efficiency, with a quantitative target of transforming 100 EIP sites (Mathews & Tan, 2011, 2016).

Evidence from other developing nations is limited. China and India rank as second and seventh largest global economies, contributing 14.8% and 2.8%, respectively, to the world GDP (WorldBank, 2015a). This makes them the only two developing economies within the top eight, with a growth rate of 7.6% and 6.9% in 2015 (WorldBank, 2015b). In spite of India and China leading the world economy, not much is known about India's strategic plans to harmonize its economic and environmental goals. Little empirical evidence of the existence of CE-linked principles in the Indian manufacturing context has been reported. As one of the world's fastest growing economies (WorldEconomicForum, 2016), India is witnessing favourable macroeconomic factors such as a growing population, a high proportion of young and skilled workforce, increased disposable income, keen international interest and improved foreign investments in infrastructure and technology (GOIEconomicSurvey, 2016), which are leading to greater pressure on its natural resource endowments. The motivation behind this study is the dichotomy of India's expected pace of growth vis-à-vis its business and policy realities. While the world's leading economic agencies are pronouncing India as potential leader of the developing world's growth in the next decade, and possibly even supersede China's economic surge, there is a lack of evidence on how sustainable this growth will be. Questions remain as to whether it will be sustainable, in terms of the time frame, but, more importantly, in terms of ecological and environmental sustainability. Some initial evidence of proactive CE initiatives is visible among Indian industry; these are explored in detail through the case of Essar Steel in Chapter 5.

Unlike China, India's democratic political structure and the division of economic, environmental and social development targets between the central government and the states pose distinct challenges and opportunities as the country pursues a policy of decoupling. The developing world's role as the torch-bearer for global economic recovery is reinforced by stagnating demand and recessionary conditions in the erstwhile large economies. As a rapidly growing and industrializing economy, India is in a unique position to avoid the costly mistakes experienced by the developed world and, more recently, by China, by taking timely action to balance its economic and environmental progress. Few previous studies have investigated the drivers of decoupling in the Indian context, and the specific aim of the present study is to determine how the Indian economy is preparing for a world in which economic expansion is constrained by the price, accessibility and availability of virgin resources. This investigation incorporated a critical evaluation of the current national policy framework, applying the CE literature to identify key indicators in Indian industry and suggesting future possibilities and directions for the Indian economy.

1.3 Research plan

With the aim of identifying India's CE progress, this study's object of analysis is the Indian manufacturing sector. Manufacturing contributes 16% to India's national output (GOI, 2014b) and, as the most material- and energy-intensive sector, it is the highest contributor to the country's emissions (GOI, 2013b). The study identifies this sector's CE landscape in a macro context, and illustrates cases of CE-linked application in Indian industry. An extensive review of the CE and IE literature forms the basis for examining the performance of key CE indicators within the Indian economy. The research question for this study is:

> **To what extent has the Indian economy achieved decoupling progress, in light of its industrial policy structure, environmental management and implementation mechanisms, with particular reference to the manufacturing sector?**

With the aim of illustrating CE initiatives at a macro scale in India, the study has the following research objectives:

1. To conduct an exploratory investigation into India's CE progress, through a review of pertinent literature and theoretical concepts.

2. To test recent CE literature evolution in the Indian context, with larger implications for developing nations.

3. To present an overview of the varied national policies, targets, implementation and measurement mechanisms in place for Indian industry to pursue decoupling goals.

4. To list and evaluate key CE indicators relevant to the Indian economy, based on a review of the literature, and to present evidence of CE progress.

5. To examine India's future agenda in pursuing balanced eco-environmental development, and to assess the nation's resource security strategies.

This exploratory study will contribute to the evolving literature on CE and offer a fresh perspective by evaluating progress within a developing nation setting. Caution is critical in assessing the application of alternate economic models to the developing world, since their economic-environmental-social foundations and goals differ from those of the developed world. Furthermore, programs such as EIP and industrial symbiosis (IS) have received scarce attention within Asian Developing Countries (ADCs) (Chiu & Yong, 2004), with the exception of China. A preliminary investigation into the status of EIP development in the major manufacturing regions in India will throw light on both its progress to date and its plans. Measurement indices for CE accomplishment are yet to be accepted globally, although China is one of the first countries to have announced a formal CE indicator system (Geng, Fu, Sarkis, & Xue, 2012; Mathews and Tan, 2016; Su et al., 2013). By reviewing global progress on CE measurement systems and metrics, this study will apply and assess established indicators in a new setting – the Indian economy.

1.4 Thesis outline

To enable a common platform for analysis, the definitions for *developing nation/economy* and *developed nation/economy* are as followed in the country classification by the UN World Economic Situation & Prospects Report 2016 (UN, 2016c, pp. 159–160). In this thesis, therefore, the terms *developing* and *emerging* in the context of nation/economy are used interchangeably. The terms *manufacturing* and *industrial* are used synonymously to signify any industrial activity involving the use of materials and energy to transform virgin resources into finished products. *Industry*, *sector* and *business* all imply a dedicated section or specialization, for example, steel industry/sector/business. *Materials* and *energy* are collectively termed as *resources* to denote any form of input into an industrial activity. *Sustainable development* or *sustainability*, as described by the The Brundtland Report (WCED, 1987), has been understood as meaning the pursuit of an equilibrium between economic, environmental and social goals, in other words as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (as cited in Murray, Skene, & Haynes, 2015, p. 5).

The next section presents an overview of manufacturing activity from a global perspective, highlighting the increasingly significant role played by developing countries in the global economy. Then the theoretical foundations and motivation for conducting the study are outlined by tracing the evolution of CE rationale in scholarly research.

Chapter 2 presents an extensive critique of the CE literature, with the objective of identifying gaps in the current state of knowledge and suggesting direction for future research. Chapter 3 outlines the methodology adopted for the study and explains the data analysis techniques used.

Chapters 4 and 5 discuss the data analysis. Chapter 4 describes the present policy framework and infrastructure for CE development in the Indian industry, and presents an overview of the nation's green growth agenda. This is followed by a quantitative assessment of its major manufacturing regions and their EIP progress. Chapter 5 presents a critical appraisal of India's CE performance based on a list of national indicators, to assess the materials use, industrial energy and emissions landscape, and progress with Municipal Solid Waste Management, and to present the case of CE application by a leading steel manufacturer.

Chapter 6 presents the key findings from the analysis, assessing India's CE standing. The chapter offers an initial comparison between the Indian and Chinese experiences with CE and their future outlook. The final chapter, Chapter 7, outlines the limitations of the study, reflects on avenues for future research and highlights the key contributions of the study.

1.5 Research background: Significance of manufacturing to the world economy

1.5.1 The materiality of the global economy

That the present economic system is highly materials based is at the root of circular economic research. The complex interdependencies between economic progress, augmented resource use, alarming levels of waste and emissions, and the resultant resource security and sustainability concerns, pose dichotomous challenges for the global economy. The expansion of the manufacturing and industrial sectors has a ripple effect on domestic and international economies, creating a surge in consumer demand, a growth in tertiary industries and formation of new industrial segments. Expansion of business, in turn, burdens the already strained sources of materials and energy, and often induces a dependence on importing key raw materials, leading to concerns over the nation's resource security. The quantities of waste left unutilized and disposed of into landfills elevate pollution and health issues. Rising resource insecurity and the ensuing risk of ecological destruction threatens the very livelihood of sustained industrial growth (see Figure 1).

1.5.2 Overview of global manufacturing

Four of the top 10 manufacturing nations are part of the developing world – China, India, South Korea and Taiwan (Figure 2). Examination of the world manufacturing output for the decade 2004–2013 illustrates the increasing share of the developing countries in global manufacturing (Figure 3). China is second only to the USA, with a 23% share of world output in 2013, at USD 2.8 trillion. India and China stand out as the top two manufacturing countries by growth rate, reinforcing their leadership as rapidly growing industrial hubs. The manufacturing sector in India grew by 159% in the decade 2004–2013, second only to China with a 344% manufacturing growth rate over the same period (UNCTAD, 2013).

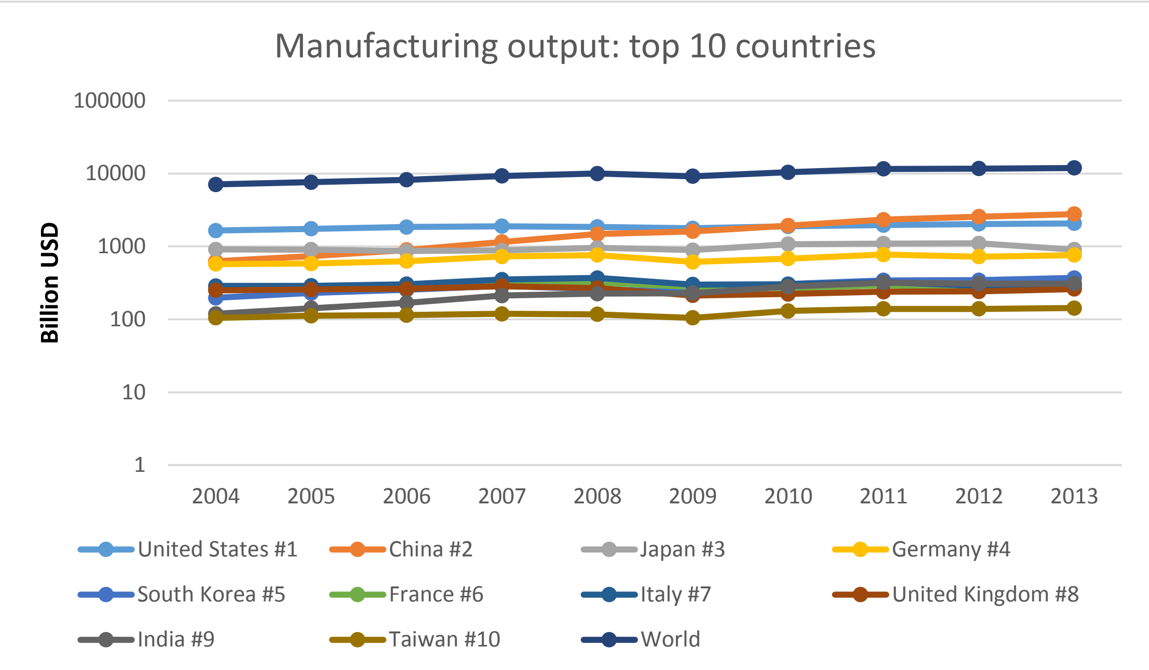

Figure 2. Manufacturing output, 2004–2013; Top 10 countries ranked on GDP from manufacturing in 2013 (USD in 2005 prices using 2005 exchange rates).

Source: Author, based on UNCTAD (2013)

India's manufacturing activity has benefitted from extensive industrial reforms, policy boost, stable governance, outsourced production patterns by developed nations, and opening up of the Indian economy to foreign investments and business infrastructure (GOIEconomicSurvey, 2016). The present government's key agenda is rapid expansion of India's manufacturing base, evident from the ongoing *Make In India* (MII) campaign that promotes international investment and interest for setting up world-class global industrial facilities across key Indian states (DIPP, 2016; MII, 2016). Reinforcing the nation's industrialization agenda is the latest outlook by OECD, which forecasts manufacturing to drive India's sustained progress for the next two decades (OECD, 2014).

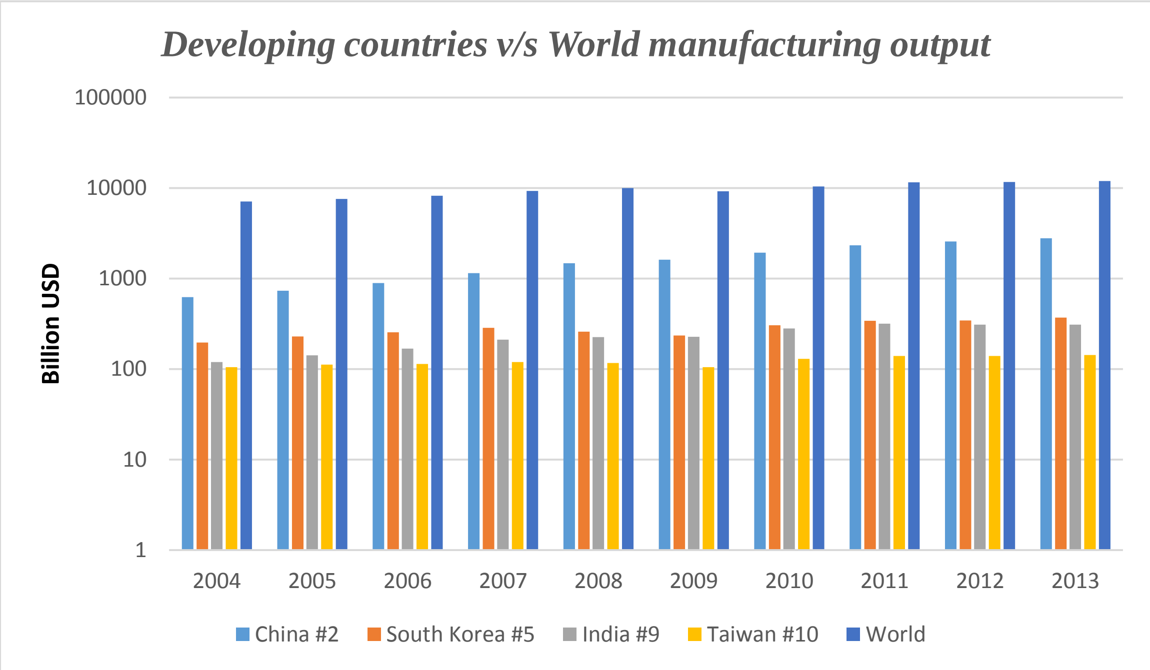

Figure 3. Developing countries v/s World manufacturing output, 2004–2013; Top 10 countries ranked on GDP from manufacturing in 2013 (USD in 2005 prices using 2005 exchange rates).

Source: Author, based on UNCTAD (2013)

In China, optimistic prospects resulted in boosting industrial activity, leading to a surge in resource consumption and nationwide adoption of CE principles. Mathews and Tan (2016) have evaluated the effectiveness of CE initiatives on China's resource use efficiency. In spite of the global manufacturing hub's rising resource consumption over the last two decades, its resource intensity (resources consumed for every dollar of GDP produced) seems to be steadying (Figure 4) (Mathews & Tan, 2016). Valuable lessons are evident not just for the Indian economy but also for any nation pursuing an aggressive growth agenda on the back of industrial expansion. The macro-economic dynamics being experienced by the Indian polity today place it in a unique position to avoid the mistakes made by previous industrializing nations, and not just learn from global initiatives – rather, to lead with innovative applications of CE thinking integrated with its industrial expansion strategy.

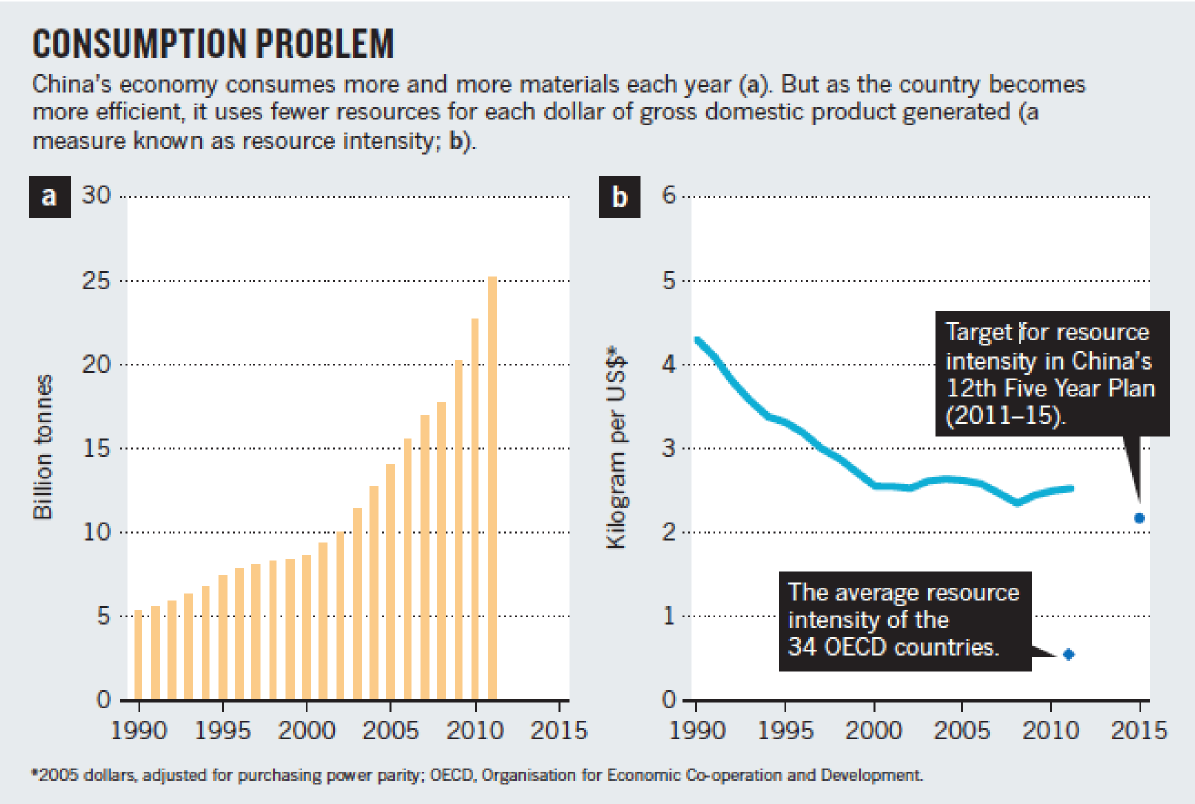

Figure 4. China's resources problem.

Source: Mathews and Tan (2016)

1.6 Circular Economy: Origins and principles

Multifaceted research into long-term and sustainable modes of attaining prosperity, and evolutionary business models founded on innovation and creating *more from less*, have led to the concept of Circular Economy gaining prominence among academic and industry thought alike. A CE, understood to have a holistic and dynamic approach rather than a linear economy, is most often implied to be a *purposefully designed regenerative business system, where material and energy processes form a closed-loop to enable reuse and recycling of resources and minimization of overall waste* (EllenMacArthurFoundation, 2013; Ghisellini et al., 2016; Mathews & Tan, 2011; Stahel, 2016; Webster, 2015; WorldEconomicForum, 2014). Although CE is a recent term formalized through industry implementation and promoted by initiatives of the World Economic Forum and the Ellen MacArthur Foundation, CE principles have been discussed and adopted for decades. The concept is credited to the works of Pearce and Turner (1989) (as cited in Ghisellini et al., 2016). In fact, Desrochers (2002b) has impressively dwelled on the historical roots of utilizing waste as a resource, which was endorsed widely by financially motivated businessmen and traders in an era when easy and cheap accessibility to new resources was constrained.

CE thinking, still in its infancy, lacks a commonly applicable and accepted definition. The ultimate objectives within a CE system are understood to be *process-wide reduction of resource consumption*, especially virgin materials and fossil energy inputs; *extension of useful life of a product*; *waste minimization*; *optimum and financially favourable re-utilization of process by-products* and *strategic design of business processes to facilitate a network of resource use reduction and exchange* (EllenMacArthurFoundation, 2012b; Ghisellini et al., 2016; Murray et al., 2015; Webster, 2015). A CE has also been linked to inculcating a lifestyle of sharing versus ownership, giving rise to sharing-economy and collaborative consumption business models (Botsman & Rogers, 2011; EllenMacArthurFoundation, 2012b; Ghisellini et al., 2016; Stahel, 2016), popular examples being Uber and Airbnb. The essence of any CE thinking is ascribed to maximizing product life and resource use, while minimizing net impact on the environment.

A CE system eliminates the very notion of waste, by finding valuable uses and applications of every input, by-product and output. Thus, in a CE world, waste does not exist, because a by-product material from one process or business becomes a value-adding input for another process, thereby closing industrial loops. In a business sense, a CE is intrinsically linked to IS, where material and energy by-products are exchanged and shared among co-located firms (Chertow, 2000). In addition to IS principles, CE advocates the reutilization of all forms of materials and energy by maximizing their useful life, and thereafter returning suitable materials and energy to the environment, by distinguishing between biological and technical nutrient cycles (EllenMacArthurFoundation, 2012b).

Furthermore, in a CE system, business processes are strategically designed to stimulate reduction, reuse and recycling of resources using technology, innovation and creativity (EllenMacArthurFoundation, 2012b; Ghisellini et al., 2016; Sakai et al., 2011; Yong, 2007; Zhijun & Nailing, 2007). In consequence, even the products manufactured through a CE process are intentionally designed to enable disassembly, reuse, reprocessing, remanufacturing and refurbishing. A recent example is the ‘Nike Grind’ by sports specialist Nike, a superior material recovered from old discarded shoes, plastic waste and the company’s worldwide factory scraps. Under its CE initiatives, the company reprocesses and utilizes these materials into a variety of applications, including new shoe production, and third-party uses such as the carpeting of running paths and gymnasiums (CE100, 2016; Gawel, 2016; Kaufman, 2016; NikeGrind, 2016).

Another inspirational effort is by Patagonia, an American outdoor performance clothes and equipment manufacturer, which has pioneered consumer-driven initiatives such as ‘Common Threads Pledge’ and ‘Worn Wear’, which enable customers to reuse Patagonia apparel and outdoor gear by repairing it themselves or through the company’s numerous workshops. The company’s ethos encourages frugal consumption by urging consumers to purchase only those products that they need, thereby defying conventional business wisdom, yet epitomizing a conscious awareness of prudent resource utilization and consumer involvement (EC, 2016; Patagonia, 2016). These examples, while profit-motivated, do offer a glimpse into the fast-increasing industry implementation, making CE thinking an all-encompassing system, distinct from waste disposal and linear recycling practices.

The next chapter traces the roots of CE literature advancement, reviewing major contributions and offering a critical account of key principles and theory linked to circular economic thinking. It presents a critique of divergent arguments and dominant issues pertinent to CE and IE, with the objective of identifying gaps in the current state of knowledge in the field, particularly with regard to CE applications in countries like India.

Chapter 2: Literature review

2.1 Introduction

Links between economic growth, environmental impact and the stage of development of a nation have been a topic of widespread empirical research and academic debate (Galeotti & Lanza, 1999; Grossman & Krueger, 1995; Holtz-Eakin & Selden, 1995). One approach focuses on the Environmental Kuznets Curve (EKC), inferred to have an 'inverted-U' shape, which has been tested to denote the evolving relationship between industrial emissions and economic growth/GDP (Grossman & Krueger, 1991; Selden & Song, 1994); typically, an increased rate of emissions in the early stages of development is followed by a stabilization and consequent reduction in net emissions as the economy progresses. The opportunity for decoupling using EKC insights, particularly for developed economies, has been argued on the grounds that technology and structural changes to the economy play a significant role in reducing environmental pressure (De Bruyn, van den Bergh, & Opschoor, 1998). However, empirical EKC results have divergent implications for developing nations. Narayan and Narayan (2010), through panel and individual country data for 43 developing countries, found that for the majority (86%) of the countries studied the results were inconsistent with the EKC hypothesis, that is, CO_2 emissions had not reduced in conjunction with the rise in incomes over the long term.

The growth of a nation's economy has traditionally been inextricably linked to its industrial activity– the higher the progress of business and industrial pursuits, the greater the economic growth (Chenery, 1960). Industrial progress is a reflection of a nation's competitiveness index, and has an influence on the country's foreign exchange earnings and currency valuation. In order to attain high industrial growth, governments initiate proactive policies, regulatory and legal frameworks, and robust physical infrastructure, to create a self-sustaining industrial base. These initiatives in turn empower job creation, globally competitive industries and standardized supply chains, but these are often a result of resource-intensive industrial expansion. The manufacturing sector's growth, in particular, has ripple effects on the creation of consumer demand and the expansion of tertiary industries, and often stimulates innovative industrial segments. However, unrestrained industrial growth, coupled with an equivalent burden on virgin resources, rising consumerist lifestyles and surging disposable incomes, have led the world economy to a tipping point, affected by the limitations of natural resources.

Economies of developed regions such as the USA, Europe, Australia and Japan witnessed rapid growth during the 20th century, and industrialized on the back of heavy manufacturing and polluting industries such as automobiles, mining and ores processing, heavy metals and engineering, chemicals, textiles, food production and exports. A similar resource-intensive industrialization approach is not feasible for presently emerging economies. India, a burgeoning economy, with stable government, expanding domestic and foreign investment, skilled young labour, and an established information and technology services sector (WorldEconomicForum, 2016), is taking the lead in strengthening its manufacturing prowess (GOIEconomicSurvey, 2016). The nation has demanded its rightful share of industrial expansion, in order to achieve rapid economic, social, political and technological growth, in addition to asserting its responsibility of creating an inclusive and environmentally sustainable development paradigm (GOI, 2013b; Ministry of Environment, 2015).

The complexity of global concern over emissions and pollution control has been compounded by the developed nations outsourcing and offshoring their manufacturing needs to emerging industrial hubs like India and China, on account of pollution problems, global pressure to reduce carbon emissions and increased labour costs in home locales. Although latecomers to the industrialization journey, developing nations do not have the luxury of relying only on traditional raw materials, non-renewable energy sources and heavy metals extraction, to achieve economic success. Moreover, shortages of resources such as water, electricity, coal and iron ore are threatening the very survival of traditional non-renewable resource-dependent industries, especially in the manufacturing sector. In order to meet the resource pressures, nations are having to import the majority of these resources, raising environmental imbalance and long-term sustainability concerns. To counter resource imbalances, developing nations are encouraging the creation and use of renewable energy sources; however, a suitable infrastructure, policy impetus and economic drive are all obstacles to be overcome to achieve a true benefit.

The above pressing arguments raise the critical question: *Can developing nations really pursue the same "pollute-now, cleanup-later" strategies adopted by the developed nations in their traditional growth trajectory* (Shenoy, 2016). Or should they instead chart their own growth paths by industrializing in a manner that accounts for and supports Nature's limitations? Can an emerging economy like India forge its own growth journey, on its own terms, using the immense technological and innovative capabilities inherent in their peoples, and available from the world's store of knowledge, to create a marketplace where economies thrive but not at the cost of the limited resources and by disturbing the ecological balance? In essence, can developing nations' economic growth be decoupled from their resource intensity and environmental harm? With a view to assessing recent global progress in decoupling through the adoption of circular economic principles, the next section traces the roots of circular economic thinking by presenting a critique of the literature and highlighting key contributions.

2.2 Industrial Ecology: Theoretical foundations for CE thinking

The theoretical roots of CE thinking lie in the field of *Industrial Ecology* (IE) – a widely researched and multifarious field. IE research is committed to studying material and energy flows within the industrial system, to identify ways of developing a harmonious connection between the economic and ecological environments (Chertow, 2000; Desrochers, 2002b; Ehrenfeld, 2004; Erkman & Ramaswamy, 2000; Gibbs & Deutz, 2005; Lifset & Graedel, 2002; Lowe & Evans, 1995; Roberts, 2004). The principles and practices of IE focus on the identification of industrial loops tying outputs to inputs. The implications span countries and economies, and at various levels. The *macro* or national level involves developing industrial and environmental policies, emissions targets and monitoring, and setting up support infrastructure to facilitate IE activities. At the *meso*, or regional, state or industrial cluster levels, IE contributes by way of creating networking and resource-exchange opportunities intra-firm, inter-firm or among industrial zones. At the *micro* or individual business level, IE thinking includes practices such as waste management, by-product exchange, recycling, reuse and energy consumption using renewable sources. IE also incorporates techniques such as Life Cycle Analysis (LCA), a well-tested method to assess material and energy wastes throughout the production life cycle of a product.

Frosch and Gallopoulos (1989) suggested that industrial systems would do well to imitate natural biological systems, referred to as biomimicry, by facilitating by-product exchanges between various industrial processes. Those authors hypothesized that successful by-product exchange between various industrial processes, with the overall aim of reducing total industrial waste, would help contain and eventually lessen the impact of industrial activities on the environment. This strategy of by-product exchange refers to the creation of 'closed-loops'; whereby, *the entire chain of industrial activities is linked, facilitating exchange and reuse of waste resources and by-products* (Frosch & Gallopoulos, 1989; Lowe & Evans, 1995). The ultimate objective of creating closed-loops in manufacturing is to enable reduction, reuse and recycling of resources, thereby obtaining maximum value from extracted resources before safely returning them to the environment.

Several studies have identified the principles of IE and the integral role of EIPs in facilitating IS, and some have evaluated the benefits, impediments and success/failure of EIPs across the world (Ehrenfeld & Gertler, 1997; Gibbs & Deutz, 2005, 2007; Mathews & Tan, 2011; Roberts, 2004; Shi, Chertow, & Song, 2010). EIPs differ from regular industrial parks in the sense that they are specifically designed (or retrofitted) to facilitate symbiotic resource exchanges or IS between manufacturing firms (Chertow, 2000). A classic example of a successful EIP is Kalundborg, Denmark (Ehrenfeld & Gertler, 1997; Lowe & Evans, 1995; Mathews & Tan, 2011), where the symbiotic exchange is suggested to have developed in an organic and gradual manner over many years, as individual firms found practical and economically efficient solutions to their resource problems. While empirical evidence about successful completion and actual success of EIP projects across the world remains limited, some noteworthy results have been obtained from Japan (Kawasaki), China (TEDA & Suzhou), Korea (Ulsan), Australia (Kwinana & Gladstone), and multiple studies across the USA and Europe (Eilering & Vermeulen, 2004; Mathews & Tan, 2011, 2016; Shi et al., 2010; Yu, de Jong, & Dijkema, 2014).

The literature has not entirely analysed the underlying principles and frameworks guiding such EIP developments, and the similarities and differences in the policy patterns across diverse geographic and economic regions. Furthermore, a widely accepted measurement system of the real impacts of by-product exchange networks, especially the supply chain wide environmental and social impacts, is still lacking. In most cases, supply chains can be spread across regions, states and even nations; yet most EIP studies have focused on immediate benefits to the industrial region where the EIP is located, and some have looked at benefits across extended regions. However, such a limited approach is criticized as it restricts a thorough analysis and understanding of a business' material and energy consumption impacts from a holistic viewpoint. Quantifiable outcomes would nurture more widespread adoption as well as objective analysis of the effectiveness of IS in contributing to eco-efficient industrial processes.

Except for China, which has been an area of significant research, there appears limited literature on EIP progress in other BRIICS (Brazil, Russia, India, Indonesia, China, South Africa) nations. Chiu and Yong (2004) have highlighted the situation of IE implementation in ADCs, arguing that IE must become a strategic initiative in developing countries, to enable them to leapfrog to an ecologically sustainable and lasting industrial development. The literature highlights that EIP models for developing nations need to be distinct from those followed by the Western developed world, designed around the specific natural and economic environment goals and constraints faced by the ADCs (Chiu & Yong, 2004; Erkman & Ramaswamy, 2000).

2.3 The transition from linear to circular

A ‘linear economy’ refers to the unidirectional extraction of virgin material and energy; transformation of resource inputs via industrial processes; consumption of finished products; and final disposal into landfills or incineration, releasing waste energy and materials into the ecological environment along the process (Webster, 2015). This conventional *linear* approach has resulted in alarming quantities of resource exploitation at one end and of wastes accumulating at the other end. An estimate by the EllenMacArthurFoundation (2013) suggests that globally the Fast Moving Consumer Goods (FMCG) sector alone generates USD 2.5 trillion worth of waste material and energy every year (EllenMacArthurFoundation, 2013; WorldEconomicForum, 2014). In addition to the excessive physical waste quantities, a large amount of embedded energy and material value too are lost, posing both a crisis and an opportunity for economic and environmental benefit.

As a strategic shift away from wasteful exploitation of virgin resources, a CE offers a means of creating a more holistic and sustainable economic system (Andersen, 2007; Ghisellini et al., 2016; Murray et al., 2015; Stahel, 2016; Webster, 2015). A CE is understood to be a *purposefully designed regenerative business system, where material and energy processes form a closed-loop to enable reuse and recycle of resources and minimization of overall waste* (EllenMacArthurFoundation, 2013; Ghisellini et al., 2016; Mathews & Tan, 2011;

Stahel, 2016; Webster, 2015; WorldEconomicForum, 2014). Although CE theoretical development is nascent, and a commonly applicable definition is still lacking, the following section discusses some accepted principles and conceptual foundations.

2.4 CE literature development

Any innovative model proposing a decoupling of the economy and ecology is founded on the inevitability of surge in production, consumption and, thereby, waste generation patterns, due to socio-economic trends improving globally. Such a surge would necessitate greater extraction of virgin material and use of fossil fuel, unless an alternative resource use model is adopted. The prevalent 'take-make-dispose' approach, symbolic of a linear economy, needs to be substituted by a closed-loop circular economic model if economies are to avoid concerns about resource security. In addition to fostering lower virgin material and energy use, the CE encourages a system-wide network of resource exchange and reuse, with the ultimate goal of positive economic progress with limited environmental footprint.

CE thinking is evolving in academia through focused research, involving the investigation of global case examples, comparative analyses and the underlying theoretical principles. Enquiry into CE practices is gaining interest in academia and industry alike, due to its underlying ideologies in economic growth, resource optimization and ecological equilibrium. This approach is an alternative to mainstream economic thinking. Pioneering industry networks and institutions such as the Ellen MacArthur Foundation are creating impact through real-time partnerships and projects with industry partners. Thus, while the emphasis in academia is to undertake meso- (regional, industrial park or cluster) and macro- (national) level CE analysis, CE research in industry is directed towards company-level implementation, tools, methods and frameworks.

Ghisellini et al. (2016) have provided an extensive appraisal of CE literature development in the last 20 years, offering a comprehensive review of CE initiatives, examples and related theoretical advancement across both the developing and developed world. The authors have evaluated varied perspectives on CE – tracking the genesis of CE thinking, core ideologies, modelling techniques and methodologies. This is the first holistic review of inter-disciplinary knowledge on the multi-dimensional aspects of a CE framework. Acknowledging the theoretical foundations of IE in creating a closed-loop CE model, Ghisellini et al. (2016) have further offered an inter-disciplinary investigation into ecological and environmental economics, General Systems Theory; and presented a contrast of CE with ‘degrowth’ and ‘steady state’ economic principles.

The literature has established three key CE principles, referred to as the 3Rs – Reduce, Reuse, Recycle (Ghisellini et al., 2016; Sakai et al., 2011; Yong, 2007; Zhijun & Nailing, 2007). *Reduce* relates to attaining eco-efficient and resource-efficient production and consumption patterns by way of reduced utilization of energy and materials inputs (Ness, 2008; Su et al., 2013; Zhijun & Nailing, 2007). *Reuse* aims to re-introduce by-products into the same or a different business activity. Within a CE framework, *recycling* refers not just to material and energy recovery, modification and reuse in a convenient, oftentimes, devaluing process; instead, recycling aims to allow strategic upcycling of recovered resources to derive their best value, and so the energy intensity of resource transformation is minimized (EllenMacArthurFoundation, 2012a; McDonough & Braungart, 2008). Although most CE initiatives around the world start with pollution prevention, energy conservation, waste management and recycling techniques – mainly end-of-pipe solutions – it must be noted that these strategies are only a first step towards attaining resource circularity; and that *reduction* and *optimization* in the use of any materials and energy is the ultimate aim of CE. In addition to the 3Rs, the EllenMacArthurFoundation (2012b) has suggested three more ideologies to facilitate integration into a CE framework – product design suited “for a cycle of disassembly and reuse”; material segregation into “technical” and “nutrient” types; and renewable energy as the principal source of energy (EllenMacArthurFoundation, 2012b, pp. 6–12).

Varied CE intentions have been observed globally – the USA, Europe, Japan and Korea have focused their efforts on waste management initiatives with the eventual aim of reducing landfill. Divergently, Chinese CE policies are seen to have been motivated by a national agenda supporting continual growth of its manufacturing prowess (Ghisellini et al., 2016; Sakai et al., 2011). CE as an environmentally supportive business strategy was initially introduced by Chinese scholars in 1990 to address China’s growing energy and resource shortage concerns in light of extensive industrial growth (Yong, 2007). Reviewing the practice of CE in industrially developed economies such as Germany, Denmark and Japan, China decided to make CE a national strategy in 2009 through the introduction of the Circular Economy Law (Geng & Doberstein, 2008; Mathews & Tan, 2011; Yong, 2007).

Case study methodology is the most prominent method of inquiry in CE literature, with only limited papers analysing the business-driven foundation of CE thinking, and even fewer studies identifying how the concept of decoupling can contribute to CE progress. The majority of the literature tracking CE progress has been published between 2004 and 2014, which can largely be attributed to the novelty of the concept itself. The keen interest and significance of CE research in academia is reflected in the February 2016 Special Volume of the *Journal of Cleaner Production*, focusing on latest advancements in the field of Eco-Industrial Development (EID). This special volume compiled 41 papers contributing an array of CE topics – including pioneering policy frameworks; wide-ranging reviews, measurement indices and tools; and successful application of IE techniques across businesses, consumers and society (Geng, Fujita, Park, Chiu, & Huisingh, 2016). Furthermore, a recent special issue in *Nature* on the Circular Economy has attracted noteworthy contributions and diverse interest on the subject (Mathews & Tan, 2016; Stahel, 2016).

However, there is a paucity of research on identifying CE indicators at various levels (micro, meso, macro) and diverse economic stages (developed, developing nations). A common measurement system is critical for assessing CE advancement, impact and policy effectiveness. Geng et al. (2012) have illustrated the Chinese indicator system, a first in the world, to track CE progress. At the primary stage, the indicators evaluate progress at the macro and meso scales within the Chinese economy, measuring factors such as resource output, consumption, utilization, waste, pollution and emissions. Su et al. (2013) have reviewed measurement systems employed at the firm or industry level, in addition to drawing parallels between varied CE dimensions and specific indicators. A detailed assessment of established CE indicators and an initial application to the Indian context is conducted in Chapter 5.

Numerous gaps exist in current knowledge on circular economic thinking. Primarily, CE application is still centred on the study of physical material and energy flows, and must transition to assessing the financial benefits to all actors (Mathews & Tan, 2011). A historical perspective on the evolution of inter-firm resource exchanges, or IS, at Kalundborg, Denmark, and similar industrial clusters, has reinforced that economic benefit is the foremost driver for both businesses and society to undertake any form of resource exchange (Desrochers, 2002a, 2002b). Economic benefits refer to cost reductions and/or increased profits, and have repeatedly been ascertained as the primary goal of IS activities.

Furthermore, it must be acknowledged that CE itself is not a new concept, and it draws extensively from Industrial Ecology and sustainability-driven concepts such as cradle-to-cradle. The application of CE initiatives globally can take different forms or incorporate distinct terminology, and future research should look at inter-disciplinary linkages to arrive at a solid conceptual footing. In addition to the core aspects of CE thinking highlighted in this section, CE thinking has also been associated with the creation of novel product (ownership) versus service (use) business models, such as a sharing economy and collaborative consumption (Egerton-Read, 2016; Webster, 2015). While these novel CE business models are gaining increased acceptance and merit scholarly focus, they lie beyond the scope of the present study.

2.5 Global circular economic policy framework and implementation

Table 1 offers a snapshot of CE policies and implementation across various countries, and its future landscape. The related literature has been listed for further assessment, and this section offers some reflections.

Assessment of Chinese CE policy implementation identifies that the country's goal is focussed on achieving sustained production and consumption growth. In contrast, the USA, Europe, Japan, Korea and Vietnam display more ties to the 3R philosophy, through sector-specific waste reduction and management initiatives (Sakai et al., 2011). Mathews and Tan (2016) have presented a critical account of China's rapidly expanding manufacturing and industrial base, the inefficiency of its current material consumption, and the strategies being adopted to overcome this challenge. Using Suzhou New District industrial park as a case example, the authors conducted a quantitative analysis of the progress in reducing resource intensity and improving waste utilization through the implementation of various CE measures. Their study reinforces the virtues of moving away from linear economic measures, such as GDP, towards circular resource utilization. An analogous appraisal of the Indian macro landscape is suggested as the basis for future research, offering scope for a critical comparison between the two Asian tigers.

Table 1

Circular Economy Evolution, Framework and Implementation Worldwide

Country	Guiding principle/ framework/ law	Reference
China	Circular Economy Promotion Law, 2009	Geng and Doberstein (2008); Mathews and Tan (2011); Yong (2007)
Japan	Law for Effective Utilization of Recyclables, 1991; Japanese CE initiative	Pinjing, Fan, Hua, and Liming (2013)
Europe	Germany – Waste Disposal Act, 1976; Closed Substance Cycle and Waste Management Act, 1996; EU – Waste Directive 2008/98/EC; Circular Economy Package, 2015	EC (2014); Pinjing et al. (2013); Mathews and Tan (2011)
United States	Resource Conservation and Recovery Act, 1976; Pollution Prevention Act, 1990 *No formal federal CE policy as yet*	Pinjing et al. (2013)
South Korea	Waste Management Act, 2007; Act on Promotion of Resources Saving and Recycling, 2008; Food Waste Reduction Policy; Extended Producers Responsibility (EPR)	Sakai et al. (2011)
Vietnam	Environmental Protection Law & National Strategy on Integrated Solid Waste Management (amended in 2005)	Sakai et al. (2011)
Australia, New Zealand	*Action agenda for CE in progress, no formal national directive yet*	Jewell (2015)

Source: Adapted from Ghisellini et al. (2016)

2.6 IE and CE in India

While CE development in China is a subject of wide-scale research and interest in academia, Indian studies are limited in number and scope. Previous studies looking at the implementation, success and impediments of CE programs in China have noted that policy structure, execution and monitoring are largely top-down, with an active role played by the government and state departments (Ashton & Shenoy, 2015; Ghisellini et al., 2016; Mathews & Tan, 2011; Shenoy, 2016). IS examination in India has revealed the potential for bottom-up approach to EIP development. Most empirical studies on EIP development in India have reviewed extant resource exchanges (Bain, Shenoy, Ashton, & Chertow, 2010; Unnikrishnan, Naik, & Deshmukh, 2004) or have undertaken case studies (Erkman & Ramaswamy, 2000), with some suggesting future possible exchanges (Singhal & Kapur, 2002). Current studies in the field of sustainability of Indian manufacturing have explored varied aspects like waste management, recycling, Material Flow Accounting and Analysis (MFA) of an industrial cluster (Bain et al., 2010) and identification and evolution of material exchanges within an EIP framework (Lowe, 2001; Von Hauff & Wilderer, 2000). Ashton and Shenoy (2015) have commented on the Indian Government's emphasis on creating 'end-of-pipe' pollution control and waste management solutions, resulting in IE techniques such as cleaner production and IS being implemented in a disorganized manner, with a major role being played by the informal industrial recycling sector.

Bain et al. (2010) conducted an empirical study in a southern Indian industrial area, to assess the existence of inter-firm material and energy exchange networks. The research quantifies waste recovery, reuse and recycling activities of 42 companies ranging from micro and SMEs to large multinationals, using structured interviews and MFA techniques. The study found that 99.5% of wastes generated (consisting mainly of agricultural and organic residues) were reused or recycled within or outside the facility. Three key methods of industrial waste recovery were identified: (i) reuse within same facility, (ii) reuse within co-located firms and (iii) informal recycling. The interesting highlight from the study was the substantial role played by the informal sector and the organic and unplanned evolution of the exchange networks. Interviews with managers revealed that practical solutions and economic benefits were the key motivators for initiating inter-company by-product exchanges. The authors identified a significant gap in studies identifying IS in developing nations, especially with respect to the integral role played by the informal recycling sector in these nations. Furthermore, IS examination in India has revealed potential for bottom-up approach to EIP development (Bain et al., 2010; Shenoy, 2016).

Shenoy (2016), a renowned academic and researcher in the field of IE, has discussed the peculiar challenges facing developing countries when looking at IE implementation, presenting a critique of the true costs of growth and rising GDP, along with a SWOT analysis of IE potential in developing economies. Examining IS activities in the Indian context, the study highlighted research and implementation gaps, offering a unique opportunity to a growing economy like India to contribute towards a renewed global understanding of IE. The EKC predicts that an industrializing country like India will worsen its footprint and emissions as it industrializes, and then the pollution should level off and start to decrease as per capita income grows. Policy intervention to speed the process of dematerialization is critical; mere reliance on increasing wealth to solve all problems will have disastrous environmental consequences. A traditional policy intervention mechanism informed by IPAT, wherein environmental impact (I) is implied to be the product of three factors: Population (P), Affluence (A) and Technology (T), introduced by Commoner (1972) and Ehrlich and Holdren (1972) (as cited in Waggoner & Ausubel, 2002), suggests that reducing population, affluence and technology would reduce environmental impact. This is hardly an appealing approach for an industrializing country, where the critical role of technology, greater affluence and increasing population to achieve sustainable development and resource management cannot be disputed (Shenoy, 2016). Waggoner and Ausubel (2002) made an improvement in their ImPACT identity, whereby environmental impact (Im) is implied to be a product of four factors: Population (P), Affluence (A, *measured as GDP per person*), Consumers' intensity of use (C) per GDP, and Technologists intensity of impact (T) per goods used. However, they found contrasting results for both India and China (Ausubel & Waggoner, 2008; Waggoner & Ausubel, 2002). This background presents an opportunity for future research to intervene and clarify the issues, and to develop a system for measuring the materialization or dematerialization of India.

Specifically, from a CE context, Govindan, Shankar and Kannan (2016) investigated the automotive remanufacturing industry in India, appraising the status of end-of-life vehicles recovery, contributing factors and implementation hurdles. Despite the nation's superior position as an automotive manufacturer and user, the study identified high costs and lack of consumer demand for remanufactured products as significant barriers. Extended Producer Responsibility (EPR) is one of the key drivers to create an efficient remanufacturing system; within the Indian context, easy availability of labour, market price sensitivity, economic gain and environmental impact play a significant role, in addition to EPR (Rathore, Kota, & Chakrabarti, 2011). Overall, scattered and inefficient product recovery methods, widespread existence of an informal sector and lagging technology ail the expansion of this critical CE practice in India.

2.7 Closing reflections

The above review highlights that CE thinking is all-encompassing and incorporates principles from varied disciplines – engineering, urban planning, economics – neoclassical, steady state and evolutionary, environment and ecology, design, business and green manufacturing. Cross-disciplinary CE research is still evolving, with most of the evidence from IE and Environmental Economics (EE). From an EE perspective, eco-efficiency and eco-sufficiency strategies have been widely debated in scholarly thought (Alcott, 2008; Figge, Young, &

Barkemeyer, 2014; Ghisellini et al., 2016). Figge et al. (2014) have presented distinctive approaches between eco-efficiency and eco-sufficiency strategies, contesting the occurrence of a "rebound effect" in various instances. A valid criticism of CE practices lies in acknowledging that no economic system can accomplish end-to-end circularity and that, beyond a point, the negative costs (both environmental and economic) outweigh the benefits achieved from recycling (Andersen, 2007). In effect, absolute decoupling is unlikely to be achievable, due to the threat of increased resource consumption as a result of eco-efficiency strategies – in contrast to the expected reduced resource intensity on account of increased productivity.

Based on a holistic review of recent literature on CE implementation across diverse geographical and industrial regions, as well as differing stages of development, the roles of government policy vis-à-vis firm-level action have been critiqued. A top-down CE approach appears to have successfully reduced the resource intensity of Chinese industry, whereas Europe and the USA have witnessed a better response from bottom-up action. It will be interesting to investigate where India falls between these two extremes. Uncertainty surrounding ready availability and regular supply of by-products, market dynamics, and geographical dispersion of global supply chains pose substantial limitations and challenges to executing IS effectively. While EIPs are an accepted means of facilitating resource exchange networks, their planning and implementation scales vary, depending on available funding, responsibility allocation, identification of suitable partner firms, and the costs associated with brownfield site upgradation versus relocation to greenfield sites. Lastly, it must be noted that any CE or EIP development is a slow and gradual process, and most results would be incremental in nature, at least over the short term.

Chapter 3: Research methodology

3.1 Introduction

This research was an exploratory study into assessing India's national policy structure, regulatory framework and key indicators relevant to circular economic principles. The literature review presented in the previous chapter has highlighted a gap in present evidence of initiatives linked with a Circular Economy (CE) in the Indian context. An assessment of the macro state of 'green growth' policies and implementation from developing nations is critical to understanding the current and future potential of achieving industrialization, in light of resource insecurity concerns worldwide. In particular, because the Indian economy hinges on the manufacturing sector sustaining its economic growth and development targets, a timely evaluation and action towards decoupling policies is warranted. The findings from this preliminary macro investigation will provide a foundation for future research into assessing individual cases from Indian industry, and successfully implementing a CE framework, along with international comparisons.

3.2 Inter-disciplinary literature review

To arrive at an in-depth understanding of CE principles and to identify the linkages to the fields of Industrial Ecology and Environmental Economics, an inter-disciplinary literature review was conducted. The objective was to trace the pattern of CE theoretical development and present a critical account of major contributions and literature advancement. Based on the literature, central problems being tackled in the field were summarized, and significant gaps in the present state of knowledge and avenues for future research were identified. For this purpose, all 'circular economy' titled literature was searched in Google Scholar, Web of Science and Scopus databases. The high-ranked peer reviewed journals and articles were shortlisted based on their title, and an initial examination of their abstracts and geographical focus. During the course of this examination, in addition to seminal literature and key conceptual papers in the field of IE, the emphasis was to find literature relevant to developing country experiences in EIP implementation, evidence of IE practices, and empirical studies on IS.

The primary journals pertinent to the topic include *Nature*; *Journal of Industrial Ecology*; *Journal of Cleaner Production (JCP*); *Resources, Conservation and Recycling*; *Ecological Economics*; *Energy Policy* and *Sustainability Science*. Recent special issues on CE and Eco-Industrial Development (EID) in *Nature* and *JCP* were thoroughly assessed. The peer-reviewed articles in these special volumes significantly shaped the line of inquiry and offered deep insight into a multitude of cross-disciplinary perspectives on CE. Relevant books and book chapters, conference proceedings of the International Society of Industrial Ecology (2015) and Circular Economy 100 Annual Summit (2016) were reviewed, in addition to publications from the Ellen MacArthur Foundation, and latest news and reports from World Economic Forum (WEF), Organisation for Economic Co-operation and Development (OECD), World Bank (WB), International Monetary Fund (IMF) and multiple United Nations (UN) organizations.

3.3 Methodology

The overall methodology adopted for the study was in line with the noteworthy contributions made by Ghisellini et al. (2016), Pinjing et al. (2013), and Su et al. (2013). The authors of these papers have offered varied perspectives, empirical evidence and updated knowledge on CE theoretical advancement and implementation progress globally. They have presented an appraisal of the key policies, national frameworks, cross-disciplinary exploration and future outlook (Ghisellini et al., 2016; Pinjing et al., 2013; Su et al., 2013). Furthermore, the approach adopted by Mathews and Tan (2016) in their latest evaluation of CE lessons from China, using specific case sites and metrics such as resource intensity of Chinese industry, served as an exemplar for the data analysis conducted in this study. A quantitative assessment of indicators such as India's energy intensity, emissions intensity, and materials consumption and intensity was conducted to present a macro background of resource use and efficiency of the Indian economy. The findings form the basis for future industry-specific case analyses, as a means of conducting research on CE implementation in India.

For the purpose of assessing India's progress towards CE achievement, the following chapter delves into the nation's eco-industrial framework at the macro level, and traces current policy developments. A review of the nation's current twelfth Five Year Plan and major initiatives contributing to the expansion of the manufacturing sector are critiqued. Data from official reports and government communication such as the 2016 Economic Survey, the Planning Commission Databook and releases by various Ministries and news are analysed. Findings from the literature review are used to assess relevant drivers of CE for the Indian economy, elaborated in Chapter 5. The nation's materials use, industrial energy and emissions landscape is presented and contrasted with other major economies of the world, using data of emissions released by the OECD Statistics database and energy-related information from the International Energy Agency (IEA), among other sources. Finally, a short case study based on secondary research is presented to assess the CE initiatives being employed by a large Indian steel manufacturer.

NOTE

The annual Economic Survey is the flagship document of the Ministry of Finance, Government of India (GOI), and is presented to both houses of Parliament during the Budget Session. The latest Economic Survey (2015–16) recapitulates the performance of major programs and initiatives in the last 12 months, presents economy-wide statistical data and analyses, and offers an appraisal of the fiscal projections and expectations across sectors and key policy. Relevant data and highlights have been used to enrich the analyses of this study. The two volumes of the most recent Survey can be accessed at the government website http://indiabudget.nic.in/survey.asp

Chapter 4: A preliminary investigation into India's CE agenda

4.1 Introduction

The realization that economic growth and environmental impact need to be decoupled is not a new phenomenon in India's development agenda. However, it has now become an urgent issue for the country to address, especially given the push to expand its manufacturing sector. Effective and strict policy implementation is needed to mitigate the ecologically costly mistakes made by other industrializing nations in the past. The actions the nation takes now will determine its pace of long-term progress and also establish its international stature in eco-industrial policy and climate action. Industrial expansion and environmental stability through the exponential adoption of renewables are at the heart of the current government's political intentions.

This chapter investigates the structure of India's national policy towards CE-linked progression; the nation's action to illustrate its standing in environmental performance; and the circumstances governing industrial activity in India's top six manufacturing states. The objective of this approach is to gain an overall understanding of one of the world's fastest growing nation's pursuit of decoupling plans. The literature contains no investigations into India's macro CE agenda, with research primarily examining approaches taken by China and other developed nations. A macro review of CE performance from an Indian manufacturing standpoint would enable future in-depth research investigating meso- or micro-level sector-specific action, global comparisons, and policy and business planning and implementation.

4.2 An overview of India's green growth plan

Since the boom of its industrial activity, India has undertaken specific initiatives in the last few decades to cut back its emissions and energy intensity levels. A critique of past initiatives and future plans is presented below. The federal government ministries crucial to policy-making, implementation and monitoring of industrial and environmental activity, include the Ministry of Environment, Forest and Climate Change (MoEFCC); Ministry of New and Renewable Energy (MNRE); Ministry of Commerce and Industry; and Ministry of Micro, Small and Medium Enterprises (MSME) (GOI, 2016b). Furthermore, each of the 29 states and seven union territories have distinct legislative policies and goals, as part of the broader national framework. There are both top-down and bottom-up policy structures, targets and implementation standards to achieve national industrial growth and environmental action targets. Budgetary allocations are made from the central government to state departments on time-based goals, in addition to private and international investment. The nation is increasingly adopting a Public-Private-Partnership (PPP) mode for major infrastructure and industrial projects.

The key economic sectors contributing to national GDP (2004–05 prices) included Services (55.79%), Agriculture and Allied industry (16.09%), Manufacturing (15.88%), and other Industry including electricity, power, mining (12.24%) (GOI, 2014b). The significant carbon emitting segments were Power, Transport, Industry (including manufacturing), Buildings and Forestry (GOI, 2013b). Within the manufacturing/industrial sector, Power and Iron and Steel were the most energy and emissions intensive industries. Maharashtra, Gujarat, Tamil Nadu, Uttar Pradesh, Karnataka and Andhra Pradesh are the six leading manufacturing states contributing an aggregate 62% to the national manufacturing GDP (GOI, 2014b). Infrastructure development (roads, ports, rail, air and waterways), power self-sustenance, Eco-Industrial Parks (EIPs), dedicated industrial corridors, Special Economic Zones (SEZs) and National Manufacturing Industrial Zones (NMIZs) are some of the focused green industrial initiatives across these major hubs. A review of the manufacturing trends and CE progress in each of the states is presented in the latter part of this chapter.

Apart from state-specific action, the nation as a whole has adopted a robust renewable energy growth target, with the aim of capitalizing on its abundant solar and wind sources. To harness the power of renewables, India has set an impressive target of achieving 40% of its power requirements from non-fossil energy sources by 2030 (GOIEconomicSurvey, 2016). As per the Intended Nationally Determined Contribution (INDC), the nation aims to generate 175 gigawatts (GW) of energy from renewables by 2022, through 60 GW of wind power and 100 GW of solar power installed capacity by 2022, and 10 GW and 5 GW from biomass and micro-hydro power projects, respectively, in addition to reducing its emissions intensity by 20–25% compared to 2005 levels (Ministry of Environment, 2015). Pursuant to its pledge at the 2015 Conference of Parties (COP21) in Paris, India has pioneered the International Solar Alliance (ISA) to be headquartered in Gurgaon, India, with the objective of creating a coalition between 121 solar-rich countries, to pursue joint technology development and shared resources, for furthering national solar targets. The next section examines the nation's policy structure and evaluates progress in regards to its sustainability goals.

4.3 National Action Plan on Climate Change (NAPCC)

One of the foremost policy agendas governing the Indian economy's "green" development is the National Action Plan for Climate Change (NAPCC), which was proposed in 2007 and formalized in 2008, to initiate action until 2017. The NAPCC is chaired by the Prime Minister's Council on Climate Change, and was formulated as an endeavour towards having a holistic national action plan, in response to global and domestic climate change mitigation requirements. The framework document of the NAPCC states: *"Our vision is to create a prosperous, but not wasteful society, an economy that is self-sustaining in terms of its ability to unleash the creative energies of our people and is mindful of our responsibilities to both present and future generations"* (NAPCC, 2007, p. 1).

The long-term plan aims to utilize innovative technologies, formal enactment and monitoring mechanisms, Public-Private-Partnership (PPP) and societal action, to create a formidable industrial nation. The NAPCC is structured to have eight key focus areas, termed MISSIONS, and the responsibility for their execution lies jointly between the Central Ministries and the state governments. These missions are incremental to the existing policies towards proactive action on climate change; it is hoped the new multi-pronged approach will align the direction and scope of climate change efforts, in order to create time-bound targets to ensure effective and fast-tracked implementation. Three of the eight core missions defined under the NAPCC are directly linked to the subject of this study, that is, their focus is towards greening of industrial activities, industrial eco-efficiency, resource efficiency and security, reduction of materials, energy and emissions intensities, industrial ecology and the circular economy. The following subsections delve deeper into these three missions and evaluate their goals, relevant policy support, monitoring, achievements and barriers/ shortcomings.

4.3.1 National Solar Mission (NSM)

India's energy balance is severely distorted, with almost 20 million households lacking access to regular power (Jai, 2016). The shortage or inadequacy of power capacity appears to the foremost impediment to the nation's growth. The nation's dependence on coal for power generation, and the substantial share of coal and oil imports, have intensified India's duality in attaining clean and efficient industrial progress. To resolve its power needs and support clean energy development, the National Solar Mission (NSM) was launched as one of the forerunning goals under NAPCC. The NSM aims to accelerate the share of solar power in total energy generation, with a target of installing 100 GW of solar capacity by 2022, planned through 60,000 MW of grid-connected power and 40,000 MW through solar rooftop and off-grid undertakings (Jai, 2016). As of 2015–16, solar cumulative installed capacity was upwards of 7.5 GW, contributing 2.5% to the nation's net installed capacity, and having the highest share among renewables at 17.4% (Dutta, 2016).

Under the effective leadership of India's current Prime Minister, Mr. Narendra Modi, and his international commitment to the ISA, significant policy, infrastructure, technology, finance and industry support are being extended to the solar power sector. In addition to solar panel and photovoltaic cell research and development, some other enablers include the installation of grid-connected solar rooftops, over 25 solar parks and ultra-mega solar power projects across states, solar pumps for irrigation and drinking water with a budgeted USD 62 million fund. Solar Parks enable all-round infrastructure development of the site, including land use, road network, water and other utility upgrades, and state-of-the-art power transmission facilities. International investment to the tune of USD 500 million has already been committed for these projects by the Japanese International Cooperation Agency (JICA), in addition to interest from the European Investment Bank and Asian Development Bank (Gopal, 2016).

Furthermore, 56 solar city projects have been approved and are at various stages of planning and implementation (GOIEconomicSurvey, 2016). Financial incentives such as feed-in tariffs and Renewable Energy Certificates (RECs) have encouraged widespread adoption of solar power generation by the public and private sectors. Solar capacity resolves not just the clean energy development needs of the Indian economy but also allows for decentralized power generation and distribution, one of the core issues ailing power transmission companies. Among the significant projects is a 11.5 MW single rooftop solar plant in the State of Punjab, spread over an area of 42 acres and touted to be the world's largest. Along with the smaller solar plants located in the vicinity, this project is expected to generate a total of 19.5 MW of power, sufficient to electrify 8,000 households (Gera, 2016).

In addition to boosting its solar prowess, the Government of India (GOI) is also developing systematic plans to capitalize on its wind, nuclear and biomass resources. As a succession to the initial eight Missions under the NAPCC, four new Missions are under review and at various stages of finalization, two of which are vital to eco-environmental development. These include the National Wind Mission and National Waste to Energy Mission, to expand renewable energy capacity and divert coal dependence by utilising alternative energy sources through waste (GOI, 2013b). These two missions would be critical in alleviating the nation's power crises.

4.3.2 National Mission for Enhanced Energy Efficiency in Industry (NMEEE)

India's commercial energy efficiency initiatives in the past have included setting up benchmark efficiency standards, labelling equipment and appliances, establishing green building codes and planning specific improvements in heavy energy-consuming sectors. A systematic approach to make energy efficiency an inherent factor within business has been initiated with the launch of the National Mission for Enhanced Energy Efficiency in Industry (NMEEE). The mission aims to create a market-managed system to make energy efficiency measures financially viable, especially for large energy-intensive businesses, by enabling energy-saving certifications and trading. Another objective is to encourage the use of energy-efficient appliances and boost the financing of demand-side initiatives, along with the creation of fiscal instruments to stimulate energy efficient practices (NAPCC, 2007).

The initial target of the NMEEE was to save 10,000 MW of energy, achieve 23 million tonnes of oil equivalent (Mtoe) fuel savings, and reduce 98.55 million tonnes (MT) of Carbon Dioxide (CO2) equivalent annually over a five-year period, via implementation of multiple energy efficiency schemes and programs (GOI, 2013b; NAPCC, 2007). The Energy Conservation Act, 2001 and the Bureau of Energy Efficiency (BEE) are the governing institutional mechanisms at the Centre. Under this mission, a PAT (Perform, Achieve and Trade) system has been initiated with the objective of enabling large industrial plants to improve the cost-effectiveness of energy-efficient activities, by allowing the trading of energy savings certificates. The PAT scheme is anticipated to function as a formal instrument for energy-intensive business units to reduce specific energy consumption and offer them an economic incentive in the form of trading certificates.

In its first phase, the PAT energy intensity cap-and-trade scheme identified nine industrial sectors as Designated Consumers (DCs), based on their excessive consumption of energy over the threshold limits. The nominated DCs in Thermal Power Plants; Iron and Steel; Cement; Pulp and Paper; Textiles; Fertiliser; Chloralkali; Aluminium; Railways sectors were assigned efficiency and emissions reduction targets. Over a three-year period (2012–15), the shortlisted DCs were expected to meet the individually assigned Specific Energy Consumption (SEC) targets, with continued monitoring by government departments, throughout the term. As of 2007–08 (the period when the DCs were identified), these nine sectors contributed around 54% to India's commercial energy consumption (GOI, 2013b). On 31 March 2015, when the first PAT cycle concluded, 478 industrial units in eight of the designated nine sectors were involved. Their compliance and performance is presently being assessed and energy certificates will be issued after review by respective State Departments and the BEE (GOIEconomicSurvey, 2016).

Another incentive is Renewable Energy Certificates (REC), which have been launched to function as a market-based mechanism to encourage renewable energy purchase mandates, and balance the disparity between renewable resource availability and mandatory procurement (GOI, 2013b). The NMEEE's current focus is on enhancing energy efficiency and attaining emissions reduction of a reasonably small number of high-polluting large industries. The scope of this Mission is expected to expand towards energy efficiency development within the small and medium industrial sector. The structure, target-setting, incentives and monitoring mechanisms, as well as technology requirements for small and medium enterprises, will be significantly distinct from the ones currently employed for large industries.

4.3.3 National Mission on Sustainable Habitat (NMSH)

Among other core action areas, this Mission highlights the nation's intentions for effective Municipal Solid Waste (MSW) Management, and sustainable energy-efficient urban planning. The plan was to initiate strong waste-to-energy infrastructure, MSW and waste water reuse and recycling technology upgrades, with the aim of optimizing energy demands by existing and upcoming commercial deployments. Due to the relevance of these goals to the CE landscape, this Mission has a significant role in shaping India's future action towards sustainable circular industry and societies. A dedicated thrust towards this Mission is lacking in the government's present agenda, and the scope of analysis is thereby limited. Nevertheless, some evidence from India's MSW initiatives is presented in Chapter 5.

The NAPCC has charted out supplementary agendas for biodiversity, sustainable development and climate change mitigation through five other Missions. Water shortages in major parts of the nation, due to uneven natural distribution between states, unrestrained use for agricultural process, exhausted groundwater sources, and increasing demand from household and industrial consumers, have placed this hitherto abundant resource into the nation's forefront for conservation and restoration. India's water use intensity is around 30–50% higher than global benchmarks; the demand for water resources is expected to increase 22% by 2025 with industry's share projected to be 11% (GOI, 2013a). With the objective of fostering judicious use, recycling and reuse, in conjunction with maintaining and improving the existing water reserves, a new National Water Mission is being framed by an Expert Panel, and is expected to be added to the NAPCC framework.

Advancement and adoption of clean energy technologies at nation-wide and industry-specific levels can ensure energy security, as well significantly reduced carbon emissions. The next step in the implementation of the NAPCC is a state-level action framework, which is in the process of being finalised under the guidance of respective Ministries and subject experts. Once state-specific agenda and targets are established, necessary economic incentives and Central support will be critical in realizing quantifiable results.

4.4 India's twelfth five-year plan

From a development standpoint, the GOI releases five-year plans (FYP) to symbolize the medium-term vision, and so Central assistance can be allocated for state plans. The current FYP, the twelfth (2012–2017), has a motto of 'Faster, More Inclusive and Sustainable Growth', with growth projections at 8% (GOI, 2013b). The plan asserts *"To sustain over 7 per cent growth for the next twenty years, (and) …. to meet the rising aspirations of our* *people…pursuit of low carbon strategies is essential, as otherwise, sustainability and energy insecurity would itself become a constraint on our growth process"* (GOI, 2013b, p. 139). While there has been a change in the ruling government during the plan period, it is encouraging to note that the present leadership has placed renewables, upfront climate action and rapid industrial advancement at the heart of its political intentions, with a view to creating a progressive, employment and GDP surplus nation.

Acknowledging the limitations of assessing growth merely in GDP terms without solid environmental indicators, an Expert Group has been constituted to formalize a green national account template – this is being done in order to quantify and evaluate national production output vis-à-vis extraction/depletion of national resources. While the Expert Group findings are anticipated, this study has computed some preliminary material consumption and intensity indicators for India's macro economy using MFA technique. Data available from international organisations like OECD Statistics and Global Material Flows Database (Dittrich, 2014; OECD, 2016c) have been utilised, and the results of this analysis are presented and discussed in Chapter 5. Simultaneously, an Environmental Performance Index (EPI) is being developed at the Centre to encourage states to pursue green goals towards reducing pollution, ensuring conservation and sustainable management of natural resources, and tackling climate change, by allocating budgets and targets. A preliminary list of 16 key indicators is under review and is expected to be finalised before the end of the current FYP (see Appendix 1) (GOI, 2013b).

In the twelfth FYP, a continuing trend with impetus to the agricultural sector is apparent, followed by a thrust on boosting the manufacturing and infrastructure sectors. India's rate of manufacturing growth is lagging in comparison with its GDP rise (UNIDO, 2016), which makes the fate of the economy uncertain when compared with other countries. Initiatives such as Make In India (MII) and Ease of Doing Business are gathering strong policy support and investment from public and private entities, as well as foreign interest. Recognizing the rising trend of industrial emissions and increasing resource intensities, an *Expert Group on Low Carbon Strategies for Inclusive Growth* has been formulated. Twelve prominent avenues have been identified for sustained government support through the ongoing FYP (see Appendix 2) (GOI, 2013b, 2014a).

In terms of monetary and non-monetary incentives to industry to reduce ecological impact and employ resource-efficient business practices, India is testing cap and trade and schemes and carbon tax mechanisms. Cap and trade schemes are expected to have a greater effect on emissions, but are more uncertain to succeed as a monetary incentive, whereas the reverse has been observed with a carbon tax, unless specific energy and emissions intensity thresholds are set (GOI, 2013b; YaleEnvironment360, 2009). The Clean Development Mechanism (CDM), an outcome of the Kyoto Protocol, has seen active participation from Indian businesses (1593 out of a total 7685 – 20% of the registered CDM projects as of January 2016 were from India, following China with a massive 49% share). In consequence, 191 million Certified Emission Reductions (CERs) have been issued to Indian CDM projects, ranging from energy efficiency, fuel substitution, industrial process improvements, MSW, renewable energy and forestry sectors, with major participation by private enterprises (GOIEconomicSurvey, 2016).

4.5 Manufacturing sector: Critical to India’s economic advancement

Indian manufacturing contributed 16% to national GDP in 2015 (GOI, 2014b), a trend visible through the last decade. Strong petroleum refining, automobile, wearing apparel, chemical, electrical machinery, furniture and wood product industries are projected to contribute to an upward trend in manufacturing (GOIEconomicSurvey, 2016). While the sector had an output contribution of 36.7%, its Gross Value Added (GVA) was only 17.4%, suggesting that a significant push is required towards improving the sector’s value addition (GOIEconomicSurvey, 2016; UNIDO, 2016). The intention is to increase share of Indian manufacturing to 25% of GDP by 2025, creating 90 million domestic jobs and making it a USD 1 trillion sector (Auroville, 2014). Impetus to manufacturing advancement is being undertaken with a double-pronged strategy – to decrease the burden on services sector, which has been witnessing sluggish growth; and as a means to creating sizeable employment opportunities for the expanding young and educated talent base.

The intensity of material inputs and waste discharge is generally quite high throughout different stages of the manufacturing process – starting from procurement of raw material and energy inputs, the actual industrial processes wherein raw materials are transformed into intermediate and finished goods, product use and final disposal, including allied logistics and transportation activities across the supply chain. This is the primary reason why the manufacturing sector has been chosen as the focus of this study. The scope for inducing reduction of inputs, circularity of resources and cutbacks in emissions is extremely high within this material- and energy-intensive sector. At the same time, expansion of manufacturing activity is viewed as a hallmark of stable economic growth.

Rapid transformation of the Indian economy was initiated on the back of heavy industrialization and the establishment of a primary manufacturing sector. The major industries include textiles; capital goods; metals; chemicals; cement & ceramics; electronics; automotive; leather & footwear; machine tools; food; tyres; textiles and machinery. Distinctively, primarily capital and skill intensive manufacturing industries thrive in the Indian economy despite the availability of abundant, low-skilled and relatively cheap labour. The key resource- and energy-intensive industries include iron and steel, cement, fertilizers and refineries. The industrial sector consists of large, medium and small enterprises, with extensive government support and incentives dedicated to creation of a robust small and medium enterprise (SME) network. Superior technology and capital-intensive goods constitute major imports, whereas export of raw materials is quite high by the manufacturing sector.

The sector is lagging on international competitiveness due to low energy efficiency, heavy fossil resource dependence and high emissions. Impediments blocking private domestic and international investment within the sector include complex entry mechanisms, lack of transparency and the absence of a unified structure, convoluted by the scattered location of enterprises. The government is attempting to remedy these shortcomings, but results are sluggish and small scale. The National Manufacturing Policy, introduced in 2011, attempts to resolve the ambiguity within the sector and provide an action framework for augmenting India’s global competitiveness.

4.5.1 Make In India (MII)

The MII initiative is a targeted program, launched in 2015, with the aim of bolstering entrepreneurial action in the manufacturing and infrastructure sectors of the Indian economy. Through an international showcase, foreign investment in 25 core areas was sought, with rigorous media and government support. It is one of the key agendas driving the current government’s development plan, and is expected to spur more than 100 million new jobs within manufacturing by 2022 (GOIEconomicSurvey, 2016). A few major incentives being extended to industry include subsidized power at fixed long-term rates, preferential land allotment, state subsidies and tax breaks (Jai & Mukul, 2016).

4.5.2 Delhi Mumbai Industrial Corridor (DMIC)

DMIC is a planned hi-technology industrial zone spread across seven Indian states; the corridor will span 1483 km, seeking an estimated investment of USD 90 billion. An initial fund of USD 147.2 million has been committed, with equal investments from India and Japan. The objective is to create a world-leading industrial corridor which augments India's international competitiveness and makes it an attractive destination for industrial investment. The master plan includes the development of 24 industrial regions, eight smart cities, two airports, five power projects, two mass rapid transit systems and two logistical hubs, and it is likely to employ 3 million people. Through latest manufacturing infrastructure and self-sustained industrial townships, local development is envisioned, offering employment incentives, boosting the economy and easing pressure off already saturated major cities (GOIEconomicSurvey, 2016).

A clear agenda on the location blueprints and site planning for DMIC is still under development; nevertheless, this presents a huge opportunity to ensure that infrastructure and systems are designed in a manner that sustainable *smart* cities of the future are created. A planned network facilitating the strategic sharing of utilities, common resources and structured resource exchange systems is critical to the long-term financial and environment sustainability of such a mega-scale project. Presently, it is unclear whether the industrial regions will be formed by Eco-Industrial Parks (EIPs), but these must be factored in at the planning stage itself. Best practices from China, Europe, USA and Australia must be reviewed to create global benchmarks.

4.6 CE progress in key manufacturing states

To aid the analysis in evaluating India's CE progress, the key manufacturing states in the country have been identified (Table 2), and evidence of Eco-Industrial Parks (EIPs) pursuits is presented in the following section. EIPs, symbolic of strategically designed resource exchange networks to develop symbiotic relationships between co-located firms, are the bedrock of CE and IE progress at a meso (industrial cluster) level (Chertow, 2000; Ehrenfeld & Gertler, 1997; Lifset & Graedel, 2002).

Table 2

Economic Profile of India's Top Six Manufacturing States

Economic Output of top six manufacturing states: India (2004–05 to 2012–13), % of GDP at 2004–05 prices						
Rank**	**State**	**% of India's manufacturing output**	**Services (%)**	**Agriculture and Allied (%)**	**Manufacturing (%)**	**Industry (Electricity, Power, Mining) excl Manufacturing (%)**
1	Maharashtra	19.98	60.55	9.19	21.25	9.01
2	Gujarat	12.83	45.85	13.74	27.83	12.59
3	Tamil Nadu	10.00	60.20	9.12	20.09	10.59
4	Uttar Pradesh	7.18	50.95	25.07	13.70	10.28
5	Karnataka	6.36	53.89	16.25	17.87	12.00
6	Andhra Pradesh	6.11	53.60	21.29	12.65	12.47
**National Manufacturing Output		**62.46** (Total)	Values in % of Gross State Domestic Product (GSDP)			
	India (National)		**56.16**	**15.75**	**15.92**	**12.17**

Source: GOI (2014b)

While there is little evidence of the intended eco-environmental benefits emanating from India's EIPs, some noteworthy studies include those by Patnaik and Poyyamoli (2014), who conducted a SWOT analyses for developing EIP projects in the diverse industrial region of the Union Territory of Puducherry, and Bain et al. (2010), who conducted a MFA of an industrial cluster in southern India, to identify extant and future possibilities for creation of symbiotic networks. The limited evidence can be attributed to a shortage of field-level data reported through academic standpoints, as well as the prevalence of such initiatives at a smaller scale, negligible in comparison to international progress.

The following discussion of India's CE progress is based on secondary research and personal discussions with relevant authorities. The methodology adopted was as follows. First, the top six manufacturing states in India were identified based on their average contributions to national manufacturing GDP from 2004–05 to 2012–13. Statistical data available through government-reported sources and literature have been utilized to analyse the economic profiles of these states, ranked based on their percentage contributions to national manufacturing output. Next, industry and academic reports on the development of EIPs in the shortlisted six states were reviewed and, finally, the planned initiatives based on recent government announcements, media reports and PPP were appraised. An updated assessment of the macro trends will help determine the future direction of EIP progress in India.

Together *Maharashtra, Gujarat, Tamil Nadu, Uttar Pradesh, Karnataka and Andhra Pradesh* constitute 62.46% of India's manufacturing output. Although Services, Agriculture, Manufacturing and Industry are the pillars of India's economic output, it is interesting to note that, even among the top six manufacturing states, Services output comprise the largest share at an average of 50%, followed by Manufacturing output at around 20% (except in the case of Uttar Pradesh and Andhra Pradesh where Agricultural output at 25.07% and 21.29% supersedes Manufacturing output at 13.70% and 12.65%, respectively). Heavy Industry, including electricity, power and mining, constitutes the lowest share of these states' output, except in the case of Tamil Nadu, where the share of agriculture is the lowest at 9.12%, compared with industrial output of 10.59% (Table 2) (GOI, 2014b).

4.6.1 Eco-Industrial Parks (EIPs)

While there is no formal mandate on development of EIPs in India, in contrast to the structured CE directive in China, the National Manufacturing Policy (2011) stipulates the creation of sustainable industrial systems in order the meet the needs of present and future economies and societies. New Special Economic Zones (SEZs), Special Investment

Zones/Regions, National Manufacturing and Investment Zones (NMIZ), and Petroleum Chemicals and Petrochemical Investment Zones (PCPIR) are gaining prominence, in conjunction with traditional industrial parks and clusters. Green buildings, renewable power usage, hazardous waste management and recycling, by-product reuse and shared infrastructure and utilities are integral to the planning of all latest industrial formats. Examples of existing industrial parks being transformed into EIP sites and future planned EIP development projects are evident. Information and infrastructure support from programs such as the Indo-German Environment Partnership (IGEP) have been encouraged for enabling implementation of Eco-Industrial Development (EID) projects across major regions.

The State of Andhra Pradesh contributes a large proportion to engineering and pharmaceutical industrial manufacturing. An early estimate of average emissions revealed that four major industrial parks in the state together released around 2.8 million tonnes of CO_2-equivalent emissions per annum. Since 2007, the Andhra Pradesh Industrial Infrastructure Cooperation Ltd. (APIIC) has green-flagged a phase-wise EIP transformation program to convert existing industrial parks under EID guidelines, in addition to a planned EIP strategy for new ones. The objective was to create a sophisticated environmental infrastructure for effluent management and reuse, combined with reducing energy intensities and emissions of key industry and enhanced use of renewable energies. Nacharam and Mallapur industrial parks were the first to begin the makeover with stakeholder consultations and setting up Environmental Management Cells (EMCs) for expert guidance. Common infrastructure such as separate pipelines for high-TDS (Total Dissolved Solids) and low-TDS effluents, waste water treatment and reuse, desalination centres, a focal power plant, renewable power generation and distribution facilities were made mandatory in the primary phases of the transformation (InternationalClimateInitiative, 2015; Nukala & Meyer, 2012).

A Common Effluent Treatment Plant (CETP) to manage effluents from 650 diverse industrial units including engineering, pharmaceuticals, chemicals and dyes was installed in the two industrial regions. For upcoming projects, Environmental Impact Assessment (EIA) was made compulsory before accepting applications from specific enterprises. Based on the EIA findings, unsuitable industries were prohibited from setting up a base, with the aim to balancing local ecology needs (Nukala & Meyer, 2012). In the SEZ at Sri City, substantial shifts have been made from conventional power sources – 100% solar power generated at the in-house 2 MW solar plant is used for street lighting on campus, and a 100% water recycling infrastructure has been implemented (Nukala, 2013). Overall, a significant improvement in environmental measures; energy and resource-savings; regular climate, environment and energy audits; emissions monitoring; and expert training in energy and resource efficiency practices were involved in leading the ground-level transformation. Based on the experience and success of the two pilot projects at Nacharam and Mallapur, the EIP transformation program has since been implemented in over 30 industrial regions across the state.

Naroda Industrial Estate (NIE), one of the oldest in Gujarat, has long been planned as an EIP project by the Gujarat Cleaner Production Centre (GCPC) – a dedicated think-tank developed under the guidance of Central authorities and the United Nations Industrial Development Organization (UNIDO). Constituting mostly chemical, textile, ceramic and engineering industries, NIE has been a large economic hub as well as the leading industrial polluter in the region. Among other planned EID initiatives, the primary accomplishment has been the institution of a biogas plant for renewable energy generation. Utilizing bio waste generated within the estate premises, the bio-reactor facilitates power generation to illuminate NIE premises at night (Jain, 2011).

The Karnataka State Pollution Control Board (KSCB) has been a forerunner in initiating field-level research on identifying IS instances in industrial regions. A MFA conducted in an industrial region in the state revealed that 99.5% of the wastes generated were reused or recycled within or outside the facility. The three main modes of industrial waste recovery included: (i) reuse within the same facility, (ii) reuse within co-located firms, and (iii) informal recycling. Eleven self-organized symbiotic relationships were identified, as were 17 cases of residual transfer outside facilities, eight facilities receiving wastes as material inputs and 16 combust residual biomass were generating energy (Bain et al., 2010). A Common Treatment, Storage and Disposal Facility (TSDF) initiated by state authorities has been commissioned to manage 40,000 tonnes of hazardous waste annually, involving a total 1,600 industrial units. Spread over 93 acres, the TSDF is self-sufficient with a landfill site, rainwater harvesting, sewage water treatment and reuse systems. Furthermore, a pilot program has been launched to formalize the operations of e-waste recyclers in the capital city of Bengaluru (Nukala & Meyer, 2012).

In comparison with international progress on EIPs, initial evidence from Indian industry is severely deficient. Adequate information on symbiotic materials and energy exchanges – the ultimate objective of implementing EIP projects – is lacking. Bain et al. (2010) concluded that most of the observed resource exchange networks in their study in southern India had evolved organically over time, and through personal connections between managers with the objective of resolving practical resource availability constraints. The authors also noted the significant role played by the informal recycling sector, an aspect distinctive to most developing nations. Initial examination suggests the possibility of extant IS networks having an informal structure rather than a planned strategic approach. Difficulties with data collection and inconsistent disclosure by units are another aspect limiting analyses. Further investigation on the evolution of IS in Indian industry is required to understand their existence and draw comparisons with global counterparts.

Recent announcements of government-supported mega-scale projects show optimism in India's action towards materials and energy recovery and co-located industry-specific cluster efficiencies. India's premier End-of-Life Vehicle (ELV) auto-shredding and recycling facility is expected to start operations by 2018, with the possibility of being located in either Gujarat or Maharashtra. A planned investment of USD 18 million through the PPP mode, the 100,000 tonnes per annum capacity plant will have a target of achieving 100% extraction and reuse of materials, especially the recycling of high auto-grade steel and become a source of raw material input into major steel plants in the country. The self-contained plant is proposed to be designed on the lines of global best practice, using ELVs aged 10+ years and white goods such as refrigerators and air-conditioners. Offering a boost to the Make In India initiative, the first ELV plant will serve as a pilot demonstration site, and similar projects are also being planned in other states. Automotive remanufacturing in India is currently a highly fragmented industry with no clear structure or technology setup to ensure high-quality extraction (Shah, 2016). Govindan et al. (2016) and Rathore et al. (2011) identified high costs, lack of consumer demand for remanufactured products, scattered and inefficient product recovery methods, and the widespread existence of an informal sector, as significant barriers. A National Scrappage Policy is under review, in order to ensure steady supply of input material, in conjunction with offering financial incentives to consumers and automotive manufacturers. The objective is to minimize emissions, extract valuable auto components and upcycle their reuse, as well as reduce dependence on imported scrap metal by processing high-quality scrap within the facility, especially for the iron and steel sectors. Presently scrap imports of more than 5 million tonnes annually are incurred by secondary steelmakers in the country (GOI, 2016a; Messenger, 2016a).

Chapter 5: India’s CE performance: National indicators

5.1 Introduction

Based on a review of the literature on CE and its associated theoretical concepts, this chapter evaluates some significant indicators relevant to India’s CE progress. Geng et al. (2012) have critically assessed the CE measurement mechanisms applied in the EU, Japan, the USA, Korea and China. In Japan, the three core indices include resource productivity, material reuse and recycling rate, and rate of waste for final disposal. Inspired from the 3R (Reduce, Reuse, Recycle) philosophy, China was the first nation to develop a formal CE measurement mechanism through a list of relevant indicators at the macro (nation, industrial region) and meso (industrial park) levels. The four vital indices are *resource output contribution to GDP; resource consumption per GDP; integrated resource utilization to signify material reuse and recycling, dematerialization of economic activities; and levels of waste disposal and pollutant emissions.* Detailed metrics were included in each of the above four categories to arrive at a list of 22 indicators in order to assess CE compliance (Geng et al., 2012). A limitation of the above list is the absence of carbon-related metrics, as these are monitored under a separate mechanism. To attain a holistic understanding of CE progress within the nation, all relevant indicators must be included within the measurement system. Su et al. (2013) reviewed measurement systems employed at the firm or industry level, in addition to drawing parallels between varied CE dimensions and specific indicators.

A formal system for CE measurement has not yet been developed for India. However, to measure environmental performance, 16 key indicators have been proposed and are under review by the government (Appendix 1). Five principal measures were developed for the current study. These can be used to identify performance in different aspects of the eco-environmental context. The first three measures evaluate the intensity levels of India’s GDP: *Material Consumption and Intensity; Energy Intensity;* and *Emissions Intensity* (Section 5.2). The next two indicators assess progress in the areas of *Municipal Solid Waste (MSW) Management* (Section 5.3) and *3Rs* (Section 5.4). A short case study of the evolution of 3R principles in Indian industry is presented in Section 5.4 using the 3R and Zero Waste programs at Essar Steel’s Gujarat plant as examples. The above measures, termed ‘indicators’, are calculated for a macro (nationwide) analysis, using time-series data released by various national and international official agencies such as the Organisation for Economic Co-operation and Development (OECD) and International Energy Agency (IEA) and United Nations (UN). Future assessment of micro (regional and individual firm level) indicators is required to gain a holistic view of CE-linked performance of the Indian economy.

5.2 India's material use, industrial energy and emissions landscape

Intensive material and energy use, especially through virgin materials and energy sources, has been an inevitable predictor and consequence of economic development. It is no surprise then that India's development agenda is closely linked with its intensive use of coal sources, making it among the top three (China, Japan, India) coal importers in 2015 (Ahmad, 2016). In 2014, 72% of India's electricity needs were met from coal sources (WorldBank, 2016). India's Power Ministry recently announced that the nation is expected to become coal self-sufficient by 2019, owing to an increased domestic coal output. A reduction of 34.26 million tonnes of coal imports in 2015 amounted to almost USD 4 billion savings, on account of an 8.5% rise in domestic coal production (IBEF, 2016). While this may yield future foreign exchange savings of over USD 6 billion, it does pose questions about the nation's continued dependence on coal resources and is inconsistent with its international commitments.

5.2.1 Material intensities of the Indian economy

Economic growth and development have historically been linked to an augmented consumption of material resources, largely virgin materials and non-renewable energy sources (SERI, & WU, 2010). While the debate on the intrinsic linkages between resource use and economic progress is ongoing, the fact that India's per capita resource consumption has been steadily rising, coupled with the upward movement of its GDP, necessitates an investigation into the nation's material use patterns. Material Flow Accounting and Analysis (MFA) is one of the principal techniques used to assess both resource flows at an economy-wide scale (Dittrich, Giljum, Lutter, & Polzin, 2012; IGEP, 2013; Mutha, Patel, & Premnath, 2006; Singh et al., 2012) and worldwide decoupling trends (Bringezu, Schütz, Steger, & Baudisch, 2004). The MFA technique applied at a national level is helpful in determining Direct Material Inputs (DMI, *the sum of raw materials extracted and imports*) and Domestic

Material Consumption (DMC, *the difference between DMI and exports*), of the economy (Eurostat, 2001; UN, 2016a). Globally, the standard used to measure material performance includes natural resources like metals (ferrous, non-ferrous), non-metallic minerals (construction minerals, industrial minerals), biomass (wood, food) and fossil energy carriers; together these values form the material basis of an economy (OECD, 2016c).

A review of some of the key indicators of MFA, such as Material Intensity (MI, *the ratio of DMC and GDP*) and Material Productivity (MP, *inverse of MI – also referred to as Resource Efficiency*), facilitates a longitudinal trend analysis of the material performance of the economy, when plotted against economic performance indicators like the GDP (UN, 2016b). Figure 5 examines India's material consumption (DMC per capita) and MI levels over three decades, in addition to comparing the material intensity of India's GDP with major industrial nations including China, Australia, USA and Japan.

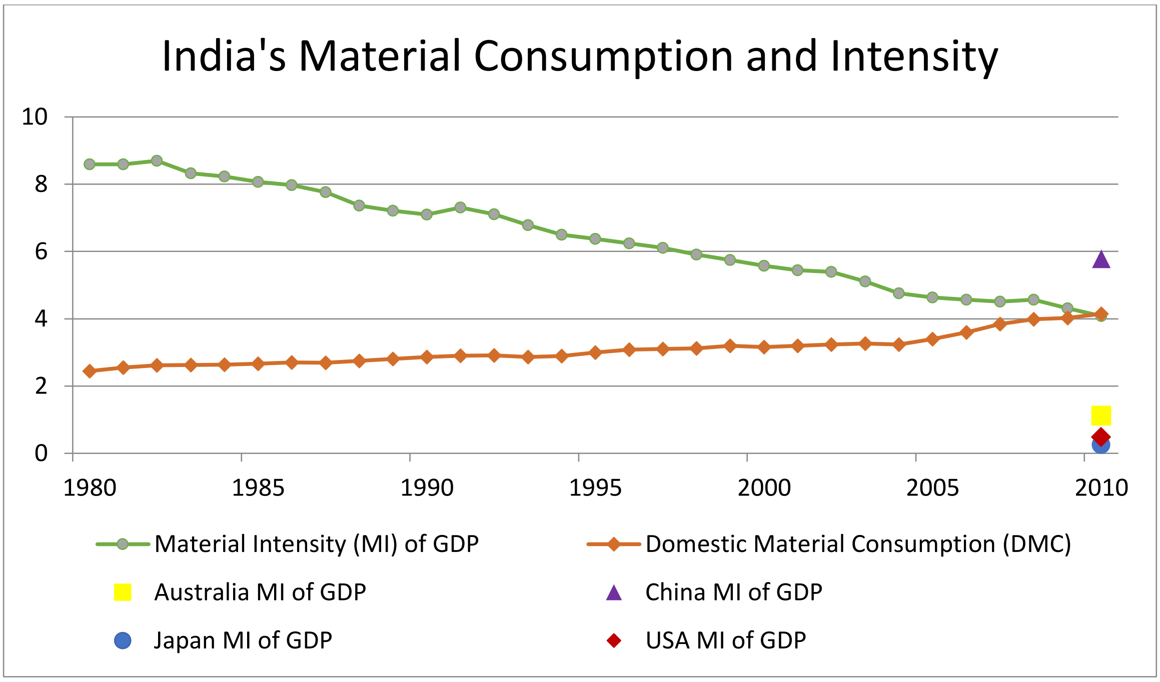

Figure 5. India's material consumption and intensity, 1980–2010.
MI (kg/USD, PPP); DMC (tonnes per capita)
Source: Author, based on Dittrich (2014); OECD (2016c)

Overall, India's material intensity shows a declining trend and in 2010 was around 4.08, second to China at 5.79 (Dittrich, 2014; OECD, 2016c). A declining trend is that MI generally indicates a relative decoupling of the economy. However, for fast-growing nations like India and China, the lowering of MI is largely due to the steady increase of their GDP owing to rapid expansion of economic activity.

In contrast to MI, India's per capita material consumption has seen a rising trend, increasing from 2.44 tonnes in 1980 to 4.15 tonnes in 2010. Although the nation's per capita consumption of materials was one-fourth that of China (17.73 tonnes) and one-fifth that of the USA (21.03 tonnes) (Dittrich, 2014; OECD, 2016c), the surge in the last decade signifies the economy's growing dependence on materials. Analysis of these indicators is limited, due to the exclusion of unused domestic extraction and indirect material flows from imports and exports; nevertheless, the indicators do give a fair approximation of the direction of material flows within the Indian economy. The findings imply the urgency in implementing absolute decoupling of resource use vis-à-vis economic growth strategies, through the implementation of long-term frameworks like CE.

5.2.2 Expanding energy demand of India's industrial sector

The efficiency of a nation's energy consumption, measured by calculating its *energy intensity* (total energy required to produce a unit of GDP), is one of the accepted indicators for assessing CE progress. A lower intensity indicates an improved utilization of energy resources, which implies lower inputs of fossil energy sources as well as greater circulation of entered resources within the economic system. India's Energy intensity (the ratio of Total Primary Energy to GDP), which includes commercial and non-commercial utilization of energy sources, has seen a declining trend (Figure 6) (GOI, 2013a, p. 130, Table 14.1). This improvement can be attributed primarily to the shift from traditional wood and cow-dung fuel sources towards natural gas use, especially for household consumption, and the steady rise of its GDP. Among the key energy sources, the share of renewables has witnessed a steady increase, with an output of 1.97 Mtoe in 2011 (OECD, 2016b).

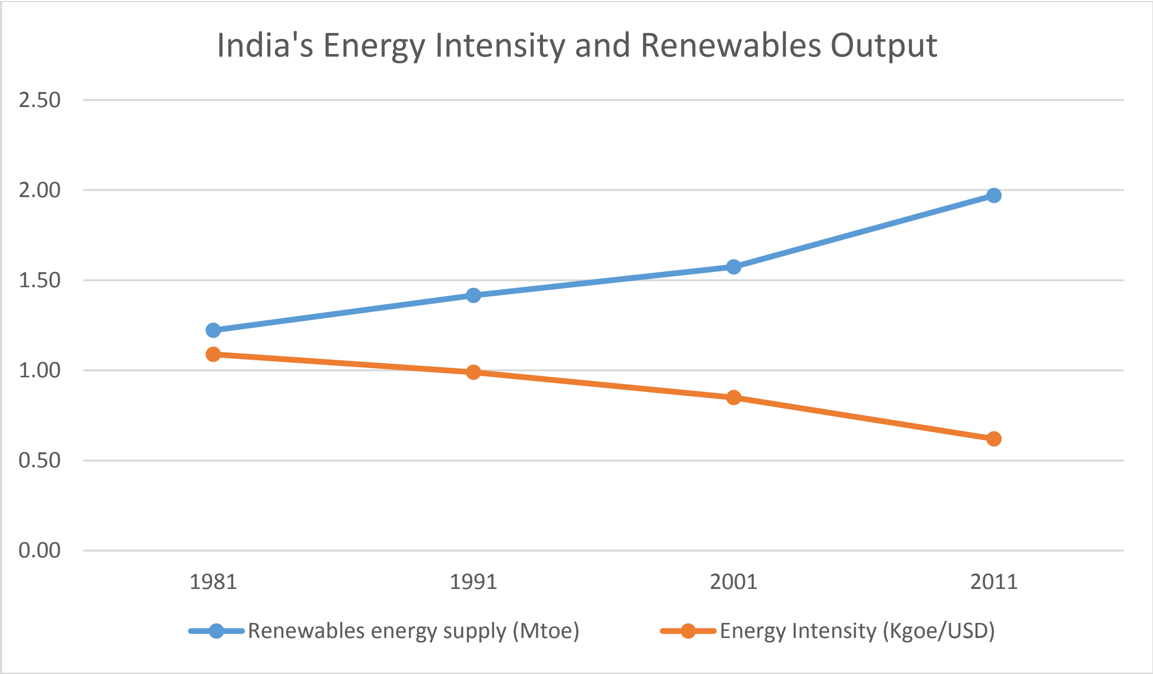

Figure 6. India's energy intensity and renewables output, 1981–2011.

Source: Author, based on GOI (2013a); OECD (2016b)

In spite of a visibly lowered intensity of energy use, India remains the third largest consumer, with a 6% share of global energy demand, after China (22%) and the USA (16%) (IEA, 2015). India's commercial energy needs remain high, particularly in the key manufacturing, transport, mining and industrial sectors. The industrial (electricity, power, mining, manufacturing) sector is the highest consumer of energy at 150 Mtoe, amounting to 38 % share of the nation's Total Primary Energy (TPE) consumption (GOI, 2013b). India's five most energy-intensive industries are Iron and Steel, Cement, Chemicals and Petrochemicals, Pulp and Paper, and Aluminium, together constituting 56% of the national industrial energy consumption. Furthermore, the manufacturing sector's energy intake has seen a rising trend, with a Compounded Annual Growth Rate (CAGR) of 9.8% for the period 1990–2008 (GOI, 2013b).

5.2.3 Rising share of India CO_2/GHG emissions

Among other policy standards, the Integrated Energy Policy 2006 provides a legal and regulatory framework for India's GHG (greenhouse gas) mitigation. Other focused policies include the Environment Impact Assessment (EIA) 2006 and the energy labelling program for electronic appliances, initiated by the Bureau of Energy Efficiency in 2006. The Power sector is highest contributor (38%) to India's GHG emissions, followed by iron and steel, and cement sectors accounting for nearly 60% of total industrial GHG emissions (GOI, 2013b). Solar power technologies, considered to be extremely clean with almost zero emissions at the point of generation, are expected to show an exponential increase in fulfilling India's growing energy needs. Shortages of funds to support renewable power infrastructure and a still-evolving nation-wide implementation action-framework appear to be the primary hurdles in shifting its fossil dependence.

The reported aggregate CO_2 emissions in India have increased by almost 64% for the period 2003–2012, witnessing the highest increase after China, with the EU, the USA and Australia experiencing a decline (Figure 7) (OECD, 2016a). This trend can be attributed to the rapidly expanding industrial activity and economic progress in the two Asian nations, coupled with limited restrictions and monitoring of emissions. In contrast, the hitherto industrialized nations have been experiencing declining economic growth rates, which explains the reduced emissions, combined with the global trend of offshoring of manufacturing (energy and emissions intensive) activities to developing nations such as India and China. India's average per capita emissions of 1.14 tonnes CO_2 equivalent were among the lowest, almost one-quarter of that of China, as well as the world average, during 2003–2012, and $1/16^{th}$ that of the USA (OECD, 2016a). Fuel, electricity and heat generation had the largest share of emissions in China, India, the EU and the USA, followed by manufacturing-linked emissions for India and China (GOIEconomicSurvey, 2016).

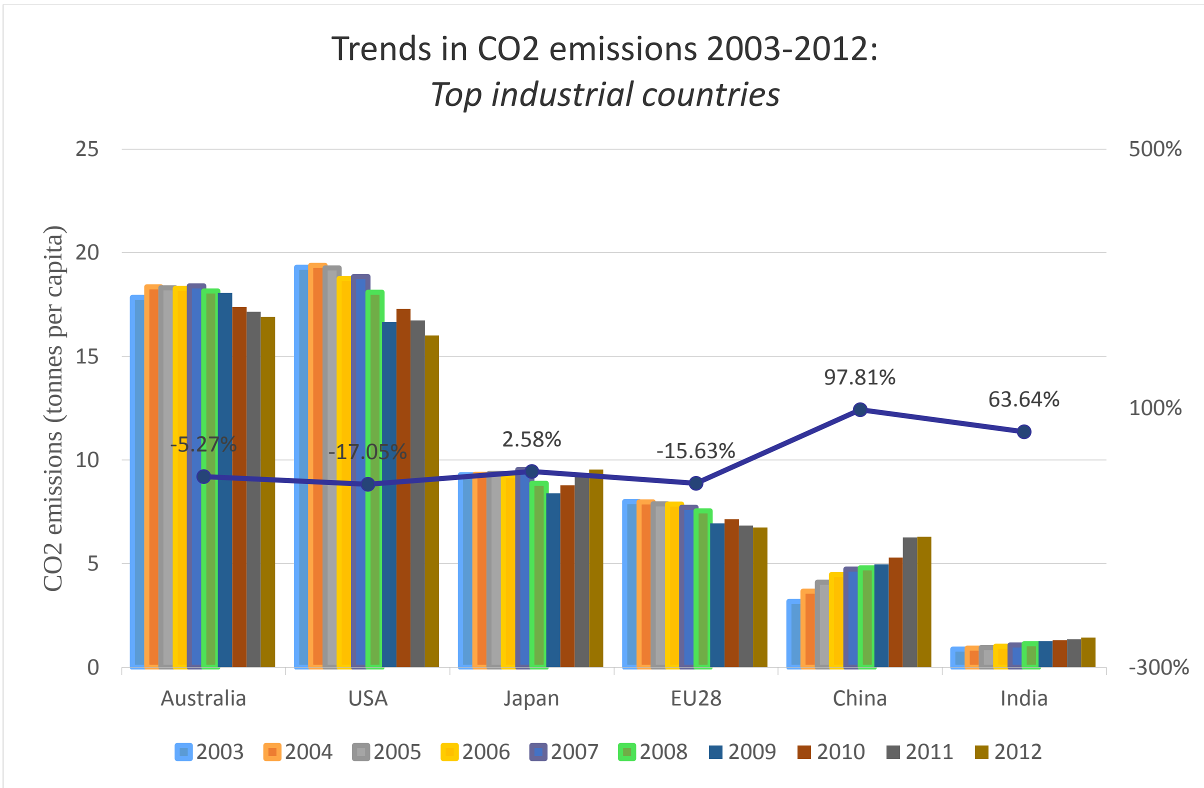

Figure 7. Trends in CO2 Emissions, 2003–2012.

Source: Author, based on OECD (2016a)

5.3 Municipal Solid Waste (MSW) management

Solid waste management is an area that requires urgent attention in India's waste management plan. GOI has set a target of generating 700 MW energy from waste by 2019 (GOIEconomicSurvey, 2016). A recent conference established the scope for generating 4–6 GW of power from waste-to-energy projects across diverse regions (Messenger, 2016b). The responsibility for waste collection, sorting, transportation and disposal currently lies with local government or municipal bodies across states. Lack of funding, limited manpower and logistics support, an absent waste-to-energy agenda and inadequate awareness of waste extraction and reuse techniques, along with unrestrained disposal in landfills, ail the sector. The informal sector plays a significant role in waste collection and sorting; however, their activities go unnoticed and lack a strategic approach, especially in regards to possible financial gains by creating an organized structure for this sector. The greatest need is a concrete action-oriented plan and ample awareness and education among the formal and informal waste management bodies, in order to exploit the full potential of waste transformation into new resources and energy.

A recent case of a small city, Kanpur, in northern India elicits the abundant opportunity present in MSW management across Indian households and industry. Kanpur has an average of 1500 tonnes of solid waste generated per day, with most of it going unsorted to landfill. In an effort to boost private participation in resolving the waste crisis, the Municipal Authorities in Kanpur initiated a BOOT (build, own, operate, transfer) project and appointed A2Z Infrastructure, a private company, to operate a 46-acre plant for solid waste processing. A tipping platform, pre-segregation unit, composting unit, Refuse Derived Fuel (RDF) unit, plastic segregating unit, briquette manufacturing unit, and secured landfill were setup through joint public-private funding. With the help of local cleaning agents termed ‘Safaimitras’, meaning *friends of cleanliness*, daily garbage collection is organized, with the waste being compressed en route the processing facility, and transformed into premium quality compost, RDF, interlocking tiles to be used in footpaths. Through this initiative, the plant has become the largest manufacturer of organic waste fertiliser, with a huge demand and market potential. Furthermore, the private company A2Z commenced one of Asia’s largest waste-to-energy plants, generating 15 MW of electricity from the RDF produced in-house. This one-of-a-kind integrated solid waste management project has been listed with UNFCC under the Clean Development Mechanism (CDM) for carbon reduction and mitigation. A similar model is now being considered by other municipal corporations in the State of Gujarat, with increasing support from the central and state governments (Ahluwalia, 2012; GOI, 2013b).

Waste of electrical and electronic equipment (WEEE) management is another area that merits urgent action; serious efforts are being taken to implement Electronic Waste (e-waste) sorting and recovery regulations across major industrial nations, yet India is lagging. E-waste has potential for recovery and reuse of multiple precious metals through automated separation of high-grade plastic and metals materials, but most of the developing world is still incinerating e-waste and losing a valuable opportunity (Huang, 2016). Waste-to-energy projects are lacking financial and policy incentives for implementation, and suggestions have been made to lower bank interest rates to encourage private investment. The levels of investment, plant capacity, regular supply of quality waste and project risk assessment are the key considerations involved in investment decisions. A revised draft Solid Waste Management Rules 2015 is presently under review in India, and is expected to stimulate industry involvement and compliance. A PPP model is proposed to be the most viable mode of operating waste-to-energy infrastructure in the country (WMW, 2016).

5.4 Case study: 3Rs and Zero Waste at Essar Steel Gujarat

Reduce, Reuse, Recycle (3Rs) have been suggested as the pillars on which any CE system is founded (Ghisellini et al., 2016; Sakai et al., 2011; Yong, 2007; Zhijun & Nailing, 2007). For the purpose of analysing these perspectives in an Indian context, an industry example was used to develop a short case study. Information was gathered through company released announcements, audio visual material, and government and industry reports. The objective is to present the diverse initiatives being undertaken at a large steel making plant in India and to establish the global opportunity of utilising 3Rs in the Iron and Steel Industry (ISI). India's steel production stands at 86.5 million tonnes (MT) annually, ranking 4th in global crude steel production, with a 5% share. A 71% rise in imports at 9.32 MT in 2014–15 made the sector a significant foreign exchange consumer (GOIEconomicSurvey, 2016). Due to near-stagnant demand for steel globally, and in particular in China, major global steel producers are pushing steel products into the Indian market, leading to a surge in steel imports. The Indian steel industry with higher borrowing and raw material costs and lower productivity is at a comparative disadvantage. A 3.9% increase in domestic steel consumption was registered in 2014–2015, at an aggregate 76.99 MT. A significant increase of 7.3% in domestic consumption is expected in 2016 (GOIEconomicSurvey, 2016).

ISI is the highest consumer of industrial energy, having Specific Energy Consumption (SEC) of about 29.2 GJ/tonne of crude steel (tcs) and emission intensity of 2.78 tCO_2/tcs (GOI, 2013b). Of the four main steel manufacturing processes in India, Blast Furnace and Basic Oxygen Furnace (BF–BOF) are the most common, while Direct Reduced Iron and Electric Arc Furnace (DRI–EAF), which have the lowest adoption rates, are the most energy-efficient processes. DRI–EAF production method depends on the availability of good-quality steel scrap, and India leads global production in DRI steel (GOI, 2013b). Emission intensity of ISI is targeted to reduce by 14–17% by 2020, compared with 2007 levels. The ISI is a critical industry for India's economic development, with a 2% share in GDP (GOI, 2013b), and has solid backward and forward linkages. Indian ISI's international competitiveness is low, due primarily to high costs and lagging technology efficiency. Evaluating the high energy intensity and emissions levels of the ISI, the necessity of employing resource-efficient measures is quite evident, and has become a matter of survival for the industry worldwide.

Essar Steel India is a global leader in steel manufacturing and exports, with an installed capacity of 14 MT of flat carbon steel production, and has operations across Asia, Canada, the USA, and Middle East. Located 27 kilometers west of Surat, India's diamond and textiles hub based in the State of Gujarat, Essar Steel Hazira is ranked as the fourth largest single location flat steel production facility in the world. It is a pioneer steel plant in India, employing all three prominent steel-making technologies – Blast Furnace, EAF and Conarc Furnace – at one location. The plant has taken concrete action to address the energy, emissions and waste utilization challenges faced by India's ISI. The company's vision of becoming a zero waste facility at their Hazira plant has led to an organization-wide drive to employ innovative waste recycling and reuse mechanisms within the industrial location. A zero waste taskforce constituting leaders and technical experts of different business verticals has been able to identify waste streams and find valuable reuse opportunities. The benefits accrued to the company have resulted in lower operational costs and, more importantly, value creation from critical hazardous waste (EssarSteel, 2016). The following subsections discuss some prominent CE initiatives undertaken at Essar Steel's Hazira plant.

5.4.1 'Zero Waste' 100% waste utilization within plant operations

The Cold Rolling Mill (CRM) and Steel Melt Plants at the Essar Steel facility generate large quantities of discharge, which have around 45% iron-bearing content. Due to its fineness and high iron matter, this discharge has been classified as 'hazardous waste' by Gujarat Pollution Control Board (GPCB). The classification by GPCB prohibits the material from leaving the premises for recycling or reuse by a third party, and must be disposed of safely, most often in landfills. To overcome this environmental hazard, Essar Steel has devised a way to synchronize the discharge from both the CRM and Steel Melt plants, to arrive at a common unit for re-processing and further utilization with their Sinter plant. Thus, annually over 2400 tonnes of sludge discharge from the Effluent Treatment Plant (ETP) of the CRM is combined with dust fines from the Fume Extraction System (FES) of Steel Melt Plant, and used to manufacture micro-pellets. These micro-pellets are transported as input material to the Sinter

Plant, leading to net profit savings of USD 2 million per annum and the accomplishment of Essar Steel's motto of *100% solid hazardous waste utilization* (EssarSteel, 2015c).

5.4.2 By-product reuse and reduction

Dust, comprising primarily iron and carbon fines, is emitted from the production processes of the Blast Furnace (BF), which is commonly classified and disposed of as 'hazardous material waste'. Through in-house research and technological development, the team devised a way to reuse this waste dust in a manner that was less polluting and wasteful. By transforming dust into briquettes, using molasses and lime as polymeric binders, the briquettes are later used as an input into the Electric Arc Furnace (EAF) as a coolant material. The use of coolant has improved the efficiency and functionality of the EAF, due to reduced erosion and longer useful life of the furnace lining. During the pilot phase, the facility produced 200 tonnes of briquettes, which after successful testing were used for commercial production within the same facility. In addition, over 150 tonnes of cold direct reduced iron (CDRI) fines released as waste on a daily basis are transformed into briquettes to be used within the EAF and Conarc processes (EssarSteel, 2015b).

5.4.3 Recovery and reuse

In partnership with global industrial services company Harsco, Essar Steel has initiated a structured process to manage steel slag from its EAF and Conarc Furnaces. Over 1 million tonnes of slag are generated annually through their steel-making operations, and this slag has high iron-bearing content. Using in-house technology, iron matter recovered from the slag will be utilized within Essar's steel-making operations; the remains of the slag will be employed in the construction industry to manufacture paver blocks, bricks, road laying and cement mix. Slag manufactured paver blocks are considered to be stronger and cheaper than cement paver blocks. The returns for the company lie not only in reducing their environmental footprint by efficient material recovery and reuse, but also receiving financial gains of USD 22 million annually from these non-core operations (EssarSteel, 2013b).

5.4.4 Water management, recycling and conservation

Based on a time-bound effluent water quality testing and ideation by the Power & Steel Plants within the complex, an in-house technology has been developed to lower the water use intensity of the steel-making process. Through a system for cascading of cooling water, the industrial processes of the plant are designed in manner that effluent water from the Power Plant becomes an input resource into the steel-making process. Essar Power releases around 4000 cubic metres of treated effluent water into artificially created waterbodies, which are then cascaded into the Steelmaker's Hot Briquetted Iron (HBI) Plant. Through this intentionally designed water management infrastructure, almost 95% of the total water input is recycled and reused within the plant's processes. In addition, a rainwater harvesting facility was setup in 2009, as a result of which almost 600,000 cubic metres of rainwater is used annually as a source of fresh water (EssarSteel, 2013a).

5.4.5 Waste recovery through power generation

A 19 MW capacity waste heat recovery power plant has been located within the premises, providing 'zero' cost fuel, as waste heat (surplus steam and gases) from steel production is used as input to generate electricity used by the plant. The company has managed to lower GHG emissions, improve energy efficiency of its operations and reduce power-related costs. Additionally, they can take advantage of carbon credits and avoid transmission losses, otherwise accrued due to distant location of national power grids (EssarSteel, 2012). The entire facility follows strict emissions monitoring and control, managed through internal audits and systems. The company has pioneered Gujarat State's largest biogas plant with 1 tonne capacity, utilizing over 1000 kilograms of food waste per day from 17 cafeterias. The generated biogas, in turn, is used to fuel the kitchen facilities with over two commercial-size cylinders powered daily, leading to a successful waste-to-energy setup and significant cost savings (EssarSteel, 2015a).

The above programs signify immense achievements in the direction of creating a circular economy. While not from an EIP perspective, Essar Steel's diverse 'Zero Waste' initiatives can become a global example of gaining CE efficiencies within a single enterprise's processes. Due to the scale of their operations, conscious action and ingenuity by the team, Essar Steel has been able to identify cost-efficient avenues for waste utilization within the

Steel Complex. The varied programs have yielded significant financial gains in addition to lowering emissions and ecological impact of the steel-making process.

5.5 ISI recovery, reuse and recycling: A global opportunity

Globally, ISI is an extremely resource-intensive and polluting sector, yet a significant contributor and key player in a nation's industrial development. In addition to diverse firm or region-specific CE initiatives within the sector, immense opportunities are presented by utilizing scrap as a resource for new steel manufacturing. Steel, due to its strength, durability and multi-functionality, is a highly recyclable metal. In spite of these beneficial properties, steel recycling lags in major steel producing developing nations like India and China. Yellishetty and Mudd (2014) conducted a Substance Flow Analysis (SFA) of four major steel producing economies – Australia, Brazil, China and India – to assess long-term sustainability of their iron ore resources. Their results show that almost 70% of produced steel is mined from new iron ore, with only about 30% recycled steel contributing to new production. The authors attributed this largely to the disparity between recycled metal availability (less) and actual demand (high), and the relative accessibility of new ores, in addition to the 15–17 years' life span of steel products circulation within the economic system. Other inhibitors to the feasibility of utilizing steel scrap include the limited availability of high-quality scrap, exorbitant prices of imports (in comparison to raw ore), uncertainty of steady supply, technological handicaps, and fragmented industry structure with a significant role played by informal actors, especially in India and China (Wübbeke & Heroth, 2014).

Steel scrap not only facilitates the reuse and recycling of waste steel but also enables significant savings in material and energy inputs within production process, and reduces emissions. Employing 1 tonne of steel scrap has the potential of saving input of more than 1100 kg of iron ore, 630 kg of coal and 55 kg of limestone, leading to a 40% reduction in energy consumption and 86% decrease in air emissions (Wübbeke & Heroth, 2014). The automotive industry is one of the key suppliers of high-grade steel scrap; this bears relevance to a much stronger thrust required in developing economies for creating technology and infrastructure supportive of steel products recovery and recycling. Similar initiatives like the planned auto-shredding plant in India, discussed earlier in Subsection 4.6.1, will create systems conducive to the recovery, reuse and recycling of steel. A robust recovery and recycling structure will be instrumental in lowering dependence on imports and concerns about insecurity, and in creating self-sufficiency in core resource production. As of 2012, Turkey (22.4 MT), South Korea (10.1 MT), India (8.1 MT), China (4.9 MT) were the leading importers of steel scrap (Wübbeke & Heroth, 2014). Lastly, it must be highlighted that 3Rs in ISI are just one of the ways of inducing circularity in heavy and resource intensive sectors. Multiple case examples from various industries and geographies present immense opportunities for further analysis and implementation.

5.6 Closing reflections

By reviewing the current state of policy and plans within the Indian economy and assessing CE and EIP progress in key manufacturing states (Chapter 4), this chapter has presented a macro synopsis of the present and future direction of CE initiatives. It has discussed the key indicators relevant to CE progress at a national level, and evaluated the Indian economy's performance vis-à-vis global counterparts. The case examples and evidence examined contribute towards offering a preliminary glimpse of specific initiatives being undertaken, and present a background for future field research. The next chapter delves deeper into the developing economy context by drawing comparisons of India's CE progress with China, and discusses the main findings of this study.

Chapter 6: Key findings

6.1 India's CE progress vis-à-vis China

China has taken a structured national approach to CE, with implementations (pilot and demonstration sites) and incentives (tax subsidies) monitored by the central government or the state. Air pollution is a major socio-economic concern in China, a result of a sharp rise in industrial activity with limited control of environmental impacts. The National Development and Reform Commission (NDRC) is the nodal authority responsible for nationwide CE implementation in China. The NDRC has welcomed participation by 178 entities, including 109 enterprises, 33 industrial parks, 7 provinces and 19 cities (Geng et al., 2012). The 12th FYP of the Chinese economy had targeted a 16% decrease of its energy intensity and 17% reduction in CO_2 emissions by 2015 (Song & Ye, 2015). While the outcome is still unavailable, a review of the nation's resource consumption suggests that consistent initiatives are enabling the Dragon Nation to lower its resources intensity over time (Mathews & Tan, 2016).

A critical comparison and contrast of Chinese CE practices vis-à-vis the world has been the subject of widespread research in academia. Mathews and Tan (2011) critically analysed eco-industrial initiatives in China, using common comparison parameters, and presented a visual representation of the Chinese cases in contrast to their well-known Western and East Asian counterparts. Key observations from the comparison of Chinese EIP cases with global counterparts are that the majority of programs have been implemented in existing industrial parks to transform linear value chains into closed-loop processes. The initiatives have evolved over decades, moving from basic pollution control and clean technology programs to more widespread and complex IS. Furthermore, China's eco-industrial progress is nascent, highly regulated by the government and monitored through mandatory policy compliance – in other words, there is top-down implementation. Conversely, Western examples are more organically grown and rather autonomous, often bottom-up initiatives (Mathews & Tan, 2011).

In contrast to China, India's political and institutional mechanisms are more participative, with mere Central implementation posing a challenge. Most industrial change in India has been initiated by individual enterprises in the past, with Centre/State guidelines and mandatory compliance as a starting point. Currently, a structured action plan and strict enforcement and financial incentives are required for the Indian economy to leapfrog to the next level of eco-efficient industrial practices. Water security is perhaps the biggest concern for Indian society and business alike, and a strategic approach to CE-linked practices has immense potential for offering a solution. Based on the assessment of present Indian policies supportive of CE thinking, India is evidently lagging on concrete action to attain decoupling success. The next section discusses some of the key findings from this study.

6.2 Current environmental taxes and schemes in India

Carbon Tax – a levy of 200 Rupees (~ USD 3) per tonne of coal – is in effect across major Indian states. Applied as form of environmental tax, the proceeds go towards the National Clean Energy Fund instituted by GOI to endorse clean energy technology and development. Perform, Achieve and Trade (PAT), a certificate-based trading scheme to induce energy efficient activities, is presently under review after its first three-year term (2012–15). Based on their allotted target achievements, the nine identified DC industries will be issued energy savings certificates, which can later be traded. The next phase of the PAT scheme is expected to increase the DCs to include inter alia the Petroleum, Chemical and Transport sectors. (GOI, 2013a, 2013b).

Eco-labelling, presently being pursued across nations due to health and environmental concerns, caught on quite early in India. In 1991 an eco-labelling program 'Ecomark' was initiated, to classify ecologically conscious consumer products which meet specific environmental and quality standards (GOI, 2013b). In the consumer electronics space, the Bureau of Energy Efficiency (BEE) has introduced mandatory energy efficiency labelling for frost-free refrigerators, room air conditioners, tube lights and distribution transformers, among other voluntary labelling mandates. The initial results of the program indicated that energy efficiency ratios of air conditioners improved from 2.2 in 2006–07 to 2.8 in 2011–12; whereas the energy consumption of a standard 300 litre refrigerator reduced from 547 kWh in 2006–07 to 368 kWh in 2011–12. All-round savings of approximately 7,500 MW of installed capacity were witnessed due to improved consumer awareness as a result of the electronic labelling program. An additional 30% reduction in energy use by air conditioners and refrigerators is expected by 2017 (GOI, 2013b). While this is only a fraction of the actual demand for consumer electronics, pegged to be around 155 billion units in 2016–17, the program is a step in the right direction and requires greater focus and support.

6.3 India's renewables stakes

GOI has reiterated claims of achieving 176 GW renewables power generation by 2022; nevertheless, an investigation into the Central Electricity Authority (CEA) has revealed that a maximum capacity of only 65 GW renewable energy transmission and distribution is envisaged by 2022, if the current pace of project setup is to continue (Mandal, 2016). Discrepancies between planned capacities for solar and wind versus their distribution are shortcomings that merit urgent attention. Insufficient use and inadequate technologies to store excess energy will result in unwarranted losses to power generation companies, consumers (industrial and households) and the environment at large. Transmission and Distribution (T&D) losses have been a constant failing of India's power infrastructure, due primarily to the prominence of majority distribution companies being state enterprises lacking financial stability. One solution can be investing in research and development to devise innovative technologies to harness the full potential of renewables. Alternatives such as the creation of *smart grids* and decentralized power generation and transmission are strong possibilities with renewables, and must be explored in greater depth to make the ambitious targets a reality.

6.4 The future of CE in India

As is evidenced from the assessment of India's material use, energy and emissions trends (Section 5.2), an increase in aggregate and per capita values is being witnessed over the long term and this rise is expected to persist, given the nation's industrialisation and social development agenda. While the intensities of material and energy consumption have shown a declining trend over the analysed period, the lowered intensities can be attributed to a rising GDP performance of the Indian economy. The inextricable impacts of these macro indicators on the nation's overall ecological systems cannot be disputed, and these pose a challenge for attaining equitable sustainable development.

Finally, India’s green development agenda is still evolving. While awareness among industry and government is driving key policy change, a concrete action framework is absent. India’s international commitments and widespread impetus to the renewable energies sector appear to be the primary mode of climate action. The evidently sluggish pace of renewable power infrastructure (Mandal, 2016) notwithstanding, India envisages a considerable shift from coal-fired power to renewables, especially, solar and wind. Slow uptake of coal-fired power, coupled with fluctuating demand and a higher proportion of energy demand being fulfilled by renewable sources, has resulted in an ongoing discussion to halt new coal-based capacity addition until 2022 (Burton & Fernandes, 2016; TERI, 2017). In light of this situation, steady advancement of solar and wind energy infrastructure through synchronized implementation, capacity-demand balance and availability of ready finance to encourage private sector participation, promise a bright future for Indian renewables industry.

Urgency in promoting EIP development and facilitating symbiotic exchange networks among industry is lacking in the present policy framework. There is a clear opportunity to plan the upcoming Make In India industrial zones and major industrial corridors, such as DMIC, with a strategic CE foundation, and to design industrial resource exchange infrastructure and smart cities by embodying CE and IE principles apart from sustainable urban planning. Independent action by states and enterprises must become widely known through further research, and global best practices must be implemented. The industry and governance structure in India is relatively participatory and it successfully functions bottom-up as well as top-down. Such networks must be used to the benefit of creating successful 3R examples and model EIPs, and a robust waste-to-energy setup in the growing industrial base.

Chapter 7: Discussion and future research

7.1 Discussion

Resource security is a grave concern to burgeoning economies such as India and China, and more serious than when the USA, Europe and Australia were industrializing (Dajian & Yi, 2007). The 'pollute-now, clean-up later' paradigm worked well for the developed world since virgin material and fossil fuel conservation was not the governing objective; rather, rapid economic growth and creation of demand and employment were the driving forces. In the last two decades, nations are faced not just with the challenge of supporting exponential economic growth and employment, but also with the finiteness of natural resources and security constraints, especially in the face of growing dependence on expensive and restricted imports, limited virgin materials and fossil fuel availability. Giving the example of the Chinese economy, Shenoy (2016) has reiterated that if a growing nation's foundation is built on consumer behaviour and disregard for the environment and its finite resources, corrective policies after the situation has become worse will not only be expensive and complicated to implement, but will also involve a reactive approach rather than a proactive one. Unless a system (or nation) is designed for sustainability right from the beginning, its future growth will not be long term (Shenoy, 2016).

From a CE perspective, implementation frameworks and theoretical underpinnings are still evolving. There is an opportunity for cases from developing nations to lead the discussion on what a *green industrial* future looks like. While China has been stimulating academic interest due to national policy emphasis and large scale implementation at an EIP level, evidence from nations such as India, Brazil and Indonesia is lacking. Although a macro CE agenda may be absent, there is no doubt that each of these nations realizes the limitations resource security and climate change pose to their economic development. This realization is driving change, and a deeper investigation into ground-level action is merited. The formal terminology may differ between economies, but as long as the accomplishment fits into the paradigms of CE and IE thinking, the lessons learnt will contribute to advancing the current state of knowledge.

At the level of a single enterprise, CE adoption symbolizes inter-process exchange of materials, energy and by-products to reduce total toxic output and waste. This in turn would enable the enterprise to maximize its resource use and output, thereby reducing costs and yielding higher savings and profits. The next stage of CE, at an industrial cluster or park level, requires setting up EIPs founded upon IS to encourage inter-company resource exchange among co-located firms, improving profitability and reducing transportation and associated costs and pollution. The strategic sharing of common utilities, infrastructure and knowledge, combined with closed-loop resource exchange networks, would enable the creation of an inter-dependent economic and environmentally sound industrial structure.

Collaboration and spontaneous evolution were the reasons the world experienced the scale of inter-firm networks at Kalundborg. Most successful and long-lasting resource exchanges advance over time, often in an unplanned fashion, and a flexible regulatory structure is critical for such organic activity (Desrochers, 2002a). Most IS activities are directed with a Business-to-Business (B2B) outlook. There is definite potential in exploring how CE collaboration from a Business-to-Consumer (B2C) perspective would take shape. CE adoption is closely linked to the actual economic benefits to companies, nations and societies at large. Subsequent research must identify sources of economic exchange to facilitate CE implementation. The findings would have significant practical implications – on increased economy-wide, business and consumer-level acceptance. Collaborative consumption models and the sharing economy have been closely linked to CE objectives (Botsman & Rogers, 2011; EllenMacArthurFoundation, 2012b; Stahel, 2016). Future research is required to assess the functioning, adoption and relevance of these models to CE advancement. How these strategies can be used to reduce consumption and waste is a gap that must be addressed through additional research.

At a broader city, region or national level, in addition to fostering a system of pollution reduction and safe and efficient waste collection, sorting/ processing, recycle, reuse and disposal, CE at a macro level nurtures the adoption of renewable energy sources and innovative technologies, to reduce interdependence on fossil energy sources. Urban planning for a future involving a holistic circular/cyclical society also identifies avenues for shared infrastructure use, creation of a waste to energy structure, and the inherent presence of a service economy within human society. The results from the analysis by Ghisellini et al. (2016) confirm that CE goals are intrinsically linked to the concept of decoupling; that different nations employ varied CE approaches (top-down in China, or bottom-up in the USA, the EU and Japan), and that CE deployment worldwide still seems to be in the primary phases, with higher emphasis on recycling practices, rather than *reduction and reuse* – which signify true attainment of CE benefits. Furthermore, the authors illustrated that major progress is being made in creating and adopting waste management strategies in certain developed nations, especially Europe. But most economies are lagging behind in effectively reducing and reusing material waste (Ghisellini et al., 2016).

From an Indian standpoint, evidence from industry implementation will be a driver for further CE action and policy evolution. As is visible from the case of Essar Steel’s Zero Waste and 3Rs philosophy, industry is making huge strides in mitigating its ecological footprint, and deriving financial gains in the process. EIP development is viewed as one of the primary modes of achieving IS, as established in the literature review; in addition, India’s informal recycling sector promises to be a key participant in facilitating resource recovery and creating by-product exchange networks (Bain et al., 2010). Other distinctive factors that have potential in enabling resource recovery include India’s first End-of-Life Vehicle (ELV) auto-shredding and recycling facility (Section 4.6.1), and the opportunity for strengthening iron & steel recycling through domestically sourced high-quality scrap (Section 5.5).

It is highly probable that multiple cases of CE exist in Indian industry, and future research must apply conceptual roots of CE at the industrial cluster and enterprise levels. As witnessed in Germany and France, enacting a polluter-pay principle has enormous impact on businesses’ consciousness of energy and reducing the intensity of emissions (Pinjing et al., 2013). India’s next big infrastructure project, the Delhi Mumbai Industrial Corridor (DMIC), is still in the planning stages, and that offers a timely opportunity to learn from the Chinese experience of transforming major industrial hubs such as the Tianjin Economic-Technological Development Area (TEDA) and Suzhou (Mathews & Tan, 2016; Shi et al., 2010; Yu et al., 2014).

It is commonly perceived that the primary inhibitors for early adoption of environment efficiency measures by Indian industry include a prevalent perception of risks, weak support for green technology adoption and funding, and low willingness of financial institutions to back innovative eco-environmental projects. A low carbon growth path will need significant technology and capacity upgrades. While the situation is improving, greater emphasis on green finance is required to facilitate large-scale adoption. Early estimates peg an expenditure of at least USD 2.5 trillion between now and 2030, in order for India to achieve its UNFCCC commitments (GOIEconomicSurvey, 2016). The Public-Private Partnership (PPP) mode adopted by GOI is a step in this direction, and is expected to garner larger involvement by private sector enterprises and banks. Knowledge exchange platforms similar to the Indo German Environment Partnership (IGEP) will be critical in enriching the available knowledge-base and technical capacity, and extending international best practices into Indian industry.

7.2 Research contributions

One of the primary contributions of this study is to offer an extensive literature review, converging knowledge from the fields of CE, IE and EE. The idea of decoupling, while looked at in specific disciplines, has not often been broached from an inter-disciplinary perspective. This study has attempted to do so by looking at decoupling from economic (business, CE), policy (laws, regulatory framework) and evaluation (measurement, monitoring) perspectives. As is evident, the experiences and challenges of developing nations are often unique, and different from their developed or industrialized counterparts. This differentiation cannot be more apparent than for the ongoing dichotomy between economic progress and environmental footprint.

Furthermore, an initial contribution to the CE literature is offered by conducting a macro review of present and near future prospects of CE in the Indian context. This exploratory study offers insightful findings of eco-environmental initiatives in a developing nation context, and can form the foundation for future primary research and field studies within Indian manufacturing sector. The results would have implications not only for the Indian economy but also for other developing nations pursuing a growth trajectory in the face of ongoing resource security and environmental degradation. It would enable policy formulation and business-level implementation of successful and long-term decoupling strategies. The research adds a dimension to the findings presented by Sakai et al. (2011), on global 3R and waste management policy developments of six regions: the EU, the USA, Korea, Japan, China and Vietnam, based on the outcomes of an international workshop of policy makers in Kyoto Japan in 2009.

7.3 Future research

Further to the data and analyses presented, the next step would be to identify industrial clusters employing resource exchange synergies with the objective of reducing waste, and encouraging materials and energy recovery and reuse. The discovery of informal exchange networks in a southern Indian industrial region was the result of a focused MFA employed at the park level (Bain et al., 2010). Such findings may be visible at other industrial parks, and only intensive field survey and analyses will enable a clearer understanding. Future research into comparing the Indian and Chinese experience of implementing CE techniques would offer interesting insights and lessons. A distinctive evaluation between these two world-leading economies merits a singular focus and, therefore, is worthy of being the subject of an independent analysis.

Finally, the present study is not without limitations. A CE not having formal application in India's national policy framework did pose challenges in analysing national reports and government documents. An assessment based on the conceptual roots of CE thinking was made and relevant policy information was gathered. The vital limitations of the present study are considered to be the lack of primary data, limited CE and IE studies reported from the Indian setting, discrepancy between domestic and internationally measured statistics and the novelty of the CE concept itself. While this incongruity posed a challenge in data collection, it also presents an opportunity for researchers to identify a commonly applicable model to identify CE progress. Future research into the creation of a commonly applicable macro list of national CE indicators will enable extensive evaluation of CE progress at a global scale, as well as aid inter-nation comparative analyses.

As is evident from the literature, CE is not a new concept; rather, it is a strategic process for convergence of the contrasting needs of ecology and the economy. CE spans an inter-disciplinary perspective relevant to a multitude of interest groups: academics from diverse disciplines; businesses seeking to incorporate 'green growth' within their strategic agenda; governments and policymakers from across the world pursuing decoupling goals; and the general public through their transition from ownership to service models such as the sharing economy and collaborative consumption. Furthermore, materials use, emissions and energy use data are recorded at diverse international platforms and a common measurement index for CE is yet to be developed. Caution was imperative in using statistics from international reports vis-à-vis official government documentation. Each country follows a distinct reporting mechanism, and the frequency of release of national data varies. Inter-ministerial variances in measuring and reporting national statistics pertinent to the economy and environment added to the complexity of the investigation. This study has incorporated the most commonly applied terms and measurement mechanisms to support the macro assessment, paving the way to further research in micro-assessment of CE developments in India.

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Appendix 1

Categories and indicators shortlisted by GOI for India's Environmental Performance Index (EPI)		
Criteria	**Indicators**	**No. of Variables**
Air Pollution	• Nitrogen Oxide (NOx) • Sulphur Oxide (SOx) • Suspended Particulate Matter (SPM)/Respiratory Suspended Particulate Matter (RSPM)	**3**
Forests	• Total Forest Cover (TFC) as a percentage of State Gross Assets and contribution to national average • Increase/decrease in forest cover • Growing stock • Afforestation efforts	**4**
Water Quality	• Percentage of waste water (DOM) • Surface water quality [Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), TFC)] • Percentage ground water extraction	**3**
Waste Management	• Municipal solid waste (MSW) • Bio-medical waste • Industrial waste—hazardous	**3**
Climate Change	• Preparation of State Action Plan on Climate Change (SAPCC) • RE growth rate including mini hydro • Electricity intensity of SGDP	**3**
		16

Source: Adapted from GOI (2013b)

Appendix 2

Twelve focus areas proposed by the Expert Group on Low Carbon Strategies for Inclusive Growth – applicable for the current twelfth Five Year Plan, India
1. Advanced Coal Technologies 2. National Wind Energy Mission 3. National Solar Mission 4. Technology Improvement in Iron and Steel Industry 5. Technology Improvement in Cement Industry 6. Energy Efficiency Programs in the Industry 7. Vehicle Fuel Efficiency Program 8. Improving the Efficiency of Freight Transport 9. Better Urban Public and Non-motorized Transport 10. Lighting, Labelling and Super-efficient Equipment Program 11. Faster Adoption of Green Building Codes 12. Improving the Stock of Forest and Tree Cover

Source: Adapted from GOI (2013b, 2014a)