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The influence of classical 'green' theories on contemporary industrial planning practices: A review study

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Review article

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Abstract

There is growing evidence that green industrial planning approaches have become the sensible alternative in the modern era, emphasising sustainability. This article reviews the influence of classical 'green' theories on contemporary industrial planning practices (eco-industrialisation in the age of climate change). The article adopts a qualitative methodological approach in the form of a desktop study. A total of 45 articles were finally selected for review after retrieval from internet databases. The study demonstrates that classical 'green' theories remain relevant in inspiring sustainable approaches to industrialisation, notably the Eco-Industrial Parks (EIPs) approach. While some of the classical 'green' theories such as the garden city theory date back to the 1900s, they are still relevant in contemporary industrial planning practices. The garden city theory provides a foundation for industrial location and regenerative theories that strongly influence the planning of eco-industrial parks. There is also a positive link between EIPs and the industrial location theory, as EIPs focus on the interaction and spatial distribution of different industries in the given geographic area, while emphasising the social and economic environment aspects. The EIPs approach also follows the ideas of a closed environment, industrial symbiosis, the regenerative theory, and the green political theory, both promoting sustainable industrial systems. The article concludes that, while planning for eco-industrial parks is still in its infancy in Africa, understanding the link between the classical 'green' theories and EIPs can help African urban planners and industrialists design and implement futuristic eco-industrial parks that ensure industrial park management performance, environmental performance, social performance, and economic performance.

Keywords: Eco-Industrial Parks, classical 'green' theories, planning practice, climate change, industrial symbiosis, Africa

DIE INVLOED VAN KLASSIEKE 'GROEN' TEORIEË OP KONTEMPORÊRE INDUSTRIËLE BEPLANNINGSPRAKTYKE: 'N OORSIGSTUDIE

Daar is toenemende bewyse dat groen nywerheidsbeplanningbenaderings die sinvolle alternatief in die moderne era geword het, met beklemtoning op volhoubaarheid. Hierdie artikel bespreek die invloed van klassieke 'groen' teorieë op kontemporêre industriële beplanningspraktyke (eko-industrialisering in die era van klimaatsverandering). Die artikel volg 'n kwalitatiewe metodologiese benadering in die vorm van 'n lessenaaroorsigstudie. Altesaam 45 artikels is gekies vir analiese. Die studie demonstreer dat klassieke 'groen' teorieë relevant bly en volhoubare benaderings tot industrialisering kan inspireer, veral die eko-industriële park (EIP)-benadering. Terwyl sommige van die klassieke 'groen' teorieë, soos die '*garden city'*-teorie, terugdateer na die 1900's, is dit steeds relevant in vandag se industriële beplanningspraktyke. Die '*garden city'*-teorie bied 'n grondslag vir industriële ligging en regeneratiewe teorieë wat die beplanning van EIP's sterk beïnvloed. Daar is ook 'n positiewe verband tussen EIP's en die industriële liggingsteorie, aangesien EIP's fokus op die interaksie en ruimtelike verspreiding van verskillende industrieë in die gegewe geografiese gebied, terwyl die sosiale en ekonomiese aspekte beklemtoon word. Die EIP's-benadering volg ook die karaktereienskappe van 'n geslote omgewing, industriële simbiose, die regeneratiewe teorie en die groen politieke teorie, wat onder andere volhoubare industriële stelsels bevorder. Die artikel kom tot die gevolgtrekking dat die begrip van die verband tussen die klassieke 'groen' teorieë en EIP, stadsbeplanners en nyweraars kan help met die ontwerp en implementering van funksionele EIP's wat nywerheidspark-bestuursprestasie, omgewingsprestasie, sosiale prestasie en ekonomiese prestasie verseker.

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TŠUSUMETSO EA LIKHOPOLO TSA KHALE TSA "NALANE EA TIKOLOHO" MABAPI LE MEKHOA EA MEHLENG EA KAJENO EA MERALO EA LITSI TSA THLAHISO: BOITHUTO BA TLHAHLOBO

Ho na le bopaki bo ntseng bo eketseha ba hore mekhoa ea thero ea litsi tsa thlahiso tse 'tala', kapa tse tsotellang tikoloho, e nkile sebopeho se seng mehleng ea kajeno. Sengoliloeng sena se hlahloba tšusumetso ea likhopolo tsa khale tsa tikoloho mabapi le mekhoa ea mehleng ea kajeno ea thero ea litsi tsa thlahiso (eco-industrialisation mehleng ea phetoho ea maemo a leholimo). Sengoloa se amohela mokhoa oa boleng ho ithuta ka komporo. Kakaretso ea lingoliloeng tsa lipatlisiso tse 45 li ile tsa qetella li khethiloe hore li hlahlojoe ka mor'a hore li fumanehe ho tsoa ho marang-rang. Boithuto bona bo bonts'a hore likhopolo tsa khale tsa 'botala ba tikoloho' li lula li le bohlokoa molemong oa ho khothaletsa mekhoa e tšoarellang ea ntlafatso ea litsi tsa thlahiso, haholo mokhoa oa Eco-Industrial Parks (EIPs). Le hoja tse ling tsa likhopolo-taba tsa khale tse kang ea toropo ea serapa li qalile lilemong tsa bo-1900, li ntse li sebetsa mekhoeng ea mehleng ea kajeno ea thero ea litsi tsa thlahiso. Khopolo ea toropo ea serapa e fana ka motheo bakeng sa sebaka sa litsi tsa thlahiso le likhopolo tse nchafatsang ebile li susumetsa ka matla thero ea lirapa tsa litsi tsena. Ho boetse ho na le kamano e ntle pakeng tsa li-EIP le khopolo ea sebaka sa litsi tsa thlahisoi, kaha li-EIP li tsepamisitse maikutlo holim'a tšebelisano le kabo ea sebaka sa liindasteri tse fapaneng sebakeng se fanoeng, ha li ntse li hatisa likarolo tsa tikoloho ea sechaba le moruo. Mokhoa oa EIPs o boetse o latela maikutlo a tikoloho e koetsoeng, tshebelisano ea litsi tha tlhahiso, khopolo ea tsosoloso, le khopolo ea lipolotiki tse hlokomelang tikoloho. Tsena ka bobeli li khothalletsa mekhoa e tsitsitseng ea indasteri. Sengoliloeng se phethela ka hore, le hoja thero ea lirapa tsa boikhathollo litsing tsa thlahiso e ntse e le litla-bocha Afrika, ho utloisisa kamano pakeng tsa likhopolo tsa khale tsa 'botala ba tikoloho' le li-EIPs ho ka thusa baetsi ba litoropo ba Maafrika le boraliindaseteri ho rala le ho kenya tšebetsong liratsoana tsa eco-industrial tse netefatsang tsamaiso e ntle ea litsi tsa thlahiso, tshebetso ea tikoloho, tshebetso ea setjhaba, le tshebetso ea moruo.

1. INTRODUCTION

Since the industrial revolution, human activities have released large amounts of greenhouse gases into the atmosphere, which has changed the earth's climate. The Intergovernmental Panel on Climate Change (IPCC) (2021: online) stated that, while some of the greenhouse gases occur naturally, the concentrations of some of them in the atmosphere are anthropogenic; that is, they are directly attributable to human activities. Carbon dioxide, methane, nitrous oxide, fluorinated gases, and carbon dioxide are the major toxic greenhouse gases. By 2020, the concentration of carbon dioxide in the atmosphere, for example, had risen to 48% above its pre-industrial level (before 1750) (Climate Action, 2022: online). These greenhouse gases and those naturally occurring in the atmosphere increase the greenhouse effect and global warming (Climate Action, 2022: online). The top five current sectors contributing to global warming are electricity generation and heat production, transportation, commercial and residential emissions, agriculture and industry (Consensus, 2022: online).

Small, medium and large industrial activity currently drives about a third of harmful climate-warming emissions (IPCC, 2021: online). These activities range from manufacturing, refining, and production, to emitting greenhouse gases when fossil fuels are utilised on-site for heat, power, or chemical processes. To curb industrial emissions, governments have passed several local and international legislations, prescribing, for example, certain norms for corporations to follow. While the effect of the legislation is apparent, as emissions have slightly decreased, industrial activity remains a threat to global warming, climate change, and humanity (IPCC, 2021: online). Recently, urban planning approaches such as sustainable industrialisation, smart industrialisation, and Eco-Industrial Park (EIPs) have become mainstream as modern ways of planning and operating industry to minimise greenhouse gases.

In every field of practice and research, classical theories play an important role in informing new thinking and approaches to emerging challenges. This article reviews the influence of classical 'green' theories on contemporary industrial planning practices, that is, Eco-industrialisation in the age of Climate Change. The article also uses practical examples of EIPs from Africa and across the globe that have adopted the principles of various classical 'green' theories. While some classical 'green' theories date back to the 1900s, they are still relevant in current industrial planning practices. These theories have also birthed new theories and concepts, allowing other industrial planning practices to emerge. Although industrial revolutions change, classical industrial planning theories often stay the same. To fully develop and implement smart industrial planning approaches, industrial planners can borrow ideas from classical theories and/or concepts that evolved from these classical theories – garden city theory, industrial location theory, theory of industrial ecology, regenerative theory, and green political theory.

2. METHODS AND REVIEW APPROACH

The article adopts a qualitative methodological approach in the form of a desktop study. First, article reviews and introduces the concept of eco-industrialisation. Secondly, the classical 'green' theories (garden city theory, industrial location theory, theory of industrial ecology, regenerative theory, and green political theory) that influence the EIP approach are reviewed and briefly summarised. These theories are reviewed because of their focus on promoting smart/sustainable/eco-industrialisation.

In the desktop literature search, relevant documents were identified through database keywords search for terms associated with

eco-industrialisation and the selected green industrial theories. The main databases consulted for the literature search for this article are Google Scholar, Taylor and Francis, Wiley Online Library, ProQuest, Science Direct, and Research Gate. Search terms for the literature search included eco-industrialisation, sustainable development, garden city theory, industrial location theory, theory of industrial ecology, regenerative theory, and green political theory.

The primary desktop research for this study was performed between 4 February 2022 and 5 June 2022, with supplementary supporting information sourced between 1 July 2022 and 16 August 2022. Preference was given to both recent and classical literature to reflect current understandings of the green theories and the EIP approach and grasp the classical insights on the theories. Recent literature, in this instance, refers to publications not more than 10 years old, that is, publications from the year 2012. Older literature prior to 2012 was also consulted because the ideas of some of the green theories were published at that time. The literature sources ranged from research papers, policy documents, textbooks, and other internet sources. Initially, a limit of 100 articles was chosen for the study, with the aim of identifying between 15 to 20 articles per category. The first 100 articles were sourced from main databases through the use of keywords (eco-industrialisation, sustainable development, garden city theory, industrial location theory, theory of industrial ecology, regenerative theory, and the green political theory), while also looking at the year of publication (recent and classical). From this initial search, articles were classified into themes: eco-industrialisation, garden city theory, industrial location theory, theory of industrial ecology, regenerative theory, and green political theory.

Articles in each theme were reviewed and compared to prevent too much repetition and overlaps. Ultimately, the main goal was to have between 6 and 8 articles selected in each category. All the articles were thoroughly evaluated for their relevance to this article. From the initially retrieved documents, 45 articles were selected, based on their connection to industrial activities and sustainable approaches, while keeping the main theories in mind. The review did not focus on any specific countries, as articles from around the globe were reviewed. However, the main contributors to research on EIPs are North America, Australia, and China. Articles were also selected based on credibility. Using literature sources with some degree of credibility is essential, as this influences the final accuracy and validity of the information presented in the article. In the discussion section, the theories are evaluated, mainly focusing on how much they inform the EIP approach and highlighting that classical 'green' theories remain relevant in inspiring sustainable planning approaches to industrialisation, particularly the eco-industrialisation approach.

3. KEY ISSUES

3.1 Eco-industrial park approach

Eco-Industrial Parks (EIPs) are increasingly being recognised as an effective tool to overcome environmental challenges associated with unsustainable industrial practices. Such parks have significant potential for unleashing inclusive and sustainable industrial development, as is already evident in developed countries such as Denmark, France, Japan, and the Republic of Korea. The concept of EIP dates to the early 1990s, with the uptake increasing in 2018. There are varying definitions of EIPs. The commonly adopted definition for an EIP, presented by the Policy Coherence for Sustainable Development (PCSD) in 1996 and still used to this day, describes an EIP as "an industrial system of planned materials and energy exchanges that seeks to minimise energy and raw materials use, minimise waste, and build sustainable economic, ecological and social relationships" (Cohen-Rosenthal, 2017: 19; PCSD, 1996: online). The United Nations Industrial Development Organization (UNIDO) defines EIP as a community of businesses located on a shared property, in which businesses seek to achieve enhanced environmental, economic and social performance through collaboration in managing environmental and resource issues (UNIDO, 2019: 7). Boix *et al*. (2015: 314) used Chertow's definition, referring to eco-industrialisation as a system with ecologically desirable goals. This includes minimising the overall environmental impact, managing materials and other resources (water and energy), and cooperative approaches to ensure eco-efficiency. Gibbs and Deutz (2007: 1685) also referred to eco-industrialisation as a community of businesses that work together to ensure resources (information, materials, water, energy, infrastructure, and natural habitat), which, in turn, support economic growth, natural habitat, and social structure.

The UNIDO and the World Bank developed an overall international framework for EIPs. This framework describes the performance requirements, along with the four key categories of EIPs. The key components include park management performance, environmental performance, social performance, and economic performance (UNIDO, 2019: 8) (Figure 1). These components include park management services and governance, resource efficiency and cleaner production, industrial and infrastructure synergies, a healthy and integrated workforce, urban industry synergies, as well as spatial planning and zoning.

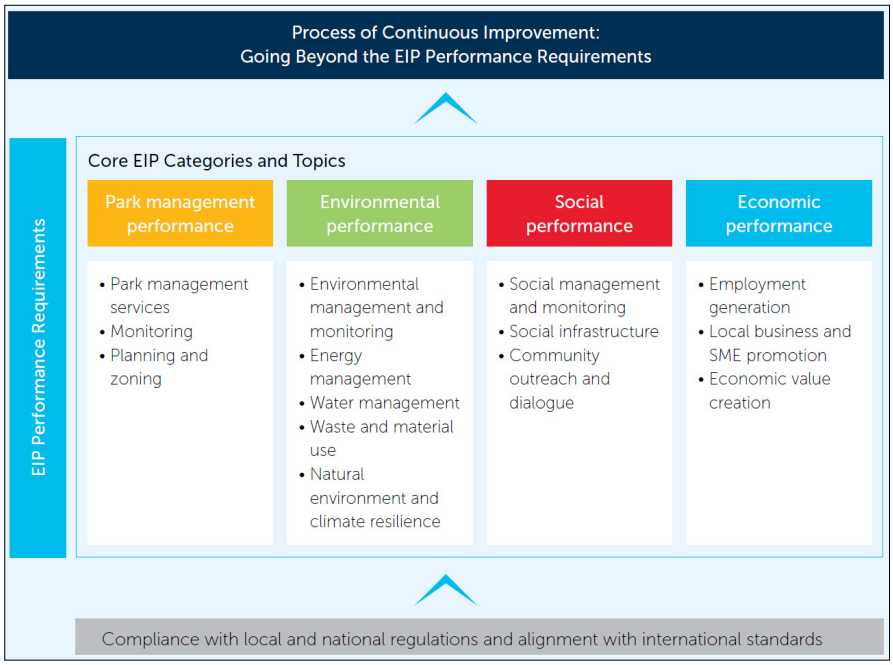

Figure 1: Framework developed by UNIDO to guide EIPs
Source: UNIDO, 2019: 8

The UNIDO provides a base and assists in defining the fundamentals and performance requirements of EIPs across different regions and countries (UNIDO, 2019: 8). EIPs can make use of the framework but are required to comply with both national and local regulations within their specific geographic location, along with the specific characteristics of the given EIP. This includes both environmental and social characteristics (UNIDO, 2019: 8).

The benefits of EIPs are diverse. EIPs enhance industrial synergies through which companies benefit from greater collaboration. EIPs reduce environmental impact through resource-efficient and cleaner production (RECP) practices. EIPs also promote collaboration among key stakeholders – companies, government, and service providers. Tenant companies and management are also enabled to turn environmental problems into solutions. The approach also capacitates parks for increased competitiveness, business development, production continuity, and a better reputation with key stakeholders. Finally, EIPs emphasise collaboration with neighbouring communities (Al-Quradaghi, Zheng & Elkamel, 2020: 1).

3.2 Classical 'green' theories for eco-industrialisation

3.2.1 Garden city theory

This study selected the garden city theory for review because it is one of the most influential urban planning theories. The Garden City movement was initiated in 1898 by Ebenezer Howard (Nabila, 2021: 1; Wheeler, 2012: 104). Due to the industrial revolution, the population in cities increased rapidly, leading to degradation of the environment (Gatarić *et al*., 2019: 34). Howard realised the importance of both the city and the environment, wanting to combine benefits of the countryside environment and city environment, while avoiding the disadvantages of both (Wheeler, 2012: 104; Gatarić *et al*., 2019: 34). The garden city theory describes a utopian city, in which people live harmoniously with nature (Nabila, 2021: 1; Gatarić *et al*., 2019: 34). It was viewed as an effective response for a better quality of life in dirty industrial towns that had deteriorated the environment and posed serious health threats (Nabila, 2021: 1).

The Garden City movement led to the development of the first garden city built in Letchworth, Hertfordshire, England, in 1903 (Lewis, 2015: 153). The city was planned to include communities surrounded by a green belt (parks), containing proportionate areas of residences, industry, and agriculture (Lewis, 2015: 155). Howard investigated three magnets that pull people to areas: Town, Country, and Town Country (Nabila, 2021: 2; Gatarić *et al*., 2019: 37), each having its benefits and challenges. The town-country magnet identified the favourable components of both country and town lifestyles and merged them into a third alternative (Nabila, 2021: 2; Gatarić *et al*., 2019: 37). The approach assumes that all benefits from city life such as a higher chance of employment, high wages, and better amenities can be enjoyed, while preserving the freshness of the healthy and beautiful natural environment of the country life (Nabila, 2021: 2; Gatarić *et al*., 2019: 38).

The principles of the garden city theory include raising the standard of life with more employment opportunities; securing healthier surroundings; collective ownership of lands instead of private individuals, which ensures benefits for the whole community; a permanent green belt around the city to control sprawl, ensuring a healthy environment, and easy accessibility and walkability (Nabila, 2021: 2; Lewis, 2015:153-155). The Garden City Theory inspired other thinkers such as Robert Owen and Walter Christaller (Gatarić *et al*., 2019: 34). The model also serves as a reference in urban and regional planning, along with the design of new human settlements, throughout the 20th century (Vernet & Coste, 2017: 49). Regional planning visualises urban planning beyond the boundaries and limitations of the city, and views it as a vital part of the global economic and ecological unit (Vernet & Coste, 2017: 49).

3.2.2 Industrial location theory

The general theory of industrial location was first developed by Alfred Weber in 1909 in *Theory of the location of industries* (Fearon, 2002: 1; Webber, 2020: 10). The model focused on different spatial factors that ensured the optimal

location for industries at minimal transportation costs (Fearon, 2002: 1; Hanink, 2016: 2; Webber, 2020: 11). The term 'industrial location' refers to the distribution of industries in a given area, along with the relation of the industries with other occurrences such as businesses and the population in the area (Webber, 2020:10). Therefore, the industrial location theory explains the spatial distribution of different industries in the given geographic area, by also referring to other aspects of the area such as social and economic characteristics (Webber, 2020: 10; Hanink, 2016: 1). The growth of an industry in a given area will influence the growth of the region and can lead to a change in the economic environment (Webber, 2020: 11; McCann & Sheppard, 2003: 650). This, in turn, influences the future growth of the area and can affect the local economy, which influences the decisions on development and policies (Webber, 2020: 11; McCann & Sheppard, 2003: 654; Hanink, 2016: 1). The location of an industry will determine the cost of real estate and of raw resources, travel distance of workers, and transportation of products to consumers (Fearon, 2002: 2; Webber, 2020: 12; McCann & Sheppard, 2003: 654). Therefore, the location must be carefully selected to ensure minimum transportation costs.

The industrial location model has been applied to other types of businesses and social-cultural structures. Other authors have also adapted the industrial location theory to help form the basis of other theories (Webber, 2020: 11). It has influenced planning practices such as EIPs. While Webber focused his theory on the economic state, other scholars such as Losch (cited by Neisser, 1956: 116) explained Webber's theory within the environment of monopolistic competition. The industrial location theory, according to Losch, focuses on finding locations where maximum profit will occur; therefore, ignoring transport, labour, and agglomeration costs, the emphasis of this theory was more on the total production cost (Neisser, 1956: 116).

3.2.3 Theory of industrial ecology

The theory of industrial ecology was first introduced alongside other terms such as industrial location (Renner, 1947: 182). The theory did not stand independently and was a combination of previous ideas regarding industrialisation and urban planning. The first research done on the theory was in Japan during the 1970s (Ogawa *et al*., 1986: 330). By 1989, Frosch and Gallopoulos popularised the term 'industrial ecology', by making use of the similarity between natural ecosystems and industrial systems (Boix *et al*., 2015: 303; Frosch & Gallopoulos 1989: 144; Heeres, Vermeulen & De Walle, 2004: 985). While the idea was still mostly influenced by the need for economic growth, the environment was also considered (Frosch & Gallopoulos, 1989: 144). Allenby (cited in Boix *et al*., 2015: 303) defined industrial ecology as "a systems-based, multidisciplinary discourse that seeks to understand emergent behaviour of complex integrated human/natural systems". This links back to the studies done in Japan in the 1970s that helped scientists, planners, and developers understand the socio-ecological systems and interactions (Ogawa *et al*., 1986: 332). The theory can be divided into five components: Industrial Metabolism, which is the rate of change of energy and materials; Dematerialisation which refers to the reduction of raw materials, energy, and waste; Life Cycle Assessment, which investigates the environmental aspects and potential impacts associated with the industry; Eco-design as a way of incorporating sustainable features into everyday products, and EIPs (Munholfen *et al*., 2004: 2). Therefore, the basic principles of industrial ecology are to analyse industrial activity from an ecological point of view. The relation between industries must be examined, as well as the interaction of each industry with nature (use of raw materials, energy and waste production). The channels used for distribution are essential to ensure movement within an industrial system and the movement of products to consumers (Erkman, 1997: 3).

3.2.4 Regenerative theory

The regenerative theory has been around for quite some time, as it is similar to Stahel's (1997) theory of product life and the substitution of services for products, McDonough's (2003) cradle-to-cradle approaches, where waste becomes a value-producing resource, and the industrial ecology system of Graedel and Allenby (1995) (cited by Geissdoerfer *et al*., 2017: 3; Kalmykova, Sadagopan & Rosado, 2018: 194; Sauvé, Bernard & Sloan, 2016: 53). The regenerative theory has been implemented within planning and development to support communities that experienced disasters or a major decline. The theory refers to the renewal of a product, city, or industry (Cole, 2012: 1). The theory is linked to the circular economy model, as it follows a closed system that can sustain itself. This means that there is a flow of materials, goods, and waste within the system (Geissdoerfer *et al*., 2017: 3; Kalmykova *et al.*, 2018: 194; Sauvé *et al*., 2016: 52).

Regenerative theory in urban planning aims to plan and develop flourishing living systems that are fully integrated. It follows the principle that society should align with the principles of natural living systems such as wholeness (society forms one with nature), change and adaption, and strong integrated relationships (Gibbons, 2020: 3). The principle of wholeness is important, since society is dependent on the natural environment. The regenerative theory also follows the eight principles of a circular economy: impact on the ecosystem; manage resources; stewardship; collaboration; transparency, and value optimisation (Huntjens, 2021: 36). According to the regenerative theory, the flow of material over borders and material life cycles form part of industrial systems. How these systems manage the flow of materials untimely impacts on the natural environment. Industrial patterns determine the extent of the impact; traditionally, industries follow a linear pattern that produces

high volumes of waste and pollution (Haibin & Zhenling, 2010: 1333). Regenerative systems are described as systems that restore, renew, or reuse their source of energy and resource materials. The regenerative theory aims to create a resilient system that is integrated within society and the environment (Haibin & Zhenling, 2010: 1333).

To be ultimately sustainable, ecosystems should evolve from an open linear system to a closed circular system. The linear economy model focuses on economic objectives and pays hardly any attention to ecological or social concerns, hence the high volumes of resources used. With a linear economy, production and consumption return to haunt the population as pollution, poor environmental quality, and loss of critical ecological systems (high volumes of waste produced) (Sauvé *et al*., 2016: 53). Regenerative theory promotes a circular economy which has been explored over the years and is also viewed as a way to address environmental challenges (Geissdoerfer *et al*., 2017: 2; Kalmykova *et al*., 2018: 195; Sauvé *et al*., 2016: 48). Closed circular systems have no defined waste, since the waste of one component is the resource of another component. Energy is still an important resource in the system, but other resources conception is limited or avoided completely (Geissdoerfer *et al*., 2017: 3; Sauvé *et al*., 2016: 53). Figure 2 illustrates the linear and circular economy models

3.2.5 Green political theory

The green political theory took shape in the 1970s and is rooted in environmentalism, non-violence, and social justice. The theory aims to narrow the gap between society and nature, since society is dependent on nature (Barry, 2014: 2). From the start, the theory was concerned with articulating the uniqueness of 'ecologism' as an ideology (Eckersley, 1992; Hayward, 1995; Barry, 2014: 2). The theory evolved and included debates between green political theory and other schools of thought such as socialism, liberalism, and critical theory (Wissenburg, 1998; Sakar, 1999). Currently, the theory focuses more on interdisciplinary approaches to governance and development (Barry, 2014: 2). The main focus is still environmentalism, ecology, and conservation (Dyer, 2018: 1).

The theory follows the ideology that human beings and natural environments are essential for growth. Both should, therefore, be managed and conserved (Dyer, 2018: 2). The theory can be described using three core principles, namely a theory of distributive (intergenerational) justice; a commitment to a process of democratisation, and the achievement of ecological sustainability (Barry, 1994: 1). The theory is based on the principles of environmentalism and ecology, while still focusing on economic growth, development, and well-being of society. It considers future generations and their ability to survive and thrive with what current society leaves behind (Barry, 1994: 1).

Green political theory can be described using many terms, including ecologism and environmentalism (Barry & Dobson, 2003: 181). However, there is an issue with only using these terms. Ecologism or environmentalism is too focused on issues of nature and human-nature relations (Dyer, 2018: 1). It does not always allow for an understanding of the 'non-ecological' and 'non-nature-related' principles (Barry & Dobson, 2003: 181; Dyer, 2018: 1). The focus cannot only be on pollution and resource management (ecological) or political ideology with views on non-resource and non-environmental concerns (non-ecological). To understand the intra-human dimensions, the ecological and non-ecological aspects need to be considered (Barry, 2014: 2; Dyer, 2018: 1; Sanjaya *et al*., 2021: 325).

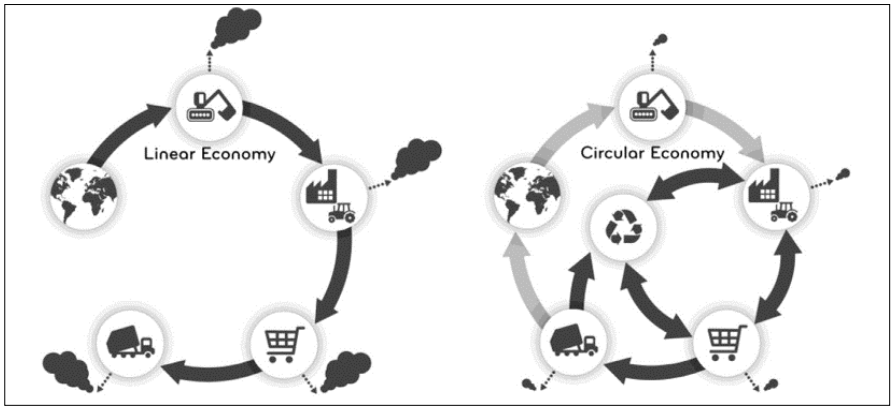

Figure 2: Linear and circular economy models
Source: Sauvé *et al.,* 2016: 53

4. DISCUSSION

4.1 Eco-industrial park approach in the age of climate change

The EIP approach's focus on the sustainability of the industrial sector is the way to go for industrial operations in the age of climate change (Al-Quradaghi *et al*., 2020: 1; Valenzuela-Venegas, Salgado & Díaz-Alvarado, 2016: 100). The approach focuses on the overall environmental impact reduction of the sector, both directly or locally and indirectly or off-site. There is also concern for the health of both the local and neighbouring communities (Al-Quradaghi *et al*., 2020: 2). The main goal is to reduce the negative impact of the industrial park on the direct or neighbouring communities (Al-Quradaghi *et al*., 2020: 2; Valenzuela-Venegas *et al*., 2016: 100). The EIP approach aims to achieve higher levels of performance to ensure a stable growing economy and a safe and healthy environment (Al-Fadhli, Baaqeel & El-Halwagi, 2020: 18324). Al-Fadhli *et al*. (2020: 18324) mentioned that the main objective of eco-industrialisation is to enhance sustainability by minimising waste. This indirectly reduces the

pollution and consumption of new raw materials, ensuring that natural resources are not as quickly depleted (Chertow, 2007: 21). The green theories – the garden city theory, the industrial location theory, the theory of industrial ecology, the regenerative theory, and the green political theory – have a strong relevance and influence on the EIP approach, as presented below.

4.2 Garden city theory and eco-industrialisation

The garden city theory, turned model, is still applicable in the 21st century in both spatial and sustainable industrial planning. The Garden City is based on sustainable planning and development and aims to combine the benefits of the countryside and the urban city (Caves, 2004: 282). An example of the influence of the garden city theory on eco-industrialisation is ChemCity Eco-Industrial Park in Sasolburg, South Africa. Kirchhofer (1982: 6) pointed out that the town's layout took inspiration from the garden city theory. The layout focused on creating green spaces between the built-up areas, allowing residents to be closer to nature (Figure 3) (Kirchhofer, 1982: 6). Over the years, new development adhered to the inclusion of green spaces, and, in 2011, Sasol's enterprise development vehicle, Sasol ChemCity,[1] and the Metsimaholo Local Municipality launched the ChemCity EIP (Sasol Limited n.d.: online).

While the garden city theory is not directly linked to EIPs, and no literature discusses the correlation, it did provide a foundation for other planning theories that focus on the environment (Caves, 2004: 282). However, to some extent, when comparing the aim of the Garden City theory and the aim of EIPs, there is a strong positive correlation. As mentioned, Howard wanted to combine the benefits of the countryside with the benefits of an urban city. EIPs aim to combine the benefits of a closed system (an ecosystem) with the benefits of industries (manufactured goods). When examining the objectives of each concept in detail, the influence of the garden city theory is evident. The garden city theory did, however, provide a foundation for industrial location and regenerative theories.

4.3 Industrial location theory and eco-industrialisation

There is a positive link between EIPs and the industrial location theory, as EIPs focus on the interaction and spatial distribution of different industries in the given geographic area, while emphasising the social and economic environment aspects (Frosch & Gallopoulos, 1989: 153; Heeres *et al*., 2004: 985). The EIP approach considers the importance of location, as this determines the cost of real estate and raw resources, the travel distance of workers, and the transportation of products to consumers (Fearon, 2002: 2; Webber, 2020: 12; McCann & Sheppard, 2003: 654). Therefore, the location must be carefully selected to ensure minimum transport costs in the operation of the industry. Webber formed his model around raw materials being distributed across a geographic area. To minimise transport costs, the optimal location central to all the materials used needs to be pinpointed (Hanink, 2016: 2). The EIP approach deals with the aspect of minimising transport costs, by concentrating related businesses together into a community of manufacturing and service businesses located together on common property. Chem City EIP in South Africa was also designed with the emphasis on the importance of location. Occupants of Chem City EIP will benefit from the location, as the park is in close proximity to other large industries and has access to a locally skilled labour force and existing road infrastructure to export/import hubs. These collaborative strategies ensure resource efficiency and cost reduction through by-product synergy ("waste-to-feed" exchanges), but can also take the form of waste-water cascading, shared logistics, shipping and receiving facilities, shared parking, green technology purchasing blocks, multi-partner green building retrofit, district energy systems, as well as local education and resource centres. This is an application of a systems approach, in which designs and processes/activities are integrated to address multiple objectives.

4.4 Industrial ecology theory and eco-industrialisation

The theory of industrial ecology exerts much influence on eco-industrialisation. It has attracted attention, due to the combination of

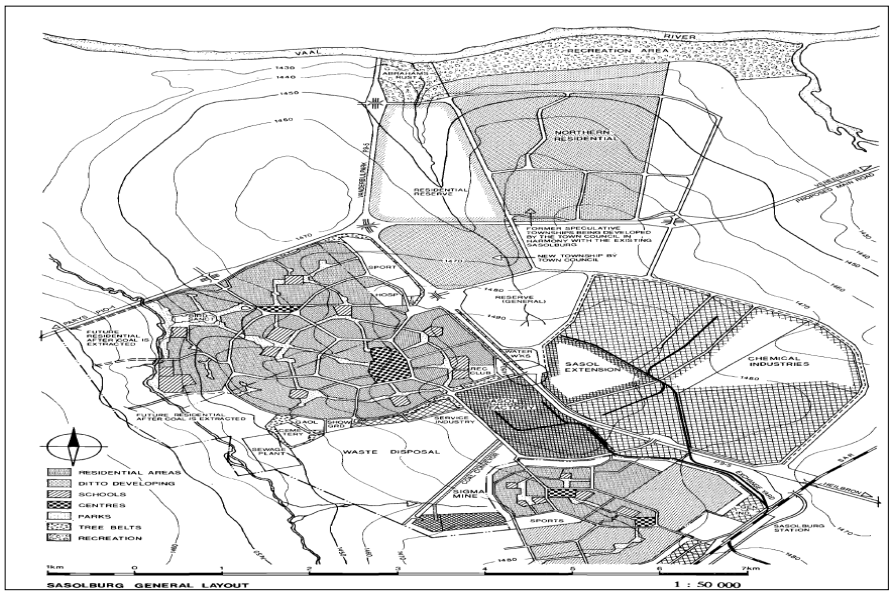

Figure 3: Sasolburg town's first general layout

Source: Kirchhofer, 1982: 3

1 As much as the authors would like to include a recent map of the Sasol ChemCity, there is no publicly available layout map. Access to the layout plan was denied upon request, as only potential property buyers are currently allowed to see it.

natural ecosystems and industrial activities that are located on two different ends of the spectrum. The industrial ecology approach promotes corporate environmental management that is proactive and inter-organisational (Sinding, 2000: 84). When combining industrial ecology and corporate environmental management, the inter-organisational focus is essential for material and energy flows across the firm, organisational, regional and national boundaries and borders (Gibbs & Deutz, 2007: 1684; Korhonen, 2004: 62). Inter-organisational environmental management includes life-cycle management, environmental supply-chain management, and regional environmental management. Network management and inter-organisational environmental management are important for EIPs or industrial symbiosis studies, one of the application areas of industrial ecology (Korhonen, 2004: 62). Since material and energy flow across firm, organisational, regional and national boundaries and borders, industrial ecology is divided into three levels: firm, across firms, and regional or global level (Gibbs & Deutz, 2007: 1684) (Figure 4).

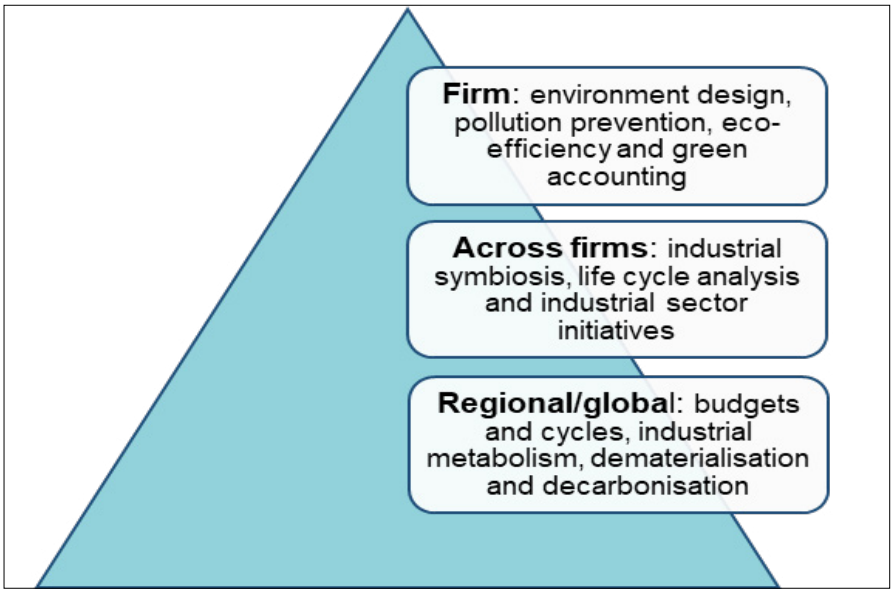

Figure 4: Levels of industrial ecology
Source: Authors' own, 2022

At the local level of the firm, industrial ecology focuses on including the environment in the design, finding ways to prevent or minimise pollution, promoting green accounting, and ultimately achieving eco-efficiency (Gibbs & Deutz, 2007: 1684). Industrial symbiosis is involved across firms. Chertow (cited in Gibbs & Deutz, 2007: 1684) defined industrial symbiosis as "separate industries in a collective approach to competitive advantage involving the physical exchange of materials, energy, water and by-products". Therefore, industries can be classified as an industrial symbiosis if all firms involved use or include the exchange of materials, water, or energy between the different firms (Boix *et al*., 2015: 304). On this level, the life cycle of the industries is analysed along with the initiatives of each industrial sector (Gibbs & Deutz, 2007: 1684). Industrial metabolism, or the flow of energy and materials, is analysed on the regional/global level. This level focuses on budgets and cycles in the industrial system, along with dematerialisation and decarbonisation, to ensure optimal performance (Boix *et al*., 2015: 303; Gibbs & Deutz 2007: 1684). An example of the application of industrial ecology is the China-Singapore Suzhou Industrial Park, which was started in 1994. The park consists of multiple industries that are interlinked with one another and with nature. The park is well known for its high import-export volumes (Wong & Lye, 2020: 11). By design, the Suzhou Industrial Park is split into different

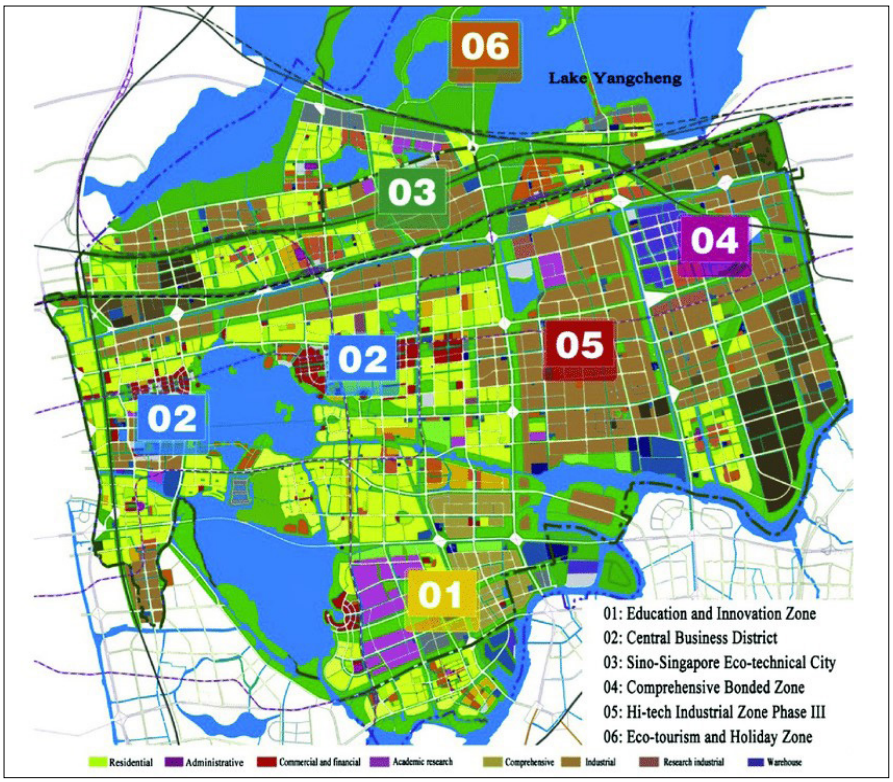

Figure 5: Map of China-Singapore Suzhou Industrial Park
Source: Beba, 2018: online

zones. For example, a CBD, the eco-technical city, the high-tech industrial zone, and an education and innovation district, as illustrated on the industrial map in Figure 5.

Widespread industrial symbiosis is essential for forming EIP firms (Al-Quradaghi *et al*., 2020: 2; Boix *et al*., 2015: 303). Gibbs and Deutz (2007: 1692) agreed that EIP could only be considered sustainable when there is sustainable symbiosis concerning the environment. EIP approaches encourage an exchange of synergies known as industrial symbiosis, a means whereby companies can gain a competitive advantage through the physical exchange of materials, energy, water, and by-products – eliminating waste of resources and reducing environmental impact. The EIP concept also embraces community collaboration, fostering inclusive and sustainable development. In Kalundborg, Denmark, a symbiosis network links a 1500MW coal-fired power plant with the community and other companies. Surplus heat from this power plant is used to heat 3 500 local homes in addition to a nearby fish farm, whose sludge is then sold as a fertiliser. Steam from the power plant is sold to Novo Nordisk, a pharmaceutical and enzyme manufacturer, in addition to a Statoil plant. This reuse of heat reduces the amount of thermal pollution discharged to a nearby fjord. In addition, a by-product from the power plant's sulfur dioxide scrubber contains gypsum, which is sold to a wallboard manufacturer. Almost all of the manufacturer's gypsum needs are met this way, thus reducing the amount of open-pit mining needed. Furthermore, fly ash and clinker from the power plant are utilised for road building and cement production (Ehrenfeld & Gertler, 1997). Figure 6 shows industrial symbiosis at Kalundborg Eco-Industrial Park in Denmark.

The industrial symbiosis at Kalundborg was not created as a top-down initiative, but instead evolved gradually. As environmental regulations became stricter, firms were motivated to reduce the cost of compliance and turn their by-products into economic products (Ehrenfeld & Gertler, 1997). Thus, the theory of industrial ecology helps understand the flow of matter and energy within and between industrial systems and the natural ecosystem (Jelinski *et al*., 1992: 793; Graedel, 1996: 70; Allenby, 1998: 75). This approach changed how industrial development was viewed and allowed developers and stakeholders to understand the complex industrial systems by comparing them to natural systems and adapting existing processes.

4.5 Regenerative theory and eco-industrialisation

The regenerative theory has a strong link to EIPs, as the primary goal of EIPs is to enhance sustainability by minimising resource consumption and waste production. This is achieved by circulating by-products, materials, waste, energy, and water in a closed cluster of different industries and circulation within each industry – a circular economy. The concept of a circular economy promotes a closed-loop of production. This means that there is a flow of materials, goods, and waste within the system (Geissdoerfer *et al*., 2017: 3; Kalmykova *et al*., 2018: 194; Sauvé *et al*., 2016: 52). The aim is to ensure that post-consumption products get reintegrated upstream into the manufacturing process (Sauvé *et al*., 2016: 52). The use of by-products, wastes, or recycled products is the main source of resources. Emphasis is also placed on reducing the amount of pollution generated at each manufacturing phase (Sauvé *et al*., 2016: 53). All industrial activities, along with different manufacturers, provide materials and waste to one another and find ways to reincorporate materials and waste into different manufacturing phases (Geissdoerfer *et al*., 2017: 3; Sauvé *et al*., 2016: 53). In other words, by-products and waste from one industry may serve as the main resources for the next industry. Therefore, energy consumption, resource supply, and waste management are optimised.

However, some scholars point out the risks of a circular model used in industrial areas, such as EIPs. Ethirajan *et al*. (2021: 226) pointed out the different risks each industry can experience: operational, financial, quality of product, reputational, and natural disaster risks. Industries are already faced with their problems and risks and, therefore, need to plan for these risks to ensure longevity and future expansion. However, when industries form part of a closed system, they also need to plan for the risks of other industries (Ethirajan *et al*., 2021: 226), because one industry shares resources with another, meaning that they are connected and reliant on one another. The entire system will stop moving if

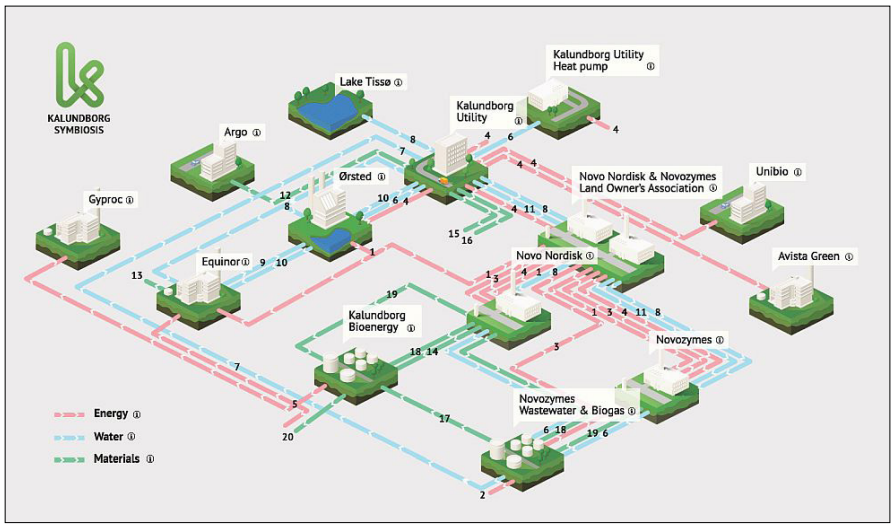

Figure 6: Industrial symbiosis at Kalundborg Eco-Industrial Park, Denmark

Source: AIVP, 2018: online

one industry experiences technical issues (Ethirajan *et al*., 2021: 227).

Nevertheless, this cannot outweigh the benefits of a regenerative approach in eco-industries. The resiliency of resources is promoted, as the model aims to imitate or copy natural processes found in ecosystems, where waste is minimised and even reused by other species (Sauvé *et al*., 2016: 53; Jelinski *et al*., 1992: 794). The efficiency of ecosystems is flexible and adaptable, due to the competitiveness and cooperation among species. Applying this idea to an economic or industrial system helps ensure healthy competition in the market and among manufacturers, while ensuring efficient usage of all available resources (Sauvé *et al*., 2016: 53). Al-Quradaghi *et al*. (2020: 1) stated that eco-industrialisation is, therefore, the result of industrial symbiosis between companies, which includes the exchange of material and energy. These companies aim to reduce their impact on the environment by sharing resources and increasing economic growth (Al-Quradaghi *et al*., 2020: 1). This directly links back to the theory of industrial ecology, which refers to using all energy and resources available in the industrial system, while simultaneously minimising waste and pollution (Al-Quradaghi *et al*., 2020: 2; Boix *et al*., 2015: 303; Heeres *et al*., 2004: 985). It can be linked to the regenerative theory, for eco-industrialisation restores, renews, or reuses sources of energy, resource materials, or by-products. A circular economy (regenerative theory) can also be used to address environmental challenges (Geissdoerfer *et al*., 2017: 2). An example of regenerative theory within an EIP is Kalundborg EIP in Denmark. The Kalundborg EIP has been developing since 1961. The evolutionary process where sets of independent by-product exchanges led to the creation of a complex system of symbiotic interactions and a regenerative process among several firms located within the Kalundborg industrial area and the local municipality (Fraccascia, Giannoccaro & Albino, 2017:155). The goal is to achieve zero waste and recycle the materials, by-products, water, and energy within one industrial area (Al-Quradaghi *et al*., 2020: 2).

An example is the Limpopo Eco-Industrial Park (LEIP), located in Musina, South Africa. It is the first zero-waste EIP in Africa that is integrated with the surrounding environment (Dyble, 2019: 4). The implementing company aims to find techno-economically viable solutions to current-day issues faced by humanity. Located on over 6 400 hectares between the border town and Beitbridge, the park will feature an integrated nature reserve; two residential eco-estates; 80 chalets on the Limpopo waterfront within the nature park; the country's first plasma waste gasifiers; syngas clean-up; two off-channel storage dams (with 20 mil m^3 capacity); 200 MW Eskom power supply and an additional 35 MW solar power for housing and agro-processing; emergency services, and a world-class logistics service, among other features. Limpopo is one of only a few EIPs in South Africa, other than those at Atlantis and Sasolburg. Figure 7 shows a 3D factory view of the Limpopo Eco-Industrial Park (illustrative). These parks will influence future development through effective engineering and technology management (Dyble, 2019: 8). Virtually, closed-loop systems can be implemented in industrial systems to ensure that industrialisation is more environmentally oriented (Dyble, 2019: 8).

4.6 Green political theory and eco-industrialisation

The green political theory is linked to eco-industrialisation, for it fully acknowledges the uniqueness of the natural environment, while also stressing its radical approach to the organisation of social, economic, and political relations (Dyer, 2018: 2). It is consistent with its focus on the metabolism between mankind and nature. Eco-industrialisation is linked to ecological processes, natural biodiversity, the flow of resources and energy, production, and the economy. The green understanding and the green theory focus on the transformative economic process and, more importantly, the ecological, natural biodiversity, resource, and energy flows. Economic growth and production of goods are of interest from a green perceptive, since it is at the centre of the material metabolism between humankind and nature. The green political theory further aims to extend the moral claims beyond humanity and the barrier formed around the species (Barry & Dobson, 2003: 182; Dyer, 2018: 2). There is a clear interaction between humanity and the natural environment, and many of the interactions have adverse effects on the natural environment. Moral claims and understanding extend into the natural environment, since humanity entirely depends on the environment. The moral claims have also temporally been projected into the future, focusing on the rights of generations yet to be born and concerning intergenerational justice (links back to sustainable

Figure 7: 3D factory view of the Limpopo Eco-Industrial Park (illustrative)
Source: Limpopo Eco-Industrial Park, 2018: 1

development and resilience) (Barry, 2014: 2; Sanjaya *et al*., 2021: 327).

Eco-industrialisation does not simply look at lessening the impact of production on the environment, but how production can continue with a decrease in the negative impacts. Thus, the green political theory can be used internationally to promote the development of eco-industrial areas. As with any theory, critics surround the theory, with scholars stating that the pro-environmentalist may still be against development, even development approached in a 'green' manner. Symons and Karlsson (2015: 188) noted that "this preservationist project is unlikely to gain mass support among traditional environmentalists". For this reason, rationalist preservationists must reform with ecologism. A balance, equilibrium, or common ground must be found to maintain economic growth and environmental health.

The influence of green political theory can be linked to the global increase in the move towards 'green' policies and support for such development initiatives. For example, the United Nations Industrial Development Organization (UNIDO) has started collaborating with various countries, assisting them in moving towards 'green' industrial development and setting up EIPs. In South Africa, the Global Eco-Industrial Parks Programme (GEIPP) (Phase 1) is being implemented from 2021 to 2023 through a collaboration of UNIDO with the Department of Trade Industry and Competition and the National Cleaner Production Centre of South Africa (NCPC) (South Africa-Global Eco-Industrial Parks Programme, 2021: 2). The GEIPP demonstrates the viability and benefits of greening industrial parks by improving resource productivity and economic, environmental, and social performances of businesses. GEIPP includes incentivising EIPs in policies or regulations, as well as identifying and implementing EIP opportunities in selected industrial parks.

4.7 Summary of the influence of classical 'green' theories on contemporary eco-industrialisation

In summary, the garden city theory, the industrial location theory, the theory of industrial ecology, the regenerative theory, and the green political theory clearly have a strong positive influence on contemporary industrial planning (eco-industrialisation). Table 1 summarises the applicability and influence of each classical 'green' theory on contemporary eco-industrialisation.

5. CONCLUSION

Industrialisation is essential for the development and progress of towns, cities, nations and regions. However, industrialisation is one of the top contributors to environmental crises, especially climate change. Criticism against industrialisation and arguments in favour of industrialisation resulted in the various theoretical approaches to sustainable industrialisation presented in this article. With the rapid environmental changes worldwide, due to industrial activities, it is essential for contemporary urban planning approaches to adopt new industrialisation models. This article demonstrates that classical 'green' theories remain relevant in inspiring sustainable planning approaches to industrialisation, particularly the eco-industrialisation approach. The garden city theory, which aims to combine the benefits of the countryside and the urban city in spatial planning, provides a foundation for industrial location and regenerative theories that

Table 1: Influence of classical 'green' theories on contemporary eco-industrialisation

Theory	Applicability of classical 'green' theories to eco-industrialisation
1. Garden city	• Based on sustainable planning and development. • Aims to combine the benefits of the countryside and the urban city. • Positive correlation between garden city theory and EIPs. • Provides a foundation for industrial location and regenerative theories. • Example: ChemCity Eco-Industrial Park in Sasolburg, South Africa
2. Industrial location	• Positive link between EIPs and the industrial location theory. EIPs focus on the interaction and distribution of industries, while emphasising the social and economic environments. • Location must be carefully selected to ensure the minimum transport costs. • The EIP approach aims to minimise transport costs by clustering related businesses on a common property. • Example: ChemCity Eco-Industrial Park in Sasolburg, South Africa.
3. Industrial ecology	• Combination of natural ecosystems and industrial activities. • Promote corporate environmental management that is proactive and inter-organisational. • Inter-organisational focus is essential for material and energy flows. • Industrial ecology is divided into three levels: firm, across firms, and regional or global level. • The goal at the firm level is ultimately to achieve eco-efficiency. • Industrial symbiosis is involved across firms. • Industrial metabolism, or the flow of energy and materials, is analysed on the global level. • Approach allowed stakeholders to understand the industrial systems by comparing them to natural systems and adapting existing processes. • Examples include China-Singapore Suzhou Industrial Park and Kalundborg in Denmark.
4. Regenerative	• Strong link to EIPs. The regenerative theory aims for a closed-loop system, while EIP aims for the flow of materials, goods, and waste within the system. • Used to address environmental challenges. • Risks are involved, as individual industries have their own risks combined with the risks of other industries. • Links to the theory of industrial ecology. • EIPs focus on restoring, renewing, and reusing (circular loop). • Examples include Kalundborg EIP in Denmark and the Limpopo Eco-Industrial Park in South Africa.
5. Green political	• Acknowledges the natural environment as well as the organisation of social, economic, and political relations. • Links back to sustainable development and resilience. • EIPs aim to decrease the negative impacts of development. • Green political theory can promote the development of EIPs. • Example: GEIPP is being implemented from 2021 to 2023 in South Africa through a collaboration of UNIDO and NCPC, supporting EIPs initiatives.

strongly influence the planning of EIPs. There is also a positive link between EIPs and the industrial location theory, as EIPs focus on the interaction and spatial distribution of different industries in the given geographic area, while also emphasising the social and economic environment aspects. The EIP approach also follows the idea of a closed environment, the regenerative theory, and the green political theory. The aim is to create a healthy industrial system where all materials are reused, ensuring the system is healthy and sustainable, while promoting pollution abatement and limiting off-site transfers. Thus, the emphasis on having multi-industrial processes taking place on one property, at the same time, resources being exchanged to ensure an improved economy, along with better environmental and social performance (Al-Fadhli *et al*., 2020: 18324). While this sounds like what typically defines the traditional industrial park model, EIP approaches go beyond that. EIP approaches encourage an exchange of synergies known as industrial symbiosis, a means whereby companies can gain a competitive advantage through the physical exchange of materials, energy, water, and by-products, thus eliminating waste of resources and reducing environmental impact. The EIP concept also embraces community collaboration, thereby fostering inclusive and sustainable development.

Eco-industrialisation is still a new phenomenon in the developing world and in South Africa. For example, there are no fully functioning eco-industrial parks in Africa that use the principles of the theories discussed in this article, such as 'industrial ecology' 'industrial symbiosis' and 'industrial metabolism', that can parallel those in the developed parts of the world. In short, planning for EIPs is still in its infancy in Africa (Greenberg & Rogerson, 2014). Understanding the link between the classical 'green' theories can assist African urban planners and industrialists in designing and implementing futuristic and functional eco-industrial parks that ensure both industrial park management performance, environmental performance, social performance, and economic performance. This is particularly so for countries such as South Africa, where efforts towards eco-industrialisation are growing compared to other African countries. South Africa's Department of Trade, Industry and Competition (the DTIC) and the National Cleaner Production Centre South Africa (NCPC-SA), in partnership with the United Nations Industrial Development Organisation (UNIDO), launched the Global Eco-Industrial Parks Programme (GEIPP) in 2022, piloting various eco-industrial projects such as Sasol Eco-Industrial Park to promote green business. Such green industrial initiatives can benefit from the ideas presented in this article.

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