Original Research Paper

The Effect of the Transportation System and City Configuration on Sustainable Urbanization (Al-Bayda City as a Case Study)

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Abstract: Despite the persistent attempts on a global level to adopt sustainability in every aspect of city planning, the complex nature of city components and the presence of many factors and variables that affect the growth and development of cities make the adoption of a specific trend not an easy matter. It may be more appropriate to identify some important elements such as road networks, the type of buildings and the shape of streets to determine the extent of their impact on the built environment. Hence it will be more practical to apply approaches based on realistic investigation. The main objective of this study is to clarify and analyze the importance of urban form and the road and transportation network on urban growth from a sustainability perspective. The Libyan city of Al-Bayda will be the practical example to explain in further detail how compact form and linear road patterns impact the sustainability of the city. Adopting the method of description, analysis and extrapolation and limiting the discussion and comparison to three basic points: first, defining the importance and impact of compact urban form by considering urban density and land use distribution throughout the urban fabric, second, the causes of problems in the road networks and how roads pattern contribute to urban problems within city's sectors, thirdly, what should be applied and adopted at city level to become more sustainable. Study methodology relies on inductive descriptive analysis to arrive at a logical conclusion that relies on discussion and presentation of details to identify in a simplified manner the existing problems and finally, providing suggestions based on theory and application. The study concluded that both the scattered urban from associated with uncontrolled distribution of land use and linear road patterns heavily impact urban growth and development leading to undesirable outcomes that should be managed to sustain the required and necessary proper development.

Keywords: Transportation System, Urban Form, Sustainable Development, Smart Cities

Introduction

Both the urban form and the road network are core in any sustainable development program and must be adequate and efficient to fulfill tasks and satisfy dependents. Transportation systems and roads connect city sectors, permitting accessibility within and between different types of activities and functioning urban patterns. On the other hand, the urban built-up environment reflects, the integration of buildings and activities with its natural or manmade surroundings. The interaction between these variables at the city level is what ultimately provides opportunities for urban development. Unfortunately, many cities worldwide, including Libyan cities, sustain insufficiency in transportation systems and urban forms and thus are incompetent to fulfill the primary prerequisites of sustainability or smart development. The transportation system is a factor in the physical form of a contemporary city and the history of transportation and city planning indicates the significance of roads and

transportation systems on urbanization. The gradual improvement of roads and transportation domains lead to the development of movement between origins and destinations. Residential areas were built far from the workplace and transporting goods from the place of production to the market became easier. However, transport modes have contributed greatly to the dilemma of overcrowded streets and road congestion. The shape of the city and the distribution of many urban activities have also increased the problem. Cities with higher population densities house more people as well as services within certain areas and this usually leads to building higher units and calling for more roads to obtain reliable connectivity. Accessibility, which relies heavily on the road network and allocation of different uses within the city became impaired mainly due to the unregulated distribution of land use (Brandon *et al.*, 2002; Dempsey, 2010). This study provides a brief overview of the influence of transportation and urban patterns on city planning through the perspective of smart urbanization.

Urbanization of cities has led to unbalanced development, which subsequently affected city structure, functions and transportation. The issue of urban growth and traffic congestion has become one of the biggest problems facing the city due to the overlapping of uses, the large number of movements, traffic and the diversity of its causes. Therefore, many studies focus on studying and enhancing the role of urban growth, land uses, transportation and infrastructure in the quality of life and sustainability of urban development.

Goals and Objectives

In this study, the city of Al-Bayda city was closely examined to determine the effect of the city's urban composition and transportation systems on urban services and urban growth. To clarify the overall objectives of this study, three research questions were posed to justify and define the analysis and interpretations, define technical terms and define the analytical framework for the research's practice the questions are:

- What is a compact form? How does this affect the structure of the city?
- How can road patterns affect accessibility and movement within a city?
- Are urban form and highways important factors in achieving sustainability

Materials and Methods

The research questions were addressed first by identifying some important terminologies that will appear frequently in the content. Then, the case study approach was applied, starting with previous documents

of the Dioxides International group. Relevant documents such as Al-Bayda's general plan, were also considered, to obtain a comprehensive and simple basic framework to correctly present the results and make interpretations scientifically valid.

Compact City

Is a terminology in urban design and urban planning means a city of short distances. A city where the transportation system is effective and designated to encourage walking and cycling, low consumption of energy and reduced pollution. Less dependent on cars hence, it adopts efficient public transport and a good-laid-out pattern of road network. As well as, the compact form induces high residential density (about 250 residential units per ha) next to mixed land uses (Dempsey, 2010; Kievani, 2010). A compact built-up environment can be implemented through good planning and appropriate urban design that takes into account the road pattern and the general shape of the city. This type of city planning has proven to be convenient and sustainable compared to many well-known settlement plans. Among its many advantages are short commuting time, minimum environmental impact and low fossil fuel and, energy consumption. This form of planning has been applied to many ancient societies and is evident in many of Arabic and Western cities (Fig. 1A-B). The physical urban environment often converges at a macro level to protect against climatic conditions, as well as to remain close to life-sustaining sources, such as water and food. It promotes better land use, encourages walking and keeps daily services within walking distance. In contemporary cities, planning this concept is known as proximity (Eisenhardt, 1989). Acceptable proximity to desired amenities is calculated according to travel time and distance. Destinations must be reached by foot and with minimal distance. Existing studies point to compact patterns of urbanization as smart growth, because they encourage walking ability and reduce dependence on automobiles. In developed countries, denser urban areas with adequate mixed land use and good public transportation have demonstrated minimal car usage and vibrant urban areas (Dempsey, 2010). In addition, the compact form, attributes to low power consumption, making servicing and movement easier and more cost-effective compared to sprawling areas.

Street Pattern and Land Use

When congestion occurs on main roads in a residential area or in the city center, it is generally caused by the segregation and concentration of single land uses such as shopping malls or parks. Street design can contribute significantly to the quality of movement and the

appearance of the community. A well-designed street not only allows efficient connection and accessibility but also creates a safe, less congested environment. Current types of street patterns are more about infrastructure, transportation efficiency and urban form quality (Frank and Pivo, 1994; Eren and Uz, 2020; Saelens *et al.*, 2003). Efficiency in land and infrastructure can be obtained by adopting a suitable type of street pattern. Traffic efficiencies can also be attained by implementing the right combination of street design and other variables such as topography, surroundings, layout and adjacent land use. Narrow, twisted and crowded streets may be favorable to pedestrians, but not to drivers. Automobiles require unimpeded flow, a safe visual connection with surrounding areas and easy accessibility to destinations. These qualities are generally achieved by reducing and simplifying intersections, increasing lane width, dividing traffic lanes and separating opposite streams of traffic (Ahmida *et al.*, 2023).


Fig. 1A: Compact planning in ancient city of Rome; (Source-2023 Google Earth)

Fig. 1B: Compact built environment, Gadamas City, Libya (Source-2023 Google Earth)

The most common type of road pattern in today's cities is the traditional grid pattern (or gridiron plan), which has evolved since its appearance after the first industrial revolution in 1800 (Fig. 2). Its orthogonal geometry, where the streets cross each other at right angles, forms the grid. This pattern was meant to facilitate pedestrian movement in the first place, but the increasing use of vehicles has required major adaptations such as one-way streets and traffic lights to accommodate automobile traffic flow. Without such adaptation, congestion is inevitable. Gradually, the grid has become an inefficient and unsafe carrier of traffic flow. Most apparent are the 16 conflict points, for which priority has to be decided by the driver or controlled by traffic lights.
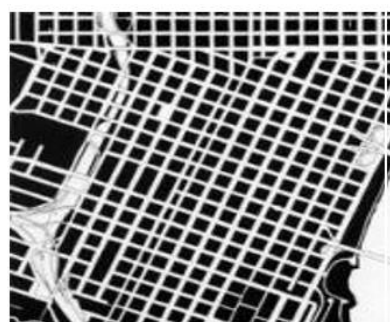
Fig. 2: Common types of street patterns source: Pintrest.com/Pin/city map illustration, 2021

Interaction between land use and transportation is always an essential part of any planning program. Through traffic impact analysis, the magnitude of influence becomes evident. Traffic volume and trip generation are influenced by the location, density and mixture of land uses. The interaction between land use and transportation will occur regardless of whether city planning has considered land use when adopting a street pattern. An effective city plan must include transportation linkages, mixed-use and high-quality urban services with long-term positive effects on the economy, the environment and the physical urban environment (Grammenos and Lovegrove, 2015).

Road Hierarchy

It is an organizational method of urban planning to provide appropriate road networks, regulate traffic and eliminate congestion. This regulatory tool has dominated the composition of city networks since the 1960s and its major task is to maintain order and safety. Classifying different road types into groups, each with specific characteristics (Fig. 3), allows a clearer understanding of the function and design requirements of each road. In the hieratical system, high speed is only allowed on external highways (regional and expressways) to move pressing traffic quickly; through traffic (internal traffic in C.B.D. areas) is only permitted on arterial roads; collectors is meant to link arterials with feeders; and local/or minor roads are to facilitate movement and accessibility to and out of residential neighborhoods. Each road type has its specifications in terms of speed limits, length, width, number of lanes, conditions of connecting to other roads and even the preferable type of nearby land use. Such regulations proved effective in controlling congestion and queuing, discouraging high-speed driving in residential areas and enabling flat accessibility into and out of urban service areas (FHA, 2013; Tsigdinos and Vlastos, 2021; Marshall, 2004).
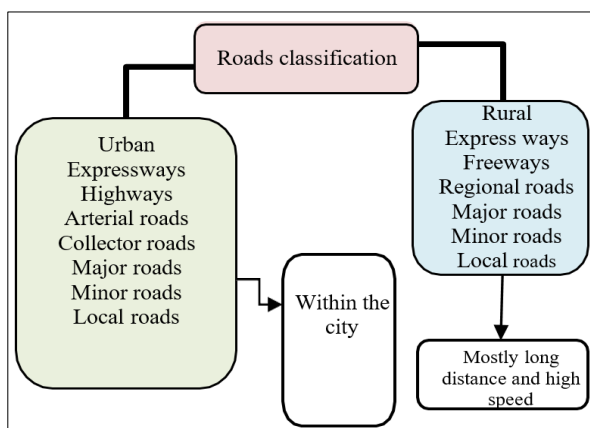

Fig. 3: Functional hierarchy of road types source: USA Institute of Traffic Management

Problems of Urbanization

Considering that urbanization is one of the most prominent factors causing major urban problems within cities (Yin, 2013; Yigitcanlar and Teriman, 2015), it is necessary to know the most prominent of these problems in order to know the most appropriate solutions to address them, the most common of which are the following:

- The depletion and consumption of natural resources in a way that affects future generations threatens their ability to withstand and continue and this contradicts the world's challenges toward sustainability
- Problems in cities result from internal migration, high demand for services, high population density and increased pressure on roads, transportation and infrastructure, along with the inability of governments and institutions to provide an adequate level of services
- As a result of the above-mentioned factors, serious environmental problems have emerged and it has become necessary to intervene in the way cities are planned to ensure control of their escalation and reduce their negative effects

Case Study: Evaluation of Urban Conditions

Al-Bayda is the second-largest city in the eastern province and its importance comes from its role as a central service area for many human settlements and surrounding towns. This factor, in particular, has contributed to the substantial level of urbanization in the city. By comparing figures from previous governmental documents and national reports, the urban population of Al-Bayda has doubled in the last 15 years. Such growth is inevitable as 70% of GDP is generated in cities, which drove residents of rural areas to migrate to nearby cities seeking an improved standard of living (Yigitcanlar and Teriman, 2015). Dioxide's comprehensive study of the city estimated an annual average rate of growth of 4.8 for 2000-2020. Based on that, the total population of the city was estimated to be around +200.000 and this figure was confirmed by the national governmental census of 2006. concluding Al-Bayda's total population as 209.000 (LBSC, 2006), But the annual rate has jumped to 7% due to high internal migration and waves of non-national workers moving into the city after the people's armed rise in 2011 (Ahmida *et al.*, 2023). By using the following formula, the total population is estimated to be above half a million by 2021:

$$M_0 = M_1(1 + \frac{P}{100})^N \qquad (1)$$

where:
M_0: Projected population
M_1: Present population. i.e., 2006 census

P: The annual average rate of growth (7%)
N: Duration in years (2021-2006 = 15 years)

Based on Eq. 1, the current population of the city is doubled:

$$M_{2021} = M_{2006}(1 + \frac{7}{100})^{15}$$

$$M_{2021} = 209.000 \ (2.76) = 576.637$$

Such an increment was projected to be obtained in 2025 not earlier (Fig. 4).

Rapid uncontrolled urbanization tends to result in some significant urban problems such as housing shortages, low levels of services, congestion and the deterioration of natural and man-made environments, which conflict with the appropriate and required level of national urban growth plans and with the global requirements for sustainability and proper development

Problems of Urban Expansion

Among the major problems posed by city growth is urban expansion at the expense of surrounding agricultural and natural land. Mainly, the objective of such expansion is to build more housing to meet escalating demand. By comparing Google's images of Al-Bayda with the official master plan of the city (Figs. 5-7), there is obvious urban expansion activity.

Figure 5, the arrows indicate the desirable directions of the future expansion, which respects zoning by law and land use regulations and follows the official master plan of the city. Unfortunately, the total areas for allowable and suitable expansion do not exceed 400 ha to the north and northeast and another 300 ha to the south. Prevent both the Al-Jabal national agricultural project and the difficult nature of the area from hindering the needed urban growth of the city.

Figure 6, the total area of the city was around 2,700 hectares and was fairly adequate to the estimations laid out in the Doxiadis plan; however, the applied urban density (104 p/ha) confirms the shortage of housing. It also shows how low density leads to insufficient use of land, contributes to unpractical sprawling, contributes more to the depletion of resources and damages agricultural and tourist lands.

Figure 7, the city's total area has reached 4,800 ha, which is extensive and at the expense of valuable cultivated land. In addition, more sprawling requires more connectivity and accessibility to ensure an adequate standard of living, which is not possible without the extra distance of roads and commuting. The extension of roads and residential areas indicates the necessity of providing infrastructure utilities and other required urban services, such as schools and shops.
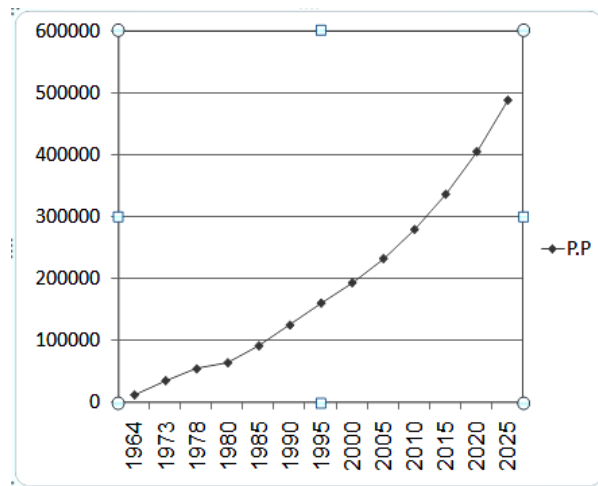

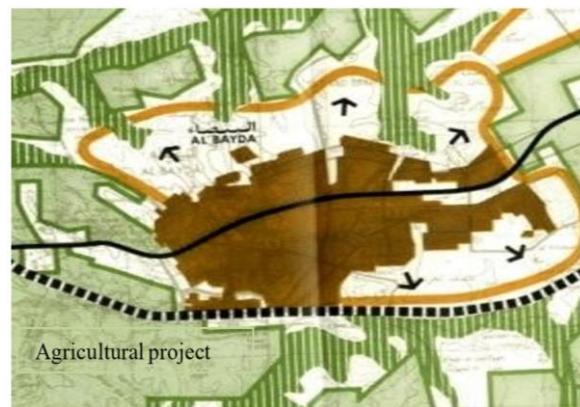**Fig. 4:** Population of Al-Bayda according. Doxiadice's report No. 4,197-1986

Fig. 5: Preferable direction of urban expansion, Al-Bayda 2000 proposed plan (Dox-LIB, 1985), Vol1
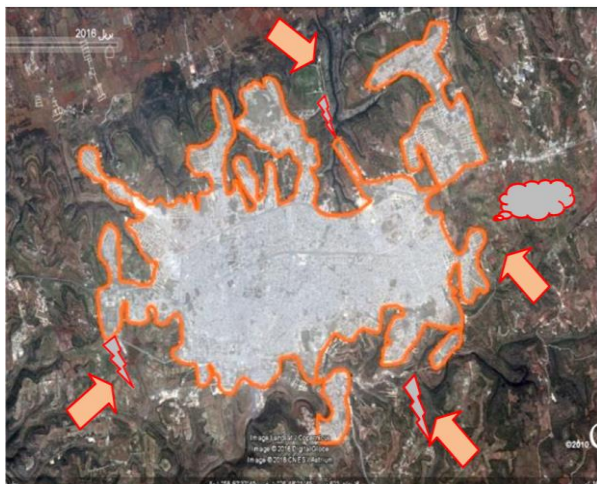

Fig. 6: Al-Bayda total area 2006
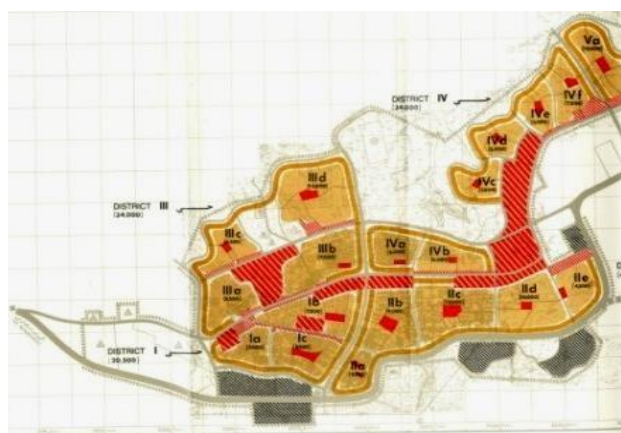
Fig. 7: Al-Bayda total area 2021

Fig. 8: Compact form for residential neighborhoods and C.B.D, dioxides proposed plan for the city in 2000

In general, residential areas and the total urban density are vital in shaping the urban form. When there is a shortage of land and a natural barrier, such as in Al-Bayda, the proper answer is to apply compact growth. Building vertically is a known mechanism to face urban expansion and reserve valuable land; it allows more space for green areas, pedestrians, park lots and even more connection with the surrounding environment. Low-density and detached housing contributes significantly to expensive urban expansion and heavily affects natural resources. The convergence of urban growth for the various services needed by urban residents, with an appropriate density rate, contributes significantly to reducing electricity and water consumption. Instead of hundreds of kilometers to facilitate access to municipal and public services and to lay electricity lines and water pipelines, they can be dispensed with by nearly half if multi-story buildings of suitable size and density are adopted.

Zoning and Land Use

Both are important to control the location, size and use of buildings and decide the density of city blocks. Adopting regulations and standards of land use according to zoning requirements enhances compact form and thus evokes more efficiency in the consumption of energy and preserves natural resources as well (Kievani, 2010; Holechek *et al*., 2022; Mróz, 2022). The Doxiadis proposed plan for Al-Bayda 2000, shown in Fig. 8, would have been successful if it was applied correctly.

The convergence of different uses in the city plan, taking into account the requirements of the organizing regulations and the conditions of urban design, provides the required positive effects and enhances sustainability. Instead of extending horizontally over long distances and large areas, the compact form contributes to strengthening the convergence of urban services, i.e., the spread of the built area of low-density housing in the form of villas and detached housing is the main reason for the problem of lack of land in the city and it is also one of the major factors beyond the de-cultivation of agricultural land and deforestation. It is necessary to move towards high-density and multi-story buildings and not cover all the land with housing. High density contributes to shorter road distances and lower costs when connecting infrastructure services and it also allows more space for parks, green areas and pedestrian paths that do not exist in the city (Hiremath *et al*., 2013; Newman and Kenworthy, 1989).

Transportation and Main Road Network

Al-Bayda is a classic example of a linear pattern or linear city (Dox-Lib-A198, 1979b; Dox-Lib-A194, 1979). The surrounding natural conditions contributed to the linear formation of the city. The steep slopes in the north, valleys in the south and the difficult mountainous nature of the region imposed the extension of roads from east to west and along the roads that were in their early beginnings' routes for trade caravans, the first features of the city emerged to refer to Fig. 9.

Fig. 9: Major highways, Al-Bayda Doxiadis Plan 1986

Road pattern determines the shape of the city, the transportation system controls the movement and accessibility, the more the road network and the transportation system in the city are designed efficiently, the more appropriate the level of services and communication between parts of the city. Among the major drawbacks of the linear pattern are: Inaccessible to the marginal areas of the city center, Unplanned urban growth causes fragmentation in the city structure and creates separate service clusters (a city within the city), the transportation system must be effective and renewable to achieve easy access and communication between parts of the city, an old or unorganized system increases congestion and leads to a high level of pollution (Norman *et al*., 2006; Jefferies *et al*., 2014; Jullien *et al*., 2014).

Results and Discussion

From what is shown and clarified above, the most prominent problems of the city regarding the urban form and the transportation system can be summarized as follows:

1. More than 85% of the total area of the city is occupied by residential units, which indicates a shortage in other land uses such as schools, shops and clinics
2. The dominance of residential use lends the character of monotony and boredom to the general shape of the city and reduces diversity and vitality. The low density affects public services such as electricity, water and roads because it requires covering large areas and distances (Dempsey, 2010; Frank and Pivo, 1994)
3. Because of the need to build more single houses and the lack of suitable land for building within the city plan, the surrounding agricultural lands are attacked, bulldozed and transformed into poor residential neighborhood plans. Plans that do not have the minimum required specifications
4. Forests and lands of private nature, such as beaches, archaeological sites and tourist areas, are also bulldozed. In the long run, the uprooting of vegetation will affect climatic conditions and lead to an acceleration of desertification
5. More residential neighborhoods (in violation of specifications and conditions and whether individuals or groups) means more roads, services and public and governmental facilities and this means more use of resources, more trips and more energy consumption (Eisenhardt, 1989; Creutzig *et al*., 2015; Norman *et al*., 2006)
6. The current road network follows the general features of the linear system (Dox-Lib-A198, 1979a; Dox-Lib-A194, 1979), which is not compatible with

the rapid growth of the There are problems with poor functional hierarchy, which causes a low level of services and congestion. Express and transit traffic interferes with traffic within the city, as there is no service classification for each type of road. The highway in the north carries regional traffic between Al-Bayda and neighboring cities such as Benghazi and Shahhat and it also carries daily traffic to connect the administrative city center in the north with central services in the city center and residential neighborhoods. The functional difference in road types and the huge daily traffic volume resulting from the combination of all that traffic with the low design specifications of the Northern Highway made it a real problem. As for the highway in the south, it does not carry the required volume of traffic due to the small size and influence of the surrounding settlements. There is no large volume of traffic generated between Al-Bayda and the residential settlements in the south and the traffic coming from Benghazi is more concentrated on the highway in the north. The most prominent problem caused by the southern road, it limits the growth of the city towards the south and forms a barrier between the two ends of the city.

7. Within the city, there is no appropriate hieratical function of road grades (Dox-Lib-A194, 1979) and for this reason, daily traffic accumulates on the two main streets (Al-Orouba and Omar Al-Mukhtar) and the problem worsens with unplanned intersections and parking on both sides of the road. Secondary roads and cal-de-sac exist in a few parts of the city, randomly and often for no apparent reason, e.g., the absence of proper functional hierarchy on most of the road network concentrates daily traffic on the arterial roads and makes the minor and local street thoroughfare (Newman and Kenworthy, 1989; FHA, 2013). There is a severe shortage of parking spaces, which leads to the accumulation of cars on the main and secondary streets, especially during rush hours and around service buildings such as schools, hospitals and malls

The high rate of private car ownership, with the complete absence of public transportation, adds another dimension to the problem, as the streets have turned into channels crowded with cars and the consumption of fossil fuels has increased (Newman and Kenworthy, 1989). Although there are no actual and realistic studies on pollution problems, indicators such as the increase in population and the high rate of car ownership, along with the problems in the road network, all indicate the existence of a problem with the high rates of air, audio and visual pollution.

Problems Related to Energy Consumption and Resource Depletion

Based on the estimation of the increase in the population of the city, which appears to have doubled within a decade, the city is typical of cities with problems associated with urbanization. Global studies issued by international institutions confirm the growing phenomenon of urbanization in developing countries and warn of its impact on the environment and the rapid consumption and depletion of natural resources (UNHSP, 2009; Cohen, 2006).

The most prominent problem associated with the increase in the population is the increase in demand for electricity and the new increase has contributed to adding a new burden to the dilapidated network. According to the local power company (GECOL, 2012), the electricity demand increased from 160 megawatts in 2006 to 395 MW in 2016 and this is a large unjustified increase, especially because Libya ranks fifth in Africa in carbon emissions and the electricity sector is the main reason for those emissions, followed by the transportation sector and then the industrial activities as depicted in Fig. 10.

The main reason for the high electricity demand is due to the increase in the residential area and local and international reports indicate 4.5% annual increases and the average electricity consumption for one housing unit with an area of 200 m^2 to 6.5 kW/day. The low level of the network and the weakness of the means of distributing electrical energy cause a loss of 17% and according to the general electricity company, only 75% of the energy reaches the citizens (GECOL, 2012). According to periodic statistics, the transportation sector consumes about 2.3 million metric tons of gasoline (LBSC,2006) and about 29 million metric tons in industries. If these numbers are confirmed, there is a dangerous consumer pattern that is against all principles of sustainability.
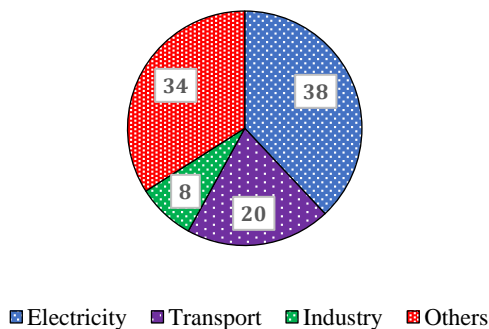

Fig. 10: CO_2 emissions by sector; source, local power company 2021

Considering the transportation sector, the high rate of car ownership adds more burden to the problem of congestion and the difficulty of movement. It also means more fuel consumption and soon there will be environmental problems, most notably air pollution. The other serious problem is the lack of water supply, although Al Jabal Al Khaddar province is known for its high rates of rainfall, the huge neglect of projects to benefit from the rainfall turns it into a waste. The problem of water supply becomes a large part of the problem of resource depletion and adds another exhausting aspect to more energy consumption. Expansion of residential areas with low density leads to the extension of more roads, for long distances, of poor quality or even in violation of specifications, which doubles the problem of depleting more land and the high energy demand.

Conclusion

The proper planning of the city contributes to making it a suitable place to live. In light of the current global conditions, there is a great acceleration in the transformation of cities in developing countries into places that suffer from problems of overcrowding, crowded roads and inefficient and insufficient services. On the other hand, this acceleration in growth affects natural sources and natural resources and causes their depletion and consumption at a rapid rate, which threatens both the current population and future generations.

International calls to adopt sustainability as a way of life to ensure better stability have become a must. Through a simple study of some aspects of the city of Al-Bayda, it was found that several problems affected the standard of living in the city and imply serious indicators of the growing problems associated with the phenomenon of urbanization.

One of the most prominent of these problems is the steady and unplanned increase in the residential area, with the excessive expansion of low density due to the Libyans' conviction of the necessity of housing in separate and independent houses. Then comes the need for access to daily services and facilities such as electricity, water, sewage, roads, schools, shops, clinics, etc. Given the impossibility and difficulty in the ability of the local or even national government to cover all these needs, difficult and complex problems emerge, foremost of which is the destruction of agricultural lands and damage to the natural environment, the depletion of natural resources such as water and the construction of hundreds of kilometers of roads to facilitate access to these newly developed residential areas.

A correct understanding of the concept of compact form with the appropriate density contributes to reducing the negative phenomena that accompany rapid urban growth

so that residential sites can be restricted to specific areas without the need to cut down more trees, raze farms and threaten biodiversity. It is also necessary to address the problems of the city's linear plan, develop the road network according to the appropriate specifications, determine the appropriate functional hierarchy for each type of road, address the problems associated with the illegal use of land and provide parking lots and pedestrian paths.

Sustainability is directly related to taking into account the surrounding ecosystem and protecting the environment and natural resources in a way that ensures their continuity for a sufficient period of time allows future generations to live in safety and does not threaten the extinction of basic life qualifications. Awareness comes first, followed by the application of regulations and laws to prevent infringements and abuses and finally, the role of specialists to develop studies and plans appropriate to requirements and capabilities. Growth or development actually can be called SMART when it takes into account those basics in order, respects the environment, applies the roles to reduce damages and considers serious implications.

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Author's Contributions

Aisha Bakar: Provided the research topic and performed data analysis of the research. Also, participated in written and reviewed the manuscript.

Ashraf Fadiel and Taher Abu-Lebdeh: Provided the research topic and guided the research development, research planed and data analysis. Also, participated in written the manuscript.

Ethics

The authors would to disclose that Dr. Taher Abu-Lebdeh and Ashraf Fadiel (Co-authors) are members of the editorial board for the American journal of engineering and applied sciences.

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