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The Urban Planning and Design of Eco-Industrial Parks Case of Asfan, Saudi Arabia

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ABSTRACT

"How does the eco-industrial park (EIP) differ from the conventional industrial area, particularly in urban planning and design terms?" is one of the questions currently posed among those concerned with the planning of industrial areas in Egypt. This is understood when considering the scarcity of local research in the field, the lack of international research and the lack of consideration of the ecological dimension in the Egyptian industrial experience, despite its relatively long history.

This documentary research contributes to answering this question through presenting a case study of which the authors were assigned the task of preparing its technical studies and urban plans. This case is an EIP located in the Asfan administrative center (AAC) in the Al-Jumum governorate, Saudi Arabia. To prepare the required study, the authors first reviewed available relevant literature looking for different concepts associated with industrial ecology and, more importantly, their physical/urban connotations. The authors also studied the AAC in terms of its locational and natural potentials/limits, the interregional supply and demand, the potentially competitive/integrative regional industrial peers, and the industrial national strategy in the Kingdom as a whole. In light of these studies, a general planning concept for the EIP in the AAC was prepared, followed by the preparation of detailed plans and urban design schemes for a selected area of 300 ha of the EIP's first implementation phase.

The authors hope that this documentation serves as a reference for academics and practitioners to contribute to the discussion on the urban dimension of EIPs, stimulate further research to build knowledge internationally and, more importantly, raise local awareness towards more sustainable industrial development in Egypt.

Keywords: *Circular Economy, Industrial Ecology, Industrial Symbiosis, Urban Dimension of Eco-Industrial Parks.*

1. INTRODUCTION

Emerged in the 1990s for the development of industrial areas, industrial ecology (IE) is one important way in which industry can contribute to sustainable development (SD) [1–4]. Indeed, SD in itself is a normative, vague and difficult idea to achieve [5]. Therefore, IE is the science of sustainability in industry [6], through which the concept of SD can be operated on the ground, and this is done with high economic feasibility [7]. So, IE is not only important because it preserves the environment but also because it represents savings in the cost of management and production [1], facilitating its marketing to governments as well as the private sector [8].

Specifically, IE looks at the flows of materials from the time they are extracted (from nature), manufactured, used and reused and then returned to nature in a manner that minimizes waste and avoids the negative impact on the environment [9]. Reducing the negative impact here means not only decreasing environmental pollution from these wastes, but also reducing natural resources depletion through the reuse of such wastes (materials, water and energy). To this end, the IE science simulates natural ecosystems by converting industrial processes from an open loop system, in which the industry drains natural resources for production and pumps waste into the natural environment, into a closed-loop system where the waste, by virtue of being seen as by-products, is transformed into inputs for new industrial processes [10–16]. In some literature, this is also known as the circular economy[1].

To achieve the concept of IE on the ground in an operational sense, the concept of industrial symbiosis (IS) emerged, which is the cornerstone of the successful application of IE [17]. IS is defined as the operational framework that brings together in a collaborative framework those conventionally separate/isolated industries in such a way as to ensure closing the loop through the exchange of by-products/waste as well as the exchange of knowledge, expertise and new technologies [1,11]. This contributes to maximizing the competitive advantage of these symbiotic industries (as opposed to conventional separate industries) by achieving joint economic returns, reducing production costs and enhancing their ability to grow and compete [26], and creating new business opportunities to meet the demand for new operations associated with IS [18].

However, IE is not only an operational mechanism to close the flow of materials between industries, but extends to changing business organizational systems, building staff capacity and developing networking among industrial firms [11,19]. This entails rebuilding human/social wealth to develop effective, creative and cooperative partners [20] who trust each other and hence exchange knowledge within a framework of transparency [11,23]. The collaboration needed is not only among industrial companies but with all partners whether educational, governmental or civil [11]. Higher education institutions and scientific research agencies have to be integrated to help build knowledge and raise awareness [9]. Top-down management should be avoided through securing private sector partnership and community participation [1]. The pursuit of community involvement comes in the context of informing them about the benefits they would gain to secure their support for achieving IE goals [21]. Finally, regulatory frameworks have to be formulated to effectively facilitate and organize this new business environment [24,25]. It is therefore important not to restrict the application of IE within the boundaries of industrial areas, since IE represents a *culture* that society must adopt. It is a culture that is able, if adopted, to achieve better environmental, economic and social outcomes [9,18].

1.1 Eco-Industrial Parks (EIPs)

IS, the bedrock of IE, can be achieved at several scales ranging from a single company, a single facility that includes several small businesses/industries [11] and an industrial area to regional and global supply chains [6]. The smaller the scale at which it is achieved, the better it will be to avoid the costs of transport, employment and pollution [26]. As IS cannot be effectively achieved at the single enterprise level, the concept of eco-industrial parks (EIPs) emerged during the 1990s [1,21,25].

EIPs are the ideal environment for incubating the idea of IS, where a number of industrial plants are clustered in one place to benefit from waste as an input to production. In this assembly, anchor industries appear as well as scavenger industries which ensure that the loop is closed as they function on the by-products of those anchor industries [11]. In the view of some literature, the more diverse and the greater the number of industries is, the greater the possibility of closing the loop [9,19,21]. Yet others argue that greater diversity constitutes a difficulty in communication and negotiation among these industries, which negatively affects the possibility of achieving the desired synergy [11,27]. Furthermore, some even point to the need for similarity and repetition of anchor industries (rather than diversity) so that their by- products are similar facilitating the easy formation of scavenger industries [26,28]. Yet, apparently, it differs from one case to another and is dependent on the types of industry to be located on site. In all cases, the allocation of industries inside EIPs is based on the performance-based evaluation of the contribution of these industries to closing the loop rather than their activity-based assessment in relation to environmental performance [26].

1.2 Types of Eco-Industrial Parks (EIPs) (in terms of their formation processes)

There are two approaches to establish EIPs. The first is the "planned" EIPs, which include a deliberate effort to identify, select and allocate industries so that they can share resources and by-products. This approach involves the formation of a group of stakeholders, including at least one governmental entity. The second is the "self-organized" EIPs where, under the pressures of scarcity [29], an industrial ecosystem is created through small, cumulative decisions taken by the private sector. Other driving forces include major environmental and economic problems, maximizing profit and expanding business [18]. Thus, self-organized EIPs emulate natural ecosystems in their unplanned characteristics (without major macro-driven goals) and self-organization status (without external interference) [21].

By testing several examples of these two approaches, the latter is most likely to be more successful [18] and most widespread [21]. However, this does not nullify the fact that the first approach is also widespread in several countries such as China, the

[1] Circular Economy, the literature of which is currently dominated by research based in China, is concerned with managing the effects of economic activities on the natural environment in the context of adopting the concepts of industrial ecology [11]. It basically aims to replace the "end-of-product life" concept with "material restoration".

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European Union, America and Australia [9,16,20,22,23,25]. Furthermore, some consider this approach to be useful and necessary, especially in the early stages of the development of EIPs, followed by a facilitating operational framework to achieve long-term transformation goals towards IE [30].

It should be noted though that the word "planned" in the first appraoch does not refer to urban planning, but means, according to literature reviewed, the development of regulatory and operational policies from the top down (through government intervention or a joint one with the private sector) to bring about IE concepts. In this context, two models have been identified for the production of planned EIPs. The first is the "Build and Recruit" model where the public sector /public-private partnership creates a new industrial park and then searches for compatible tenants. The other model is the “Retrofit IPs” where existing industrial areas are targeted for conversion to EIPs [18]. The latter represents the prevailing trend according to the existing literature.

1.3 Urban Planning of Eco-Industrial Parks (EIPs)

Only few literature pointed to the urban dimension of EIPs. From this literature, we have drawn out and logically constructed the following theoretical framework of new EIPs’ urban planning principles:

1. Plan the EIP within the carrying capacity of the natural ecosystem and without inducing significant alterations to its components, in particular natural water drainage systems, natural landscaping and natural habitats.

2. Achieve integration between the EIP land uses and those of its wider urban and environmental contexts, thus creating opportunities for the economic development of the EIP’s region (while maintaining its identity) [18], and contributing to the optimization of closing the input and output loop by exchanging waste not only industrial but also urban [20].

3. Plan the EIP as a closed ecosystem by creating a set of interconnected sub-systems that, within each and between eachother, aim to reduce waste by reusing it within the EIP. Industrial activities within these subsystems are grouped into clusters. The exchange of these wastes is facilitated by the application of two basic types of land use schemes for these clusters (as implicitly indicated in section 1.1). The first is to assemble similar anchor industries that have the same byproducts. This facilitates the addition of scanvenger facilities/industries that process/use these by-products in manufacturing. The second pattern mainly involves the collection of a variety of industries, each benefiting from the other, so that the remnants of an industry are inputs to another industry [31].

4. Utilize new types of uses, scavenger plants, and services that help generate the closed-loop system, such as:
   - "The Networking Smart System" that facilitates the establishment of exchange networks of waste and energy among industries by measuring and analyzing information from the installed monitoring devices of industrial processes. This smart system further provides scenarios that benefit the closed-loop system [26].
   - "The IE Scientific Park" that develops research and conducts laboratory experiments on waste treatment and on new methods of reuse instead of disposing it in nature. The scientific park also helps raise awareness of the economic gains and the environmental and social benefits arising from the application of IE [25,27].
   - “The Material Recovery Facility” (MRF) which is a centralized plant within the EIP (with sub-stations distributed across the EIP) that recovers waste to be available as raw materials for potential industries.
   - "Scavenger Plants", such as feed, fertilizers and biomass plants, that operate on organic waste.
   - "The Industrial Wastewater Separate Network and Treatment Facility" which purifies industrial wastewater to be reused in appropriate industrial processes. Level of treatment is identified according to the required level of water purity [31].
   - "The Artificial Lake" which works as an open reservoir for surplus treated wastewater to be stored and subsequently re-pumped and reused for manufacturing and/or irrigation [31].
   - "Environmental Protection Zones and Green Barriers" for separating not only the EIP from the surrounding environment, but also among the different polluting levels of industries and between industrial and non-industrial uses inside the EIP. The aim is to increase the environmental capacity of the site and reduce potential negative impacts in seasonal wind variations [31].

5. Adopting green design approach to develop the EIP, including compatibility with natural landscape, adoption of climatic and environmental criteria in designing the EIP’s urban form, the use of environmentally friendly networks [21], such as generating power through solar cells, windmills [20] and biogas [18], and the use of less polluting and more efficient transportation methods (to carry by-products and labor).

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2. RESEARCH PROBLEM

In general, research into industrial ecology (IE) is still in its early stages [1], and the application of its principles and the transformation to the circular economy have recently begun [9,20][2]. In particular, existing literature has not paid enough attention to the urban dimension of EIPs. As regards to the planned EIPs (in the general sense of the term), it has mainly focused on developing the operations of the existing industrial areas which have been transformed into EIPs, and which represent the majority trend (as previously mentioned in section 1.2). Concerning the self-organized EIPs, it has attempted to only understand and map out their industrial operations. The physical/urban formation of these parks has not been adequately addressed. Only few references discussed some concepts of EIPs' site selection and urban planning (referred to in the previous section). In addition, existing literature rarely addressed examples of industrial areas that were planned from the beginning on the basis of IE [24,25].[3]

The study therefore aims to contribute to bridging this research gap by addressing the urban planning and design of a new EIP of which the authors were assigned the task of its urban planning and design. This attempt constitutes a contribution to the ongoing scientific discourse which makes this study a pioneering research in the field of urban planning and design of new EIPs. This study focus is supported by the fact that many of the EIPs that have started as conventional industrial areas have not been successful in ecological terms, since the transformation of a conventional industrial area into an eco-industrial one is a major challenge facing many internal and external constraints [24,25].

3. STUDY AREA

Figure 1 shows the location of the site assigned for the targeted EIP (with a total area of 3549.3 ha) in the Asfan administrative center (AAC) in Al-Jumum governorate, Makkah region, Saudi Arabia. The figure also shows the site location in relation to regional roads network and major urban communities (Makkah and Jeddah) as well as the main uses (e.g., the surrounding industrial areas and transportation facilities).

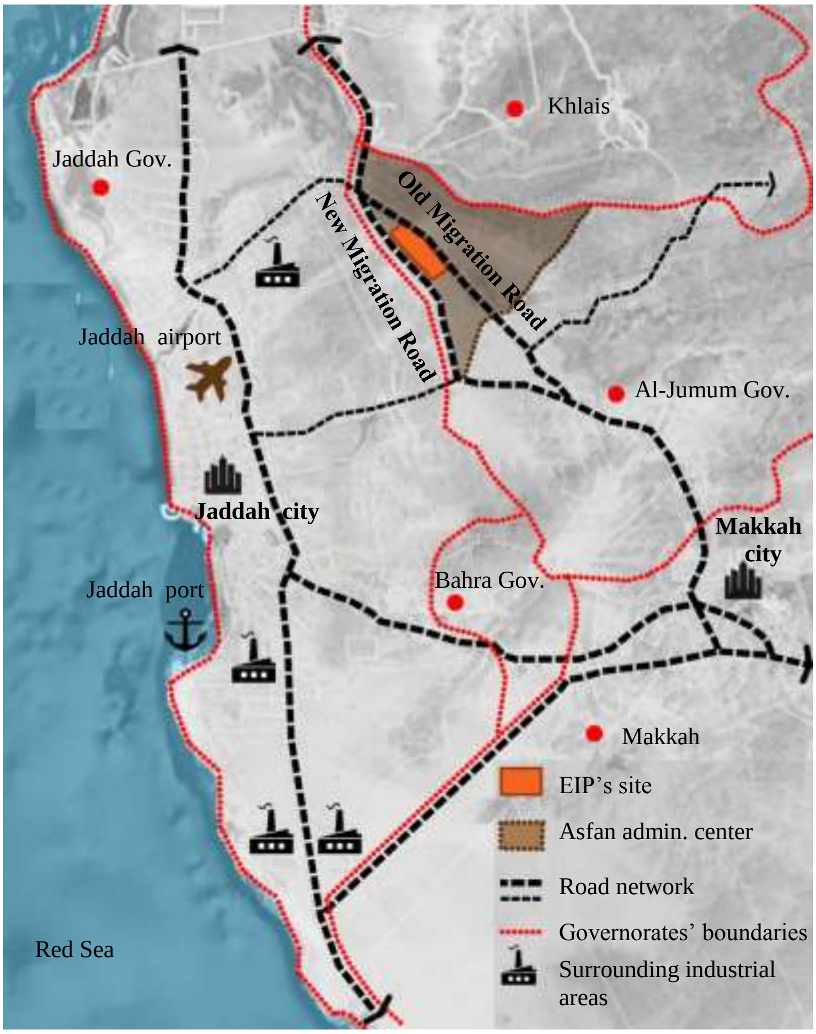

Figure 1. Study Area

4. METHODOLOGY

This section presents a brief explanation of the methodological steps taken to plan the proposed EIP in the AAC. These steps were carried out in 4 overlapping, and sometimes parrallel, phases. The section also points to some of the basic findings of these steps to avoid repitition and make the study presentation flowing and short.

Phase 1: The determination of the EIP's role

1. Reviewing the proposed policies and programs of the national industrial strategy of the Kingdom as well as the national and regional inudstiral plans, since the role of the AAC's EIP would not be properly formulated without that role being an integral part of the Kingdom's overall industrial goals.
2. Extrapolating the industrial demand based on the study of the market needs and the investment atmposhere within both the direct and the broader regions of the EIP (in which the former is the AAC, and the latter includes Makkah and Jeddah).
3. Analyzing the current status of the AAC to identify its natural, social and urban resources. In addition, the existing/proposed major projects in the broader region were identified along with their implications on/mutual interactions with the EIP.

[2] In addition, there are Western countries that have not yet begun to apply it [18].
[3] Exceptionally, Veleva et al.[19], as a rare example, addressed the industrial park in Devens, Massachusetts, USA.

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These steps led to the determination of the role of the targeted EIP as a serving sector to Makkah with its needs to host more pilgrims in addition to supplying its local residents with their needs, and as an integrative/complementary sector with the industrial area in Jeddah to establish an industrial base for export abroad. These steps also helped determine and prioritize the industries *initially* proposed to be allocated in the EIP.

Phase 2: The preparation of the EIP's eco-industrial composition

In this phase, we decisively determined the types of industries and their land use ratios to be allocated. This was concluded considering the industrial relations that would help close the loop ecologically, as follows.

1. Studying the possible industrial links between the proposed industries (identified in the first phase) on one hand and the economic activities of the surrounding urban context in and outside the AAC (in Makkah and Jeddah) on the other to identify which of these industries are potentially better integrated with both the direct economic context and the broader industrial one.

2. Studying the production systems (inputs - operational processes – outputs) of the proposed industries identifying their needs for materials and energy (mapping out their material flow analysis), and their spatial organization criteria. The aim was to first identify the possible industrial linkages among the proposed industries to formulate initial proposals for industrial integration among them (including their allocation ratios and their needs of services). Second, the refinement of these intial proposals to evolve into integrated eco-industrial composition scenarios was sought in which IS is considered and the loop is closed (as far as possible).

3. Evaluating these eco-industiral scenarios in order to determine the most appropriate scenario (on which the proposed planning concept for the EIP in phase 4 was based). In evaluating these scenarios, we adopted a set of criteria which included closing the industrial loop through the efficient exchange of materials, by-products and energy, enhancing economic gains, improving the collective environmental performance of the EIP, and boosting the local community. Figure 2 illustrates the flow chart of materials and energy of the most appropriate scenario chosen.

Phase 3: The EIP's site analysis and basic urban planning decisions

1. Preparing the EIP's site analysis studies which were culminatetd into the general analysis map that read, summarized and integrated the findings of the site analysis, and thus helped determine the site's characteristics, potentials and limitations.

2. Drawing the land suitability map and dividing the site accordingly into a number of homogeneous domains taking into account the requirements of the relevant stakeholders (investors – the local community – governmental and non-governmental organizations).[4]

3. Formulating the main urban planning decisions that contributed to defining the EIP's planning concept.

Phase 4: The preparation of the EIP's planning concept and the detailed urban plans and designs of a selected area

1. Preparing the EIP's planning concept taking into consideration its industrial role and site analysis. Preparting the concept included the development of a general land use program for the EIP (describing types and areas of industrial activities, and their needs of services and facilities) and the preparation and evaluation of planning alternatives in order to identify the best concept to adopt. To develop this best concept, we took into consideration, in addition to the most appropriate eco-industrial scenario (see Figure 2), the international planning principles and land use ratios followed in similar cases (if few) but within the limits permitted in the Kingdom. The EIP's development priorities were set up which led to identifying the first implementation phase of the project.

2. Preparing the material and energy flow chart for a selected area (SA) of 300 ha of the first implementation phase, studying in details the methods of IS to maximize the SA's environmental and economic performance, and finally developing its detailed framework of eco-industrial composition.

3. Preparing the SA's detailed land use budget and formulating and evaluating its planning alternatives towards the determination of the best alternative followed in the preparation of its detailed plans.

4. Preparing the SA's urban desgin schemes following analytical studies performed on the existing local urban structures.

[4] These requirements were investigated through a questionnaire designed by the authors and distributed and collected by the relevant local administrative units.

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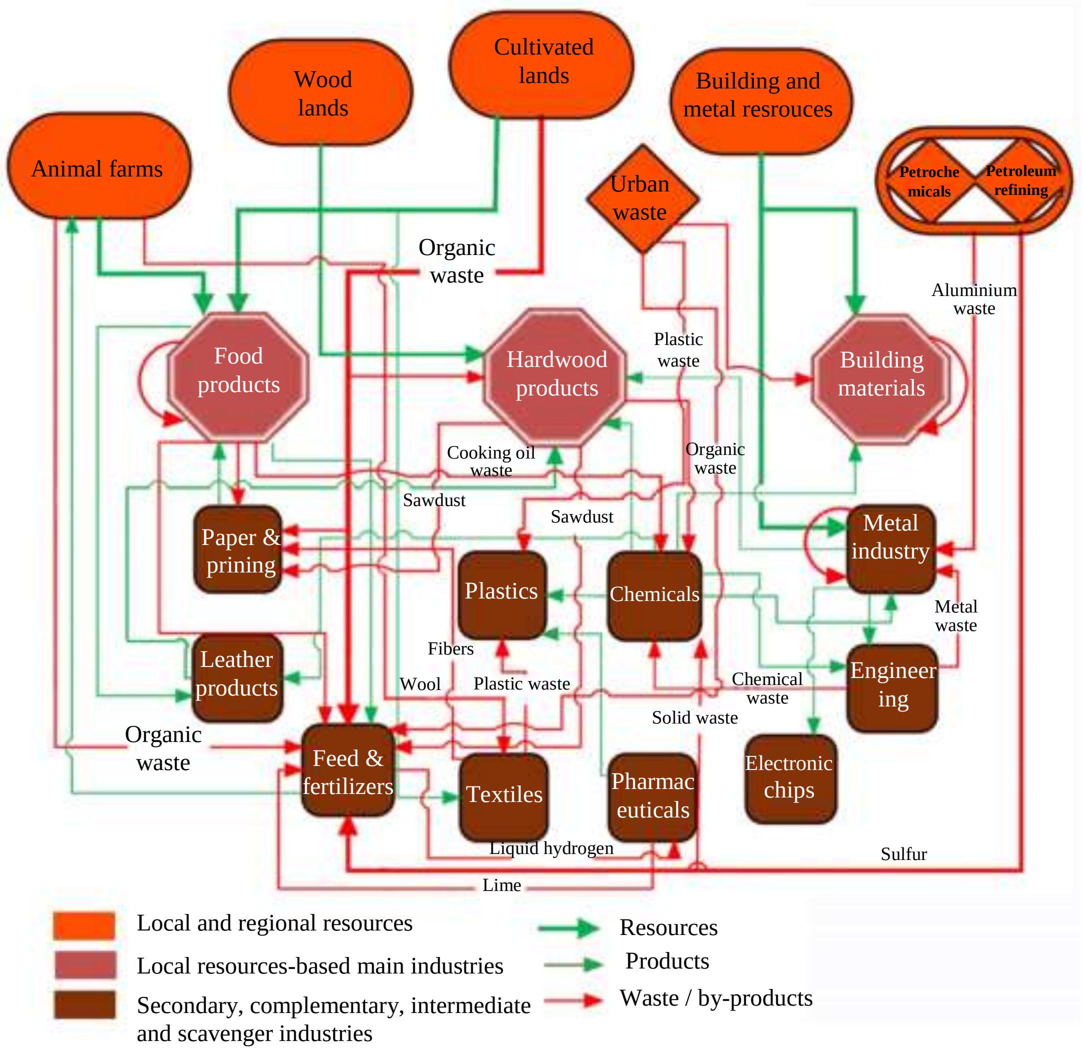

Figure 2. The flow chart of materials and energy of the chosen eco-industrial composition scenario

5. RESEARCH STRUCTURE

The rest of this research comes in 3 parts. The first provides a brief description of the planning concept of the EIP, followed by the identification of the first implementation phase of which a selected area (SA) was detailedly planned. The second part then reviews the detailed plan of the SA and presents its urban design scheme. The third part concludes the study.

6. PLANNING THE ECO-INDUSTRIAL PARK (EIP) AT THE ASFAN ADMINISTRATIVE CENTER (AAC)

6.1 General Site Analysis

Figure 3 shows the general site analysis of the EIP which demonstrates the following site potentials and limitations.

Urban and Environmental potentials

The EIP's site is located about 65 kilometers away from Makkah and about 50 kilometers away from Jeddah, which gives it the ability to achieve economic integration with these major urban centers. In support, the site is located on a major regional road network. One important regional road is the old migiration (Hijrah) road which carries the regional trade movement (between Makkah and Madinah). This road also connects the EIP's site with the surrounding urban agglomorations within the AAC, and hence supports the potential role these small and medium size communities could play in accommodating the EIP's labor. In addition, the site's longitudinal exposure to this trade road means the presence of highly accessable areas that can be used as trade fairs and a business park. These potential land uses could work as a front for the EIP. The EIP site is also bordered on its other longitudinal side by the new migration road which works as a regional route for pilgrims linking Makkah to Madinah. It indeed increases the EIP exposure and provides another easy access to it.

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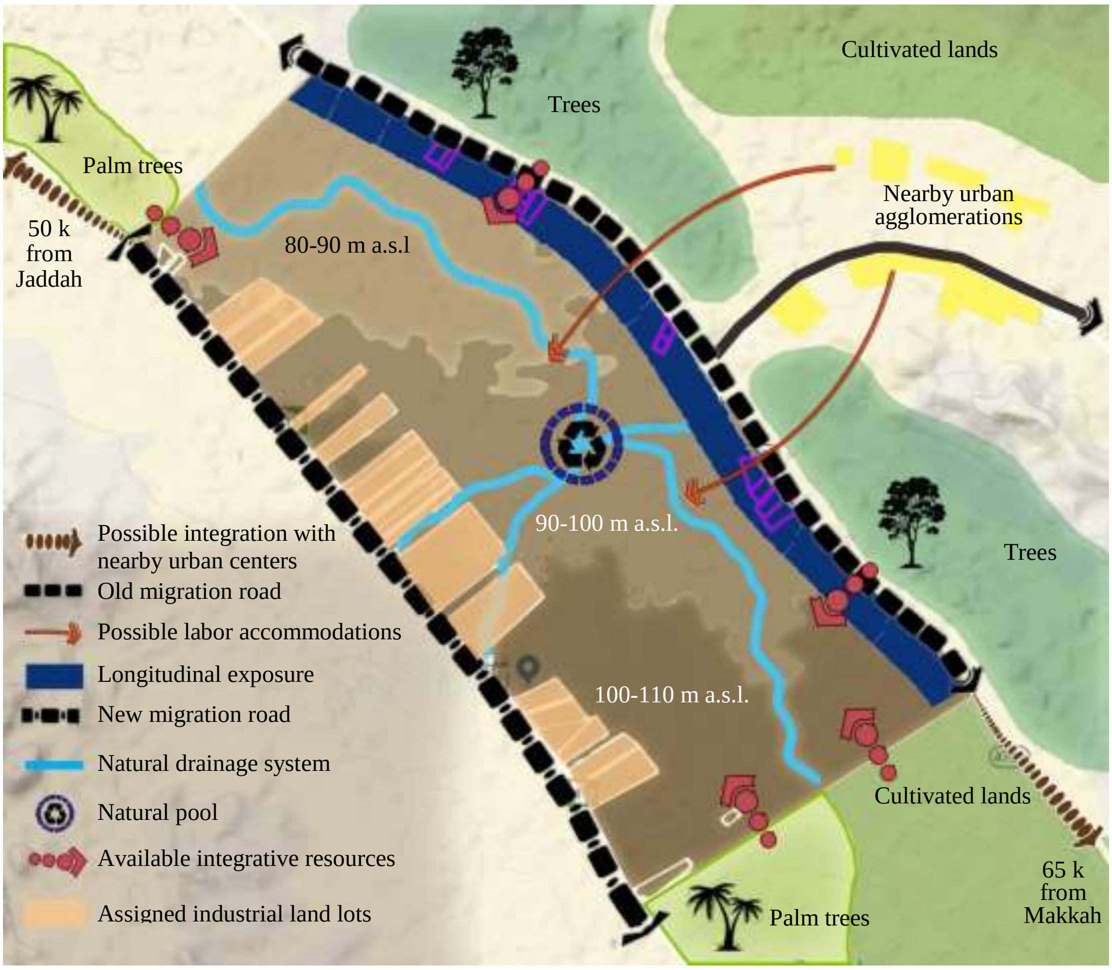

Figure 3. The general site analysis of the eco-industrial park

A group of small valleys passes through the site. They can be used in providing green/recreational corridors/areas. Also there is a natural pool that can provide water for industrial or human uses or as a focal point for a recreational park. However, the EIP's site is almost flat which increases the flexibility of distributing different types of land uses. Finally, the EIP's surrounding environment is characterized by the availability of raw materials, agricultural lands, livestock, palm and trees, which could be easily integrated with the EIP eco-industrial activities.

Urban and Environmental limitations

The assignment of some landlots inside the EIP on the new migration road to some industrial activities may negatively affect the degree of flexibility in planning the EIP and the efficiency of allocating uses in the various implementation phases taking into account the IE concepts. In addition, the existence of valleys, natural drainage systems and pools may also represent a limitation on the allocation of different land uses considering their environmental sensitivity that should be observed.

6.2 Basic Planning Decisions

Based on the results of the general analysis, the following basic planning decisions were taken:

1. Using the site's natural elements (natural drainage systems and landscaping) as the bases on which the main planning concept of the EIP is to be built. This highlights the importance of considering the coexistence between industrial activities and natural elements in such a way that does not induce significant alterations to these elements (being one of the EIPs' urban planning principles, as stated in section 1.3). This utilization of natural elements are to take the following forms:
   - Utilizing the existing longitudinal natural drainage path in the creation of a green corridor to which is placed parallel a central logistic support corridor.
   - Utilizing the central natural pool to be the nucleus for founding an artifical lake (a water surface reservoir for ecological, aesthetical and recreational uses). The main EIP recreational park is to be placed around this lake accompanied by land uses that can benefit from the good view in the middle of the EIP.

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2. Distributing industries from the least to the hightest polluting industries down wind in order to minimise the possible pollution that might be inflected from the higher polluting industries on the lower polluting ones as well as on the rest of the EIP's non-industrial uses.
3. Developing a green barrier between the EIP and the surrounding urban and natural environments to prevent the transfer of any potential pollution or emissions.
4. Providing a circular electric tram line parallel to the logistic support corridor to transport labor, raw materials, goods and waste within the EIP. This contributes to the realization of IS between the EIP's industries and facilities. This internal electrical tram is to also be connected to an external one that is proposed to link the EIP with its surrounding urban communities to transfer various resources, goods and urban wastes to the EIP in addition to the transfer of labor and visitors.
5. Considering the main access to the EIP to be mainly from the old migration road for the latter's role in trade transportation.

6.3 The EIP's Land Use Budget and Planning Concept

The EIP was planned as a complex of multiple landuses which contain many non-industrial activities. Table 1 shows the EIP's land use budget, and figure 4 delineates the EIP's planning concept which resulted from the overlay of a set of sub-concepts proposed for the various main components of the EIP. These components were formed together as follows:

1. The central business district (CBD) is located at the main entrance of the EIP on the old migration road. This CBD is a good front for the EIP to increase the exposure of the project and thus achieve the highest degree of attractiveness to investors. The CBD includes the bussiness park with related activities and the recreational park placed around/directed to the artificial lake. The CBD extends to the new migration road in the shape of a commercial park (wholesale and retail) directed to pilgrims travelling on this road along the year.
2. The circular logistic support corridor ensures the equitable distribution (especially during implementation phases) and freedom of choice of services to basic industries, which is facilitated by the electrical tram line. It includes central logistic support (e.g., transport and storage), industrial (e.g., machinary repair centers), and urban[5] services as well as scavenger facilities (e.g., MRFs). This corridor was based on the existing longitudnal natrual drainage path (as indicated in section 6.2) completing it into a circular form. The rest of natural paths were used as green corridors/barriers to emphasize the ecological function of the EIP.
3. The road network combines the conventional grid-iron shape (preferred for the ease of large vehicles' movement) and the organic one which is more consistent with the IE's consideration of the natural site characteristics. The three main roads horizontally crossing the site starting from the three main entrances of the EIP on the old migration road divide the EIP into four industrial districts. In each district, integrated industrial types along with their local services were distributed considering the pollution minimization terms referred to in section 6.2. Put in order from North to South, they

Table 1. The eco-industrial park's land budget

Land uses		Sub-uses	Area (ha)	%
Industrial districts and central services	Industries based on local resources	Food products	354.93	10.0
		Building materials	354.93	10.0
		Hardwood products	106.48	3.0
		Paper and printing	70.99	2
		Textiles and leather	53.24	1.5
	Complementary and intermediate industries	Chemical & pharma.	283.94	8.0
		Engineering & metal	177.47	5.0
	Scavenger industries/facilities		159.72	4.5
	Local industrial and logistic support services		212.96	6.0
	local urban services		70.99	2.0
	Labor housing		177.47	5.0
	Total area of industrial districts		2023.1	57.0
	Central logistic support corridor	Logistic & industrial services and scavenger facilities	106.48	3.0
		Urban services	70.99	2.0
	Total area of logistic support corridor		177.47	5.0
	Total area		2200.6	62.0
Green corridors	Green corridors and Barriers	Outer green barrier	300	8.5
		Natural drainage paths	212.96	6.0
		Internal green barriers	53.24	1.5
	Total area		566.2	16.0
Central District	Central Business District	Business park and related activities	124.22	3.5
		Recreational park	88.73	2.5
		Commercial park	113.58	3.2
	Total area		319.44	9.0
Roads and parking lots			461.41	13.0
Total area of the EIP			**3549.3**	**100**

[5] In this research, the term "urban services" is used to indicate educational, healthcare, commercial, recreational and religious services.

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are pharmaceutical and electronic chips, food products, textiles and building materials, and hardwood, metal and engineering.[6] The central crossing road connects the two migration roads (old and new) to maximize the movement especially around the early implementation phases of the EIP.

6.4 The Area Selected for Detailed Planning

The selected area (SA) for detailed planning preparation is a part of the first implementation phase (Figure 4). The criteria used in identifying this SA were that it has to be well exposed, directly related to the old migiration road (the main regional spine of trade transportation) and with a strong reciprocal relationship with the surrounding urban environment and its economic activities. This relationship was seen to contribute to the development of small and medium sized communities in the ACC, and increase the ACC's economic development opportunities. Also, the SA was meant to include a variety of different integrated uses to meet the various investment aspects. With regards to the generation of a closed eco-industrial system, the SA includes a size of anchor industries and intermediate and complementary industires enough to generate scavenger industries/facilities that will recycle the waste of these industries (as well as the wastes of the surrounding urban areas).

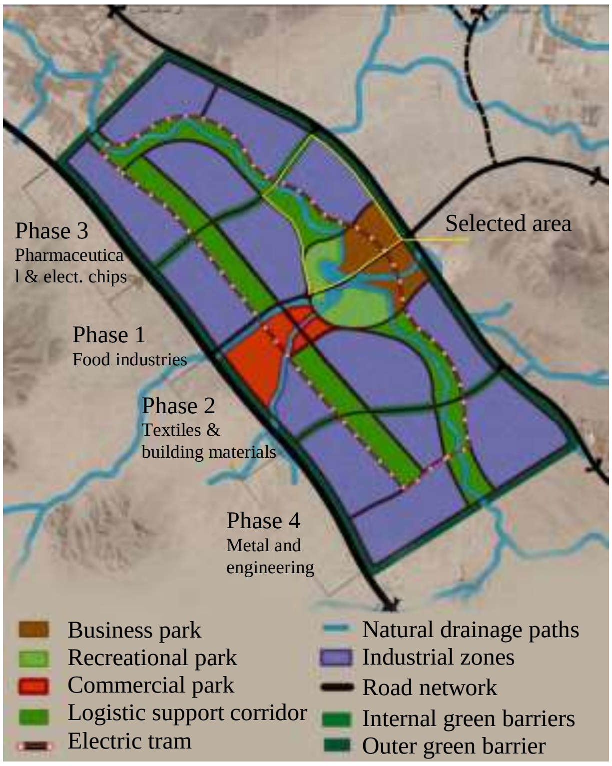

Figure 4. The eco-industrial park's planning concept

7. THE DETAILED PLANNING OF THE SELECTED AREA (SA)

The SA contains three specialized functional zones which are the industrial zone, the logistic support zone and the central zone. The SA's detailed land use budget is presented below, followed by a brief explanation of the planning concepts of its three main zones.

7.1 The SA's Land Use Budget

Table 2 shows the SA's land use budget which was formulated according to the programs calculated and prepared for its three components, as follows.

The industrial zone and its services

In order to integrate industrial activities, in a way that depends on natural resources and economic activities available at the AAC, and to create opportunities for the exchange of by-products and waste, the SA's industries were divided into:

- Basic industries (based on local resources) which are within the food products manufacturing (dates, meat and poultry, dairy products, etc.).
- Intermediate industries such as chemical industries and complementary industries such as plastics and paper industries.
- Scanvenger recycling and reuse industries such as organic fertilizers, feed production and paper and plastic recycling. They also include scavenger facilities such as the material recovery facility (MRF), the biofuel and energy production plant and the water treatment plant. These industries/facilities are aimed at reducing the outflow of pollutants, increasing reuse of material and resources, reducing the cost of environmental treatments within factories and thus increasing the economic efficiency of industrial facilities.

Figure 5 illustrates the the flow chart of materials, waste and energy of the industrial zone, which includes the following beneficial industrial integartive and symbiotic relationships:

- Organic waste represents a large percentage of the waste of the industrial zone as well as that of the surrounding communities. Due to its large size, it is used in fertilizer and feed industries whose products are used in agricultural lands, woodlands, animals farms[7], which in turn supply food industries with raw materials for production.

[6] Paper & printing and chemical industries are distributed across these categories as relevant.
[7] They are also used in the the cultivation of green areas and barriers inside/around the EIP.

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- The biofuel plant is also dependent on the multi-source organic waste, which contributes to the operation of the power plant suppling the SA with electricity, the surplus of which is directed to the surrounding urban communities and the rest of the EIP (when implemented).
- Paper and plastic waste is collected from the industrial zone and the surrounding urban communities into the MRF and then transported to paper and plastic recycling plants that supply the packaging stage of the food industries.
- The chemical industries supply the basic food industries with intermediate industrial products such as food additives, and supply the fertilizer and feed industries with feed additives and fertilizer concentrates.
- Intermediate chemical industries also recycle and use some of the wastes generated by the food, fertilizer and feed industries.
- Liquid industrial drainage is channelled into several networks according to the degree and type of pollution to be treated in the treatment plant to the degree of purity necessary for use in industry and/or other activities.

The industrial zone's local services include logistic support services (warehousing and distribution services) and industrial services (repair and maintenance centers, marketing services and industrial guidance). These sub-services contribute to the stability, integration and productivity of industrial activities inside the industrial zone. The industrial zone also includes housing accommodation and urban services for labor (working and residing in the zone) as well as others frequenting/visiting the industrial zone.

Table 2. The selected area's land budget

Land use	area (ha)	%
1. The Industrial Zone		
Basic industries	37.99	32.11
Intermediate, complementary and scavenger industries	19.97	16.88
Local industrial, logistic support and urban services	6.81	5.76
Green areas and barriers	15.53	13.13
Roads, pedestrian paths, tram line and parking areas	26.54	22.43
Labor housing	11.46	9.69
Total area of the industrial zone	118.3	
2. The Logistic Support Zone		
Logistic support services	19.06	33.38
Scavenger facilities, and industrial and urban services	16.24	28.44
Green areas and water paths	11.32	19.82
Roads, pedestrian paths, tram line and parking areas	10.48	18.36
Total area of the logistic support zone	57.1	
The Central Zone		
Management & operation park	4.11	3.43
Business park	22.67	18.92
Research & technology park	7.4	6.17
Central zone services	9.25	7.72
Recreational & touristic park	29.78	24.86
Green and open areas	21.44	17.89
Roads, pedestrian paths, tram line and parking areas	25.16	21.00
Total area of the central zone	119.8	
The Interfacing Uses		
Environmental protection green barriers	27.43	40.78
Roads and parking areas	39.84	59.22
Total area of the interfacing uses	67.27	
Total area of the selected area	362.47	

The logistic support zone

This zone contains a variety of uses/services that are central to the EIP's industrial zones and divided into:

- Logistic supprot services such as warehouses, refrigrirators, loading and unloading decks, maintenance stations of the electrical tram line.
- Central scavenger facilities including integrated systems for the regeneration and treatment of contaminated water, extraction and filtration facilities of industrial gases, and central stations for the collection, sorting and processing of waste (central MRFs) for reorientation to the plants that can benefit from it.

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- Central industrial and craft services, such as machinary and vehicles maintenance centers, as well as central urban services.
- The central electrical tram line which facilitates the exchange of materials and waste between scavenger facilities and the EIP's industrial zones.

The central zone

The central zone of the selected area includes a management and operation park (which is equiped with a networking smart system), a business park, industrial products fairs and exhibitions, a research and technology park (encompasing a research center

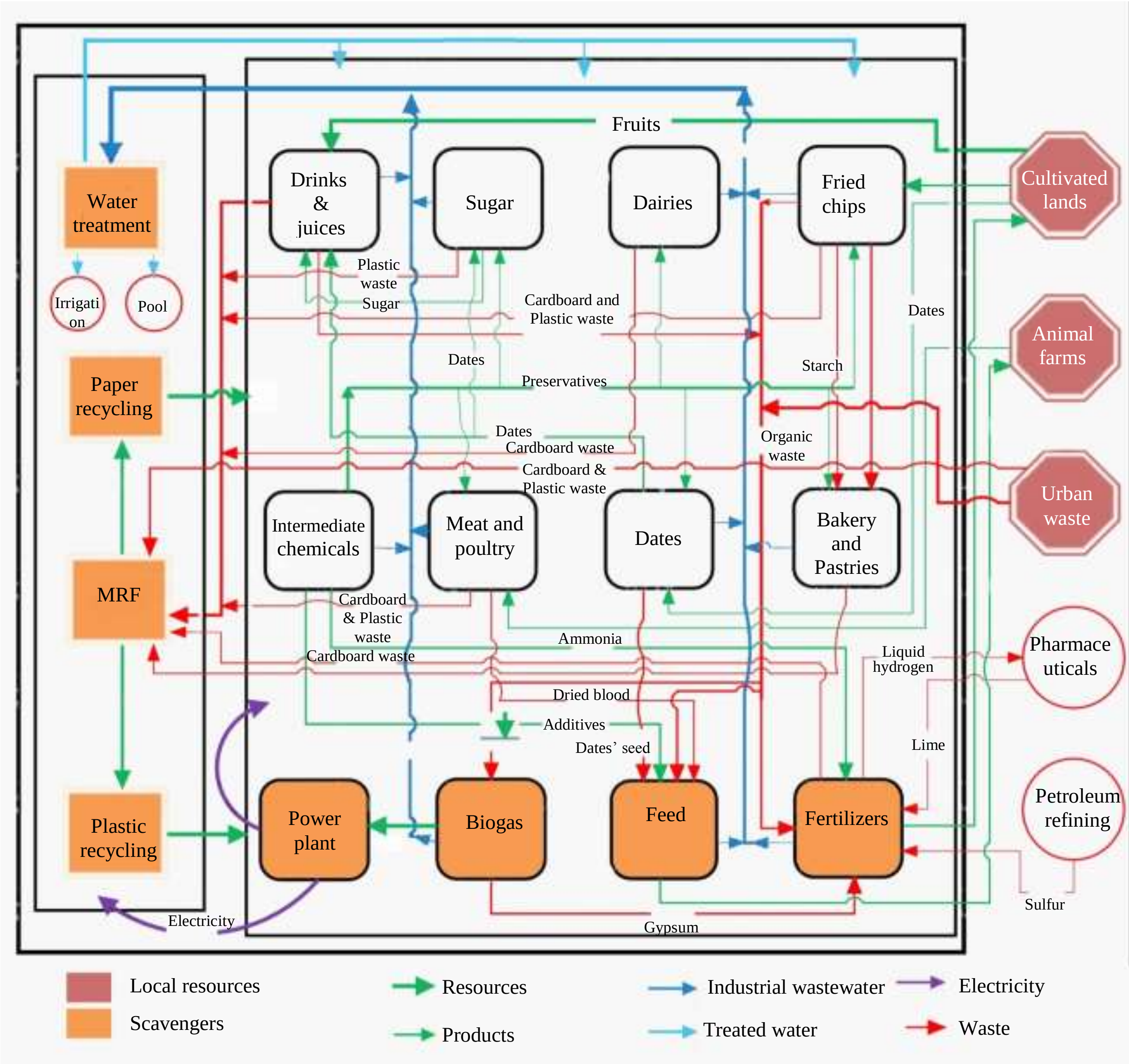

Figure 5. The flow chart of materials and energy of the SA's industrial

and a specialized university in industrial sciences), a recreational and touristic park, and relevant services (e.g., an integrated medical center, an information and marketing center, conference venues, and banks).

The interfacing uses

These include the green barriers among the three zones of the SA, the purpose of which is to increase the environmental capacity of the site, reduce the polluting emissions and achieve a moderate climate conducive to ease of living and work inside the SA. This was achieved through:

- Surrounding the EIP with an environmental protection barrier consisting of two sub-domains. The first is a safe buffer zone separating the EIP from the surrounding urban area with 5 km width and the second is a heavily cultivated green barrier.
- Penetrating the industrial zone with green barriers in such a way as to support the preservation of natural vegetation found on site while increasing the environmental capacity of the site.

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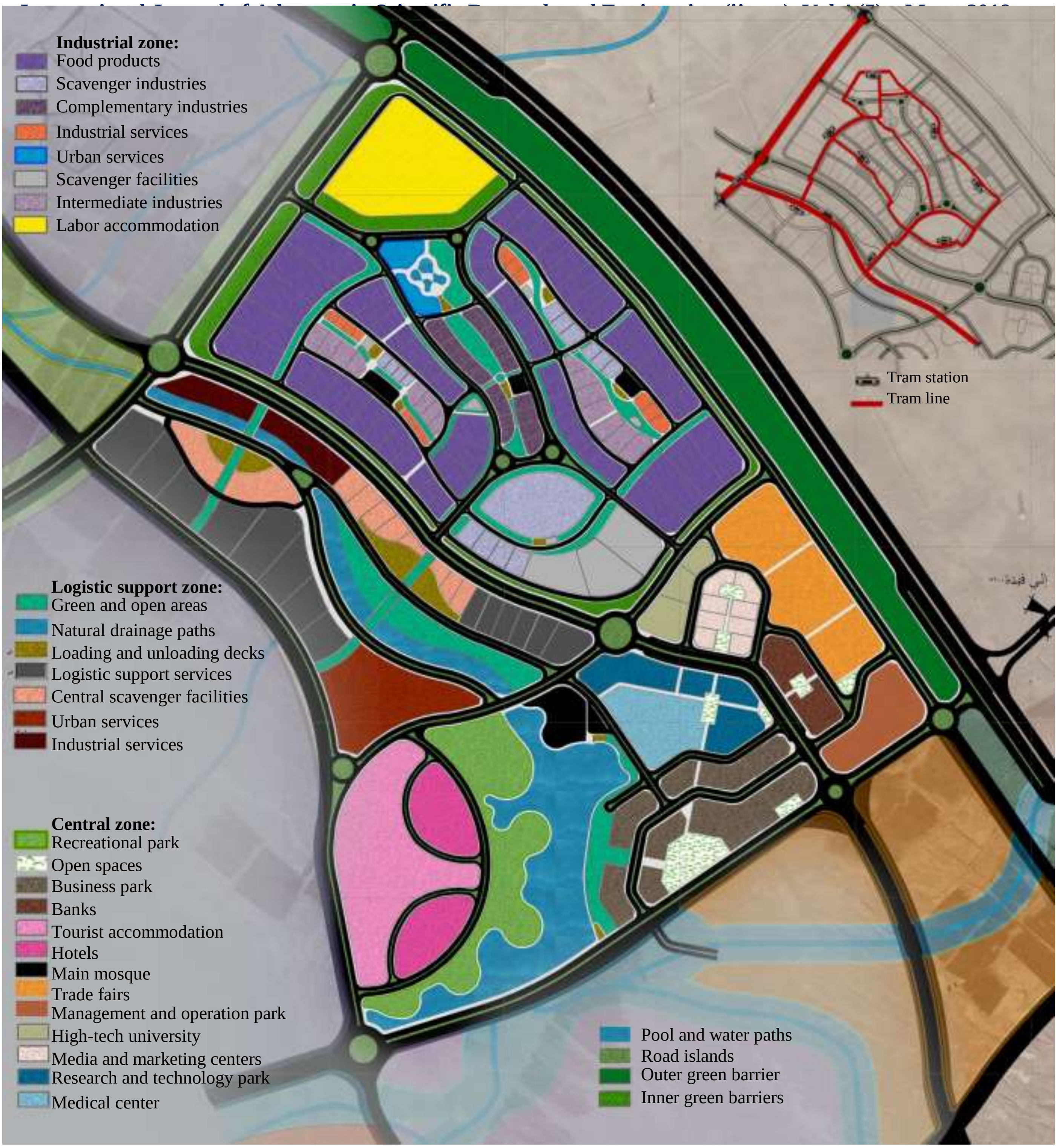

Figure 6. The selected area's detailed plan

- Surrounding the scavenger industries and facilities with a green barrier separating them from different types of industrial activities.

7.2 The Selected Area's Planning Concept

The final formulation of the SA's planning concept was based on the development of a set of initial free concepts for each specialized zone within it, followed by the synthesis of these different concepts to reach the best integrated planning concept. It was not sought to choose the best concept for each zone by itself but the ones that together best perform functionally and environmentally and are well integrated planning wise (figure 6). The planning concepts adopted for the constituent parts of the SA are as follows:

The industrial zone

The industrial zone's planning concept was based on the fact that although it is one of several industial zones in the EIP, it is treated as an *independant* operational and ecological entity. It is consisted of a center and 4 surrounding parts. The center is a

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service hub that includes urban services, a green corridor and an artificial mini lake. It also includes industries complementary to the basic food industries (e.g., paper and printing and plastic products industries). The center is surrounded by two clusters of food industires, each with a sub-center comprising intermediate industries (e.g., chemical industries) and industrial services. In the far north, close to the zone's urban services, the labor housing accommodation is located and bordered from the south by a green barrier separating it from the adjacent industrial clusters. In the southern part of the zone, the scavenger cluster of industries/facilities is located and also surrounded by a green barrier separating it from its surroundings. The isolating green barrier around the industrial zone is given a changing width depending on its function: a 50-meter green barrier on the old migration road (and the natural and urban environment beyond it) and a 20-meter green barrier around the rest of the industrial zone separating it from the other SA's zones as a confirmation of the functional roles of each zone, and in a way that does not interfere with the interconnectivity among them.

The industrial zone has a number of entrances that well connect it to its surroundings. One main southern entrance is from the central zone, another western one is from the logistic support corridor, the third is located north of the industrial zone at the old migiration road and the fourth is in the southeast of the zone on the internal EIP's ring road. The main roads connecting these entrances together provide enough access to the center of the industrial zone in a manner that achieves an easy flow of traffic. There is also an internal ring road surrounding the industrial zone for further connectivity.

In order to limit the vehicle movement within the industrial zone and thus the accompanying air pollution, a local electrical tram line network was proposed to help transport labor, goods, raw materials and waste inside the zone (during time periods assigned for each throughout the day) using special tram cars suited to the nature of the transported element. This internal network is connected to the main tram line (parallel to the logistic support corridor). Terminals of the main tram line within the industrial zone are considered to be extra entrances to the zone.

The industrial zone's wastewater network was planned to separate the industrial wasterwater network from the sewage network. This represents a wider possibility of using treating methods suitable for the nature of the existing pollutant and a wider possibility of pumping the resulting water to be reused in industrial processes according to its degree of purity. The surplus of this treated water is pumped into the artificial lakes (within the industrial zone and the main one located in the central zone), which act as a water reservoir to be used in irrigation (especially non-fruit trees) and industrial processes when needed.

The logistic support zone

The concept plan of the logistic support corridor was based on the fact that it should be well connected to the EIP industrial zones as well as the central zone to facilitate the exchange of materials and by-products and the movement of labor and visitors. In addition to the ring road surrounding the corridor, the main electric tram line supports the transportation system[8].

As an example of the layout of the logistic service corridor, this detailed zone of the corridor - within the SA - consists of a variety of uses that are central to the industrial zones (other than the sub-centers within these zones). The planning concept is based on two loading and unloading decks associated with two electric tram stations. Each of these two decks serve a range of scavenger facilities, such as the central MRF, where waste is sorted and transported by type and quantity either to warehouses or factories or to the scavenger cluster within the industrial zone. As part of the logistic support corridor, a green corridor is proposed along the exisitng natural water path which acts as a conveyor for treated water between the central and the local artificial lakes. In addition to its function as a connector among different services allocated around it, the green corridor also minimizes their potential negative environmental impact.

The central zone

The planning concept of the central zone was meant to accentuate the role of this zone as a good front to the EIP on the old migiration road to which the zone is adjacent and with which the zone should be well connected and exposed. As stated earlier, this road is the main regional trade road. Therefore, the management and operation park is placed adjacent to the road to maintain the highest operational efficiency. Also, the firm's products' exhibitions and trade fairs are allocated as an attached stip to the road with maximum exposure to it. This exposure is achieved by replacing the heavy green barrier in this interface between the road and the exibition strip with palm trees. Thus, the management park and the exhibition strip together serve as a good interface that helps to expose the project and thus attract investors as well as visitors.

The planning concept was also based on utilizing the natural water catchment area, which exists in the middle of the site, in the creation of an artificial lake with a recreational park to the west of it. Both together act as an environmentally friendly and aesthetically pleasing component of the central zone (in addition to the lake's ecological role referred to earlier) and a good view

[8] In this context, the electric tram lines are hierarchically divided into three levels: a regional line which connects the SA to the surrounding urban communities for the transfer of labor and raw materials as well as the transfer of products of the scavenger cluster to farms, a main tram line within the EIP for the exchange of materials and the movement of labor and visitors, and the internal local line within each industrial zone which transport labor, materials and byproducts among its different parts.

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to which other components could be oriented. Thus, the touristic area (hotels and residential accommodations) as well as the business park are located on the lake. The research and technology park and the medical center are also shaped with an orientation towards the lake. The research and technology park was meant to be also placed near the industrial zone to symbolically highlight the strong relationship between them. Other components such as the banks and the information and marketing centers are placed in the middle of these main components for equal and easy access.

7.3 The Selected Area's Mass Plan

To articulate the urban character of the SA, the study analyzed the urban pattern of Makkah (the wider urban context most relevant to the site) including its urban tissue and street network both traditional and contemporary to come up with a set of urban vocabulary that could be used in the urban design of the project. Figure 7 shows the mass plan of the SA and figure 8 illustrates some bird's-eye views of the project masses, assuring both the distinction and homogeneity between the regular urban form, which is applied to the central zone and thus based on visual and functional axes, and the free organic urban form which is applied to the rest of the SA and thus based on maximizing connectivity and ease of transport of materials, waste, goods, labor and visitors.

8. CONCLUSION AND RECOMMENDATIONS

This paper identified a research gap in the study of the urban planning dimension of industrial ecology (IE). The existing literature studied the concepts of IE and developed their operational implications, but did not pay enough attention to the urban dimension of these concepts. This may be explained by the fact that IE is relatively a new science and that its applications for the production of EIPs emerged in the early 90s of the last century. The attempts to apply IE concepts therefore have been carried out on existing industrial areas with a view to transforming them into eco-industrial parks (EIPs), not to found new ones from scratch. Thus the greatest effort has been focused on the operational mechanisms that would guarantee such transformation. However, with several studies pointing to the inadequacy of this transformation because of internal and external difficulties, and with the scarcity of research on the urban dimension of EIPs, the importance of studying the urban planning and design of new EIPs has become more sound to effectively apply the concepts of IE.

Hence appears the importance of this research in its attempt to study the urban planning and design features necessary for the establishment of new EIPs. These features not only aim at physically embodying the well established international concepts associated with IE, but also take into account the specificity of the local context in which the EIP is locataed, in our case, in the Asfan administrative center (AAC), Saudi Arabia.

Therefore, the research, after updating the status of what has been written internationally about IE and its urban dimension (if scarce) in the form of a theoretical framework, examined the demand and supply in relation to industry in the region and defined the role of the EIP considering the dimensions of competition and integration with its interregional peers as well as the compatability with the particular contextual characteristics of the AAC.

The research came out from marrying this theoretical framework of IE concepts with the local contextual framework of the case study with the preparation of a planning concept for the EIP and the detailed physical plans and urban design schemes of a selected area of 300 ha of the first phase of the EIP.
The prerequisites and lessons that could be learned, generalizing from the findings of this specific case study, can be summarized in the following points:

1. Prepare an eco-industrial composition of the EIP that aims to close the industrial loop and which conforms at the same time to national industrial strategies, the EIP's regional resources, and the supply and demand on industrial products and investment.

2. Consider the surrounding urban and natural environments of the EIP as a major integrative contributor to closing the industrial loop. These wider environments could positively achieve reciprocal relations with the EIP to absorb their by-products or help operate the EIP's scavenger activities.

3. Study the production systems (inputs - operational processes – outputs) of the proposed industries, map out their material flow analysis, identify their urban planning requirements, and set up different alternatives to possible industrial relations between them bearing in mind the achievement of industiral integration and symbiosis. Then, develop planning alternatives and evaluate them based on their ecological performance.

4. Plan the EIP's industrial clusters in such a way to ensure the closure of the industrial loop. This could take one of two basic types or a mix of them (which will be dependant on the types of industries and the possible symbiotic scenarios among them). The first is that similar anchor industries (along with their complementary and intermediate industries) are to be assembled together to produce enough one-type waste on which scavenger industries could effeciently operate. The second is where different types of industries are assembled together but on the basis that the remnants of an industry are inputs to another.

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5. Plan the EIP in heirarchy in such a way that ensures that the produced waste of each level is recycled and reused within the same level, or transfered to other levels for proper operation to ensure the industrial loop closure.
6. Establish and integrate new types of uses, industries and facilities that contribute to the achievement of IS such as the networking smart system, the IE's scientific park, the material recovery facility (MRF), the scavenger plants (such as biofuel, fretilizers and feed plants), the industrial wastewater separate network and treatment facility, and the artificial lake that serves as an open reservoir for excess treated water.
7. Establish the EIP planning concept, including the allocation of land uses and the planning of movement networks, on the basis of observing and utilizing the site's natural elements and features.
8. Plan the EIP in a way that mimics nature in its closed system of biodiversity. That is, the EIP has to have multiple integrating, self-sustained and self-contained land uses.

Figure 7. The selected area's mass plan

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Figure 8. Bird's-eye views of the selected area

9. Create not only a buffer zone and green barriers around the EIP but inside it, separating its potentially polluting uses.
10. Design the EIP with green communities concepts, including learning from sustainable traditional urban forms (but in contemporary terms), using environmentally friendly energy generation methods such as biogas, and using the least polluting and the most efficient transportation systems such as the electric tram line.

It should be noted, however, that the case presented in this research or these generalized lessons learned should not be treated as a model to follow or as a checklist to adhere to during the urban planning of other EIPs. This is not only because of the specificity of the case studied in this research or the logical obligation to consider the specificity of any new planning case before copying this case’s features and lessons (to test their relevance to the new case), but also because these features and lessons are still within the framework of academic discussion and empirical testing, subject therefore for scrutiny, development and likely challenge not adherence.

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