University of Stuttgart
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IMPLAN
INSTITUTO MUNICIPAL DE PLANEACIÓN SALTILLO

Tecnológico de Monterrey

CITY PROFILE SUMMARY REPORT

CITY LAB SALTILLO, MEXICO

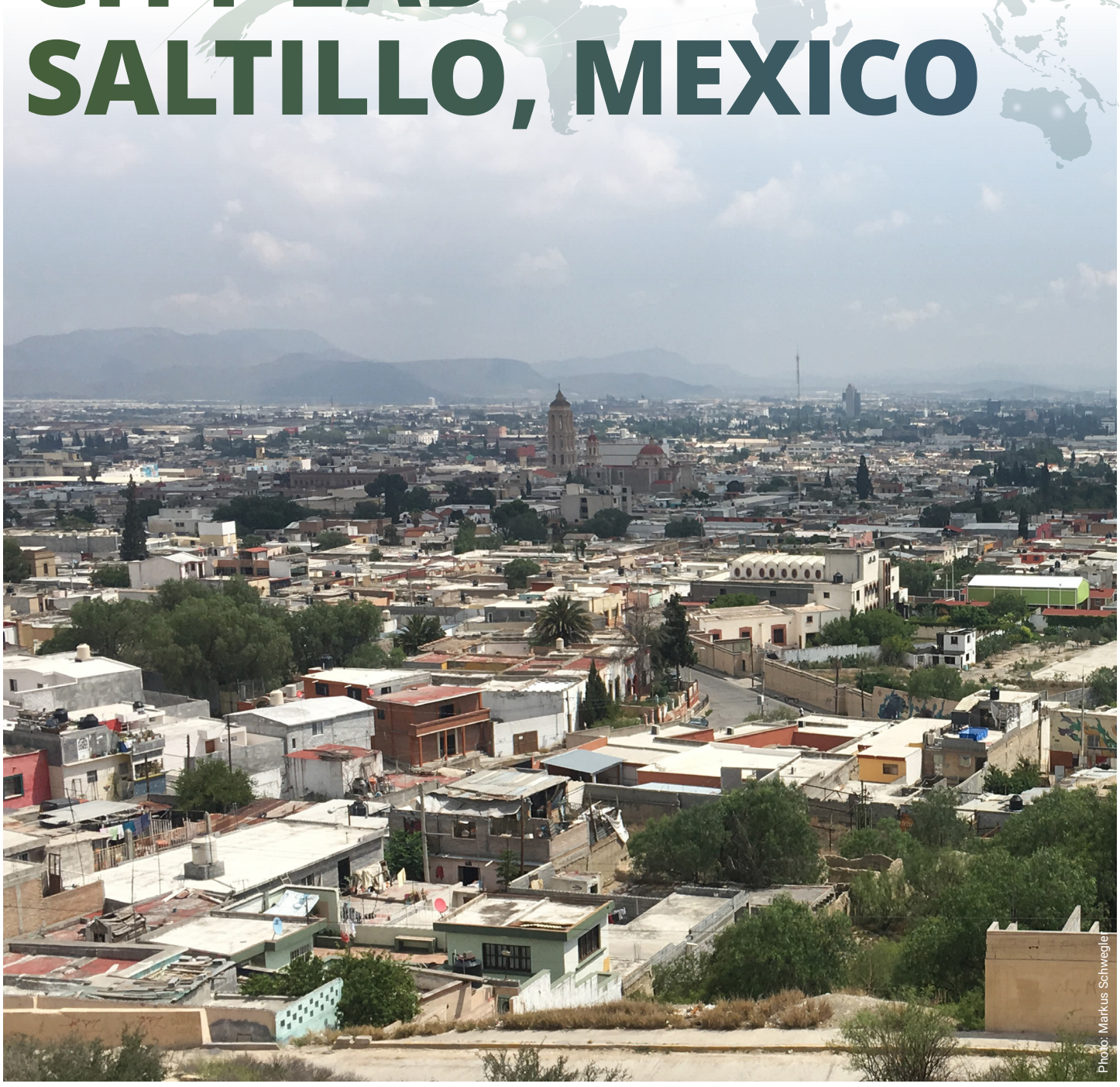


Photo: Markus Schwegler

mgi MORGENSTADT GLOBAL SMART CITIES INITIATIVE
GLOBAL APPROACH – LOCAL SOLUTIONS

MorgenStadt City of the Future

Supported by:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

based on a decision of the German Bundestag

FOREWORD

FOREWORD BY THE MAYOR OF SALTILLO

The city of Saltillo was selected as a City Lab by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the International Climate Initiative (IKI) to design and implement projects that combine technology and social participation to find local solutions to face the global challenges imposed by climate change.

The City Lab project is part of the Morgenstadt Global Smart Cities Initiative and aims at supporting three cities in different countries - Mexico, India, and Peru - to generate viable and replicable projects with the use of technology and knowledge exchange. With international and local experts, the project supports the cities in developing the capacity to promote smart and sustainable urban development.

Three strategic areas of work were defined for Saltillo: water, energy, and mobility, as they are fundamental for the quality of life of the population, for the city´s competitiveness, and as they are priority areas for climate change mitigation and adaptation in the city.

With international cooperation and the work of researchers, public officials, business leaders and citizens concerned about the environment, we were able to concentrate our efforts and work towards the same objective to create a diagnosis of the city and a portfolio of specific projects.
With this work, Saltillo makes progress in fulfilling its Environmental Agenda and contributes from the local level to the accomplishment of the multinational agreements promoted by the United Nations to reduce carbon emissions and promote sustainable development.

MANOLO JIMÉNEZ SALINAS

FOREWORD BY THE DIRECTOR OF SALTILLO MUNICIPAL PLANNING INSTITUTE

Climate change poses a new challenge in planning for development and in finding solutions to the increasingly complex problems that cities face. Local governments are the first instance of contact with the people and, therefore, those who face the commitment to mitigate and prevent the impacts of global warming to preserve the quality of life and well-being of the population.

The link between international cooperation, research, knowledge exchange, management and experience is an essential process in the design and implementation of local projects to guarantee a favourable impact and good results. This is what we hope to achieve with the Morgenstadt Global Smart Cities Initiative, a cooperative effort with the University of Stuttgart and the Fraunhofer Society.

Based on the participation and knowledge of 60 local experts, including researchers, businesses, citizens, and government from national, state, and municipal levels, we jointly identified the challenges that we need to address in Saltillo to turn it into a smart and sustainable city in the water, mobility, and energy sectors. It has been a collaborative and enriching process, guided by a strict participatory methodology and the excellent-quality work of the Fraunhofer Society.

The result of this initiative is just the beginning of a strategic change for Saltillo. This is our commitment.

OSCAR PIMENTEL GONZÁLEZ

1. INTRODUCTION

CITY LAB SALTILLO AND THE MORGENSTADT GLOBAL SMART CITIES INITIATIVE

The *City Lab Saltillo* aims to point the way forward for the city of Saltillo, Coahuila, Mexico, to become a sustainable and resilient city of the future. The United Nations Sustainable Development Goals and the Paris Agreement highlight the urgency for the transformation of cities into climate-neutral and sustainable settlements, while becoming more resilient to the inevitable adverse consequences of climate change. The *City Lab Saltillo* is part of the Morgenstadt Global Smart Cities Initiative (MGI) funded by the German Federal Environment Ministry through the International Climate Initiative (IKI). The aim of the MGI project is to stimulate transformational change in urban systems through an integral and cross-sectoral analysis of the status quo. It identifies potentials to improve the sustainability performance in selected sectors and develops tailored, sustainable and integrated solutions to improve urban infrastructure processes or services. While the City Lab approach has been applied in numerous contexts,[1] the current MGI deals with three cities: Saltillo (Mexico), Kochi (India) and Piura (Peru).

At the heart of the MGI project is the Fraunhofer Morgenstadt Initiative, which has been instrumental in establishing the network of experts leading the City Labs for the three selected cities. The Fraunhofer Morgenstadt Initiative is a network that includes Fraunhofer Institutes, municipalities and companies. Launched in 2011 by the Fraunhofer Institute for Industrial Engineering (IAO), it was established to conceptualize, develop and test innovations for the cities of tomorrow. Recognizing that climate change represents a global challenge that can only be mastered through international cooperation, the MGI's primary objective is to mitigate climate change by reducing greenhouse gas (GHG) emissions within the boundaries of the pilot cities and increasing their resilience to unavoidable climate impacts and risks. Mexico ratified the Paris Agreement on climate change in 2016. In the country's Nationally Determined Contribution (NDC), initially issued in 2015 and reaffirmed in early 2021, Mexico committed to reducing its GHG emissions by 22% compared to business as usual (BAU) as part of its unconditional goals. Cities across the country, characterized by a high population concentration and high economic activity, present unique opportunities to contribute to reaching this target.

The selection of the three MGI cities of Saltillo, Kochi and Piura is no coincidence. It is precisely these mid-size urban settlements in that are experiencing the most rapid growth and will face severe challenges in the future, both in terms of adaptation and mitigation in terms of climate change and sustainable urban development. The MGI aims to support these cities in developing a coherent approach that underpins urban climate resilience and sustainable urban development with innovative policies and efforts to develop cross-sectoral interventions and infrastructures.

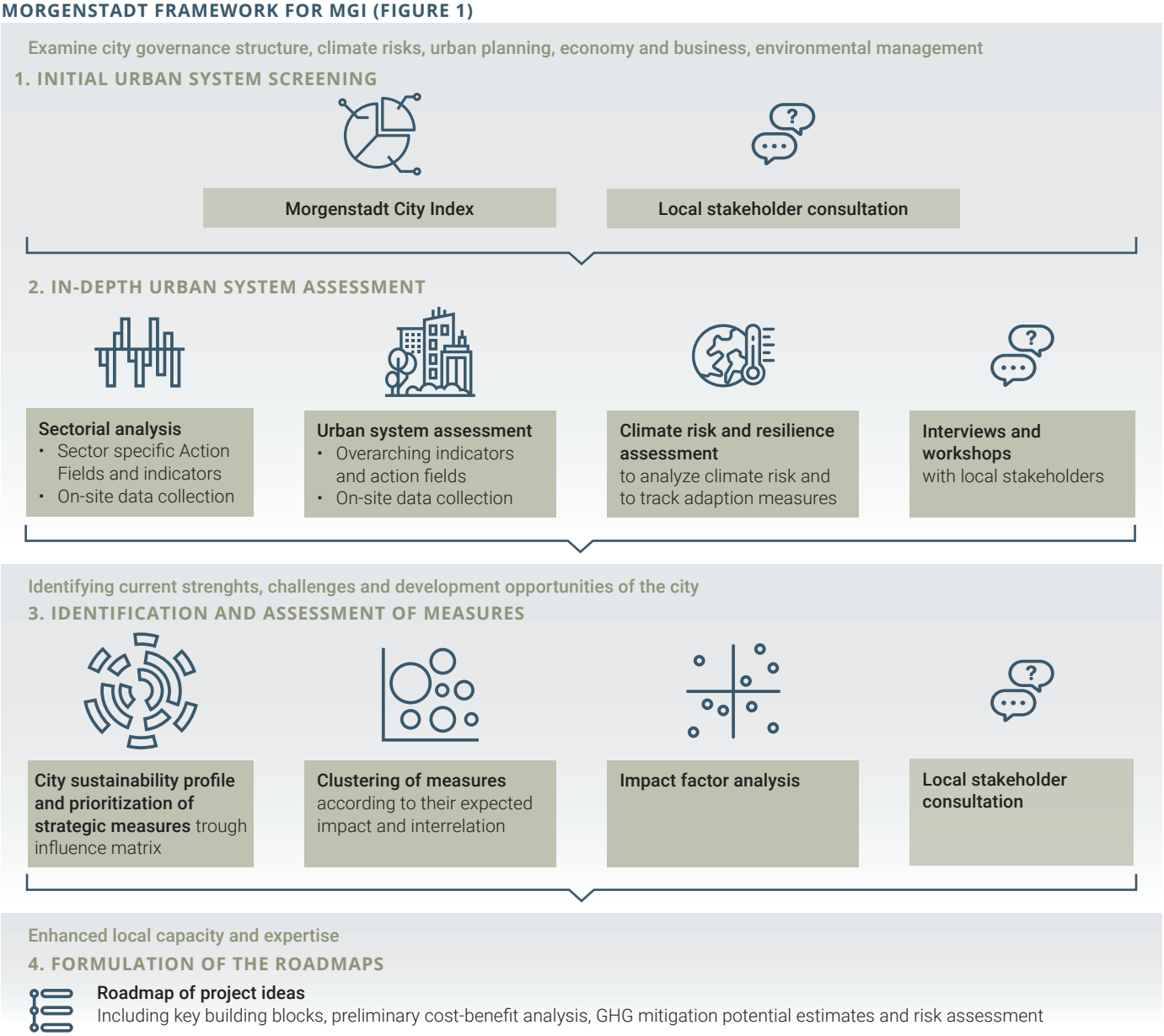
METHODOLOGY

The Morgenstadt City Lab Methodology involves an in-depth analysis of a given city based on performance indicators for assessing the quantifiable sustainability performance, the key action fields necessary for sustainable development and the unique impact factors that operate in each city. In addition to these quantitative elements, expert interviews and workshops with key stakeholders in the public, private and academic sectors are carried out, assuring a high degree of involvement of

1 For more information visit https://www.morgenstadt.de/en/projekte/city_labs.html

local stakeholders and complementing the quantitative analysis. Furthermore, the involvement of local stakeholders in the co-creation of solutions assures tailored rather than generic solutions, while guaranteeing a high degree of local ownership of the proposed measures. The results of each City Lab include an individual sustainability profile report, a detailed analysis of specific sectors (e.g., mobility, urban development, buildings, energy and others), an action-oriented roadmap and the development of innovative measures and projects. Figure 1 illustrates the comprehensive framework used in all three City Labs.

MORGENSTADT FRAMEWORK FOR MGI (FIGURE 1)



ABOUT SALTILLO


Photo: Jesús Cadena Cepeda

The Mexican city of Saltillo has a population of approximately one million inhabitants. Due to its flourishing economy in one of Mexico's most affluent regions, it is characterized by high demographic growth, adding more than 25,000 inhabitants to its metropolitan area every year. Saltillo is the capital of the northeastern state of Coahuila de Zaragoza – a state with above-average economic indicators neighboring Texas, USA, with which it shares a border of more than 500 km. The city is located in the desert of Coahuila, despite of its location it has grown extensively as a sprawling city. It covers an area of 270 km², ranking sixth in Mexico in terms of lowest population density.

Saltillo and the state of Coahuila are among Mexico's most industrialized regions (INEGI 2020). The economic activity of the city of Saltillo is centered on industrial activities, which represent 83% of its total economic activity. Within this sector, the manufacturing industry represents 97.3% of the total activity (INEGI 2020). The city has a high concentration of automotive manufacturing, metallurgical, and machinery and equipment companies. Its metropolitan area is home to over 40 industrial parks[2]. Notably, over 8% of Mexico's automobile manufacturing

2 For the full list visit http://www.setcoahuila.gob.mx/parques1.htm

OVERVIEW OF SALTILLO (FIGURE 2)

POPULATION
Above one million inhabitants and 2.6% growth per year, among the top 10 fastest growing Mexican cities.

GEOGRAPHY
Area of 270 km², ranking sixth in terms of the lowest population density of Mexico.

ECONOMY
Located in Coahuila, among Mexico's wealthiest states, with a per capita income 25% above the national average and a per capita Gross Domestic Product 33% above the national average (Gobierno del Estado de Coahuila de Zaragoza 2021). Firmly based on industrial activities, in particular automobile, machinery and steel products manufacturing. More than 40 industrial parks are located in Saltillos industrial zone

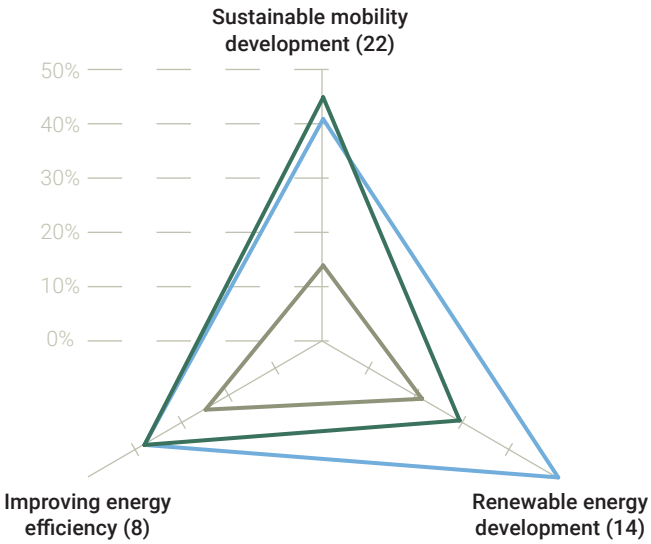
WEATHER
Semi-arid, dry weather with high solar radiation and low precipitation throughout the year. Vast solar potentials above 1,900 kWh/kWp (~22% of the year).

industry and 6% of Mexico's metal industry are located in Coahuila. The region's prosperous economy is reflected in its above-average economic indicators, including a higher per capita GDP and wages and a lower unemployment rate (Gobierno del Estado de Coahuila de Zaragoza 2021).

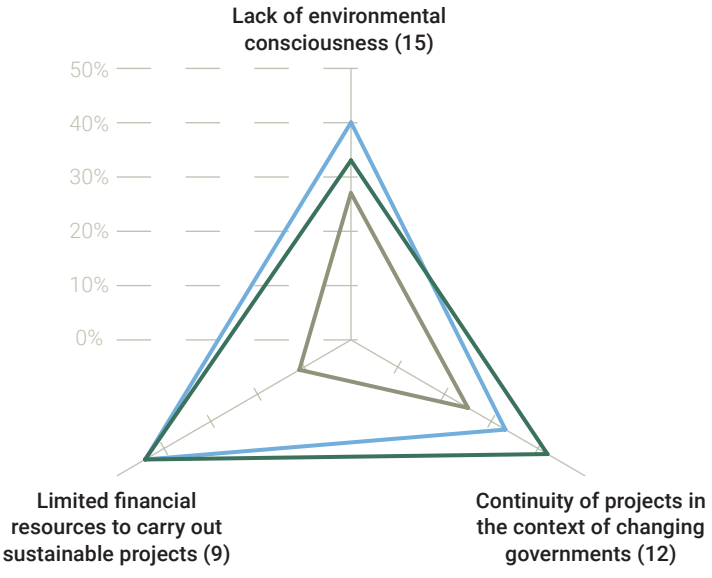
In terms of sustainability, the city has great potential for action. Considering the city's dry weather and already-present water shortages, there is opportunity to improve its resilience against aggravating water

OPPORTUNITIES AND CHALLENGES FOR SUSTAINABLE DEVELOPMENT IN THE METROPOLITAN AREA OF THE CITY OF SALTILLO, COAHUILA. (FIGURE 3)

Opportunities for sustainable development



Challenges for sustainable development



The percentages refer to the proportion of mentions from the public, academic and private sectors against the total number of mentions (in parenthesis). Own representation based on 46 expert interviews with key stakeholders from the public, academic and financial sectors.

Map by Free Vector Maps, http://freevectormaps.com

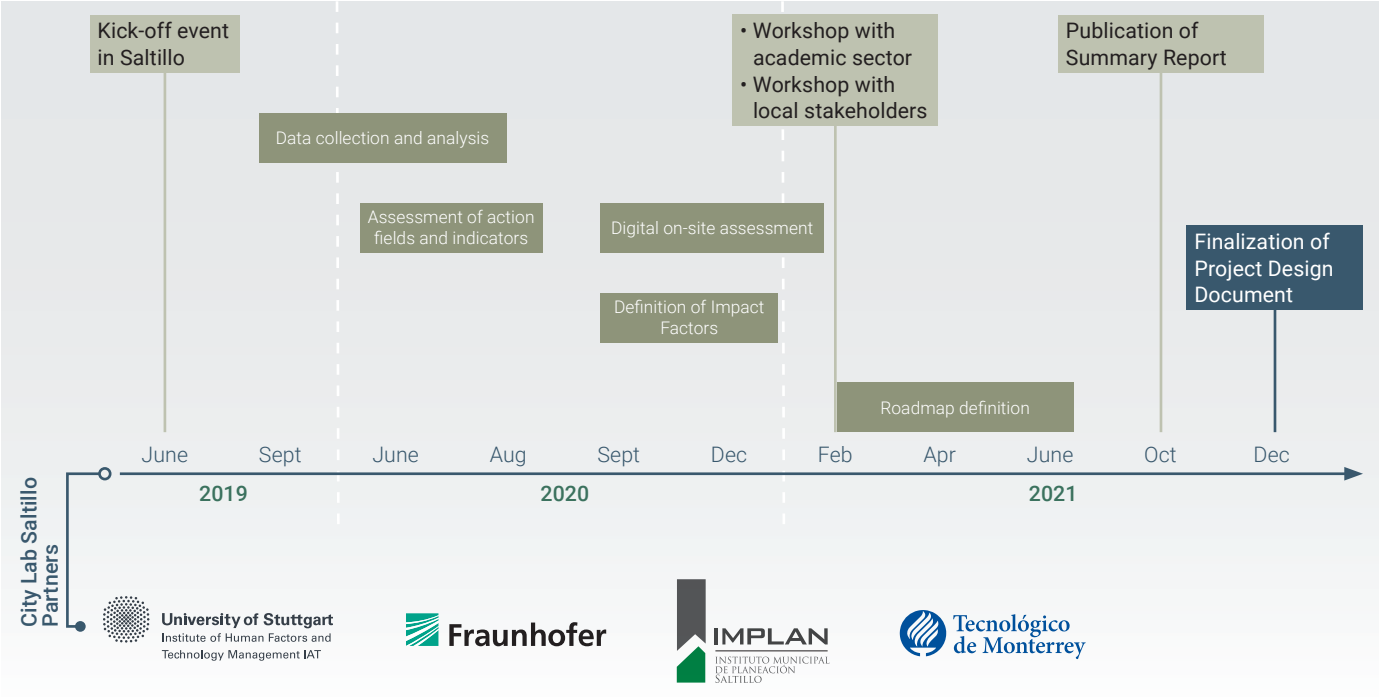
scarcity. Being located in an area with outstanding solar potential (figure 2), the city of Saltillo could harvest solar energy by integrating solar photovoltaics (PV) technologies to cover its energy demand. Being one of Mexico's most industrialized zones, Saltillo has great potential to reduce its GHG emissions in the industrial sector by improving energy efficiency and upscaling renewable energies. Considering the continual urban expansion, Saltillo could improve its sustainable mobility services by both extending its public mobility services, encouraging non-motorized mobility and by integrating mobility and urban planning. These opportunities for sustainable development were a repeated subject of discussion in over 40 interviews conducted with expert local stakeholders in the academic, public and private sectors, and civil society (figure 3, top). Likewise, the interviewees mentioned many salient challenges that impede sustainable development. The most important factors that inhibit transformational change in the long term are a lack of environmental consciousness, limited financial resources and the challenge of implementing long-term incentives in the face of changing governments (figure 3, bottom).

2. CITY LAB SALTILLO

The *City Lab Saltillo* builds on Saltillo's development priorities to support the city's efforts in working towards sustainable and inclusive initiatives. The goal of this City Lab is to help Saltillo become a model for innovative, locally-tailored, climate-smart solutions targeted at increasing its resilience to climate change impacts while preserving the natural resources and stimulating the local economy. The City Lab focuses on three sectors. These were selected after an initial assessment of the city executed under the project's methodology and local stakeholder consultation during the kick-off visit in 2019. The resulting sectors are energy, water, and mobility. In each of these sectors, measures were identified and assessed as a part of the City Lab process. These are discussed in the following chapter.

The timeline of the first phases of the project is shown in figure 4.

CITY LAB SALTILLO TIMELINE (FIGURE 4)



2.1 SUSTAINABILITY PROFILE OF SALTILLO

Based on the results of the analysis with the Morgenstadt methodology, Figure 5 summarises the recommendations for Saltillo with a systemic city perspective. The analysis covers different areas in addition to the three working sectors of the City Lab thus giving a holistic view of the opportunities for Saltillo.

ACTION FIELD ANALYSIS OUTCOMES (FIGURE 5)

Energy
Potential to promote renewable energies, in particular solar PV. Focus on increasing effciency of industry.

Information and Communications Technology (ICT)/ Data Governance
More work needed in intelligent traffic management and effective data management between municipal departments and agencies.

Mobility/Transport
- Improve public mobility services and promote soft mobility modes such as cycling or walking.
- Technological upgrade of public and private mobility (e.g. electric mobility).
- Integrate mobility planning and urban planning.

Regulations and Incentives
- Policies required to integrate green infrastructure and nature-based solutions in urban planning.
- Need for air quality and water management policies.

Research and Development
Potential to create experimental areas within the city for deploying innovative technologies.

Buildings
Incorporate updated standards for new buildings and for refurbishments and assure compliance with exisiting regulations.

Solid Waste and Resources
Focus on the improvement of the waste management collection and disposal infrastructure.

Urban Planning
Incorporate development goals and guidelines for sustainable districts with mixed uses. Integrate mobility and urban planning concepts to promote the vertical and compact growth of the city.

Water
Improve the management of the urban water cycle and urban pollutants in the water system.

Resilience Engineering
Recommended addressing integrated risk management and flood protection strategies. Integrate urban planning with risk management.

Business Tactics
Recommend involving business actors for supporting the sustainability strategy of the city, as well as for engaging the private sector in urban development.

Blue Green Infrastructure
Greening of urban space required to reduce heat stress, improve natural recharge of aquifers, reduce risk of flooding events and offer recreational spaces for citizens.

Municipal Strategy and Planning
- Develop a municipal innovation strategy that addresses resilience and climate change management in planning.
- Pursue long-term political stability through planning and management approaches to ensure continuity despite election periods.
- Incorporate sustainable development into strategic planning documents.

2.2. CLIMATE OBSERVATIONS AND IMPACTS OF CLIMATE CHANGE


Photo: Jose Antonio Ordonez

As a part of the *City Lab Saltillo*, a risk and vulnerability assessment of climate change impacts was carried out, including a literature review, a systematic expert consultation and a survey involving local and City Lab experts.

Heavy Rainfall and Stormwater Flooding

Although precipitation levels in Saltillo are generally low throughout the year, the intensity of cyclones and heavy storms is expected to increase due to climate change (INECC 2019a). Experts perceive the magnitude of individual, rapid precipitation events as a considerable risk to the city. Extreme precipitation episodes cause flooding in urban spaces, often causing structural damage to urban infrastructure. Experts highlighted the fact that flooding has increased due to recent urbanization patterns and the sealing of surfaces. In addition, the construction of new dwellings and building complexes on unauthorized sites and the intensified blocking of creeks with solid waste have also been identified as causes of the obstruction of the natural flow of stormwater (Ríos and Chantaka 2019).

In terms of socio-economic vulnerability, low-income areas and informal settlements are especially at risk. According to the Saltillo Risk Atlas (2015), the city's southern zone has a high susceptibility index to pluvial flooding (ITESM 2015, p. 349). Heavy rainfalls in Saltillo have also historically impacted key urban system operations and services, such as disruptions on the main highways, a lack of electricity supply and interruptions to the solid waste collection system (El Demócrata 2019).

Water Scarcity and Droughts

Saltillo's location in the Coahuila desert makes it an area highly vulnerable to water scarcity and drought. Due to climate change, it is expected that most of Mexico's land will become drier and droughts will increase in intensity and frequency (INECC 2019a). When considering the volume of water extracted for the metropolitan areas and industry in proximity to Saltillo, the water supply for domestic and economic activities comes mainly from aquifers already suffering from overexploitation (CCRB 2019). Despite evident water shortages in Saltillo, the municipal water management organization, *Aguas de Saltillo* (AGSAL), has made a considerable effort to keep the city supplied with water. Saltillo's water supply coverage is high, at 99.60% (Aguas de Saltillo 2018). Although the average water per capita consumption in Mexico is 184.6 liters per day (L/d), users in Saltillo consume around 170 L/d (FCEA 2017).

The main concern raised by multiple experts was the magnitude and irreversibility of water scarcity and drought, considering that recovery would be a challenge in the event of aquifer depletion. Overall, sustainable water management is regarded by the experts as a priority in Saltillo in order

to effectively manage the limited existent water resources.

Temperature Increases and Urban Heat Islands

Due to Saltillo's semi-arid climate and urbanization patterns characterized by the concentration of the population in the downtown area (Saltillo Gobierno Municipal 2019), temperature increases and urban heat islands (UHIs) represent critical risks to the city, which will intensify with climate change. Studies undertaken by Mexico's National Institute of Ecology and Climate Change (INECC 2019b) have determined that between 1985 and 2018 in the state of Coahuila, annual maximum and minimum temperatures have tended to become warmer. A continuation of this trend in the coming years could lead to drier seasons and harmful effects on the environment, such as desiccation, forest fires and crop losses (ITESM 2015).

A significant contributor to the higher temperatures in cities is the UHI effect, where there is a lack of vegetation and surface moisture and extensive paved surfaces in the urban space (Mok et al. 2021). Between the years 2000 and 2018, the population in Saltillo increased in 32% going from 637,273 habitants in 2000 to approximately 935,663 in 2018 (SEDATU et al. 2018).This accelerated urban and population growth (Saltillo Gobierno Municipal, 2019) could be an intensifying factor of the UHI effect when natural ventilation and cooling structures, such as vegetation and water bodies, are blocked in cities. Both the exposure to and vulnerability of Saltillo's population to temperature increases and UHIs were perceived as high among multiple experts, considering the associated risks to human health, including dehydration and loss of comfort in vulnerable groups, such as the elderly and children. Lastly, UHIs generate higher demand in water and electricity (e.g., for cooling and refrigeration devices), which would further increase Saltillo's energy consumption.

Forest Fires

Forest fires occur naturally every year between March and May in Coahuila (Secretaría de Medio Ambiente 2018). State records indicate that 60% of the forest fires are caused by human activities relating to agriculture and recreation in housing complexes in forested areas (Secretaría de Medio Ambiente 2018, p.3). According to Mexico's Secretariat of Environment and Natural Resources (2018), the number of fires and the affected area has increased in the last decade, partly due to more intense and frequent meteorological phenomena (e.g., prolonged droughts and frosts) that have altered environmental conditions, modifying the availability of fuels and creating both more extensive and more intensive risk periods.

The risk of forest fires was perceived by experts as high due to a combination between their magnitude, probability and irreversibility. Experts highlighted the irreversible damage that fires caused in the mountains near Saltillo, especially in the Zapalinamé mountain range, located in the southeast of the state. It was noted that the tremendous damage from forest fires affects the environment as it poses a high risk to biological diversity and causes erosion and the loss of vegetation and fauna. Since the forest fires originate in the areas surrounding Saltillo, the population in the city is not highly exposed to this risk. However, many of the experts noted that the level of exposure is higher in the rural highland areas. In contrast, indirect impacts can be observed in urban areas, including air quality problems caused by pollutants from fire smoke.

Snowfall and Frost

While experts describe the magnitude and probability of snowfall and frost in Saltillo as medium, the southern area of the municipality is classified as a critical risk area due to an average frost season of more than 50 days per year (ITESM 2015, p.147). The

frost season in the northern and central parts of Mexico occurs between November and February. This climatological phenomenon affects mainly crops through the loss of leaves and tender stems, the destruction of the leaves, fruit and flowers and even the complete death of the plant (ITESM 2015, p.147). In addition, damages to crops can impact the region's agriculture sector due to reduced or complete loss of income for producers, unemployment, loss of foreign currency and competitors replacing the local market (INIFAP and SAGARPA 2005, p.1).

Climate variability is a significant uncertainty for the future of agricultural production. Therefore, the study of this phenomenon is of fundamental importance for adopting strategies to mitigate the probability of damaging effects on production (INIFAP and SAGARPA 2005, p.2). In terms of infrastructure, an increased frequency and magnitude of these events could also impact dwellings and their utility systems. Since the hydraulic networks are the most vulnerable due to water pipes damages, it is necessary to adapt these to extreme temperature conditions.

Changes in the Biological System

Because Mexico is an enormously diverse country – home to nearly 10% of the world's recorded species – the consequences of climate change pose high risks to the country's biological diversity and endemic species. The main concern for Saltillo, raised by multiple experts, relates to temperature variations and their negative impact on flora and fauna. An increase in both temperature and severe cold events could result in crop losses or degradation. Changes in biological systems due to climate change also increase competition between native species and invasive species, where the invasive species sometimes displace native species, causing them to disappear. This issue requires special attention, especially in streams, where reeds can cause severe problems.

Experts further stated that the deviation in temperature levels could impact public health by an increase in the spreading of diseases. Saltillo already experiences the occurrence of diseases from non-local species, including mosquitoes transmitting Chikungunya and Zika.

Climate Change Adaptation Measures

In the face of the risks mentioned above, adapting to climate change needs to play a more critical role in urban planning and development. As part of an international partnership, the *Climate Action Plan for Municipalities* (PACMUN) was launched in Mexico in 2011. This program was initiated by ICLEI – Local Governments for Sustainability, receiving technical support from the INECC and financial contributions from the British Embassy in Mexico (Climate Initiatives Platform 2019). Saltillo is currently developing its PACMUN to identify the primary sources of GHG emissions in the municipality and propose courses of action for mitigation and adaptation measures. The research undertaken during the two first phases of the MGI project constitutes a scientific contribution that the Municipality is considering for completing the PACMUN. Because the Urban Development Master Plan of the next administration (2022–2024) is also being drafted in 2021, an opportunity for mainstreaming climate change in planning exists by aligning both documents.

In terms of available financing and funding sources, the Ethos Public Policy Lab (2020), states that although Mexico is a pioneer in climate finance mechanisms, at both the national and subnational level, weak enforcement has jeopardized the Climate Change Fund (FCC). Hence, Saltillo has relied on international cooperation and the possibility of tapping into international funds to implement climate change initiatives. Regarding the availability of climate information, the most used source is the Saltillo Risk Atlas,

developed by the Instituto Tecnológico y de Estudios Superiores de Monterrey in 2014. Even though this document presents an extensive overview, with maps of the principal risks and vulnerabilities, the city requires additional sources of climate information and more up-to-date data. In general, awareness among stakeholders on climate risks and impacts is relatively high as they actively participate in environmental and climate protection activities, such as campaigns for reducing plastic use, reforestation programs and the protection of the Zapalinamé mountain range. In particular, Saltillo Municipal Planning Institute (IMPLAN) works with the Citizen Council of the Environmental Agenda[3] to promote the participation of stakeholders from different sectors (i.e., public, private, academic and civil society) in the design and follow-up of the activities of the Environmental Agenda.

The Climate Finance Landscape

Saltillo has a substantial budget and high liquidity in addition to zero debt commitments. As a result, the city has a positive credit rating by both Fitch Ratings (AAA) and Standard & Poor (mxAA). In the past, Saltillo has implemented several green infrastructure projects, including a water treatment plant, sanitary landfill and public light-emitting diode (LED) lighting, mainly with national funds or with third-party financing. Nevertheless, the city's attempts to participate in international initiatives, such as the Transformative Actions Program (TAP), were unsuccessful, as they lacked a portfolio of projects with financial analyzes and proposals. Therefore, looking towards the future, Saltillo would like to have access to a register of projects that have been assessed in order to seek alternative financing solutions, chiefly third-party financing (e.g., vendor finance) or international grants, without any concessional or commercial debt. Although the city is currently in transition due to an administration change in 2022, it is not expected that this will result in any change to the priorities in terms of green infrastructure. However, an alignment of the new city administration's objectives and the existing and proposed climate action plans and programs are vital in order to ensure the continuity of climate change mitigation, adaptation activities and green financing options.

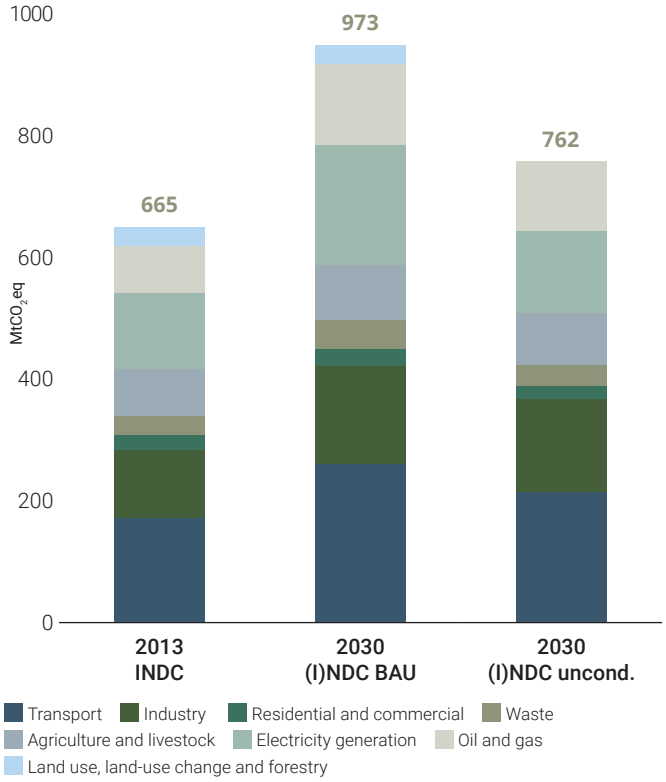
For the full report on the assessment of risk and vulnerability to climate change impacts in Saltillo visit: https://mgi-iki.com/en/library/

3 The Environmental Agenda presents key courses of action started by Mayor Manolo Jimenez in 2019. In this, the city demonstrates its commitment to improve and work on its most critical environmental aspects to mitigate the effects of climate change.

2.3. CO_2 EMISSIONS

Mexico's Nationally Determined Contribution (NDC) was submitted in advance of the 2015 United Nations Framework Convention on Climate Change. This specifies mitigation targets for the reduction in GHG emissions relative to a Business-as-Usual (BAU) scenario. In the BAU scenario, GHG emissions increase by factor of 1.5 from 665 to 973 $MtCO_2eq$ by 2030. The unconditional scenario corresponds to a decrease in GHG emissions of 22% (reaching 762 $MtCO_2eq$) by 2030 (figure 6) compared to the BAU. Transport sector emissions in the unconditional scenario correspond to a decrease in GHG emissions of 18%, industry emissions of 5%, residential and commercial emissions of 18%, and waste emissions of 29%. These sectors typically represent the majority of energy-related emissions of cities. Reductions could serve as a guide for Saltillo to contribute to reaching the national GHG emission targets, as stipulated in Mexico's NDC.

MEXICO'S NDC MITIGATION TARGETS BY SECTOR (ECKSTEIN ET AL. 2020) (FIGURE 6)



Saltillo's total GHG emissions are around 3.7 $MtCO_2eq$. Approximately three-quarters of these emissions come from the two largest energy-consuming sectors: industry and transportation. With an electricity demand of approximately 2,100 GWh and a grid emission factor of 473g CO_2/kWh, electricity generation to supply the city amounts to an additional 994 $MtCO_2eq$. With a population of approximately 1 million inhabitants, this translates to 3.7 tons of CO_2 per person per year, excluding electricity emissions, or 4.7 tons of CO_2 per person including electricity emissions. While this value is rather on the middle range of the scale in an international comparison, limiting global warming beyond 2°C above pre-industrial levels and thereby complying with the goals of the Paris Agreement will require a carbon neutral global economy by the second half of the century (Rogelj et al. 2018). Because the industrial and transportation sectors are overrepresented in Saltillo compared to the national average, Saltillo can and should drive transformation away from fossil fuels. In the mobility sector in particular, this could include the provision of a non-motorized transportation infrastructure and the adoption of transport-oriented urban development planning. While energy and industrial policy are largely the domain of the national level, the city could also foster the reduction of GHG emissions via indirect measures. The energy sector analysis of this report, and the list of project ideas developed, present different measures that have potential to achieve significant emission reductions in Saltillo and beyond.

2.4. SECTORIAL ANALYSIS

The *City Lab Saltillo* focuses on the sectors of energy, water, and mobility. These sectors were selected based on critical urban development challenges identified in consultation with local stakeholders. A general overview of the three sectors and the sectoral sustainability vision that was developed, together with the main challenges and solutions, are discussed in the following subchapters.

2.4.1. Energy

Saltillo could improve its sustainability in the energy sector by significantly improving its energy efficiency performance and by becoming self-sufficient in electricity provision by exploiting the unique, vast solar radiation potential associated with its location. Cooperating with its heavy industries, raising awareness and incorporating its numerous universities as solution providers, are parts of the solution to the challenges identified to improve sustainability and energy efficiency and the use of renewable energies (figure 7).

With approximately one million inhabitants and located in a highly industrial area, Saltillo's final energy demand is strongly driven by its industrial and transportation sector and to a lesser extent by its residential sector.

This can be seen when looking at the distribution of its electricity consumption. Saltillo's total yearly electricity consumption is about 2,100 GWh (CFE 2021). About 35% of this total electricity consumption is assigned to "industry" tariffs, 45% to "general" tariffs, which include both industry and businesses, 17% to the residential sector, 2% to the agricultural sector and 1% to the public sector. Hence, 80% of total electricity use is attributed to the industry and business sectors. The distribution within the industrial sector is also very uneven. There are only fourteen very large industrial users in Saltillo, who account for 35% of the city's total electricity use, or an average consumption of 52 GWh per year per user. To put this in perspective, this is about 40,000 times the average electricity use of a household in Saltillo – Saltillo's 250,000 households consume an average of only 1,400 kWh per year.

In terms of total energy demand, providing a reliable picture of the city's energy balance remains a challenge, as energy data is not collected and published systematically at the subnational level. Nevertheless, we can provide estimates for the total energy consumption of Saltillo's most relevant energy-consuming sectors. For the transportation sector, we estimate a total yearly demand of approximately 5,500 GWh (or 20 PJ). Of this, cars represent 35%, taxis 32%, sport utility vehicles 17%, pickups 10% and public buses 5% of the total energy consumption. To derive these numbers, data from the remote sensor study was used. The study was recently conducted in Saltillo's metropolitan area to calculate the number of vehicles in circulation (INECC 2019), and their fuel intensities.

VISION, CHALLENGES AND SOLUTIONS IN THE ENERGY SECTOR (FIGURE 7)

VISION

WORLD-LEADING INDUSTRY AND BUSINESS IN ENERGY EFFICIENCY, SOLAR ELECTRICITY SELF-SUFFICIENCY BY TAKING ADVANTAGE OF UNIQUE SOLAR POTENTIAL

CHALLENGES
- Improve energy efficiency
- Use renewable electricity
- Promote public mobility
- Promote electric mobility

SOLUTIONS
- World leaders in sustainable industrial parks, harvesting potentials in energy efficiency and photovoltaic self-supply
- Awareness events
- Universities as solution providers
- Streetcars to industrial parks, electric busses

It should also be noted that all the vehicles (99%) are gasoline vehicles because freight transport occurs mainly outside the city and is thus largely omitted in these estimates. In addition to the transport sector, the industrial sector is one of the largest energy-consuming sectors in Saltillo. A total yearly energy demand of approximately 5,700 GWh was calculated, which is slightly higher than the transport sector, excluding freight transport. This figure for the industry is derived from value added data from the National Institute of Statistics, Geography and Informatics (INEGI) and industry-specific energy intensities and fuel-use breakdowns for Mexico (Ordoñez et al. 2016). For the residential sector, we estimated a yearly consumption of approximately 1,000 GWh, based on the reported electricity consumption of 350 GWh (CFE 2021) and the fact that electricity accounts for about one-third of the total residential consumption in Mexican households (Enerdata 2021).

In terms of supply, Saltillo's electricity and oil and gas products are, for the most, supplied by the Comision Reguladora de Electricidad (CFE), Mexico's state-owned electricity utility and the Petroleos Méxicanos (PEMEX), Mexico's state-owned oil company. These companies represent the backbone of Mexico's energy sector. The CFE produces more than half the electricity requirements of the country, owns over 60% of the generation capacity and, until recently, was the sole retail supplier in the country (International Energy Agency 2017). Similarly, PEMEX and its subsidiaries domestically produce and supply a considerable fraction of Mexico's total oil requirements, with the production of approximately 1.65 million barrels per day, contrasting with Mexico's requirements of approximately 2 million barrels per day. Saltillo's electricity is provided by Mexico's national grid, which is primarily based on electricity from fossil fuels – mostly natural gas (60%), followed by oil (10%) and coal (9%). Low carbon, clean electricity sources make up the remainder, with hydroelectric electricity at 7%, wind at 5%, nuclear at 3% and geothermal and solar at 2% each. In terms of the large share of gas in the grid, the CO_2 emissions factor for grid electricity amounts to 473 grams of CO_2 per kWh.

Mexico's energy sector is still governed at the national level, with the federal states and municipalities having no jurisdiction over energy-related matters. In 2013, Mexico launched a major energy reform aiming to restructure its energy sector away from the monopolistic state-owned enterprises, the CFE and PEMEX, to a more liberalized market open to private actors. In the power sector, although independent power producers were already permitted to operate under power purchase agreements and captive generation was allowed for industrial consumers, the energy reform unbundled the CFE into separate companies, strengthening further access for the private actors. In this newly liberalized electricity market, two rounds of

energy auctions were held in 2016 and 2017, allowing private sector participants to bid for long-term contracts for the generation and distribution of electricity in the market (Wood 2018). The auctions had record low outcomes. In particular, Mexico's 2017 auction had average prices of 2 US cents per kWh and the lowest bids broke world records. In fact, Mexico ranks globally among the top nations in terms of solar radiation and practical solar PV potential, making this technology particularly affordable if financing conditions are good (Timilsina 2020). Coahuila and Saltillo are among Mexico's best locations in terms of solar radiation, meaning the potential for solar PV electricity generation is exceptional (Global Solar Atlas 2021, Marcel et al. 2020). However, the development of renewable energies is currently on hold, as President Andres Manuel Lopez Obrador and his administration have taken a critical view of the energy reforms (Eckstein et al. 2020b). The Lopez Obrador administration has put much effort into rolling back energy reforms and private sector participation, based on the belief that state-owned enterprises should be the agents of development (Gastelum et al. in preparation). This has created a highly adverse climate for renewable energy development, as the CFE has been instrumentalized to use gas and oil products from the financially struggling PEMEX (Mexico News Daily 2020).

The state of Coahuila has significant energy endowments, in terms of both renewable and non-renewable energy sources. In addition to its exceptional solar

SELECTED INDICATORS IN THE ENERGY SECTOR (TABLE 1)

INDICATOR	VALUE FOR SALTILLO	CHALLENGES AND SOLUTIONS
Total energy use per capita	**>12,000 kWh** PER PERSON PER YEAR	The high per person energy consumption reflects the high energy demand of the city due to its numerous industrial parks and high transportation-energy demand. Implementing energy-efficient measures in the industrial sector together with the measures proposed in the mobility section of this report could substantially lower this value, reducing GHG emissions and at the same time also reducing costs and improving competitiveness for Saltillo's economy and the wellbeing of its citizens.
Share of renewable energies in the power mix	**< 20%** GRID ELECTRICITY **< 0.1%** SELF-SUPPLY	Although the city uses the municipal landfill for electricity generation, this currently only generates between 0.1% and 0.5% of the total electricity consumed in Saltillo. Located in a leading global area for solar potential, Saltillo could aim for a double-digit proportion of renewable energy self-supply in the following decades, in particular solar PV.
CO_2 emissions per capita	**3.7 TONS OF CO_2** PER PERSON PER YEAR EXCLUDING ELECTRICITY EMISSIONS, OR 4.7 TONS INCLUDING ELECTRICITY	Although this value is relatively low in an international context, complying with the goals of the Paris Agreement will require lowering this value to net zero by the second half of the century. This implies a shift away from fossil fuels towards renewable energies, most notably in the industrial, transportation and electricity generation sector.

PV resource, the area also boasts vast wind energy potential (Global Wind Atlas 2021) and around 45% of the total shale gas of Mexico is within the Sabinas, Burro and Picachos basins in the north and center of Coahuila. It is estimated that these basins have 14 million barrels of equivalent crude oil (Energy Cluster Coahuila 2018). Furthermore, Coahuila state is the highest producer of coal in Mexico, with more than 90% of the coal reserves, having two (Río Escondido and Carbón II) of Mexico's three coal-fired power plants.

In the energy sector, Saltillo has taken the first steps to improve its sustainability performance. Since 2013, the methane produced in Saltillo's landfill has been used for electricity generation. Since its operation it has generated between 2 and 9 GWh annually. However, this represents only a small fraction (0.1–0.5%) of Saltillo's final electricity demand (see also Table 1). Similarly, since 2019, Saltillo has implemented several programs to improve energy efficiency. In particular, is has improved the energy efficiency of public lighting by replacing low-efficiency lighting with LEDs, leading to savings of about 0.5 GWh per year. Similarly, it has implemented an energy-savings program in offices, aiming to reduce the annual electricity demand that public buildings consume substaintally.

Considering both the vast potential for solar radiation (figure 2), as well as the very high energy consumption in the industrial and transportation sector, Saltillo could substantially reduce its energy use and GHG emission profile by significantly improving energy efficiency in these sectors, while expanding the self-production of renewable electricity, most importantly solarPV. Table 1 presents three selected indicators and challenges and solutions as part of the energy sector analysis.

2.4.2. Water

In the water sector, Saltillo could improve its sustainability by integrating blue and green infrastructure into urban spaces, thereby enhancing soil permeability, improving the recharging of the already overused aquifers and preventing flooding events by achieving a sponge city effect. Water shortages and a lack of adequate pluvial drainage systems are identified as the main challenges. They can be tackled by combining two measures. On the one hand, providing grey infrastructure and nature-based solutions, and on the other, improving the water efficiency of its users (figure 8).

Water is one of the essential resources linked to social and economic development. Due to Saltillo's geographical location in the Coahuila Desert, water scarcity is a real threat, and climate change-induced effects, such as extended droughts and flooding events, are expected to increase in intensity and frequency. Over the past decades, water has played a vital role in the urban and economic development of Saltillo. Thus, sustainable water management is regarded as a high-level priority by the city's administration, as can be seen in their Environmental Agenda.

The water for the city is sourced from groundwater from the Rio-Bravo-Conchos basin. Three aquifers

VISION, CHALLENGES AND SOLUTIONS IN THE WATER SECTOR (FIGURE 8)

VISION

SPONGE CITY WITH GREEN AND BLUE INFRASTRUCTURE INTEGRATED INTO THE URBAN FABRIC AND EXCELLENT WATER EFFICIENCY

CHALLENGES
- Absolute water shortage
- Dependence on overexploited aquifiers
- Flooding and lack of rainwater drainage
- Rivers in bad condition

SOLUTIONS
- Water resource master plan
- Reduce overexploitation of aquifiers
- Restoration of surface water bodies
- Urban green space strategy
- Sustainable buildings with green roofs
- Promotion of wastewater reuse for irrigation and industrial uses

serve the water demands of Saltillo's domestic and economic activities. The total annual recharge requirement of these aquifers is estimated at around 103.1 hm³. Based on this estimation, the annual water availability for Saltillo would be around 119.3 m³/cap when considering a population of 860,000, while the Falkenmark Indicator considers any value below 500 m³/cap as absolute water scarcity (Global Water Forum 2012). In addition, according to the national water authority, when considering the total water extraction of the aquifers, including other municipalities, the aquifers suffer an added overexploitation of 109.5 hm³/a, thus posing a significant threat to water security in Saltillo (CONAGUA 2020a).

In 2001, the responsibility for municipal water management was transferred to the private-public partnership Aguas de Saltillo (AGSAL), which has made noticeable efforts to improve the city's hydraulic system. Water supply to the city is around 146 million L/day (MLD), extracted from 90 wells and treated through 6 chlorination plants distributed around the city before reaching the final users, thus making it safe for drinking. While the average per capita water consumption in Mexico is 184.6 L/day, users in Saltillo consume around 170 L/day (FCEA 2017).

The National Water Commission (CONAGUA) has implemented control measures for the depletion of aquifers, limiting daily water supply for Saltillo in 2019 to 18 hours per day (Saltillo Gobierno Municipal 2018a). This non-continuous water supply is compensated for at the household level by storing water in tanks called *"Tinacos,"* usually located on the rooftops. Thanks to the treatment applied to water before supplying it to users, more than 99% of samples comply with the national standards for potable water (e.g., residual chlorine values).

Furthermore, over 97% of households in Saltillo are connected to the sewer network and a wastewater treatment plant (WWTP). However, only 12% (7% of the total extracted water) is currently reused for industrial and urban purposes. This demonstrates the enormous potential for developing the capacity for water reuse in Saltillo (Saltillo Gobierno Municipal 2020).

The responsibility for rainwater management lies entirely with the municipality and not AGSAL. There are no records of the percentage of households or businesses that collect rainwater. According to the stakeholders interviewed, rainwater, as an alternative water source in Saltillo, is neither economically nor technically attractive due to the low average annual rainfall of around 370 mm that falls over a short period of time (CONAGUA 2020c). Furthermore, the existing pluvial drainage system and the combined sewer system have repeatedly proved incapable of preventing flooding

events. This type of natural disaster is expected to become more frequent in the upcoming years due to climate change. Thus, the risk of flooding has been identified as one of the main challenges faced by Saltillo in the framework of the City Lab project.

In the last century, sanitation projects in the city were limited to building wastewater collectors and drainage systems. It was not until 2006–2008 that, in compliance with the norms set by the Secretariat of Environment and Natural Resources (SEMARNAT), Saltillo built two public WWTPs, which add up to a total treatment capacity of 1,270 L/s (this figure increases to 1,568 L/s when the seven private plants in the metropolitan area are included). However, it should be noted that none of the WWTPs are operating at total capacity. Rather, their operation in 2019 was in the range of 65–80% capacity (Aguilera et al. 2013).

As previously mentioned, the most critical risks that Saltillo faces in terms of water are absolute water scarcity (< 500 m³/cap/year) and, at the same time, flooding events. However, authorities in Saltillo are showing a clear commitment to addressing these risks by building Saltillo's resilience capacity to climate change to reduce the occurrence of significant negative consequences.

Potential measures for contributing to the city's transformation include implementing nature-based solu-

SELECTED INDICATORS IN THE WATER SECTOR (TABLE 2)

INDICATOR	VALUE FOR SALTILLO	CHALLENGES AND SOLUTIONS
Water sustainability (CCRB 2019)	**–16,100,000.00 m³/YEAR**	Although this value could be considered relatively low in an international (and even national) context, this value should always be ≥ 0 for sustainable resource management. This implies that the extracted water for economic activities should not be higher than the water resources infiltrating the exploited aquifers.
Water security (CONAGUA 2020a, 2020c, 2020b)	**1,119.32 m³/CAP/YEAR**	This value falls within the category of absolute water scarcity according to the Falkenmark Index. Therefore, in the medium to long term, Saltillo could aim for the category of water stress (500–1,000 m3/cap/year), and, in the long term, it could aim to reach or even surpass the water stress category (1,000–1,700 m³/cap/year). However, a limiting factor is undoubtedly annual rainfall in the region.
Water Metering (AGSAL 2020)	**100%**	The interviews revealed a comprehensive coverage of water meters in the water supply area of Aguas de Saltillo. Water at the point of consumption is accounted for and billed, providing a solid base to reducce water wastage a losses. The collected data can be used as further input to quickly identify leakages in the supply network and develop strategic measures.
Percentage of reused treated wastewater (Saltillo Gobierno Municipal 2020)	**7%**	This indicator describes Saltillo's opportunity for developing its capacity to use alternative water resources. By increasing the reuse of treated water, the pressure on the aquifers can be decreased.

tions. For instance, suitable green infrastructure around the city in the form of rain gardens, green rooftops, vegetated median strips or pedestrian walkways, among others, considering the climatic conditions of Saltillo. Alternatively, a combination of grey infrastructure and nature-based solutions could be implemented, strategically located in infiltration zones. Significantly, this type of measure focuses on increasing aquifer recharge and flood prevention and has the advantage of requiring less space than solely green infrastructure. Finally, in terms of water scarcity, the discussion is centered on how to increase the percentage of rainwater that permeates the soil so that a significant volume reaches the groundwater reservoirs. One way of achieving this is by decreasing the impermeable surface area, namely street asphalt or impermeable rooftops, and changing it to permeable surfaces, such as porous gravel or gardens, respectively.

Another approach for increasing water availability is to decrease the volume of water extracted from the aquifers. This can be done by preferably using alternative water resources, such as rainwater or treated water. In the case of Saltillo, the reuse of treated wastewater has enormous potential considering the already existing infrastructure of the Línea Morada[4].

To build resilience capacity against flooding risks, nature-based solutions represent an interesting and sustainable alternative to grey infrastructure by intercepting the surface runoff and acting as a temporary storage, referred to as the sponge city effect. This sponge effect would allow the partial infiltration of water into the aquifers and would discharge the reduced runoff at a constant flow into the drainage system.

In addition to the abovementioned actions for adapting to climate change, it is recommended that the city increases environmental awareness and education and builds synergies between experts from academic institutions and the public and private sectors. The reuse of treated water in both industry and the residential areas as well as taking advantage of the natural and urban environment to implement green infrastructure are also recommended.

2.4.3. Mobility

Photo: Gobierno Municipal de Saltillo

Saltillo could improve sustainability in the mobility sector by improving public mobility and promoting non-motorized mobility with the corresponding infrastructure, such as pedestrian zones and bicycle lanes. Adopting a transport-oriented urban planning approach is pivotal in designing the city, so that everything is in easy reach without the need for long travel times. Reducing individual mobility and shifting towards cleaner transportation technologies are identified as the main challenges for the mobility sector. Unlike the energy sector, where jurisdiction takes place to a large extent at the national level, the city has juris-

4 Línea Morada (or Purple Line in English) is the name of the project that began in 2011 with the main objective of transporting treated wastewater from the main WWTP to the industrial parks located to the north in the municipality of Ramos Arizpe. Once the second stage is completed, the Purple Line is expected to enable the reuse of up to 450 L/s of treated water for industrial use, which would reduce the current overexploitation of local aquifers.

diction to tackle the challenges of the mobility sector, which is one of the most relevant sectors in terms of its potential for reducing energy consumption, GHG emissions and local pollution (figure 9).

In the City of Saltillo, as in many other Mexican cities, the city's expansion combined with a gradually increasing population has meant a decrease in urban density with a particularly negative effect on mobility, public finances and sustainability. Expansion in the peripheral overvalued areas with a simultaneous shortage of services contrasts with a reduction in residential activity in the central areas. The latter are provided provided with basic facilities and services, and over time, become less populated and devalued, resulting in a cycle of deterioration in the urban centers. Because Saltillo is a sparsely populated city, some of the sustainable mobility facilities, e.g., for walking or cycling, have not been continually maintained. In addition, public transportation systems where demand is highest are difficult to implement. For this reason, citizens choose to travel by car or other motorized vehicles (IMPLAN 2018a). This has thus led to a vicious circle in which the expansion of peripheral urban infrastructure stimulates urban growth in this area. This situation has increased the dependency on individual mobility, requiring the development of additional infrastructure.

Evidence for this is that the main areas of origin of the routes are found at the perimeter of the center of the municipality, where the highest housing density areas are concentrated (IMPLAN 2016a). The Saltillo Metropolitan Area (SMA) is one of norther Mexico's areas of industrial concentration and one of Mexico's fastest-growing economic areas in recent decades. In this sense, its dynamic economic activity has driven its urban expansion and transport infrastructure.

According to the findings from the interviews, there has been progress in alternative means of transport.

VISION, CHALLENGES AND SOLUTIONS IN THE MOBILITY SECTOR (FIGURE 9)

VISION

EXCELLENT PUBLIC MOBILITY, USE OF NON-MOTORIZED TRANSPORTATION, A CITY WHERE EVERYTHING IS ALWAYS WITHIN FIFTEEN MINUTES' REACH

CHALLENGES

- Reduce individual mobility
  - Public mobility and intermodality
  - Non-motorized mobility
- Transport-oriented urban development
- Vehicle verification

SOLUTIONS

- Comprehensive Mobility Master Plan
- Pedestrian areas (e.g. historic center)
- Mobility as a (public) service
- Technological updating of public transports
- Vehicle verification program
- Strategic Alliances: business, government, academia

However, achieving this is still very complex considering that there is still significant resistance due to the widespread belief, in a large sector of society, that the car represents superior social status. In addition to this, other reasons why citizens do not consider public transport a viable option include deplorable public transport service with units in poor condition, inefficient routes and the fact that public transport is not multimodal. In contrast, the cycling infrastructure covers a considerable part of the city, representing a significant area for improvement to promote non-motorized mobility. However, this requires maintenance and mobility educational programs to ensure cyclist safety on the roads.

The city is more dispersed due to the existence of void urban land set aside by speculators, who leave the land idle while waiting for price increases until it is considered a profitable investment. As a conse-

quence, new developments are often located far from the city center. Furthermore, there is no policy or regulatory incentive to promote mixed land use that could support the development and revitalization of the downtown area or promote sustainable transport.

The SMA has 2,987 km of roads[5] within its 14,009 km² (INEGI, CONAPO, SEDESOL 2010), which means 21 km of roads per 100 km² and a road density of 411.9 km per 100,000 inhabitants (IMPLAN 2015a). Paved roads service 68.5% of Saltillo's city blocks. Full access to paved roads is mainly concentrated in the center of the municipality. In contrast, only partial access to paved roads is widespread on the city's perimeter, concentrated mainly in the southwest and northeast of the city.

In the municipality of Saltillo, the greatest degree of sidewalk accessibility is concentrated in the city center and those areas with the highest density of housing. The lowest levels of sidewalk infrastructure are found on the periphery of the municipality. Improving the safety of sidewalks for pedestrians was repeatedly mentioned during the interviews, as the existing sidewalks are in poor condition.

In terms of pedestrian streets and alleys, Saltillo is underdeveloped, with 6.54 km throughout the city, representing 0.90 km per 100,000 inhabitants (IMPLAN 2015a). Therefore, urban planning that encourages the development of pedestrian streets and alleys is recommended. Currently, this type of infrastructure exists mainly in the west and in the city center and is linked to the commercial city blocks in Saltillo.

Bicycles represent less than 1% of the city's modal share, despite the efforts of the city and infrastructure built for this purpose. Furthermore, bicycle user numbers have decreased in recent years, with a 60% reduction between 2014 and 2017 (IMPLAN 2018a). According to a survey conducted in Saltillo in 2018, the main motivations for bicycle use are health and leisure. The survey revealed that the people in Saltillo mainly cycle to school and work, and trips are mainly made to the north and the city center. Despite the unfavorable assessment of Saltillo's cycling infrastructure by its users, there is willingness among interviewees to switch from using cars or other means of transport to cycling if optimal street conditions in terms of infrastructure quality and safety exist.

Public transport in the SMA is covered by 54 routes operated by 894 buses that travel an average of 238,000 km daily. Most routes converge in the city center, resulting in traffic problems for the service. For instance, in some cases, up to 20 routes cover the same road. In addition to this, low speeds, at an average of 16 km/h, are also problematic (IMPLAN 2015a). In terms of distance travelled each day in the city, it is estimated that most trips (34%) are between four and seven kilometers (IMPLAN 2015a).

The motorization rate in Saltillo in 2014 was 314 vehicles per 1,000 inhabitants. In 15 years, the vehicle fleet increased by 150,000 cars. Car purchases are concentrated in higher-income segments; however, due to easy access to credit and longer life cycles of vehicles, car purchases in low-income sectors have increased (IMPLAN 2016b). In Saltillo, car use is still more efficient than public transport in terms of trip duration and the challenges mentioned above. The average travel time by car is 25.6 minutes, while the average travel time by public transport is 39.52 minutes (IMPLAN 2015a). A wide range of stakeholders are involved in the supervision and operation of public transport in the municipality of Saltillo, which makes it difficult for the city to work on a comprehensive public

5 Measured using the length of the central axis.

transport system. Local public organizations, such as the municipal government, institutions at the state level and citizens organizations, all play a role. Other key stakeholders include the public transport concessionaires who provide the service. In terms of regulations, different instruments address different aspects, such as the conditions and principles of quality, infrastructure characteristics, subsidies and accessibility.

Potential measures for contributing to the city's transformation include expanding and intensifying cycling infrastructure and restructuring the public transport system, including network, infrastructure and payment models. Furthermore, for Saltillo's historic center, transport and urban planning interventions and strategies enhancing consolidation, revitalization and densification, supported by mixed land use, are crucial areas of scope.

During the local stakeholder consultations, a main area of opportunity was identified in the generation of participatory democratic mechanisms so that citizens could influence budget allocation, especially in terms of infrastructure projects in the city. Furthermore, integrating social variables in the design of urban development plans was considered fundamental when designing a more inclusive and socially sustainable city.

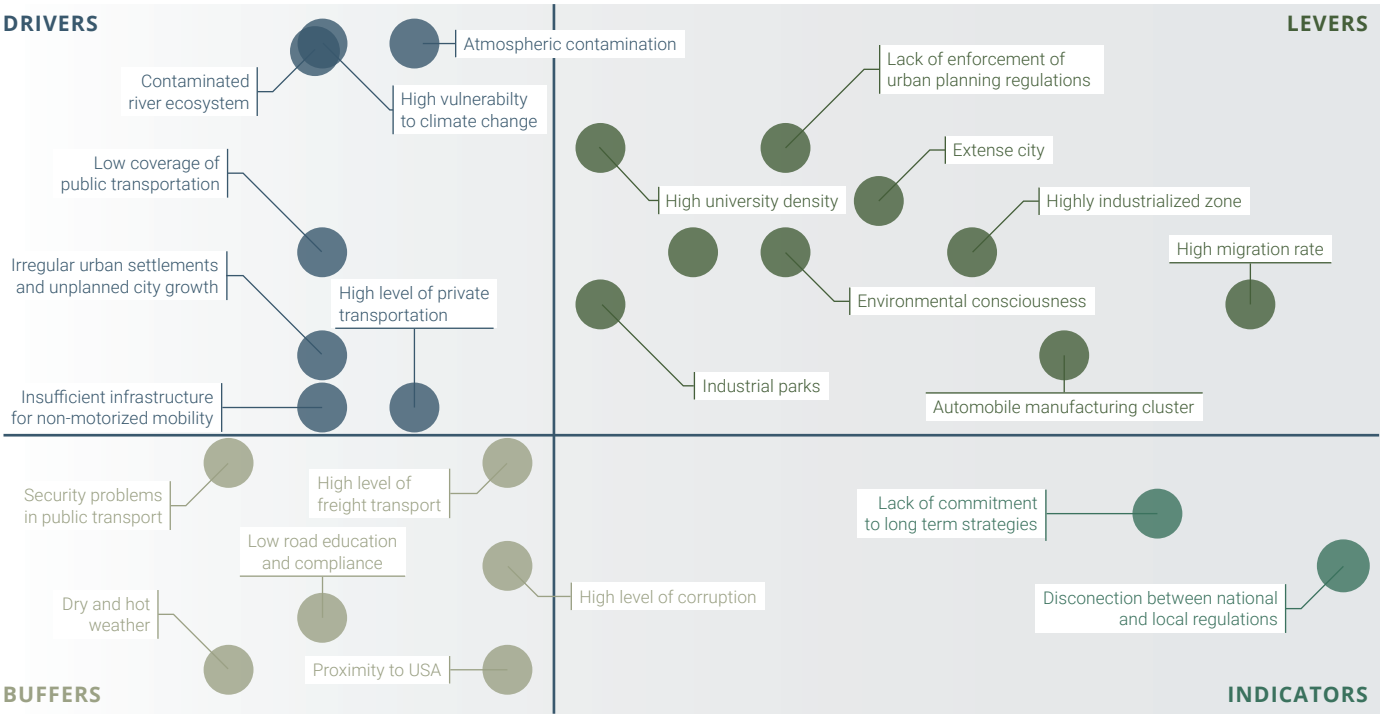
Other potential areas of work include updating the technology of public transport units, e.g., electric vehicles rather than diesel. In addtions to this, the following measures should be promoted: industry's preparation for the transition to creating auto parts for electric vehicles, promoting circular economy projects in the industrial sector and promoting the implementation of pedestrian areas and climate-friendly mobility means.

SELECTED INDICATORS IN THE MOBILITY SECTOR (TABLE 3)

INDICATOR	VALUE FOR SALTILLO	CHALLENGES AND SOLUTIONS
Road density (IMPLAN 2015)	**411.9 km PER 100,000 INHABITANTS; 21 km PER 100 km²**	While OECD countries have, on average, three times the road density (1,454 km per 100,000 inhabitants), with a coverage of 122 km per 100 km², Saltillo, has a considerably better road coverage compared to other Latin American countries, such as Bolivia, Brazil, Paraguay and Peru, which have 368 km per 100,000 inhabitants and a road density of 11 km per 100 km² (OECD 2014).
Annual growth rate of total private vehicles (IMPLAN 2015)	**3.78%**	This rate shows that the private vehicle fleet in Saltillo is increasing. Travelling by car is still more efficient than travelling by public transport in terms of trip duration, comfort, reliability and safety. This is further enhanced by the improved social status that owning a car has.
Percentage of traffic light intersections with total pedestrian crossings in relation to total traffic light intersections (IMPLAN 2015)	**5%**	This value indicates how well a city is designed for automobiles, an aspect mentioned by different local actors in the interview. Additionally, it reflects the need to work on concepts such as the fifteen-minute city or pedestrian-friendly city, supported by the revitalization and densification strategies for the downtown area.

3. SENSITIVITY ANALYSIS

IMPACT FACTOR ANALYSIS OUTCOMES (FIGURE 10)



Based on more than 40 interviews with local stakeholders, the virtual on-site assessment of Saltillo revealed a total of 39 impact factors that have a substantial influence on the development of the city.

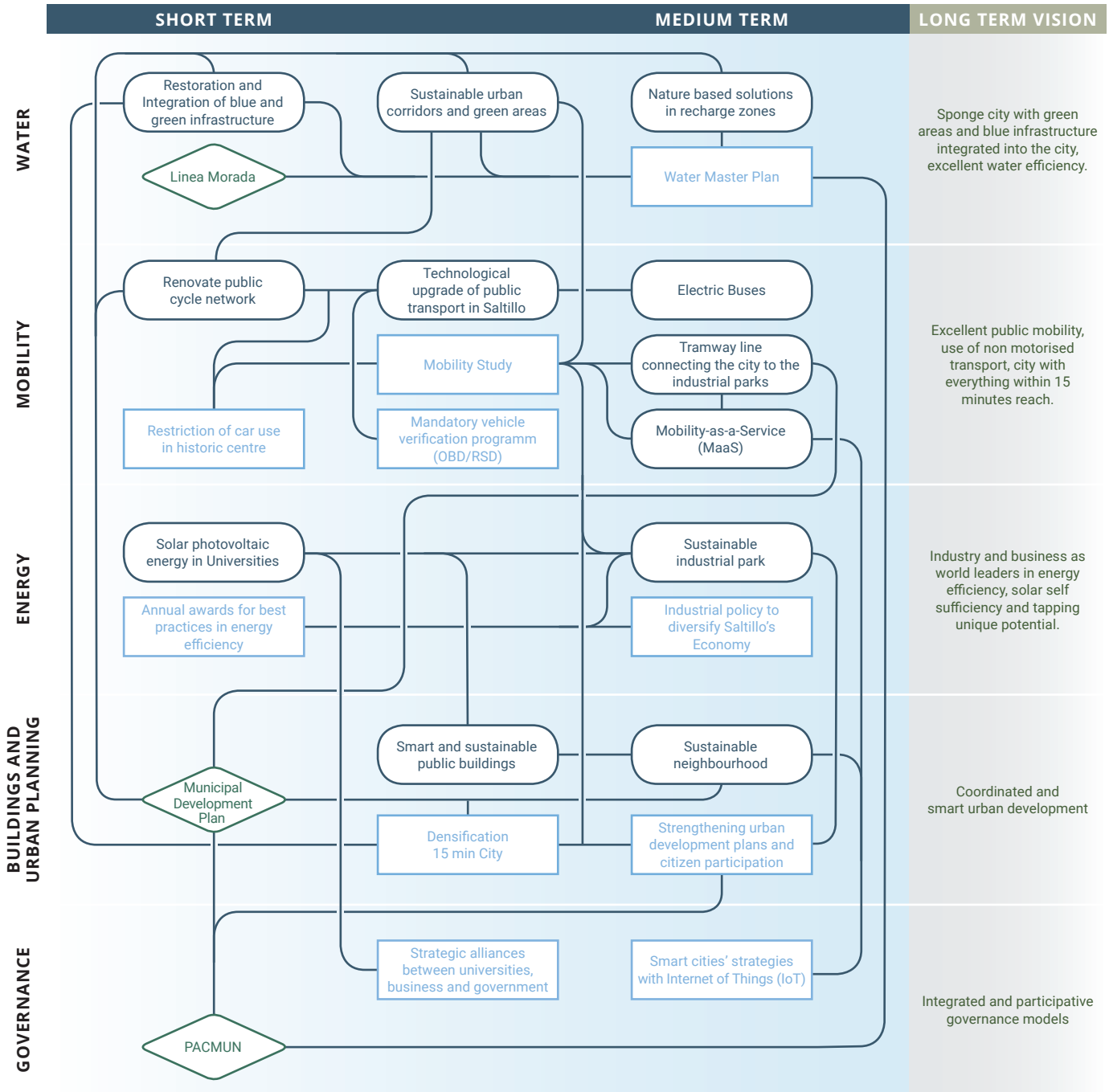
Using Frederic Vester's Sensitivity Model, a cross-impact analysis of these factors distinguished four different categories: drivers, levers, indicators and buffers. Drivers have the potential to drive change and remain stable over a longer time, but are often resistant to change. Levers have a high impact on many other factors, and are also influenced by many other factors. These include the crucial factors that need to be addressed in order to transform the system in the desired direction. Indicators have little influence on other factors, but are strongly influenced by other factors. Buffers are relatively inactive in both directions. A comprehensive analysis of the prioritized action fields and the most crucial impact factors gave rise to the following fields of intervention for the city system of Saltillo:

- Highly industrialized zone
- Industrial parks
- Automobile manufacturing cluster
- Extense city
- High migration rate
- Environmental consciousness
- High university density

4. ROADMAP: STRATEGY AND MEASURES

4.1. STRATEGY ROADMAP FOR SUSTAINABLE DEVELOPMENT OF SALTILLO

PROJECT IDEAS (FIGURE 11)



The strategy roadmap was developed from the analysis and assessment in the first three phases of the project, as depicted in figure 1. It is a portfolio of projects that aim to address the challenges identified and contribute to achieving a long-term vision in the different sectors. The roadmap is a graphical representation of the projects and depicts the complexity of the relationships between them and other essential instruments in the city, such as master plans or similar measures. It illustrates that the implementation of the projects is neither linear nor isolated.

The roadmap in figure 11 presents the project ideas arranged in a possible implementation time frame, i.e., short and medium term. At the same time, the projects are organized into three categories. The first category includes projects that involve physical-tangible interventions. These are depicted in the oval-shaped boxes. The second category corresponds to projects of a regulatory nature, such as measures, studies, master plans or events, which are, in some cases, relevant for implementing projects within the first category. The second category is represented by the rectangle-shaped boxes. Third, projects or plans that the city is already developing are depicted in the diamond-shaped boxes. A short description of the projects in the first category can be found in section 4.2, Suggested Measures.

The projects located on the left-hand side of the graph are those that, in general terms, can be more easily implemented in a short period of time. For instance, it is worth mentioning the *annual awards for best practices in energy efficiency* – a project that, by its nature as a yearly event, can be easily organized, does not require significant initial investments and could bring on board stakeholders from different sectors to commit to energy efficiency in their daily business. The project itself could be replicated in other areas and with other areas of focus, such as water efficiency, which plays a significant role in Saltillo.

Another example of this type of project is the *mandatory vehicle verification program (OBD/RSD[6])*, whose objective is to reduce emissions for in-use vehicles by ensuring that owners provide proper mechanical maintenance to their vehicles. The project itself is easy to implement and could result in a considerable improvement in the air quality of the city by prioritizing safer and less costly methods, such as OBD and RSD for vehicle verification. It would require the support and cooperation of key stakeholders, such as the public transport providers, private car owners and the secretary of mobility of Saltillo, among others.

On the right-hand side of the graph are the projects that require more time, resources and infrastructure for their execution. This is the case for the *sustainable industrial park*, which involves parties from different sectors, addresses diverse matters, such as water and energy efficiency, green mobility and circular economy principles, among others, and therefore requires more time, organization and economic resources for its implementation.

The roadmap serves as a guideline for the city to execute the projects in a timely and articulated manner, thus achieving the long-term visions through interventions that cover the different needs and areas in the city.

6 OBD (on-board diagnostics) and RSD (remote sensing devices) are technologies used to measure performance across the different systems in a vehicle.

4.2. SUGGESTED MEASURES

This section presents the list of concrete ideas developed within this project to improve the sustainability of the city within the sectors of water, mobility and energy. These measures were developed based on the challenges identified in each sector, the possible solutions and the long-term sustainability to be achieved. Together with the participation of external stakeholders, two workshops were conducted for co-creating and refining the project measures. Sectoral discussions and voting sessions were held, together with an objective evaluation of the different criteria (e.g., GHG emission reduction potential, climate change adaptation potential, project financial viability, etc.), in order to identify the most promising ideas.

Renovation of the Public Cycle Network

Although Saltillo has a public cycle network, the external perception is that it has not been adequately promoted or properly planned. This is due to the perception of insecurity in the population when it comes to using of this means of mobility. On the other hand, in other cities in Mexico, such as Mexico City, Guadalajara, as well as in Latin America, these systems have been successful due to their properly defined implementation, scope and use. Therefore, a renewal of the existing system in the city is proposed so that it operates solidly, consolidating the formation of an integrated public system using various modes of transport. The cycle network should be inclusive, with the citizens being the primary beneficiaries.

Restoration and Integration of Blue and Green Infrastructure

This project aims to restore a section of one of the main creeks in Saltillo so that its fluvial capacity is restored, while also converting the riverbank into a recreational area that offers environmental, social and even economic benefits. The main expected impact is an improvement to the drainage system, not only from the recovered fluvial capacity of the creek but also through a so-called sustainable urban drainage system (SUDS). The latter is achieved by the capacity of vegetation to retain and absorb water and allow it to infiltrate the soil. When implemented on a larger scale, this green infrastructure can be analogically viewed as a vast sponge that can significantly improve the capacity of the city to avoid flooding events while also offering multi-sectorial benefits.

Sustainable Neighborhood

The intention behind creating a sustainable neighborhood in Saltillo is to reduce water and energy consumption, reduce the heat island effect and mitigate floods. This can be achieved through the implementation of best water and energy management practices, green technologies and ecotechnologies. The initiative includes green walls and roofs, rainwater harvesting, collection systems, solar energy generation, implementation of technologies for the treatment and reuse of wastewater (for garden irrigation) as well as adapting green spaces with green infrastructure (rain gardens) or functional recreational areas (to reduce the effects of heat islands).

Mobility-as-a-Service (MaaS)

Mobility-as-a-Service (MaaS) combines the different current mobility trends with the public transport offer without considering a dependence on the private vehicle. This establishes a challenge and opportunity for the evolution of traditional mobility services and actors in the city, representing an opportunity for new ideas and participants. In Latin America, there are several providers of this service in the main cities on the continent that have demonstrated success in the results obtained using these platforms. The implementation of MaaS is a global trend that transforms mobility through technological innovation. This new way of thinking of transport and new methods of collaboration is fundamental for guaranteeing a continuous urban flow using more efficient alternative modes of transport. MaaS is based on the connectivity, access and affordability of the different transport options present in the region of interest.

Technological Update of Public Transport in Saltillo

The policy for modernizing public transport is based on technical instrumentation to improve performance indicators and user perceptions. These renewed systems must include information technology and the permanent monitoring of all units that meet current emissions standards.
The main impacts include the reduction of pollutants, GHGs, noise and traffic and should be more efficient than the traditional services. For the development of these initiatives, government support is essential and should focus on the user: improving quality, various mobility options, integrated fares, exclusive-use lanes and modern and adequate infrastructure.

Sustainable Urban Corridors and Green Areas

This project aims to implement diverse and native green infrastructure (such as xeriscape gardens, trees, green rooftops, etc.) within a strategic corridor to achieve multiple environmental, social and economic benefits. The main expected impact is the improvement of the drainage system through a so-called sustainable urban drainage system (SUDS), which is achieved by the capacity of vegetation to retain and absorb water and allow it to infiltrate the soil.
The envisioned corridor would also encourage walking and cycling by offering an attractive green street with an improved microclimate through shading and evapotranspiration from the vegetation. As the number of people moving by foot or bike increases, the number of people moving by car is expected to decrease, along with the related CO_2 emissions. A further decrease in emissions is expected to be achieved through the lower need for air conditioning, as green infrastructure has the capacity to decrease the UHI effect.

Energy Efficiency, Renewable Energy and Sustainable Water Use Awards

Achieving substantial reductions in energy use and GHG emissions requires the active involvement of the industrial and commercial sectors that, compared to the national average, are overrepresented in Coahuila and Saltillo. However, regulation of the energy and industrial sector is largely in hands of the national government. The municipality still has an opportunity to contribute to sustainable development in these sectors through awareness-raising events. A well-known practice is the hosting of sustainability awards. These awards could be given to best practices in, e.g., energy-efficiency improvements, renewable energy integration or sustainable water use. The awards can have different criteria (e.g., greatest absolute impact, greatest relative impact, most innovative, etc.) and different participant categories (very large, large, medium and small industrial users, commercial users, public users, etc.). Awards should be given in such a way that visibility is maximized in order to encourage best practices across the pertinent user groups. These kinds of awards are carried out in other countries and regions and have shown to be very impactful at low costs. Notable examples are the German energy-efficiency awards of the German Energy Agency or the ASEAN sustainability awards of the ASEAN Centre for Energy.

Tramway Line Connecting the City with the Industrial Parks

Saltillo's mobility requirements are largely determined by the individual transportation of its workforce to its 40 industrial parks and numerous other industrial facilities. After the industrial sector, the mobility sector is one of the most energy-consuming and GHG-emitting sectors, both in Saltillo as well as in the whole of Mexico. Achieving substantial emission reductions in the transport sector will require the expansion of public mobility services and the provision of infrastructure for non-motorized transport (e.g., pedestrian and bicycle lanes), as well as a technological transformation away from internal combustion vehicles. Among the most promising technological options is the electrification of mobility, which would allow vehicles to be powered by (low-carbon) electricity and thereby reduce emissions. A tramway line would substantially expand public mobility by offering a huge transportation alternative between the city of Saltillo and its industrial parks. The tramway would be powered by electricity, enabling an effective decarbonization of Mexico's economy by coupling the electricity sector with the transportation sector. Such a project implies a massive infrastructural investment and thus could only be realized in the medium to long term.

Sustainable Industrial Park

Saltillo's manufacturing industry is, to a large extent, located in its approximately 40 industrial parks in the metropolitan area and beyond. A single large industrial company might consume as much energy as 40 thousand households. The clustering of industrial companies in physical proximity to each other provides an opportunity to improve the sustainability profile of Saltillo's industry by addressing industrial parks as organizational units. The decarbonization of industrial parks by implementing best-in-class energy-efficiency measures and renewable energy self-supply, in particular solar PV, offers great potential for reducing energy consumption and GHG emissions, while improving industrial competitiveness. Indeed, many energy-efficiency measures in Saltillo have reportedly paid off within short periods of time (a few months) by amortizing investments with cost savings in energy expenditures. Additionally, solar PV equipment has seen substantial cost reductions in recent years, and the vast solar radiation potential in Coahuila makes self-supply a viable option. As mentioned, Mexico has the potential to achieve very low prices for solar PV electricity, as demonstrated during the third round of auctions for clean energy in 2017. The decarbonization of a pilot industrial park could serve as a showcase for tangible sustainability options and enable the project to be replicated in other industrial parks. In this way, Saltillo could become the heart of the transition towards a low-carbon economy in the industrial sector, becoming a first mover nationally and an example for Latin America and the world.

Solar Photovoltaic Energy in Universities as a Real Laboratory

Saltillo has numerous universities, four of which explicitly offer sustainable energy as a study track. Although solar PV and wind energy are technically mature and can already compete with fossil fuel-based electricity alternatives, the main challenge hindering their implementation is often variability in supply. Solar PV depends on radiation conditions, while wind energy depends on available wind resources. This project proposes using universities as laboratories with high expertise in achieving a balance between supply and demand. Thus, the proposal is to install solar PV panels at universities for a real-life investigations of supply patterns, storage opportunities and flexibilization of demand. Universities could become solution providers for industrial, commercial and residential users in Saltillo and thus be crucial actors in enabling the transformation towards a low-carbon energy system.

Smart and Sustainable Buildings

With the current climate challenges, it is necessary to have adequate technologies for the efficient generation and use of water and energy resources. This project aims to install different technologies and identify best practices to be implemented and tested in a public building for the sustainable use of water and energy, emphasizing off-grid solutions and monitoring and control instruments. In addition, these buildings will promote sustainable development models for the city that can be used as urban living labs.

Nature-Based Solutions in Recharge Zones

Hydrological basins have elements of vegetation and soil in their ecosystems that promote hydrological environmental capabilities. The soil fulfils the functions of storage and filtration of water and influences the quality and recharging of aquifers. The vegetation in the hydrological cycle, on the other hand, intercepts and retains the rain, allowing it to infiltrate the soil through its roots, thus opening the pores in the soil. Vegetation, water and soil must be conserved and managed to ensure their ecological functionality in the natural recharge zones.
This proposal aims to implement conservation and rehabilitation strategies for natural recharge sites, namely the Sierra de Zapalinamé, and create priority infiltration zones through the implementation of nature-based solutions (NBS). The proposal seeks to contribute to the recharging of aquifers, reduce the erosive water processes that cause sediment dragging, reduce runoff speed and reduce the maximum flows that can cause flooding in the low-lying areas of the region. In addition, carrying out this type of project is expected to improve the environmental, social and landscape conditions of the area or of the natural reserves. This project will help achieve the goal of Saltillo to become a sponge city. It will contribute to the recharging of aquifers and compensate for the pressure of water stress in the region.

Electric Buses

The electrification of the mobility sector offers a tangible opportunity for decarbonizing the transport sector. Electric vehicles are already being used for urban transportation in leading Asian and European cities, despite the high initial cost of implementing this technology. There are several car manufacturers worldwide who are interested in promoting its application. The operating environment must be analyzed based on energy consumption during the actual operation of traditional buses to ensure that the proposed fleet meets actual demand due to the autonomy of electric vehicles. In addition, a feasibility analysis is required in order for the proposal of various scenarios of a pilot project on specific routes. Economic efficiency analyzes must be subsequently conducted in order to measure the benefits of this project. Results in other cities and countries show economic benefits after five years of implementation. The city of Saltillo would benefit significantly from this type of infrastructure by getting more of its citizens to use the public transport system.

5. CONCLUSIONS AND OUTLOOK

This summary report presents the results of the *City Lab Saltillo* as one of three pilot cities within the Morgenstadt Global Initiative project. It describes the status quo of Saltillo with regard to its sustainability performance in the mobility, energy and water sectors, presenting the most salient challenges, solutions and a sustainability vision for each sector. Furthermore, it presents a list of concrete project ideas developed for the city of Saltillo or other interested stakeholders to develop and move towards the defined sustainability vision. The integrated analysis and the evaluation of challenges and potential for improvement in each sector, together with the list of concrete project ideas was developed based on the holistic Morgenstadt City Lab methodology. This methodology is based on quantitative and qualitative methods, with a focus on the participation of local stakeholders from the public, private and academic sectors through expert interviews and workshops. This co-creation and participative approach ensures tailored solutions and a high degree of local ownership.

As the capital city of the state of Coahuila de Zaragoza, Saltillo has the potential to become a role model for sustainable development for other cities in the region. In the water sector, the city can tackle water scarcity and flooding events by integrating green and blue infrastructure into the urban space, improving the city's soil permeability and the recharging of already overexploited aquifers through creating a sponge city effect. In the mobility sector, the city can reduce the use of individual transportation and traffic congestion by improving public mobility services and developing infrastructure for non-motorized transportation. Integrating urban and mobility planning would provide a great opportunity for designing the city in such a way that the basic needs of the citizens are within easy reach, without the need for extensive travel. In the energy sector, the city can self-supply its electricity requirements by developing solar PVs. Coahuila is considered globally to be a region with very high solar radiation potential, and its abundant solar resources make solar electricity a feasible and viable alternative. In one of Mexico's most industrialized zones, improving energy efficiency is a great opportunity to not only reduce energy use and GHG emissions, but also to reduce costs, improve industrial competitiveness, improve air quality and create employment opportunities, among many other benefits.

Saltillo has already begun tackling the sustainable development challenges faced by salient mid-size urban settlements of the Global South. The city has issued an Environmental Agenda, highlighting its interest in and commitment to improving the sustainability of its urban environment. It has also begun implementing sustainable projects, such as its use of landfill for electricity generation, its public lighting efficiency program, its public buildings efficiency program and its public cycle network, among others. Key stakeholders in the public, private and academic sectors who actively contributed to this project also highlighted the extraordinary commitment of Saltillo's society to sustainable development.

Nevertheless, achieving the sustainability vision developed in this project and beyond will require a long-term commitment to sustainable development. As a first step in this direction, Saltillo has anchored the results of this project into official planning documents, such as its Urban Development Plan and its Municipal Climate Action Plan (PACMUN). Indeed, institutionally anchoring sustainable development and defining clear future targets is considered the way forward in order to cope with the challenge of continuity in the face of changing governments. Additionally, it will be crucial for the city to allocate financial resources for implementing sustainable development projects. It is also essential that the city defines its monitoring schemes for improved sustainable urban development and decision-making.

Two prioritized project ideas from the suggested roadmap in this report are already on their way to being implemented and are currently being analyzed in terms of their technical and financial components, feasibility and corresponding climate change mitigation and adaptation impacts. Further projects on the list of project ideas and the roadmap developed in this project offer great potential for fostering the transformation of Saltillo into a sustainable city of the future.

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